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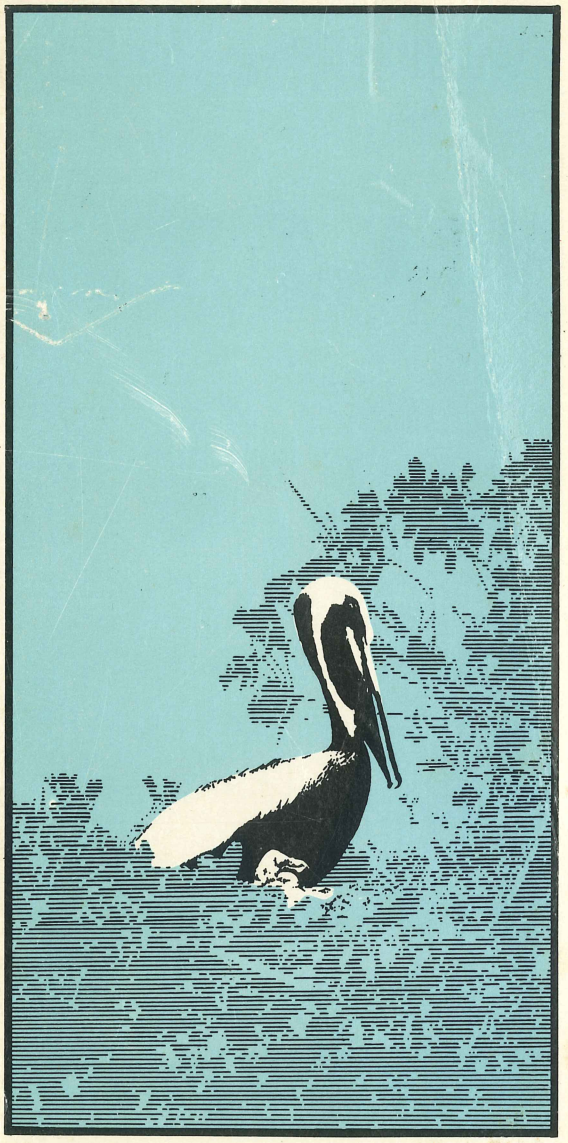

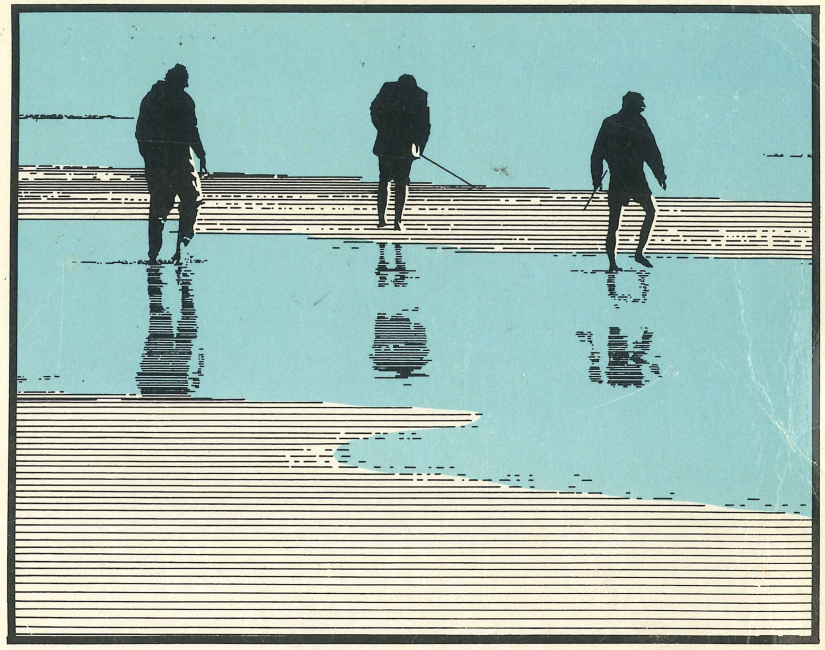

TAMPA BASIS

BAY AREA SCIENTIFIC INFORMATION SYMPOSIUM

Michael J. Perry

PROCEEDINGS
TAMPA BAY AREA SCIENTIFIC INFORMATION SYMPOSIUM

May 1982

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TAMPA BAY AREA SCIENTIFIC INFORMATION SYMPOSIUM

SCOPE AND PURPOSE

The Tampa Bay Area Scientific Information Symposium or BASIS had as its main goal the summary of all existing scientific information on Tampa Bay. Invited review papers were presented on the physical, chemical, geological, meteorological, biological, anthropological and economic aspects of Tampa Bay and the immediate Bay area. The public presentation of the invited and contributed papers occurred on May 3-6, 1982. Although the information presented here is largely technical in nature, efforts have been made to make presentations of use to non-technical persons.

SPONSORS

Major funding for Tampa BASIS was provided by a grant from the Florida Seagrant Program, to Joseph L. Simon. Additional financial support was obtained from:

Mangrove Systems, Inc.
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as granted to the Tampa Bay Area Scientific Information Society, Inc. These contributions are gratefully acknowledged.

Tampa BASIS was organized by:
J. L. Simon
R. R. Lewis III
E. D. Estevez
S'K. Mahadevan

EDITORS' PREFACE

Little did we know, in May of 1982, that we would be producing a volume of this magnitude (even lacking nine of the papers originally presented). The delays in publication have been many and for a variety of reasons. But in essence this became a volunteer effort on the part of just a few people. Almost all of the graphics were redrawn by Bob Whitman from "originals" submitted with the manuscripts. Typing was done by Sally Treat on an NBI System 3000 word processor, with support from Information Decisions, Inc. of Tampa. Proofreading assistance was provided by Dr. E. D. Estevez and the staff of Mangrove Systems, Inc.

Some lack of consistency is to be expected in any collection of papers by various authors, but we have made every effort to achieve uniformity. The most challenging aspect of this task has been to maintain a single train of thought throughout the duration. Therefore, discrepancies should probably not be attributed to the authors. Not all of the authors were able to review their contributions before going to press; for this we apologize. Some authors had the advantage of being able to update their manuscripts as editing proceeded (which was not always an advantage to the editors!). We sincerely thank all of the authors for their patience.

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SCIENCE AND THE MANAGEMENT OF SAN FRANCISCO BAY

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California Legislature
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For those of you who have been to San Francisco, I do not have to tell you of its beauty and uniqueness. As Alistair Cook once said, "San Francisco Bay is a fortuitous mating of marine grandeur and terrestrial snugness."

The Bay and the Sacramento-San Joaquin Delta together form one of the world's largest and richest estuarine systems. This system is the only true estuary in California with a classical salinity wedge, a zone of maximum turbidity (entrapment zone), and a constant input of fresh water from an inland watershed.

Much like Tampa Bay, the San Francisco Bay system is geographically separated into several distinct compartments (Fig. 1). The South Bay is a large blind pocket which is flushed during periods of heavy rain. This end of the Bay receives only 10% of the total supply of fresh water entering the system. Except for inadequate circulation, this portion of the system has all the other physiographic characteristics of an estuary - large marsh areas, mudflats, shallow areas, and a deep central channel. The north end of the Bay (including San Pablo Bay and Suisun Bay and Marsh) functions as a typical estuary. This portion of the Bay receives the direct input of fresh water from the interior Delta, where two major river systems, the Sacramento and the San Joaquin, converge.

San Francisco Bay stretches approximately 50 miles from north to south and varies in width from 12 miles down to 1 mile. Tides in the area are mixed and semidiurnal, with salinity highest in the summer months. The weather pattern is exactly opposite that of Tampa Bay, with winter being the rainy season. It is difficult to describe general characteristics of the Bay because of its extremely complex geographic and bathymetric configuration.

Like Tampa Bay, San Francisco Bay is truly an urbanized estuary. Some 5 million people live around its shores, benefiting from the Bay's strategic location. The huge natural harbor makes the bay the gateway to the East. In addition to the economic value of port and harbor related activities, the mild climate and aesthetic beauty of the area attract multitudes of tourists. The Bay offers a wide variety of water-oriented recreation, including boating and fishing. The principal fisheries for commercial and recreational purposes include:

Salmon. In 1880, 21 salmon canneries processed 10 million pounds of fish. Landings have declined to 10% of the historic level.

Striped Bass. Introduced from the east coast in 1879, 1 million pounds were caught in 1899. With a declining population, the commercial fishery closed in 1935. The present population is only one-half that of the mid-1960s.

Herring. Due to diminished stocks, this is now a limited entry fishery with a short season. Herring roe brings a high price on the Japanese market. The historic spawning grounds in the Bay have been severely impacted by siltation.

Dungeness Crab. A San Francisco delicacy, 3 million pounds were taken in 1892. In its twentieth season of decline, the catch is now only 10% of the mid-1960s.

Oysters. Three million pounds were harvested in 1899. Due to pollution problems in the South Bay, the last commercial shellfish operation closed in 1933.

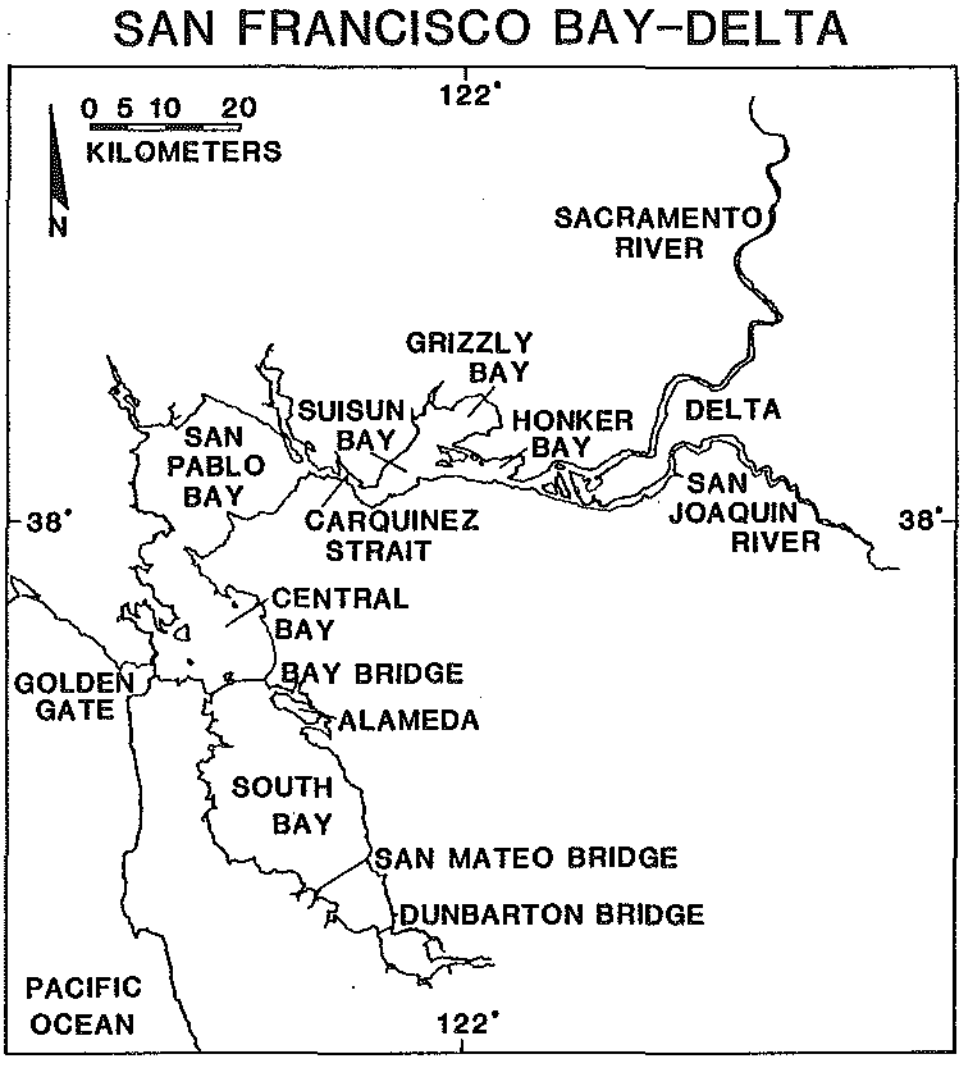

Figure 1. Location of San Francisco Bay delta.

Water pollution, siltation, and overfishing are all factors contributing to the decreased stocks. These and other perturbations impacting the Bay will now be discussed.

PERTURBATIONS

Although most of the impacts on the Bay ecosystem have been due to man's activities, natural events have been significant. In 1862, a flood turned the Bay into a freshwater lake, keeping salt water from entering the system for over one week.

Hydraulic mining, used extensively between 1853 and 1884 in the Sierra foothills, caused massive sedimentation problems. The upper arms of the Bay filled in as much as 2 to 3 meters from the mining debris carried by rivers from the gold country. In its natural state (100 years ago) the Bay had a surface area of approximately 2 billion square meters. Sedimentation and the diking and filling of marshes have decreased the Bay area by 37%. Even with this lost area, the Bay has the most extensive marshland in California.

The transfer of tidelands to private ownership in the mid-1800s promoted land speculation and large-scale reclamation, diking, and filling of the Bay's margins. The Leslie Salt Company diked off vast areas in the southern part of the system for evaporation ponds. In addition to commercial and residential development around the edge of the Bay, airport and port expansions have brought about an additional loss of habitat.

Presently some ninety municipal and industrial sources discharge into the Bay. With thirty municipal sewage outfalls discharging over 500 million gallons per day, one in every eight gallons of fresh water entering the Bay is sewage. Urbanization around the Bay has increased the amount of non-point source discharges, including urban storm runoff. Pesticides and other pollutants enter the system from agricultural runoff in the Delta. A proposed Central Valley salt drain would add more waste material to the already overstressed system.

Other Bay area activites affecting water quality and beneficial uses include several power plants which entrain and impinge small fish and other biota, several tanker terminals and refineries which experience small accidental oil spills, and ship channel dredging and port maintenance dredging projects.

By far, the most important impact on the San Francisco Bay/Delta system has been upstream water development projects. The State Water Project and the federal Central Valley Project have diverted huge quantities of water for use in Southern California and the San Joaquin Valley. Before upstream developments began in the mid-1850s, freshwater flows into San Francisco Bay were appproximately 30 million acre feet (maf) per year. This water reflects the runoff of a watershed equal to 40% of the total California land area. With the large-scale state and federal projects of the mid-1900s, the volume of fresh water entering the Bay has been reduced to 21 maf/year.

With present proposals on the books for additional water development projects, the projected volumes for flows entering the Bay in 1990 are 5.5 maf in normal years, 3.3 maf in dry years and 2.7 maf during drought years. Recent work by Rozenqurt and Haydock (1981), who examined estuaries in the Soviet Union, suggests that decline in biological productivity sets in after approximately 25% of the mean river flow has been diverted. Similar work in Texas estimated the threshold level to be 32%. San Francisco Bay has already exceeded this critical level.

SCIENTIFIC INQUIRY

Although its shores had been populated since before the turn of the century, San Francisco had received surprisingly little scientific study until the environmental awareness movement of the late 1960s and 1970s. Until 1977, no scientific meeting or symposium devoted to the Bay's ecosystem had been convened. Then, at the annual meeting of the Pacific Division, American Association for the Advancement of

Science, held at San Francisco State University, a series of papers dealing with the natural history of the Bay and Delta, with reference to the influence of man, were presented. The proceedings of this symposium (Conomos 1979) serve as a useful reference to both scientists and resource managers as to how the system functions biologically, chemically, geologically, and physically.

Motivation for conducting research on the system has been primarily related to the economic aspects of the alteration of the environment by acts of man. A brief history of past research efforts follows:

1. (1905-1908) Gilbert study of hydraulic mining debris. His 1917 paper remains as the best baseline of physical characteristics of the Bay.
2. About 1912, the University of California showed an interest in conducting a baseline study of the entire system but the effort was later abandoned.
3. (1912-1913) The Albatross expedition investigated causes of decreased fishery stocks in the Bay.
4. (1920s) Marine borer studies conducted during drought period which saw extensive damage to piers and other wooden structures in Bay.

By the 1930s there was such general unawareness of the significance of the Bay ecosystem that major decisions for upstream diversion of water were made as if the Bay did not exist. Serious consideration was given to schemes to dam off the north and south arms of the Bay, turning them into fresh water lakes. Ecological studies didn't even begin until some 30 years after major engineering decisions were made.

Tests conducted at the U.S. Army Corps of Engineers' Bay Hydraulic Model, completed in 1960, showed the devastating impact various barrier proposals would have had on the Bay and finally laid these engineering plans to rest. It is interesting to note that the term "estuary" was not even applied to the Bay until the 1960s. In the late 1960s, the U.S. Geological Survey demonstrated the upstream movement of seabed drifters into the Bay. The state director of the Department of Water Resources said at the time, "there must be a mistake, water doesn't move uphill." What he and many others failed to realize was that in an estuary, with a salt water wedge and stratification, it does.

Most, if not all, of the Bay baseline and pre-discharge studies conducted for the State Water Quality Board in the 1960s and 1970s were done by engineering groups. The lack of ecological sophistication, coupled with limited time constraints, in conducting these studies is best summarized by Nichols (1973):

> "The size and species composition of faunal assemblages are largely controlled by the salinity of the water, the texture of the bottom sediments, and locally by wastes discharged into the bay. Efforts to describe the structure and function of benthic communities of the bay and to quantify the effects of waste discharge on them have been hampered by inconsistent and often faulty sampling methodology and species identification. Studies made show a lack of information on the normal life processes of the organisms concerned. The diversity index (a mathematical expression of the number of kinds of organisms present at a location), commonly used to describe the "health" of the benthic community, has been employed without regard for the need for standardizing methodology and species identifications or for understanding natural biological processes that affect such mathematical indices. There are few reliable quantitative data on the distribution of benthic organisms in San Francisco Bay with which future assessments of the "health" of the benthic community might be compared. Methods for study of the benthos must be standardized, identifications of species verified by

trained taxonomists, and new field and laboratory studies undertaken before we can expect to obtain an accurate description of the benthic fauna and its relations with the environment."

Major management decisions affecting the Bay estuary have been made over the past fifty years. The decisions to dredge deeper ship channels, divert large quantities of fresh water, and discharge wastewater into the Bay, were all made without adequate scientific information. The future decisions on construction of a Peripheral Canal around the Delta and completion of a Master Agricultural Salt Drain discharge into the estuary will also be made without close ecological scrutiny. The height of ignorance regarding the functions and requirements of an estuary were perhaps best shown at a recent legislative hearing on the proposed Peripheral Canal, when a state Senator demanded to know, "How long has all this fresh water been flowing into the ocean?"

MANAGEMENT

In the early 1960s, a group of concerned citizens, alarmed at the rate of development in and around the Bay, formed the "Save San Francisco Bay Association." Led by University of California President Clark Kerr's wife, the group began lobbying efforts at the local city council level. For various political reasons, the 32 city, 9 county and one regional governments were unable to halt the indiscriminate dredging, diking, and filling of the Bay. The organization subsequently turned to the state legislature in Sacramento for action. After a long, hard fought battle, legislation was passed in 1965 creating the Bay Conservation and Development Commission (BCDC).

In 1968, BCDC produced a comprehensive and enforceable plan for the conservation of the water of San Francisco Bay and the development of its shoreline. The "Bay Plan" contained a series of findings and policies for the following resource elements: fish and wildlife; water pollution; water surface area and volume; marshes and mudflats; smog and weather; shell deposits; and fresh water inflow. The Plan also contained findings and policies for the following development elements: safety of fills; dredging; water-related industry; ports; airports; recreation; transportation; salt ponds and other managed wetlands; public access; appearance, design and scenic view; and other uses of the Bay and shoreline.

To a large extent, the indiscriminate filling of San Francisco Bay was terminated with the advent of BCDC. However, once the BCDC plan came into place, people became complacent and assumed that the Bay had been "saved." Unfortunately, the Bay Plan was oriented primarily toward the shoreline; BCDC's role in water quantity and water quality issues was very limited.

Although the Bay has been saved once, it will be necessary to save it again, perhaps three times. The second crusade is now underway to curtail industrial and municipal wastes that are entering the system. The results of millions of dollars for improved wastewater treatment are beginning to show in better water quality. Areas of the Bay that have been closed to shellfish for decades are now approaching the point of being certified once again.

The third battle will be waged in an arena where governmental drift and public ignorance are allowing the estuary to be destroyed. As previously mentioned, the major perturbation facing the estuary is the continued diversion of fresh water from the system. The vitality of the entire San Francisco Bay area depends on adequate fresh water flows into the Bay. This has been the hardest lesson to learn.

CONCLUSION

As we listen to the papers over the next four days, I cannot stress enough the concept of a holistic management approach. Florida is very similar to California, with dozens of local,

regional, state, and federal resource management and regulatory entities. For the proper management of an area like Tampa Bay, there must be coordination between these disparate groups. Where possible, there should be consolidation, with a few, preferably one, agency having comprehensive jurisdiction.

I also want to stress the importance of a watershed approach to research and planning. Surrounding upland activities are critical to an understanding of the Bay. Freshwater inflow may not be as important an element as it is in San Francisco Bay, but you will find that it is still a critical factor.

It will be important for you to attempt to understand how Tampa Bay's physical and biological systems benefit man. Education is sorely lacking. The public and our elected officials do not know what is out there. It is our job as scientists and educators, as planners and public officials to get the word out. BASIS seems like an excellent way to get started, so let's begin.

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THE RATIONALE FOR TAMPA BASIS

Tampa Bay is a large semi-enclosed body of brackish water located in one of the nation's most rapidly growing regions. Three counties and 19 municipalities border the Bay; its watershed encompasses another 2 counties and 6 more cities. A combined population of 1.3 million people live within 50 miles of the Bay. Florida's most industrialized coastline and largest port - the seventh largest in the country - front the Bay.

Uses and abuses of the Bay and its resources have grown in proportion to the regional population. Rivers have been channelized, impounded, and rerouted. Industrial and municipal effluents, storm waters, oil spills and hazardous wastes challenge the Bay daily. Immense wetland areas have been lost to dredging and spoiling for shoreline development or ship channels. But more people swim, fish, and boat in waters of Tampa Bay than ever before. Virtually every corner and backwater of the Bay has a place name, as do many underwater features. The value of waterfront property has literally skyrocketed. The three-county area is known nationally as "Tampa Bay" and several professional sports clubs, the major media, and hundreds of businesses take their public identity from the Bay.

Exactly what is Tampa Bay, and what is known about its geology, chemistry, biology, and archaeology? In prehistoric times local cultures must have perceived the Bay with awe and respect equal to its importance in their lives for food, materials, and transportation. We can safely guess that the average knowledge about the Bay shared by those early "Spirits of Tampa Bay" must certainly have exceeded ours. Theirs was a personal knowledge of necessity, imprecise and ignorant of causality, but linked immediately to every moment and detail of their lives.

Today we still relate topically to Tampa Bay in the same ways as prehistoric man, by fishing, moving goods or people, extracting materials of value or disposing of wastes, and by admiring sunsets (a form of philosophy). But now our interactions with Tampa Bay have become highly specialized, so one sector of society catches our fish, another ferries oil from shore to shore, and a third installs gutters to drain shopping center parking lots. Knowledge of Tampa Bay has become impersonal and specialized; the ship captain, fisherman and engineer all study currents with scientific precisions for their own purpose, but at what cost to accuracy?

The past century of settlement around Tampa Bay saw impacts which resulted from developments that were accepted as reasonable. The major developments were definitely planned, as in construction of the ship channel, St. Petersburg sewage treatment system, or Port Manatee. Their impacts were reasonable because the benefits to society appeared to outweigh the costs, at least in the existing economic terms. Information concerning the Bay was acquired with each project to the extent it mattered. In the 1870s the bathymetry and currents of Hillsborough Bay were scrutinized in preparation for a new channel to Tampa. Crustacean taxonomy got an early start in the Bay because wood-boring isopods were destroying pilings under railroad bridges in 1917. During the 1970s several major studies of water quality were made in Hillsborough Bay to document the impacts of sewage treatment plant effluent and changes due to plant improvements.

Not all changes to the Bay were planned, nor were all studies made in connection with development. The destruction of Boca Ciega Bay by finger-fill dredging and spoiling was clearly an opportunistic, unplanned phenomenon, and annual bird-counts by the Audubon Society have never been part of any development scheme. But in retrospect much scientific information concerning the Bay has naturally concerned navigation, marine engineering, fisheries and human health. It is not surprising

therefore to find that these are also among the oldest regulatory or management systems relevant to the Bay. Examples are several. All submerged lands of Hillsborough County are titled in the Tampa Port Authority, which controls the use of Bay bottoms, channels and maritime structures. Local health departments and pollution control agencies have long been involved in regulating the bacteriological levels of Bay water by monitoring sewage treatment plants. Mosquito control departments have either ditched or sprayed nearly every acre of mangrove forest and tidal marsh in the name of disease and nuisance control. Cities, counties, the State of Florida and federal agencies have regulated sport and commercial fishing with size, gear, season or site limits. In recent years the federal Environmental Protection Agency (EPA) and state Department of Environmental Regulation have come to manage water quality in and around Tampa Bay. The U.S. Army Corps of Engineers and the Southwest Florida Water Management District now continue activities of the once active Soil Conservation Service by planning and constructing dams, levees, channels and salinity barriers. Some of the important wetlands in the Bay are in aquatic preserves administered by the State Department of Natural Resources (but other equally important wetlands are no better protected than mud flats). Like the ship captain, fisherman, or drainage engineer, each agency had its portfolio of scientific studies on Tampa Bay, and there were as many technical images of the Bay as there were observers.

The materials and forces needed for grinding a lens to focus the kaleidoscopic images of Tampa Bay into a meaningful picture began to appear about twenty-five years ago. By then, attempts were underway to review the literature of the Bay; an unpublished review by Franklyn C. W. Olsen and John B. Morrill in 1955 would be used for decades as the standard bibliography. The University of South Florida was established and making tentative studies of its community and environment. The Florida Department of Natural Resources Marine Research Laboratory was taking over research projects of the now defunct Bureau of Commercial Fisheries Laboratory. By the late 1960s the "environmental movement" had reached the Tampa Bay area. With one foot in conservation ecology and another in political regionalism, the movement stood for a holistic approach to Bay management and science. Then the pace quickened.

The National Environmental Policy Act (NEPA) was adopted just as the Tampa Port Authority and the Army Corps of Engineers were to begin the most ambitious dredging project in the Bay's history. Because of NEPA these agencies were required to prepare an environmental impact statement which addressed Tampa Bay as an ecological unit. A citizen group called Save Our Bay (emphasis added) was formed. Scientists and resource managers met for the first time to discuss long range effects of Bay dredge and fill, and Hillsborough County enabled its Environmental Protection Commission to monitor all waters of Tampa Bay on a routine basis. Graduate research was in full swing at the University of South Florida. Consulting companies were busy preparing other impact statements. Governments sponsored studies of sewage, stormwater, toxic substances, and industrial effluents. Library shelves were filling with "grey literature" which nevertheless reported facts about the Bay unknown to readers of professional journals. In 1974 the Florida Academy of Sciences published a synopsis of literature on Tampa Bay, prepared by Joseph L. Simon. The review became the standard reference and conceptual framework for Tampa Bay until 1980.

As a part of the EPA-sponsored City of Tampa National Urban Runoff Program (NURP), the city co-sponsored (with the Florida Department of Environmental Regulation, the University of South Florida, Hillsborough Community College and Mote Marine

Laboratory) a workshop entitled "Hillsborough Bay and the Hillsborough River - a history, a study of pollutant influences, and the importance of the Bay and the river to the citizens of the area" on November 8, 1980. One of the conclusions reached at that workshop was the immediate need for a more comprehensive technical and scientific summary of information on the entire Bay system. It was obvious to four participants, all of us ecologists, that a compilation and synthesis of available information on Tampa Bay into a single source would be useful to a larger audience including educators, other scientists, and resource managers. The group held four major meetings between November 1980 and April 1981 to plan for the Tampa Bay Area Scientific Information Symposium, or Tampa BASIS. Our objectives were to convene a symposium of invited scientists to present review papers on the biology, chemistry, geology, hydrology and anthropology of the Tampa Bay system and to publish and widely distribute the symposium proceedings. Financial support for BASIS was provided by a grant from the Florida Sea Grant Program, Mangrove Systems, Inc., Mote Marine Laboratory, Tampa Electric Company, the U.S. Army Corps of Engineers, and the University of South Florida. A Steering Committee was established comprised of representatives from potential users of BASIS data, and direct or in-kind support came from dozens of sources. BASIS was held on four days in May, 1982. A cumulative audience of about 300 persons attended 49 invited and contributed papers by 75 authors.

The experience of BASIS, and hopefully, the value of these proceedings is three-fold. First, and of greatest significance, is the view that Tampa Bay is an ecological unit comprehensible to man despite its size and complexity, and that large amounts of information about the Bay can be assimilated and distilled for application to problems or projects of small scale or short duration. Second, Tampa Bay is a resilient and productive estuary. With proper management and restoration, the Bay would become perceptably more productive and valuable to its users. And third, despite the imposing length of the proceedings and the larger original literature to which it refers, there remain whole areas, things and events about the Bay that are poorly known or completely unstudied. In this sense the proceedings are an agenda for new work.

We hope to have assembled a structure of knowledge for Tampa Bay into which its users may incorporate missed or new information. No review is ever finished. That this review will one day become obsolete and require another, perhaps conducted by computer and disseminated electronically, we are quite confident.

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S'Kumar Mahadevan
Joseph L. Simon

A NEW GEOGRAPHIC DESCRIPTION OF THE BOUNDARIES AND SUBDIVISIONS OF TAMPA BAY

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INTRODUCTION

Olson (1953a) first proposed dividing Tampa Bay into four subdivisions and arbitrarily established boundaries for these four subdivisions as seen in Figure 1. The four subdivisions were:

1. Old Hillsborough Bay
2. Hillsboro (sic) Bay
3. Boca Ciega Bay
4. Tampa Bay

Table 1 gives the area and length of shoreline as determined by Olson (1953a), using a technique described in Olson (1953b), which is basically a gridding of a map followed by counting the number of intersections or points to calculate area and shoreline length. The actual values in Table 1 were based upon the U.S. Coast and Geodetic Survey (USCGS) chart of 1943 (#1257, 6th edition), and were termed "provisional" and noted as having "not been subjected to an independent check" (Olson 1953a, p. 3).

The Bureau of Commercial Fisheries (now the National Marine Fisheries Service) began water quality sampling in Tampa Bay in 1961 and terminated in 1972. In the published reports of their data (Saloman et al. 1964; Saloman and Taylor 1968, 1971a, 1971b, 1972; Saloman 1973a, 1973b), a slightly different system of boundaries is used (Figure 2) for a total of six subdivisions. These are:

1. Old Tampa Bay
2. Hillsborough Bay
3. Upper Tampa Bay Proper
4. Lower Tampa Bay Proper
5. Boca Ciega Bay
6. Terra Ceia Bay

The only significant area added to the system was Terra Ceia Bay while the "Tampa Bay" section was divided into two areas. No additional areal determinations were published in these reports. Taylor (1973) reported the same six subdivisions as being accurate and cited the total area of the Bay as 350 square miles (905 km^2) per Olson and Morrill (1955).

Table 1. Areal coverage and shoreline length of the four Tampa Bay subdivisions proposed by Olson (1953a). Refer to Figure 1.

	Area		Shoreline Length	
Subdivision Name	mi^2	km^2	mi	km
Old Tampa Bay	78.3	202.8	54.0	86.9
Hillsboro Bay	40.4	104.6	34.7	55.8
Boca Ciega Bay	26.9	69.7	23.6	38.0
Tampa Bay	200.4	519.0	99.2	159.6
Total	346.0	896.1	211.5*	340.3

*Incorrectly added to give 212.4 in Olson (1953a).

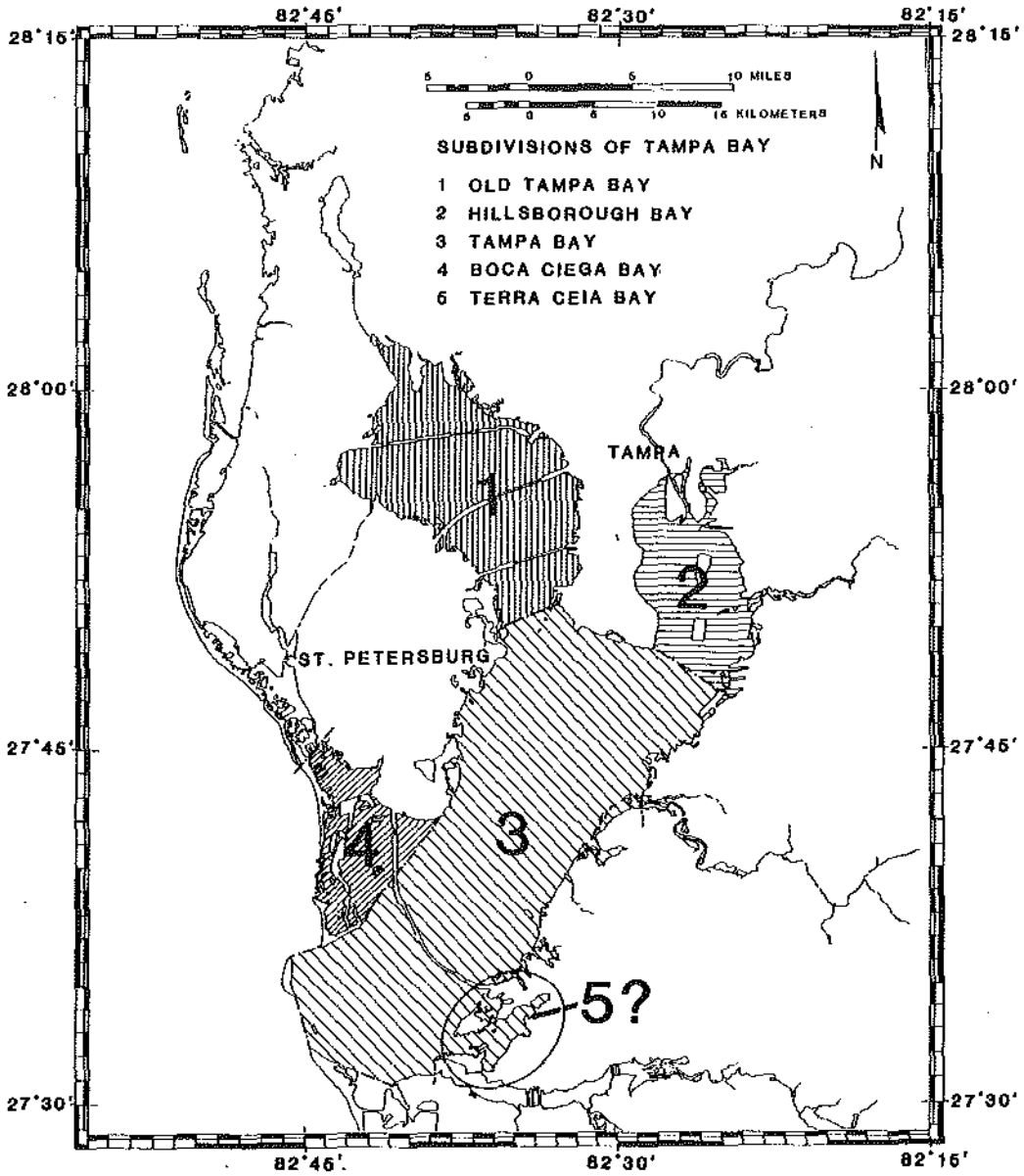

Figure 1. Subdivisions of Tampa Bay, Olson (1953a).

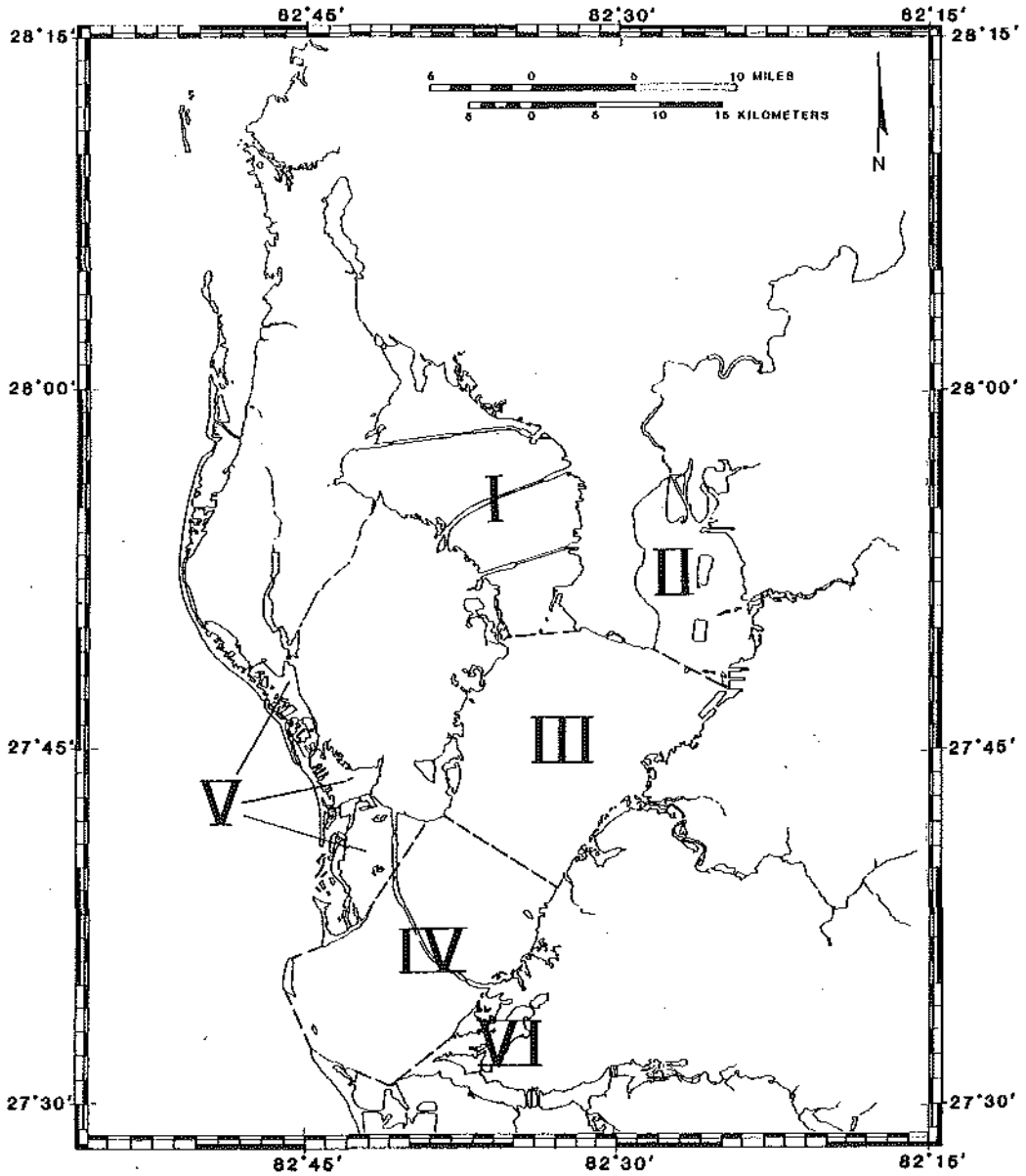

Figure 2. Subdivisions of Tampa Bay, Bureau of Commercial Fisheries (now National Marine Fisheries Service), 1961-1972. See text for references.

Simon (1974) also cited Olson and Morrill (1955) for figures on the size of the Bay and listed five subdivisions with a note that Tampa Bay proper was "often subdivided into upper and lower on the basis of differing salinity regimens" (p. 219). Simon (1974) modified one of the areal measurements of Olson and Morrill (1955) by reducing the area of Boca Ciega Bay from 26.9 sq. mi. (69.7 km^2) to 21.5 sq. mi. (55.7 km^2) and increasing the shoreline length from 23.6 mi. (38.0 km) to 124.0 mi. (199.6 km) as a result of massive dredge and fill activities during the 1950s and 1960s (Taylor and Saloman 1968). This modification increased the reported shoreline length to 311.7 mi. (501.6 km), and decreased the reported area of the Bay to 340.6 sq. mi. (882.1 km^2). This was based upon a 1971 map of the Bay (USCGS chart No. 858).

Due to the lack of recent, comprehensive examination of all of the previously discussed literature and to the large scale changes that the Bay has experienced in recent years, it was decided to recalculate areas of the Bay using recent charts (Appendix I) and more sophisticated techniques and instrumentation. It was also obvious that the boundaries described by Olson (1953a) were somewhat ambiguous and needed clarification. Certain marine areas (e.g., the Manatee River) that are functionally part of the Bay also needed to be included in the boundaries of the Bay.

MATERIALS AND METHODS

The Tampa Bay estuarine system was divided into 7 subdivisions. These are:

1. Old Tampa Bay
2. Hillsborough Bay
3. Middle Tampa Bay
4. Lower Tampa Bay
5. Boca Ciega Bay
6. Terra Ceia Bay
7. Manatee River

Delineations of these subdivisions appear in Figure 3. The areal extent of each subdivision was calculated using a LASICO (Los Angeles Scientific Instrument Co.) compensating polar planimeter, model L-40.

To facilitate planimetric measurement, each subdivision was divided into smaller subsections. To ensure planimetric accuracy, each subsection was measured twice, and an arithmetic mean ascertained and employed in final areal calculation. The areal extent of a subdivision was determined by summation of subsections within that subdivision.

Shoreline length determinations were made using a Minerva Curvimeter (linear measuring device).

Islands were excluded in calculations of areal coverage of open water and were included in measurements of shoreline length unless otherwise noted. Tributaries were measured to a point of hydrologic modification (e.g., dam) or to the point of dissolution on NOS chart no. 11412 (1979).

Maps and charts utilized are referenced in Appendix I.

RESULTS

Table 2 lists the revised areal figures and shoreline length figures based upon our recent analysis. We have combined open water measurements (Table 3) and intertidal wetland areas (Table 4) to give the total area figures in Table 2. Combining these figures gives a total area for the Bay of 398.1 sq. mi. (1,030.8 km^2). Total shoreline length is 903.7 mi. (1,454.2 km) (Table 4).

These figures are quite different from previously reported values, partly due to some minor revisions in areas included in Tampa Bay (e.g, the Manatee River), but mostly due, we believe, to more accurate measurement of existing maps. The total emergent wetlands figure of 7,164.4 ha (17,696.3 acres) is larger than the 5,630 ha (13,906 acres) reported by Lewis (1977) due to the addition of 1,534.1 ha (3,789.2 acres) of emergent wetlands along the shores of the Manatee River (Table 5).

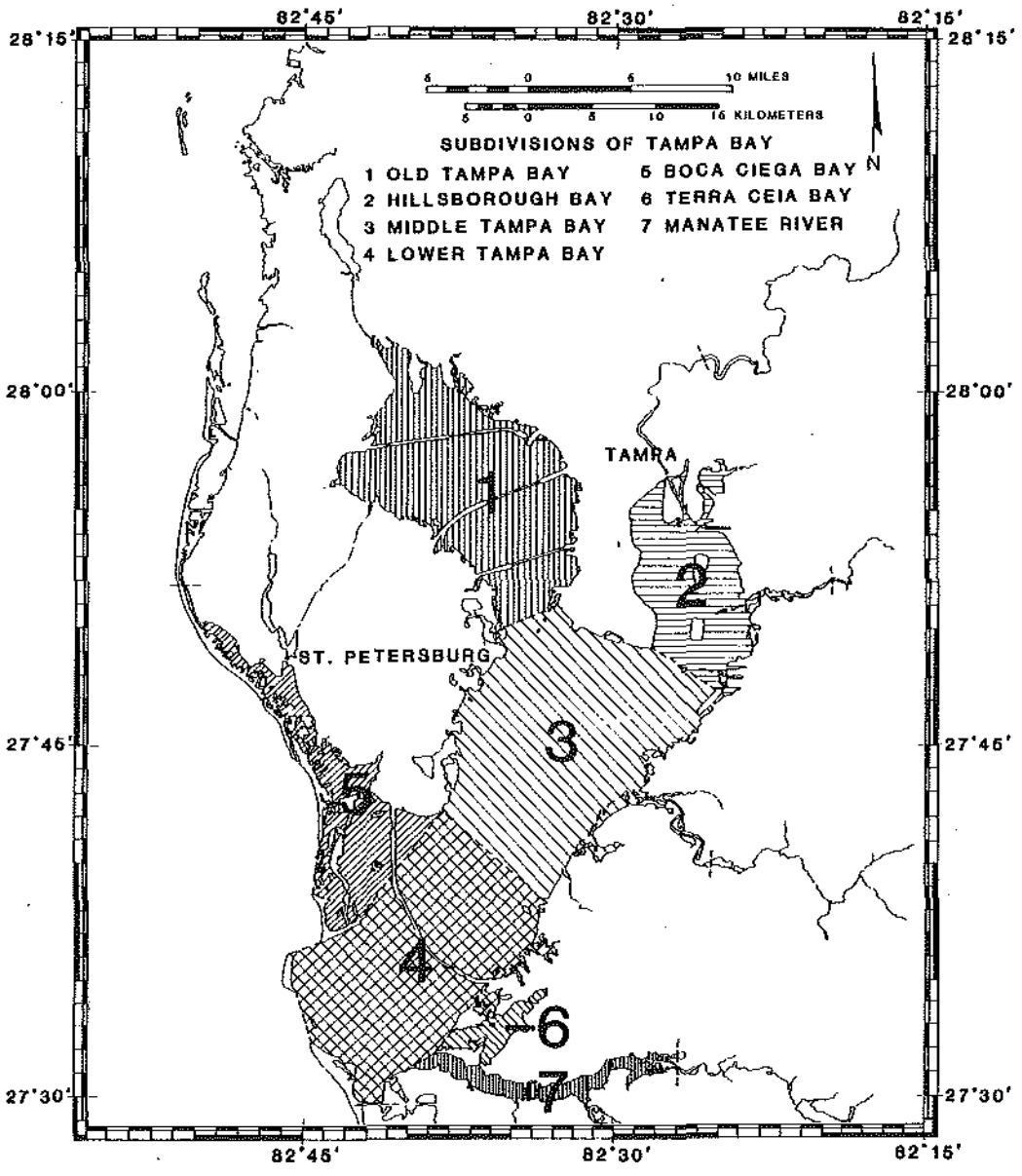

Figure 3. Subdivisions of Tampa Bay.

Table 2. Summary of areal measurements for subdivisions of Tampa Bay, including emergent wetlands.

Subdivision Name	mi^2	km^2	acres	hectares
1. Old Tampa Bay	80.5	200.7	51,542.0	20,067.2
2. Hillsborough Bay	40.2	105.3	26,119.6	10,534.3
3. Middle Tampa Bay	119.7	309.9	76,547.1	30,990.7
4. Lower Tampa Bay	95.2	246.6	60,906.4	24,658.4
5. Boca Ciega Bay	35.9	93.1	22,985.6	9,305.9
6. Terra Ceia Bay	8.0	20.6	5,098.3	2,064.0
7. Manatee River	18.6	54.6	11,935.1	5,462.0
Total	398.1	1,030.8	256,164.9	103,082.5

Table 3. Open water areas of subdivisions of Tampa Bay.

Subdivision Name	mi^2	km^2	acres	hectares
1. Old Tampa Bay	73.3	190.0	46,926.5	18,998.6
2. Hillsborough Bay	38.4	100.8	24,890.9	10,077.3
3. Middle Tampa Bay	113.1	292.9	72,354.8	29,293.4
4. Lower Tampa Bay	92.2	238.9	59,011.8	23,891.4
5. Boca Ciega Bay	34.5	89.5	22,098.8	8,946.9
6. Terra Ceia Bay	6.1	15.8	3,909.1	1,582.6
7. Manatee River	12.7	39.3	8,145.9	3,927.9
Total	370.3	967.2	237,337.8	96,718.1

Table 4. Shoreline lengths of subdivisions of Tampa Bay.

Subdivision Name	mi	km
1. Old Tampa Bay	211.1	339.8
2. Hillsborough Bay	207.0	128.6
3. Middle Tampa Bay	163.3	262.8
4. Lower Tampa Bay	75.6	121.6
5. Boca Ciega Bay	180.5	290.4
6. Terra Ceia Bay	25.9	41.6
7. Manatee River	118.7	191.0
Total	903.7	1,454.2

Table 5. Emergent wetland areas of subdivisions of Tampa Bay.

Subdivision Name	mi^2	km^2	acres	hectares
1. Old Tampa Bay	7.21	18.7	4,615.5	1,868.6
2. Hillsborough Bay	1.76	4.6	1,128.7	457.0
3. Middle Tampa Bay	6.55	17.0	4,192.3	1,697.3
4. Lower Tampa Bay	2.96	7.7	1,894.6	767.0
5. Boca Ciega Bay	1.38	3.6	886.8	359.0
6. Terra Ceia Bay	1.86	4.8	1,189.2	481.4
7. Manatee River	5.92	15.3	3,789.2	1,534.1
Total	27.64	71.7	17,696.3	7,164.4

ACKNOWLEDGEMENTS

The authors would like to acknowledge the assistance of G. Jeffery Churchill during the data acquisition and assimilation phase of this effort.

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Appendix I. Maps and charts utilized for areal computation.

National Ocean Survey nautical charts of the United States, Gulf Coast. U.S. Department of Commerce, National Oceanic and Atmospheric Administration.

Chart #	Title	Date	Scale
11412	Tampa Bay and St. Joseph Sound	May 1979*	1:80,000
11413	Tampa Bay, northern part	May 1980*	1:40,000
11414	Tampa Bay, southern part	Mar 1979	1:40,000

U.S. Geological Survey 7.5 minute topographic quadrangles, all at scale 1:24,000:

Title	Date
Anna Maria	1964-(69PR)
Bradenton	1964-(69PR)
Bradenton Beach	1964-(69PR)
Brandon	1956-(69PR)
Citrus Park	1956-(69PR)
Cockroach Bay	1972
Egmont Key	1964-(69PR)
Gandy Bridge	1956-(69PR)
Gibsonton	1956-(72PR)
Lorraine	1973
Oldsmar	1974
Palmetto	1964-(69PR)
Parrish	1973
Pass-A-Grille Beach	1956-(69PR)
Port Tampa	1956-(69PR)
Riverview	1956-(69PR)
Ruskin	1956-(69PR)
Safety Harbor	1956-(69PR)
Saint Petersburg	1956-(69PR)
Seminole	1974
Sulfur Springs	1956-(69PR)
Tampa	1956-(69PR)

*indicates maps updated by the authors using various photographic sources and field verification.

THE METEOROLOGY OF TAMPA BAY

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Tampa Bay lies in a zone of transition between temperate conditions to the north and tropical weather to the south. Maritime tropical air dominates the area for nine months out of the year. Summers are long, hot and humid. Winters, although punctuated with periodic invasions of cold continental polar air, are very mild because of the southerly latitude and warm adjacent Gulf of Mexico. Because of its history of mild climatic conditions and abundant sunshine, the area surrounding Tampa Bay has become known as the "Suncoast."

TEMPERATURES

Tampa Bay has a mean annual temperature of 22.7°C. The average monthly maximum and minimum temperatures, along with extremes, are shown in Figure 1. The coldest official temperature ever recorded was -7.8°C in 1962; the warmest temperature ever recorded was 36.7°C, and this reading has been recorded several times during the summer months. The last recording of this extreme maximum was in June, 1977.

It has been suggested that because of rapid industrial and residential growth, the Tampa Bay complex has become a heat-island. According to Changnon (1968) in his study of LaPorte, Indiana during the 1960s, the heat-island effect, combined with the many air pollution particles present in urban air, appears to cause a general increase in urban precipitation, although this effect is somewhat controversial to date. However, a plot of temperatures for the last five decades seems to refute the idea of Tampa Bay becoming a heat-island (see Figure 2). Temperatures by decade indicate less than 1°C deviation from the calculated mean.

PRECIPITATION

Tampa Bay experiences a mean annual rainfall of 123.7 centimeters. Figure 3 provides a profile of normal and extreme rainfall for the past fifty years. While rainfall may vary greatly from year to year, Tampa Bay has a "rainy season" which lasts from June through September; in fact, fifty-nine percent of all rainfall occurs during that period, and can be attributed primarily to afternoon thunderstorms. However, it should be noted that every month of the year has experienced, at one time or another, extreme wetness and severe dryness.

Current climatological data do imply that Tampa Bay's annual rainfall is gradually decreasing (see Figure 2). In fact, close investigation reveals that deficits for the decades of the 1960s and 1970s were greater than the surpluses for the decades of the 1930s, '40s, and '50s (see Tables 1 and 2). The reasons for this decrease in annual rainfall still remain controversial; however, I do contribute it largely to urban growth and an overabundance of condensation nuclei. Furthermore, I personally do not foresee that this area will ever return to climatological conditions where precipitation averages over 127 centimeters a year.

THUNDERSTORMS

An outstanding feature of Tampa Bay's climate is the summer thunderstorm season. On the average, the area has 87 days with thundershowers occurring mostly in the late afternoons of June, July, August and September. During the period from 1959 through 1981, thunderstorm-produced lightning resulted in 229 fatalities in the entire state, which is over 100 more than any other state.

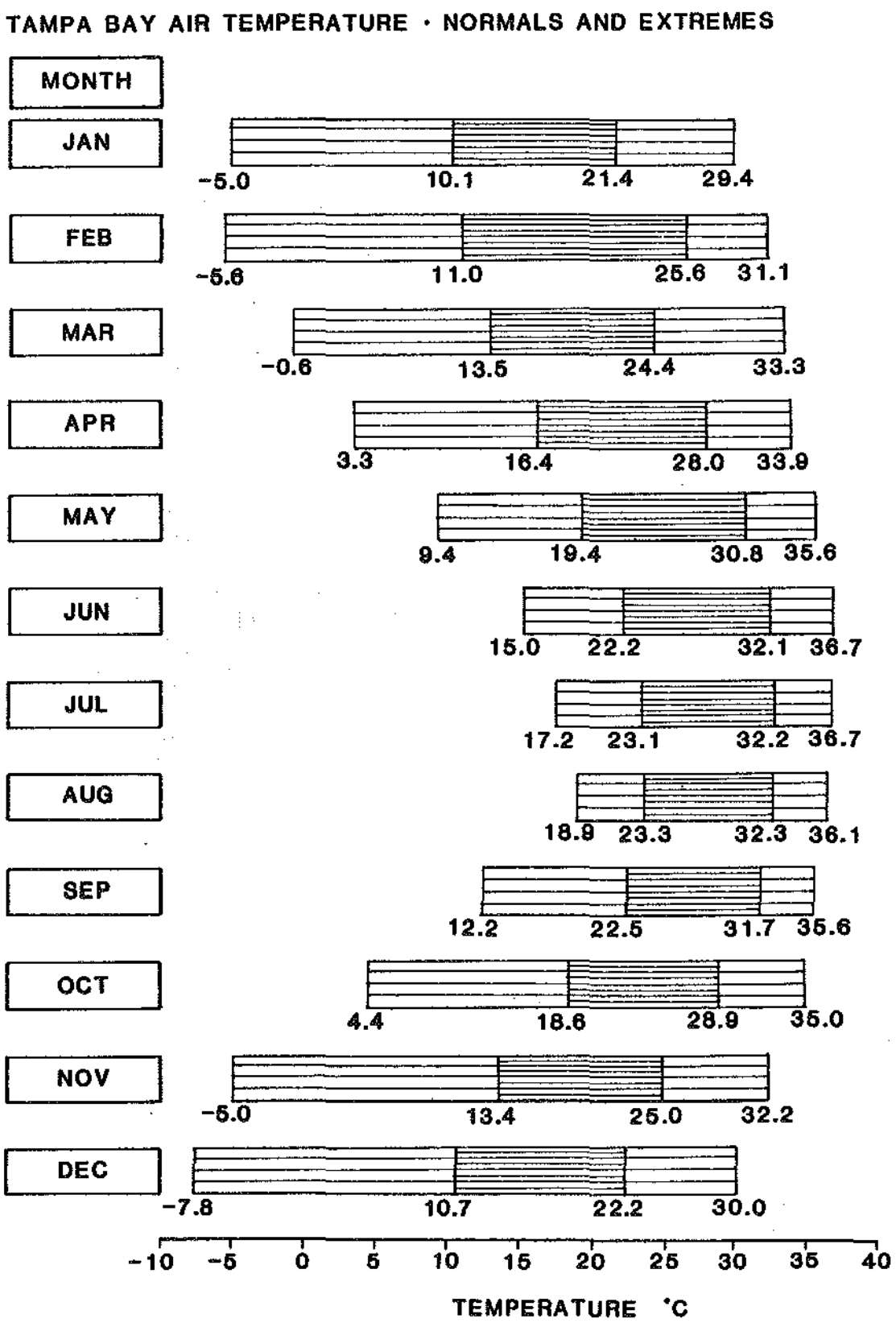
TAMPA BAY AIR TEMPERATURE · NORMALS AND EXTREMES
MONTH
JAN
-5.0
10.1
21.4
29.4
FEB
-5.6
11.0
25.6
31.1
MAR
-0.6
13.5
24.4
33.3
APR
3.3
16.4
28.0
33.9
MAY
9.4
19.4
30.8
35.6
JUN
15.0
22.2
32.1
36.7
JUL
17.2
23.1
32.2
36.7
AUG
18.9
23.3
32.3
36.1
SEP
12.2
22.5
31.7
35.6
OCT
4.4
18.6
28.9
35.0
NOV
-5.0
13.4
25.0
32.2
DEC
-7.8
10.7
22.2
30.0
-10 -5 0 5 10 15 20 25 30 35 40
TEMPERATURE °C

Figure 1.

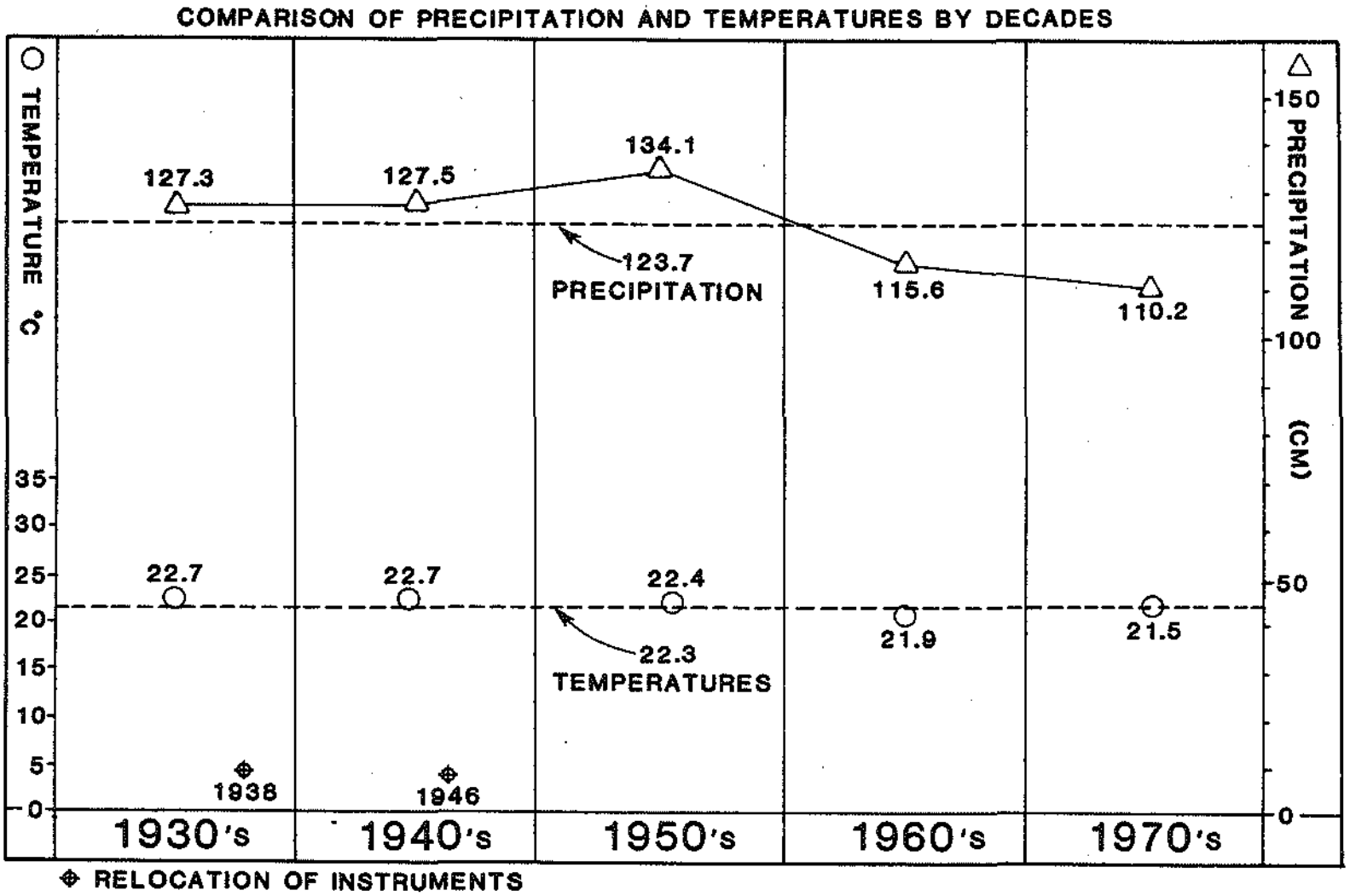
COMPARISON OF PRECIPITATION AND TEMPERATURES BY DECADES
TEMPERATURE °C
PRECIPITATION (CM)
127.3
127.5
134.1
115.6
110.2
123.7
PRECIPITATION
22.7
22.7
22.4
21.9
21.5
22.3
TEMPERATURES
35
30
25
20
15
10
5
0
150
100
50
0
1938
1946
1930's
1940's
1950's
1960's
1970's
RELOCATION OF INSTRUMENTS

Figure 2.

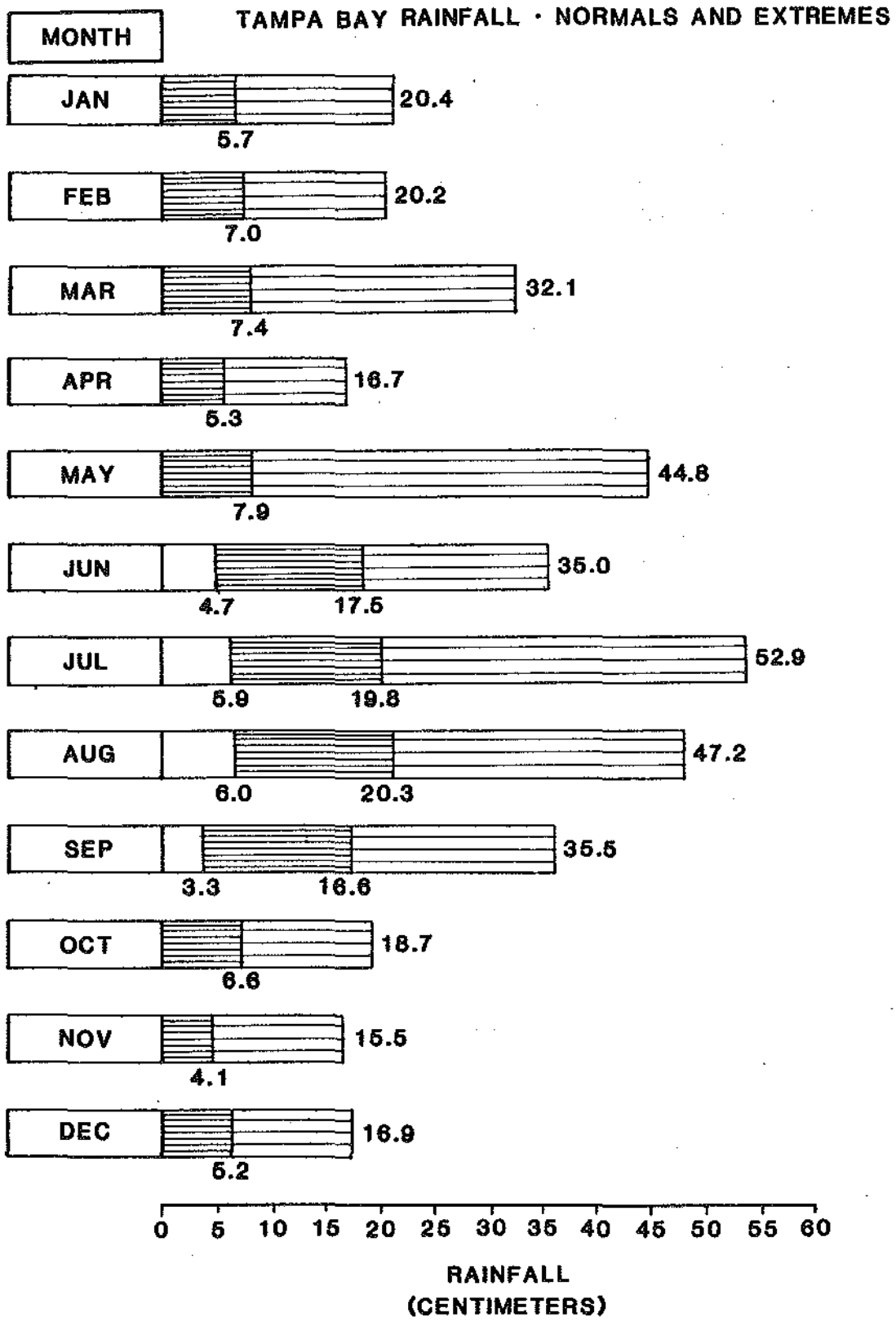
TAMPA BAY RAINFALL · NORMALS AND EXTREMES
MONTH
JAN
20.4
5.7
FEB
20.2
7.0
MAR
32.1
7.4
APR
16.7
5.3
MAY
44.8
7.9
JUN
35.0
4.7
17.5
JUL
52.9
5.9
19.8
AUG
47.2
6.0
20.3
SEP
35.5
3.3
16.6
OCT
18.7
6.6
NOV
15.5
4.1
DEC
16.9
5.2
0 5 10 15 20 25 30 35 40 45 50 55 60
RAINFALL
(CENTIMETERS)

Figure 3.

Table 1. Precipitation: above/below normal by decades.

Decade	No. Years Above			No. Years Below		
	0-10 cm	10-20 cm	20 cm	0-10 cm	10-20 cm	20 cm
1930s	4	3	0	1	2	0
1940s	0	1	3	3	1	2
1950s	1	1	4	1	2	1
1960s	0	1	2	0	3	4
1970s	1	0	1	1	3	4
TOTALS	6	6	10	6	11	11

A second by-product of thunderstorms is the tornado. Tampa Bay ranks number one in the occurrence of tornadoes within the state of Florida, while Florida ranks fourth in the United States for the occcurrence of this phenomenon. Tampa Bay can expect an average of 27 tornado days each year.

TROPICAL CYCLONES

Tropical cyclones are of never-ending concern for Tampa Bay. Not since 1848 has Tampa Bay been struck by a major hurricane. On September 25, 1848, Fort Brooke (an Army outpost at the present site of Tampa) reported tides rose to 4.2 meters as the pressure dropped to 71.57 centimeters of mercury.

Table 3 shows the history of tropical cyclones for the past 50 years. There have been a total of five tropical storms (winds greater than 33 knots, but less than 64 knots), and a total of eight hurricanes (winds 64 knots or greater) to pass within 75 kilometers of Tampa Bay. However, climatic data seems to indicate that we are past due for a major storm. Statistics reveal that Tampa Bay has a 1 in 25 chance of hurricane force winds in any given year.

RELATIVE HUMIDITY

Tampa Bay has a humid climate. Humidities will average near 88 percent in the early morning hours and range in the fifties during the afternoon hours. Dew can be expected every night due to the high humidity. Table 4 provides a summary of monthly average relative humidity for four time periods.

FOG

Heavy fogs are usually confined to the night and early morning hours in the late fall, winter, and early spring. On the average heavy fog (visibilities less than one-quarter mile) may be expected to occur on 23 days each year. Heavy daytime fog is seldom observed in Tampa Bay; however, because of the flat terrain, late night and early morning ground fogs occur frequently during the cool weather season. Seldom does the ground fog reduce visibilities below one mile. Table 5 provides a yearly distribution of heavy fog days.

BAROMETRIC PRESSURE

Tampa Bay's subtropical location provides for a small range in barometric pressure readings. Table 6 provides the monthly averages for the barometric pressure.

FREEZES

On the average Tampa Bay will experience freezing temperatures four (4) nights each year. Freezing temperatures are confined to late night and early morning hours; and, freezing temperatures have never been reported

earlier than November, nor later than March. Table 7 provides the mean number of days, by month, with freezing temperatures. Extreme temperatures for the five months of the year that have produced freezing temperatures are contained in Table 8.

Table 2. Precipitation: total deficit or surplus, by decade.

Decade	Deficit (cm.)	Surplus (cm.)
1930s	-	32.06
1940s	-	38.33
1950s	-	105.20
1960s	80.89	-
1970s	135.15	-
TOTALS	216.04	175.59

Table 3. Tropical cyclones for the past 50 years. TS - tropical storm; H - hurricane.

Type storm	month/year	Path with respect to Tampa Bay
TS	Sep 1930	moved over northern shores of Bay
TS	Aug 1933	moved westward 45 km S of Bay
TS	Sep 1933	moved northwestward 75 km NE of Bay
H	Sep 1935	moved northward 75 km W of Bay
TS	Jul 1937	moved northeastward across Bay
TS	Sep 1939	moved northwestward 48 km NE of Bay
H	Oct 1941	moved northwestward 65 km SE of Bay
H	Oct 1944	moved northward through eastern Hillsborough County
H	Sep 1945	moved northward 75 km E of Bay
H	Oct 1947	moved northward 10 km inland of Pinellas coast
H	Sep 1950	moved eastward 50 km N of Bay
H	Sep 1960	moved northward 55 km E of Bay
H	Oct 1968	moved northeastward 60 km N of Bay
	TO DATE	none

Table 4. Summary of relative humidity (%).

Month	Local Time 0100	0700	1300	1900
Jan	84	86	59	73
Feb	82	85	56	68
Mar	82	86	55	66
Apr	81	87	50	61
May	81	85	52	62
Jun	84	86	59	68
Jul	85	87	63	72
Aug	87	91	64	76
Sep	86	90	62	75
Oct	84	88	56	71
Nov	85	87	55	73
Dec	84	87	58	74

Table 5. Mean number of days with fog, by month.

Month	no. days	Month	no. days
Jan	6	Jul	0
Feb	3	Aug	0
Mar	3	Sep	0
Apr	1	Oct	1
May	1	Nov	3
Jun	0	Dec	4

Table 6. Barometric pressure (Mb), monthly averages for 3.35 m above sea level.

Month	Pressure	Month	Pressure
Jan	1020.2	Jul	1016.0
Feb	1019.7	Aug	1017.3
Mar	1018.2	Sep	1015.2
Apr	1017.7	Oct	1016.5
May	1015.4	Nov	1018.8
Jun	1016.5	Dec	1019.7

Table 7. Mean number of days with freezing temperatures.

Month	no. days	Month	no. days
Jan	2	Jul	0
Feb	1	Aug	0
Mar	*	Sep	0
Apr	0	Oct	0
May	0	Nov	*
Jun	0	Dec	1

*Average is less than 1 for past 18 years.

Table 8. Extreme cold temperatures.

Month	temperature (°C)	year
Jan	-5.6	1981
Feb	-4.4	1958
Mar	-1.7	1980
Nov	-5.0	1970
Dec	-7.8	1962

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A SHORT SUMMARY OF THE GEOLOGY OF TAMPA BAY

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INTRODUCTION

Although there is a considerable body of data on the geology of Tampa Bay, there is a surprisingly sparse representation in the refereed literature. Still the most complete description of the geology and sedimentology of Tampa Bay is Goodell and Gorsline (1961). Of a more specialized nature are papers by Walton (1964) on the ecology of benthonic foraminifera and by Doyle (1975) on the economically exploited shell deposits of the Bay. Except for Walton's work even these are not in the readily available literature.

In the grey literature are works by Stahl (1970), Simon and Dyer (1972), Simon and Doyle (1974a, b), Ross (1975), and Simon et al. (1976). Taylor and Saloman (1969) contains a massive amount of data which has never been fully interpreted. In addition, there are several review survey reports and environmental impact statements prepared by the U.S. Army Corps of Engineers, EPA and various other government agencies. From these sources and from a series of seismic lines and vibracores which we have obtained, I have distilled the following summary of the geology of Tampa Bay.

GEOLOGIC SETTING

Tampa Bay lies in the midst of the Florida Platform, a Mesozoic and Tertiary accumulation of over 5,000 meters of sedimentary rocks which are predominantly carbonates. Although carbonates make up the bulk of the deposits, evaporites are intercalated throughout the section and clastics become increasingly significant near the top, so that much of central Florida is veneered with quartz sand terrace deposits of Late Tertiary and Pleistocene age.

Detailed stratigraphy underlying the Bay and its environs is confusing, however. The best descriptions may be found in Vernon and Puri (1964) and Walton (1964). The surface of the area surrounding the Bay is covered by Pleistocene quartz sands which are described in the soil surveys of Hillsborough, Manatee, and Pinellas Counties. Beneath lies a poorly mapped sequence of Pliocene and Miocene units. According to Walton (1964), the middle-Pliocene Caloosahatchee Marl is widespread throughout the area, and the Middle Miocene Hawthorne Formation is thought to underlie Pleistocene sands to the southeast of the Bay. Hawthorne units are phosphatic and their inferred presence beneath the Bay is reinforced by sand sized phosphorite found in Bay sediments (Walton 1964). The Tampa limestone of Early Miocene Age underlies the northwestern and northern parts of the Bay.

Lithologies of most of these formations are complex, with lenses of unconsolidated marine sands and muds of varying carbonate content interspersed with well lithified limestones and cherts. Such a variety of lithologies in turn represents an equally complex melange of closely spaced depositional paleoenvironments from marine through estuarine, paludal, fluvial, and even lacustrine systems.

STRUCTURE AND GEOLOGIC HISTORY OF TAMPA BAY

Like most estuaries, Tampa Bay is a product of the fluctuations in sea level caused by Pleistocene glaciation. During lowered stands of sea-level associated with glacial advances, at least the four

rivers (Hillsborough, Alafia, Little Manatee, and Manatee) which now empty into the Bay became rejuvenated and cut the valley which, when sea level rose again during glacial retreat, was flooded and became Tampa Bay. The detailed history of these streams is complex with each glacially triggered event tending to obscure the next, but our geophysical data show some large channels incised as much as 30 meters beneath the present Bay floor (Fig. 1). One series of channels extends beneath the sand spit that is now Pinellas County and out onto the floor of the continental shelf. Vibracores taken within the Bay reveal a complex set of environments associated with fluctuating sea level. While most of the ancient channels are now filled with sand and buried oyster bars, peat layers in vibracores from interchannel deposits and the rich vertebrate fossil assemblage recovered in dredging operations attest to the variety of paleoenvironments represented.

SURFACE SEDIMENTS

Goodell and Gorsline (1961) and Doyle (1975) showed that quartz sand with varying amounts of carbonate, mostly in the form of mollusc shells, fill the old channels and form the surface layer within the rest of the Bay as well. Figures 2 and 3 (modified from Goodell and Gorsline 1961) show mean grain size and percent of carbonate distribution in the Bay. Regional trends for both decrease up the Bay toward the northeast. Shell fragments compose the coarsest portions of the sediments. As expected, largest grain sizes and correspondingly highest carbonate values are found in the channels in the lower Bay where tidal current velocities can be expected to be greatest.

Total organic content increases with decreasing grain sizes, a normal relationship. Extremely high organic carbon values have been reported in the polluted portions of Hillsborough Bay. Walton (1964) has also reported a band of

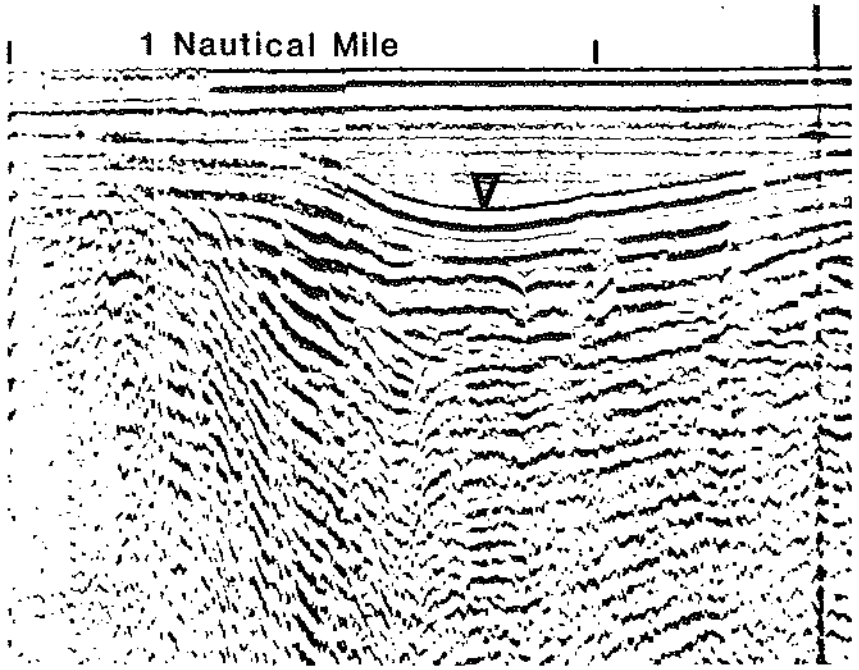

Figure 1. A portion of a N-S trending seismic line east of the St. Petersburg City Pier which shows an east-west oriented channel system containing 37.5 meters of fill.

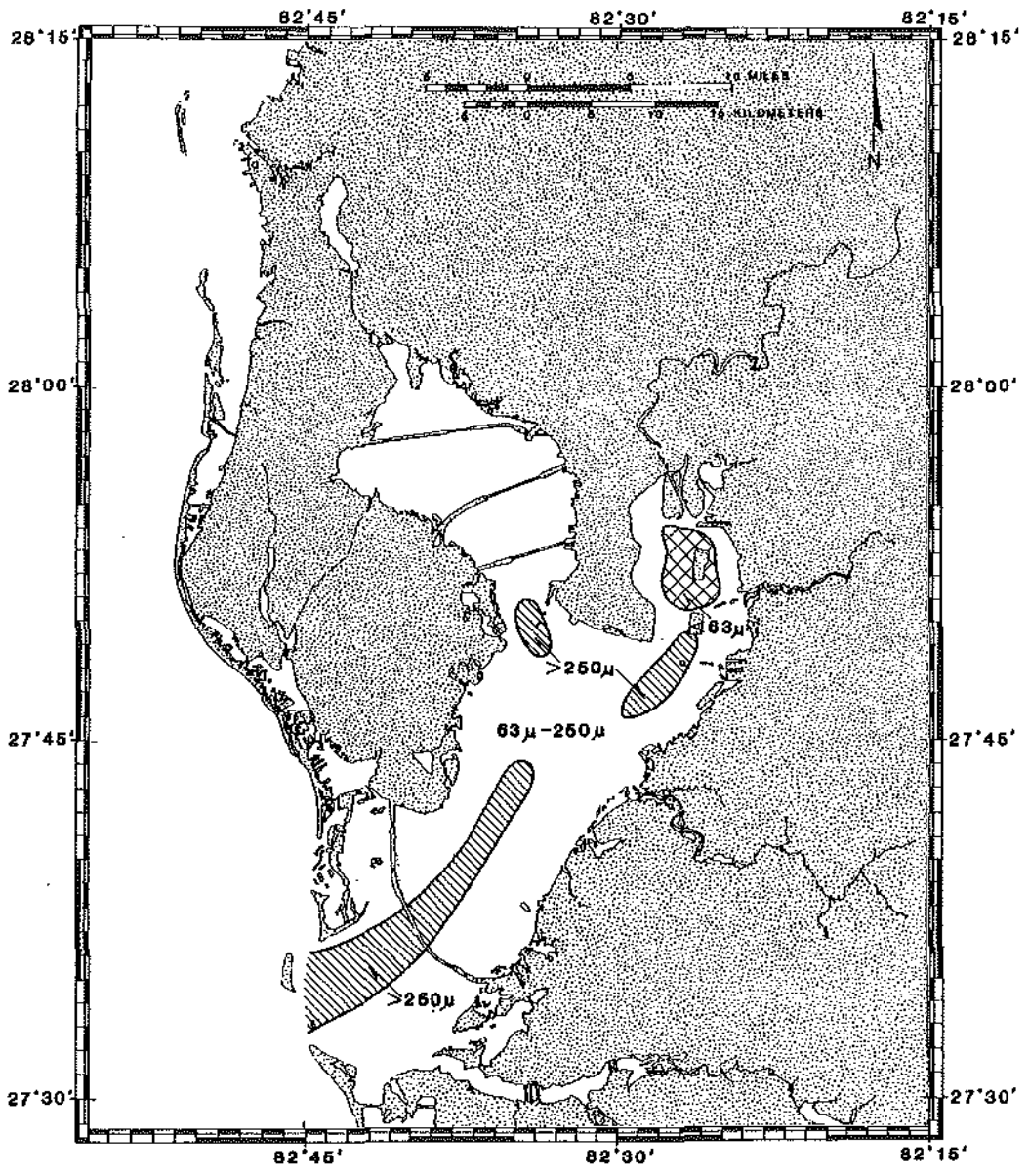

Figure 2. Mean grain size distribution in Tampa Bay, modified after Goodell and Gorsline (1961). All near grain sizes are in the sand range except for the patch in the northeastern corner.

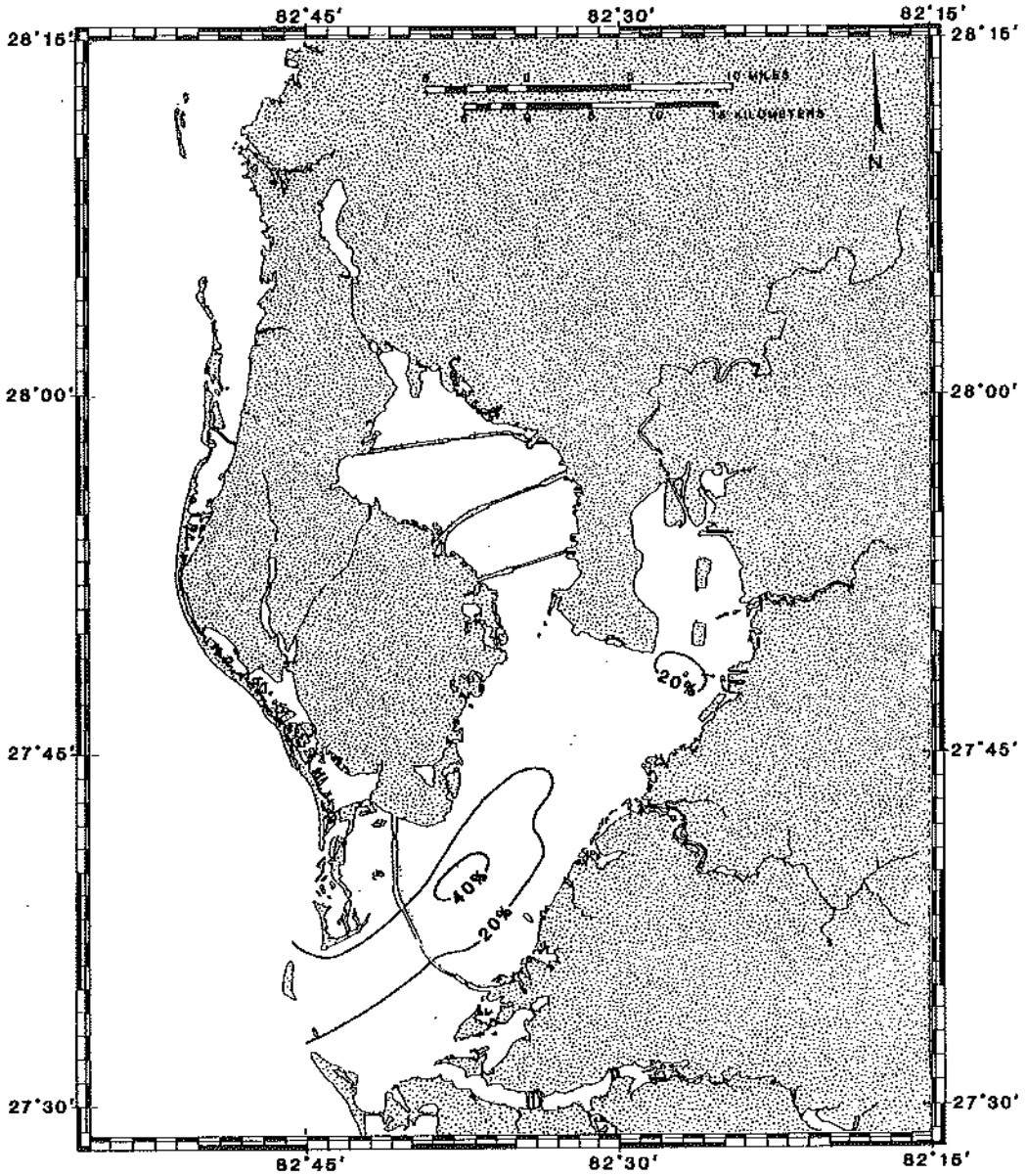

Figure 3. Percent $CaCO_3$. Highest percentages are in the channels with the highest currents. Carbonates are predominantly molluscan shell fragments.

phosphate-bearing sand running from just west of the Interbay Peninsula due south to the eastern shore of the Bay, then southwest to the entrance off Bradenton.

SEDIMENTARY PROCESSES

Sand size sediments which fill the Bay at the present time were probably derived from the four rivers, Hillsborough, Alafia, Little Manatee and Manatee, when they were more competent, during the last rise in sea level. Essentially no sand sized material is being added from these streams to the system under the present high stand of sea level. None of the rivers has formed a delta within the Bay. Streams carry only small loads of fines but it may be that considerable amounts of fine materials are added through surface run-off. Surface sediment within the Bay is constantly being reworked by tidal currents and wind generated waves as well as by dredging. When the sand veneer is dredged from the surface, mud deposits irregularly located beneath may become mobilized. In addition, William Taft has pointed out (personal communication) that dredging tends to be a fining process for the Bay sediments. When spoil is impounded in the physical process of dredging, coarser material is selectively removed but the fine fraction tends to leak back into the system.

Depending on the state of run-off at any one time, Tampa Bay can be classified as a moderately stratified to vertically homogenous estuary (Meade 1972b). Meade (1972a. b; 1982) has postulated (and his theory is widely held) that these types of estuaries serve as fine sediment sinks, that little fine sediment escapes them, and that bottom water movement even tends to bring sediment into the system from offshore.

ACKNOWLEDGEMENTS

Seismic lines were collected in cooperative projects with Dr. Charles Holmes, then of the U.S.G.S., now at Marine Minerals Management Service, Corpus Christi, Texas.

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TERRACES AND SOILS OF THE TAMPA BAY REGION

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ABSTRACT

Soils of the Tampa Bay area are derived from marine deposits known as the Suwannee, Tampa, Hawthorn and Bone Valley formations laid down during the late Oligocene and lower and middle Miocene periods. These geologic formations were further modified by the marine environment and fluctuating sea levels during Pleistocene and recent times with the formation of three Bay proximal (Pamlico, Talbot and Penholoway) and three Bay distal (Wicomico, Sunderland and Coharie) marine terraces in the tri-county Tampa Bay area. Surficially, these are expressed as various soil associations within the terraces as influenced by climate, drainage, mineral and organic content. Residual mineral and organic plus recent marine mineral-shell deposits have developed into approximately 96 classifiable and 23 non-classifiable soil series with measurable chemical and physical properties. Interpretations for potential usage for agricultural, engineering and urban purposes have been determined. Modern soil surveys are available for each of the three counties. A current soil survey using the latest of technological and edaphic correlation procedures has recently been completed for Manatee County and is currently in progress for Hillsborough County, Florida.

INTRODUCTION

Formations. The various soils of the Tampa Bay area are derived from four residual marine deposits which have been subsequently modified in situ by the rising and falling seas and by extensive weathering processes over extended periods of time. Three of these marine deposits are shown in Figure 1, outlining the proximal Tampa Bay and surrounding county areas. The oldest of these is expressed by an outcrop of Suwannee low clastic limestone in northeastern Hillsborough County (Vernon and Puri 1965). This Suwannee limestone is from the upper Oligocene series and contributes to the headwaters of the Hillsborough River which empties into Hillsborough Bay.

Northwestern Hillsborough and northern Pinellas Counties are comprised of soils formed from the sandy, chalky, Tampa limestone of the St. Marks Formation of the lower Miocene period. Relatively minor streams drain this area and empty into Old Tampa Bay.

The southern three-fourths of Pinellas County, a coastal band 13.75-16.5 km (10-12 mi) wide in Manatee, and a band 13.75-27.5 km (10-12 mi) wide running generally southwest to northeast across Hillsborough County comprise the remainder of the lands bordering the Tampa Bay. The soils formed in these areas are from materials deposited during the Hawthorn period of the lower third of the Miocene series. The Hawthorn Formation is composed of marine sands, clays, marls, and sandy limestones, all of which are phosphoritic.

The Bone Valley Formation consists of phosphatic boulders and pebbles in a matrix of phosphatic, sandy clay formed during the middle of the Miocene period and covers the extreme southeastern one-tenth of Hillsborough and the eastern and southern two-thirds of Manatee Counties.

A fifth formation, the Caloosahatchee, once occupied the Tampa Bay and Charlotte Harbor areas. The Caloosahatchee, composed of soft,

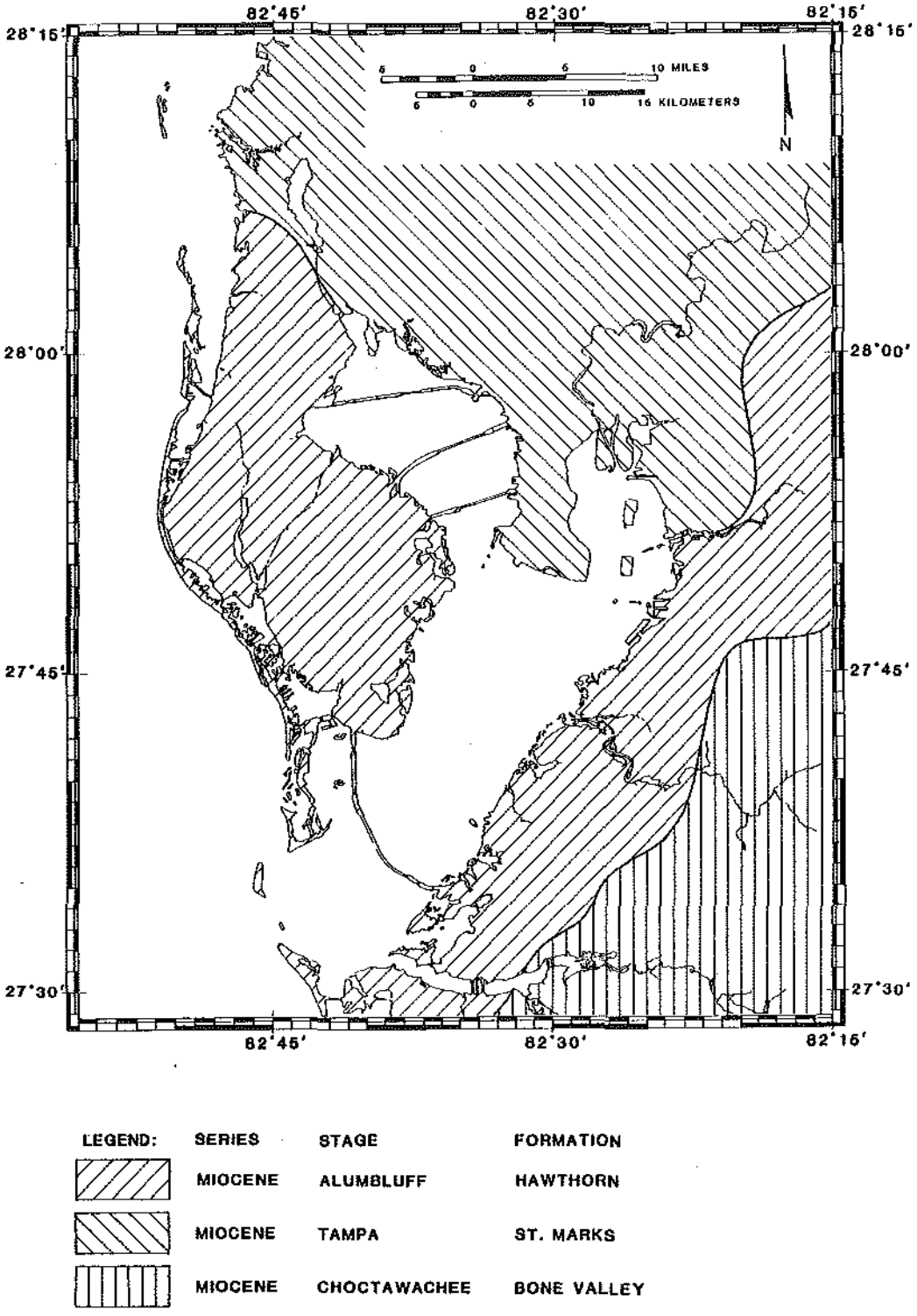

Figure 1. Residual marine deposits in the Tampa Bay area.

low clastic coquina limestone was readily dissolved by the acid waters draining through the Gulf coastal territories occupied by these materials. As a result, little residual siliceous material was deposited and these areas on the west coast of Florida are now dominated by two shallow marine basins. The Caloosahatchee Formation is from the very lowest Pleistocene series.

Drainage. The four principal and remaining formational areas are drained by minor streams and drainageways in Pinellas County (Heath and Smith 1954); by the Manatee River in Manatee County; and principally by the Hillsborough, Alafia and the Little Manatee Rivers in Hillsborough County. The Hillsborough, Palm and Alafia Rivers emptying into Hillsborough Bay and the Little Manatee and Manatee Rivers into Tampa Bay (Rosenau et al. 1977). Each of these rivers, their lesser tributaries, and several other lesser streams carry dissolved and suspended mineral and organic matter into Tampa Bay and its two principal northern subdivisions. All, therefore, contribute to the continual drainage, dissolution and erosive degradation of the land areas surrounding Tampa Bay while concurrently contributing to the continual chemical and physical modification of its waters as well as to the continually shifting land forms on the bottoms and margins of all the lesser and greater Bay areas.

Terraces. Marine terraces may be defined as a terrestrial surface of erosion or deposition (White 1970). Marine terraces are the former bottoms of shallow seas, usually floored with deposits of sand, clay, silt, and shells, and are bounded along their inner margin by shoreline features such as relict beach ridges, swales or inner lagoons, seaward facing wave-cut scarps or sea cliffs, and offshore and bay bars (White 1958).

Portions of five such marine terraces are represented in the three bay area counties (Healy 1975). Four of these terraces are outlined in Figure 2. The Silver Bluff Terrace or most recently formed terrace which bounds much of Florida is not represented in the west central Florida coastline and thus does not appear in the Bay area. The Pamlico Terrace exists at 2.4-7.6 m (8-25 ft) above sea level throughout the Gulf of Mexico and Tampa Bay areas of Pinellas, Hillsborough and Manatee Counties. The Talbot Terrace is found at 7.6-12.8 m (25-42 ft) elevations in Hillsborough and Manatee Counties. The Penholoway Terrace occurs as a relatively narrow band in all three counties and stands at 12.8-21.3 m (42-70 ft) and is generally an outcrop remnant of the Hawthorn Formation. Both Hillsborough and Manatee Counties exhibit a long, narrow, tortuous band of the Wiconico Terrace at 21.3-30.5 m (70-100 ft) with a very small outcrop in central Pinellas. Hillsborough and Manatee contain portions of the Sunderland Terrace from the Hawthorn Formation in northeastern Hillsborough and from the Hawthorn and Bone Valley Formations in southeastern Hillsborough and northeastern Manatee Counties. This terrace occurs at 30.5-51.8 m (100-175 ft) elevations. A very small remnant of the Coharie Terrace occurs at 51.8 m plus (170 ft. plus) in extreme northeastern Manatee County and is from the Bone Valley Formation.

In some areas of each of these three counties the evidence of marine terraces and marine formations are generally co-located. In other areas the marine terraces cut into or across the formations with little regard to their origin. Soil associations or groupings, on the other hand, appear to be the product of terrestrial and/or marine weathering and erosion processes; formational parent materials or minerology; and inherent internal and external drainage regimes as further modified by vegetation, organic degradation and/or accumulation. The greater portions of the soils from the degraded formations are acid in reaction without regard to formational origin or terrace location. Exceptions to this are generally found in the lower terraces adjacent to marine areas. These may consist of mildly alkaline sands, clays and marls. Acid soils, of varying phosphatic content, are

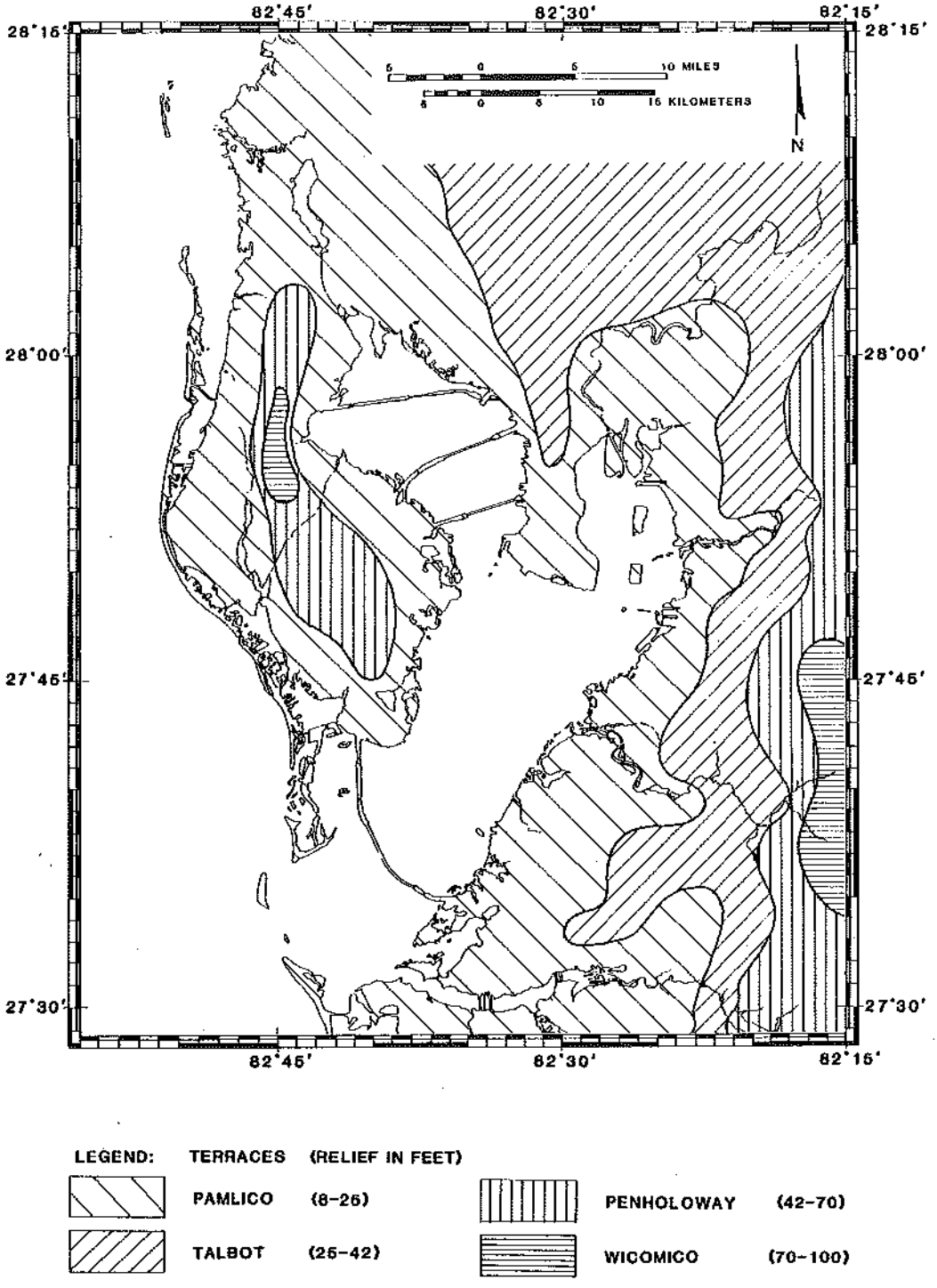

Figure 2. Terraces of the Tampa Bay area.

commonly found in those derived from the Hawthorn and Bone Valley Formations as generally bounded by the Penholoway, Wicomico, Sunderland and Coharie Terraces.

Discussion. Cooke and Mossom in "Geology of Florida", 1929, give an excellent summary of the earlier known facts concerning the formations and structure of Florida. Their work covers the five known geological formations in considerable detail for the counties of the Tampa Bay area plus a detailed map indicating their statewide and local distribution.

White in "Some Geomorphic Features of Central Peninsular Florida", 1958, presents excellent photomosaic and topographic evidence for the existence of widespread marine terraces throughout Florida, including the Tampa Bay area. White, again in "The Geomorphology of the Florida Peninsula", 1970, presents a summary of a wide collection of printed information and much additional photomosaic and topographic data indicating and outlining drainageways and marine terraces throughout much of Florida. He also depicts outcrop formations of broad sections of the State including the terraces and formations on the west side of the peninsula. The publication includes several colorful maps outlining numerous coastal terraced areas.

Pirkle et al. (1970) in "Ancient Sea Level Stands in Florida" outlines a procedure for the in-depth study of shallow to deep stratigraphic formations. This system is equally applicable to geologic investigations in the Bay Area.

Heath and Smith in "Ground Water Resources of Pinellas County, Florida", 1954, present much detailed data concerning not only the groundwater resources of the county, but also much useful and interesting data on the physiographic and stratigraphic aspects of the county.

Rosenau et al. in "Springs of Florida", 1977, (Rev.) give colorful pictorial coverage of most of the major springs of Florida and much information concerning both major and minor springs. Excellent coverage is given on the stream flow and the chemical and physical characteristics of same for the major streams emminating from the springs of Florida, including those of Hillsborough and Pinellas Counties.

Vernon and Puri compiled a "Geologic Map of Florida", 1964, showing in good detail the general outlines of the geologic formations in Florida together with an excellent but brief explanation of each of the formation series.

Healy likewise has compiled a map showing the "Terraces and Shorelines of Florida", 1975. This map covers in excellent general detail the outlines of the Florida marine terrace system and provides an excellent but brief description of each.

SOILS

As stated previously, soils are the product of their mineral composition as modified by all the environmental factors affecting them. However, the net effect is the development of distinct soil series within moderate ranges of differentiation in mineralogical composition and developmental environmental factors. Transitional soils are also recognized in the zones between taxonomically recognized units but are not characterized or named as such. Approximately 96 classifiable soil series and 23 non-classifiable soil series have been identified, taxonomically characterized and recorded in the three soil survey manuals prepared for Hillsborough (Leighty et al. 1958), Manatee (Caldwell et al. 1958), and Pinellas (Vanatta et al. 1972) Counties.

The soil survey for each individual county sets forth the general nature of the area; its location and extent; the physiography, relief and drainage of the area; climate; water supply; native vegetation; social and industrial development; organization and current population; various sociological and industrial data; agricultural development and utilization of the soils and other agriculturally related factors. Their areal extent is shown in Table 1.

Table 1. Approximate acreage and proportionate extent of siliceous soils of Hillsborough, Manatee and Pinellas Counties.

I. CLASSIFIED SOILS	HILLSBOROUGH			MANATEE			PINELLAS		
A. Carbonate-siliceous origin	ha	ac	%	ha	ac	%	ha	ac	%
Adamsville fine sand	2,740	6,767	1.0				1,033	2,551	1.4
Arzell fine sand				285	703	0.2			
Astatula fine sand							8,326	20,564	11.6
Astor fine sand							3,513	8,677	4.9
Blanton fine sand	24,251	59,900	9.0	2,325	5,742	1.2			
Braden fine sand				46	113	<0.1			
Bradenton fine sand	2,417	5,971	0.9	3,586	8,858	1.6			
Broward fine sand				1,391	3,435	0.8			
Delray fine sand	496	1,224	0.2	1,563	3,860	0.9			
Elred fine sand							2,006	4,956	2.8
Eustis fine sand	1,587	3,921	0.6						
Felda fine sand	1,066	2,632	0.4				1,129	2,789	1.5
Huckabee-Kalmia fine sand				191	473	0.1			
Immokalee fine sand	7,589	18,745	2.9	24,635	60,848	13.6	3,206	7,918	4.4
Keri fine sand	496	1,224	0.2	194	480	0.1			
Lakeland fine sand	16,643	41,407	6.2	1,502	3,709	0.9			
Lakewood fine sand	415	1,025	0.2	195	481	0.1			
Leon fine sand	71,336	176,200	26.5	81,455	201,194	45.0			
Manatee fine sandy loam - sandy clay	895	2,210	0.4	1,440	3,558	0.8	243	601	0.3
Myakka fine sand							15,837	39,118	21.8
Oldsmar fine sand							1,481	3,657	2.0
Ona fine sand	12,263	30,289	4.6	2,598	6,417	1.4			
Palm Beach sand							1,779	4,395	2.4
Parkwood fine sand				694	1,715	0.4			
Pinellas fine sand							870	2,148	1.2
Plummer fine sand	7,647	18,889	2.9	2,130	5,260	1.2			
Pomello fine sand	6,185	15,276	2.2	9,489	23,438	5.2	1,190	2,940	1.6
Pompano fine sand	1,934	4,776	0.7	1,104	2,728	0.6	799	1,973	1.1
Ruskin fine sand	3,969	9,803	1.5	1,088	2,688	0.6			
Rutledge fine sand	12,472	30,806	4.6	11,596	28,641	6.4			
St. Johns fine sand				1,239	3,060	0.7			
St. Lucie fine sand	3,787	9,355	1.4	3,728	9,208	2.1	1,458	3,601	2.0
Scranton fine sand	7,930	19,586	2.9	458	1,132	0.3			
Stough fine sand				232	572	0.1			

Table 1 continued.

I. CLASSIFIED SOILS	HILLSBOROUGH			MANATEE			PINELLAS		
A. Carbonate-siliceous origin	ha	ac	%	ha	ac	%	ha	ac	%
Sunniland fine sand	3,187	7,872	1.1						
Wabasso fine sand							1,682	4,154	2.3
Wauchula fine sand							561	1,386	0.8
other (fine sands)	1,484	3,666	0.6				1,292	3,190	1.7
B. Phosphatic-siliceous origin									
Alachua loamy fine sand	91	224	< 0.1						
Arredondo fine sand	6,084	15,028	2.2						
Ft. Meade loamy fine sand	4,090	10,102	1.6						
Gainesville loamy fine sand	2,007	4,658	0.7						
Orlando fine sand	987	2,438	0.3	224	554	0.1	300	742	0.4
C. Organic-siliceous origin									
Brighton peat	862	2,130	0.4						
Istokpoga peat and mucky peat	153	377	< 0.1						
Okeechobee muck							207	512	0.3
Pamlico muck	133	328	< 0.1				236	584	0.3
Terra Ceia peaty muck	343	846	0.1	50	123	< 0.1	474	1,171	0.7
II. UNCLASSIFIED SOILS									
A. Origin various									
Alluvial sand	11,322	27,965	4.2	5,523	13,642	3.0			
Coastal beach				583	1,439	0.3	307	758	0.4
Fresh water marsh				2,909	7,185	1.6			
Fresh water swamp	16,822	41,550	6.2	3,521	8,696	1.9			
Made land	1,652	4,080	0.6	257	635	0.1	6,877	16,987	9.5
Mines, pits and dumps	1,370	3,384	0.5	14	35	< 0.1			
Mixed alluvium	600	1,483	0.2						
Peace River soils	6,406	15,824	2.4						
Shallow ponds (with grass)	6,647	16,419	2.5	9,599	23,710	5.3			
Shell mounds				32	80	0.1			
Spoil banks							177	437	0.2
Tidal marsh	1,950	4,817	0.7	918	2,268	< 0.5	566	1,397	0.8
Tidal swamp	2,631	6,499	1.0	2,791	6,894	1.5	2,169	5,357	3.0
Urban areas and airports	14,739	36,406	5.5	1,243	3,071	0.7	15,334	37,876	21.3

The main topics of the soils survey, however, are the soil series; their areal extent and location; soil association groupings; drainage ranges or characteristics; utilization and productivity; taxonomic characterization; minerology; and residential, urban, commercial, industrial and transportation interpretations.

The soils of Hillsborough and Manatee Counties are recognized by several drainage ranges from those that are excessively drained to those that are very poorly drained. Table 2 gives an alphabetical listing of the soil series common to these three counties and sets forth their relative drainage and flood frequency characteristics. Other categories include tidal marshes and swamps, organic soils, soils of alkaline nature or calcareous association; and urban, disturbed and made lands. The soils of Pinellas are grouped more in regard to association as they influence urban utilization.

The soil series as individually and taxonomically recognized, characterized, described and recorded are set forth briefly in profile descriptions in each of the respective soil surveys. Included along with these descriptions are narrative statements regarding drainage, acidity, alkalinity, or phosphatic nature, basic mineral content, color, textures, organic or mineral content, and other features readily recognizable in the field. Included in these narratives are present or applicable use, agricultural productivity potential, potential urban or industrial usage, and native vegetation.

The local extent of each soil series as it meanders and ramifies over the landscape is depicted on aerial photographs by soil series boundaries and included symbols. Each symbol is referenced to a legend which identifies the soil series or mapping unit if more than one unit is identified within the series.

For each county the soil survey presents interpretive data for use in the development and utilization of the basic soil series for such items as building foundations; lawns and ornamental plants; septic tank filter fields; paved highways, airports, streets, roads and parking areas; unpaved transportation facilities; campsites and picnic areas; playgrounds, golf courses, paths and trails, fallout shelters and basements; and cemeteries. Basic physical data for engineering applications are set forth in the Pinellas Soil Survey.

Careful correlations are performed within the state and within adjacent county areas to assure continuity within and between the recognized taxonomic series.

Basic soil physical characteristics applicable to engineering purposes are detailed very briefly in the Hillsborough and Manatee reports but are much more extensive in the Pinellas Soil Survey Report.

Data for the field soil survey data for Hillsborough and Manatee Counties were compiled in 1948. Engineering and other investigations were completed later and both surveys were published in 1958. Major field work for the Pinellas Soil Survey was performed during the period 1960-1968. Engineering data was completed subsequent to this time and the survey was published in 1972. All are good and accurate presentations of the voluminous data obtained.

Data for updating and revising the Manatee Soil Survey have been obtained, correlated and presented for publication which is anticipated for late 1982. Current investigations for updating and revising the Hillsborough Soil Survey are underway with completion of the field work anticipated by the end of 1984. In both cases the soils are being investigated to a greater depth. The original soil penetration for field mapping was 127 cm (50 in) with pits dug for soil profile characterization 183 cm (72 in) plus. New, correlative mapping is being done manually to 203 cm (80 in) with characterization pits to 254 cm (100 in).

Ground penetrating radar is being widely used in Hillsborough County for soil profile determination along numerous selected soil transects. As the radar unit passes over the selected

Table 2. Soils series, names, their relative drainage and frequencies of soils common to common to the Bay area counties of central Florida.

SOIL SERIES NAME	DRAINAGE	FLOOD FREQUENCY
Adamsville	somewhat poorly	none
Adamsville variant	very poorly	frequent
Anclote	very poorly	none
Apopka	well	none
Arredondo	well	none
Astatula	excessively	none
Basinger	poorly	none
Blanton	moderately well	none
Blanton low	moderately well	none
Boca	poorly	none
Blichton	poorly	none
Bradenton	poorly	none
Brighton	very poorly	none
Broward	somewhat poorly	none
Charlotte	poorly	none
Chobee	very poorly	frequent
Delray	very poorly	none
Delray	very poorly	rare - common
Eustis	somewhat excessively	none
Elred	poorly	occasionally
Eureka	poorly	none
Felda	poorly	none - common
Felda (depressional)	poorly	none
Fellowship	very poorly	none
Ft. Meade	well drained	none
Gainesville	well	none
Holopaw	poorly	none
Immokalee	poorly	none
Istokpoga	very poorly	common
Kanapaha	poorly	none
Kendrick	well	-
Lake	well - excessively	none
Lakeland	excessively	none
Leon	poorly	none
Lochloosa	somewhat poorly	none
Lynne	poorly	none
Malabor	poorly	frequent
Manatee	very poorly	none
Manatee depressional	very poorly	none
Manatee flooded	very poorly	common
Myakka	poorly	none
Oldsmar	poorly	none
Ona	poorly	none
Orlando	well	none

Table 2 continued.

SOIL SERIES NAME	DRAINAGE	FLOOD FREQUENCY
Orlando	moderately well	none - rare
Pamlico	very poorly	rare
Parkwood	poorly	occasional
Pineda	poorly	frequent
Placid	very poorly	none
Plummer	poorly	rare - common
Pomello	moderately well	none
Pomello - occasionally flooded	moderately well	occasional
Pompano - flooded	--	common
Pompano - frequently flooded	--	frequent
Portsmouth	very poorly	rare
Raines	poorly	none
Rutledge	very poorly	common
Satellite	somewhat poorly	none
Scranton	somewhat poorly	rare
Smyrna	poorly	none
Sparr	somewhat poorly	none
St. Johns	poorly	very frequent
St. Lucie	excessively	none
Tavares	nmoderately well	none
Terra Ceia	very poorly	very frequent
Terra Ceia	very poorly	none
Terra Ceia	very poorly	frequent
Tomoka	very poorly	none
Wauchula	poorly	common

landscape the reflected radar wave is recorded by computer type printout. Examples of four soils which are widely distributed in the three Bay Area counties are shown on the following pages (Figs. 3-6). From these, surface and subtending horizons are depicted in graphical fashion. Well-drained sands and deep organic soils provide a reduced reflective pattern and allow deep soils penetration, whereas argillic (clay) and spodic (hard pan) horizons provide strong reflective patterns and consequently reduced depth of penetration. High water tables and shallow bed rock considerably reduce radar penetrability. Soil series within the transects are being verified by manual and visual means.

During the course of a field soils survey and especially during the latter stages, observational pits are dug to depths greater than those generally used for mapping purposes. These pits are selected in areas most typical of a given soil series. Vertical faces of the pits are very carefully observed for all field available data including textures, colors, depths, uniformity, etc. Along with these observations, soil samples are carefully collected from each horizon and properly identified. The samples are then taken to a soils laboratory for detailed chemical and physical examination. These samples are carefully examined for particle size, extractable bases, cation exchange capacity, organic matter content, pH, pyrophosphate extracts such as carbon, iron, aluminum, carbonate content, saturated hydraulic condition, bulk density, water content by weight and volume, clay fraction by spectrographic x-ray and optical analysis as characterized by the Soil Conservation Laboratory of the University of Florida (Carlisle et al. 1981). Averaged data for selected soil series are set forth in the following pages for sand, silt and clay particle sizes; total sand, silt and clay composition of the analyzed samples; and their clay mineralogical composition. These data are representative of many of the more commonly occurring and widely distributed soils of the three county bay area and are shown in Table 3.

The above book also contains the detailed characterization data in direct page by page presentation for ready comparison of the field-collected taxonomic data with the laboratory analytical data. This data is equal to or usually considerably greater in extent than that found in the earlier soil survey reports.

The Florida Department of Engineering Laboratory further analyzes these samples to determine such factors as maximum dry density, optimum moisture content, mechanical analysis of particle sizes, bearing and liquid limits, plastic limits and indices, AASHO class, volume and linear shrink and shrink-swell potential. All these data from the two laboratories are cooperatively published in a series by the University of Florida, Institute of Food and Agricultural Sciences - Soil Science Department, and the U.S. Department of Agriculture, Soil Conservation Service in a series entitled "Characterization Data for Selected Florida Soils" (Carlisle et al. 1978).

CONCLUSIONS

We see, therefore, that a great amount of careful work has been done in Florida to identify, describe, characterize, analyze, tabulate, report and publish not only the soils, regions and origins of Florida in general, but also much work has been done either locally or in associated ways relating directly to the Tampa Bay area. This work has continued over several decades and even now is continuing with renewed and intensive efforts using the latest of scientific means of investigation.

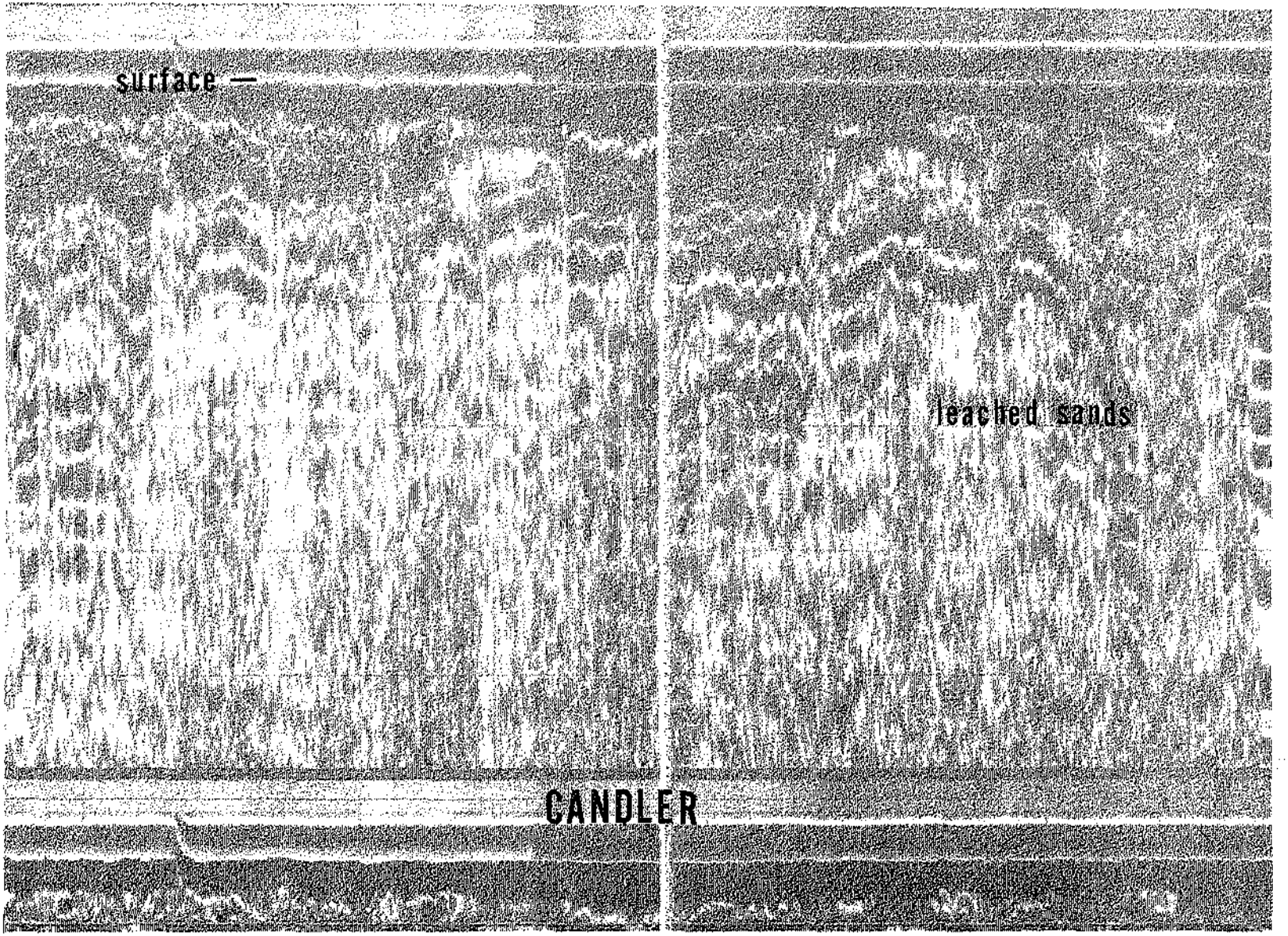

Figure 3.

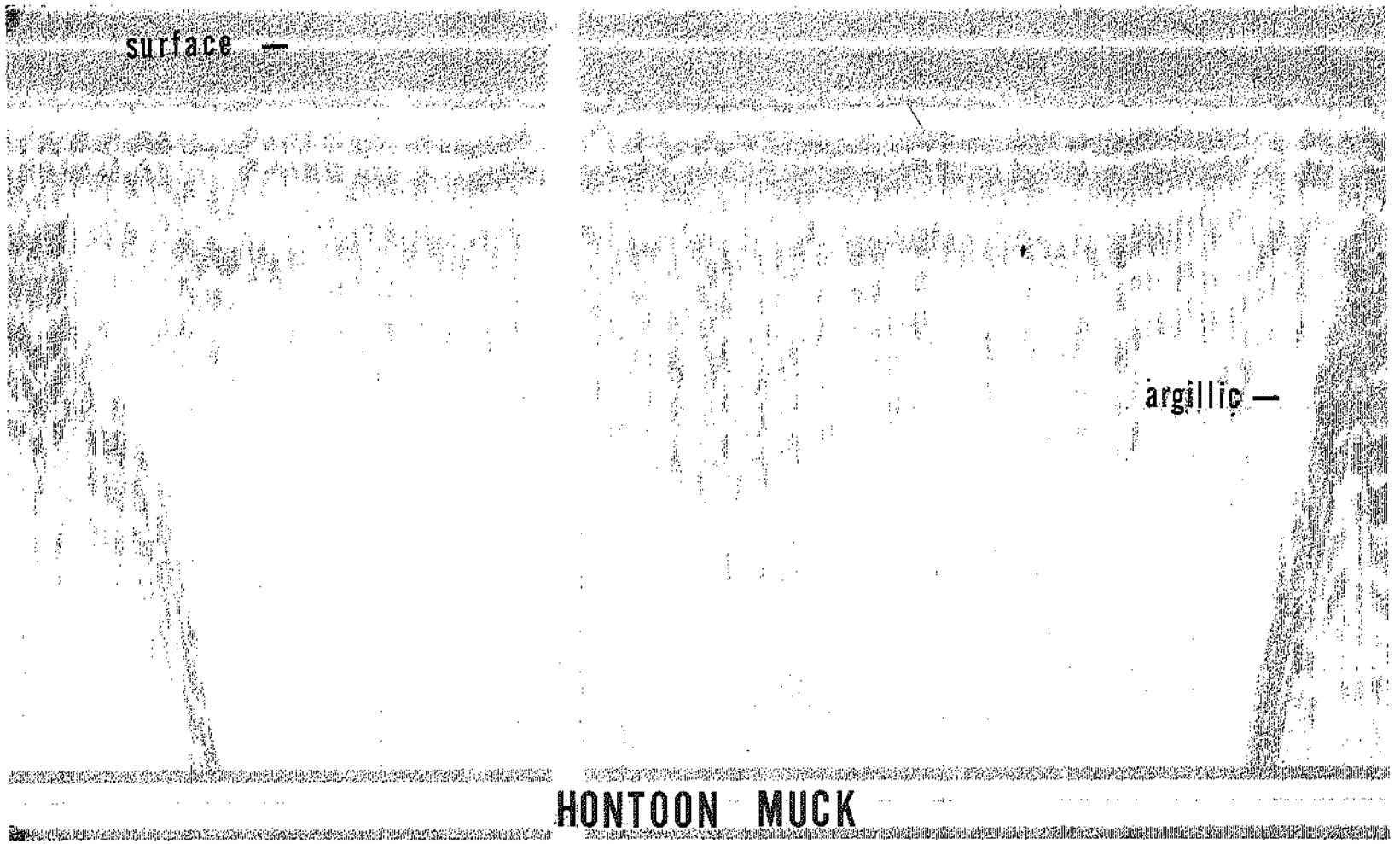

Figure 4.

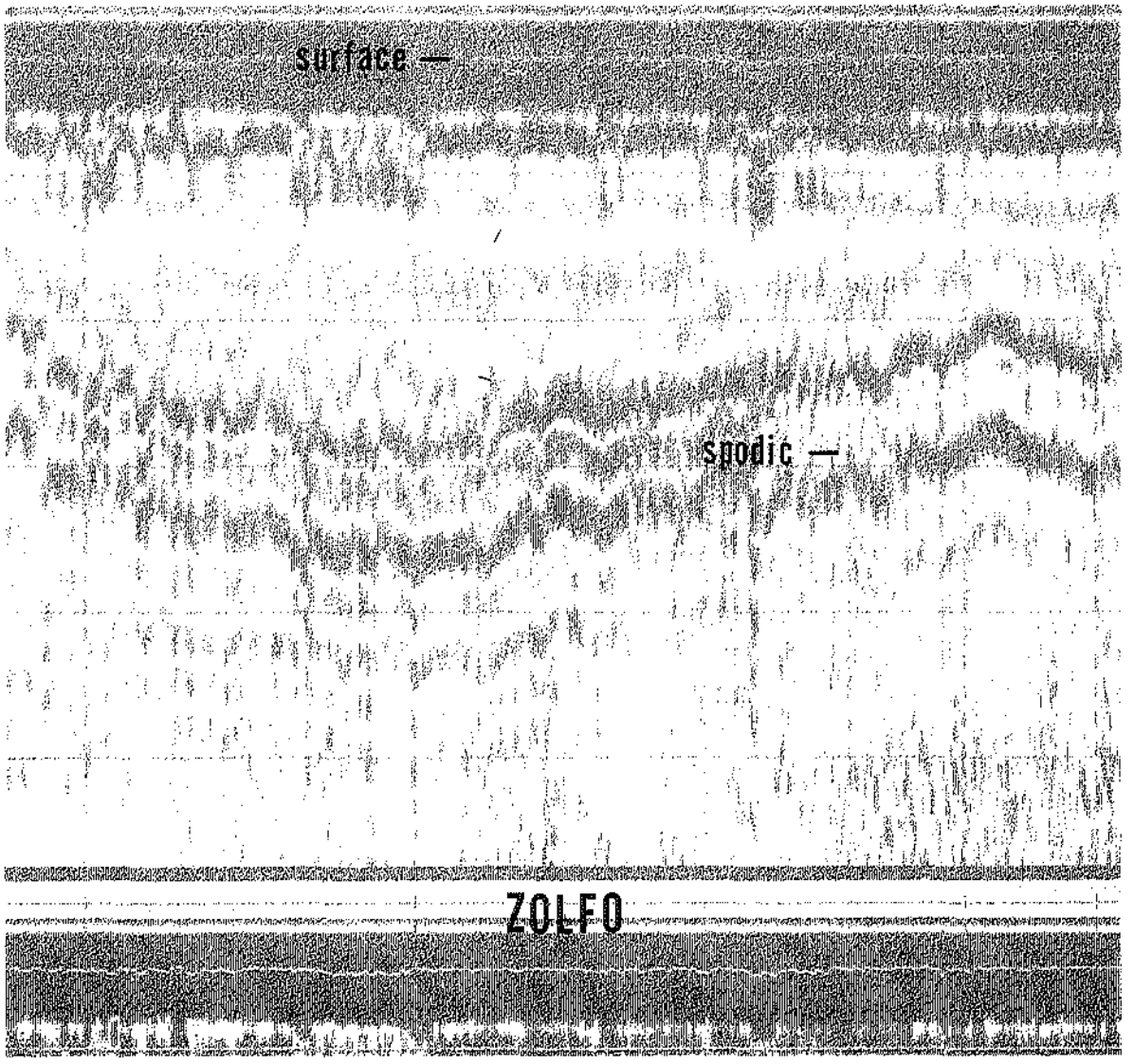

Figure 5.

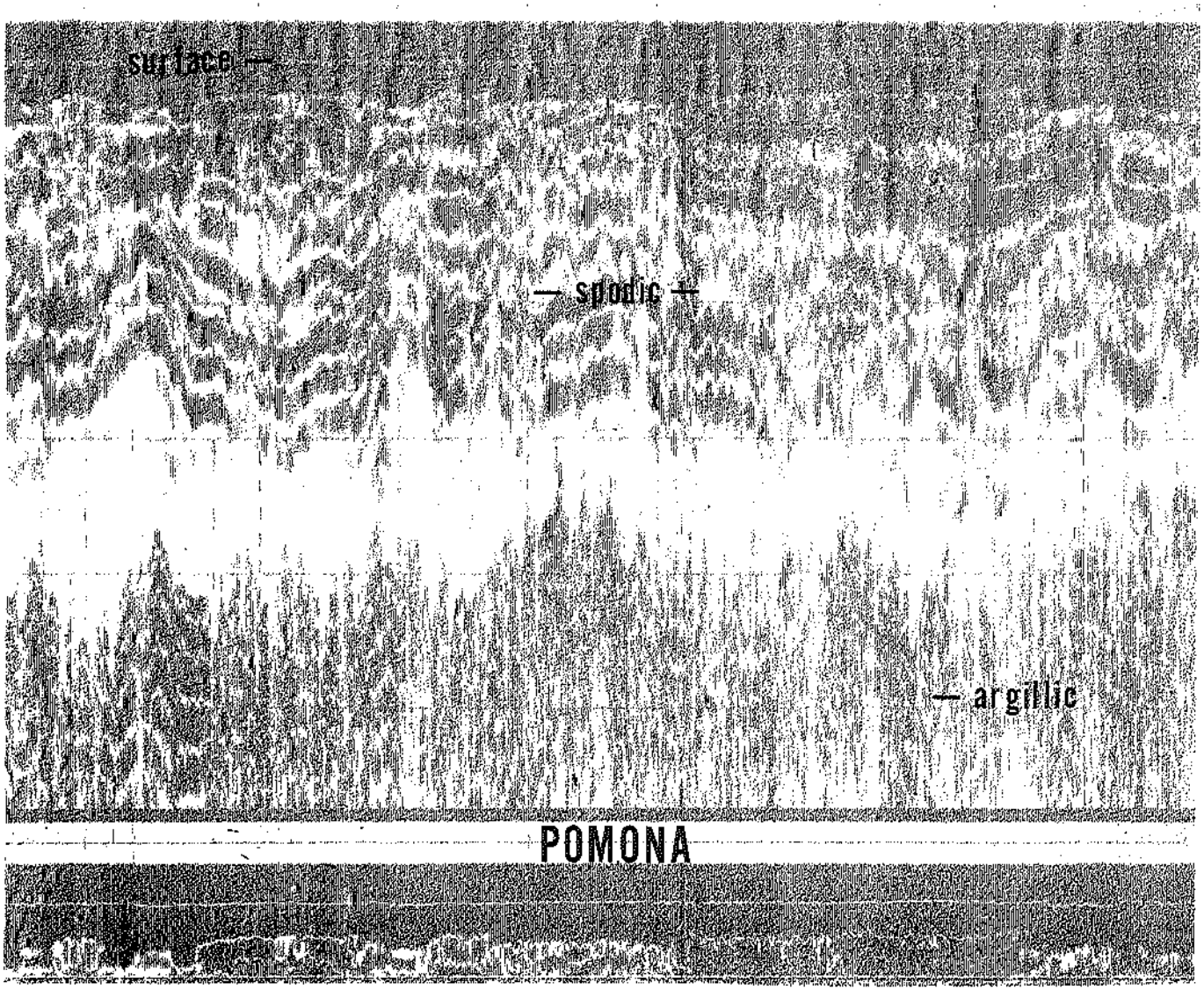

Figure 6.

Table 3. Average soil particle size distribution and mineralogy for selected soils prevalent in the Tampa Bay area.

Soil name and classification	Depth	AVERAGE PARTICLE SIZE DISTRIBUTION (mm) (percent) Sand Fractions VC 2.0-1.0	C 1.0-0.5	M 0.5-0.25	F 0.25-0.10	VF 0.10-0.05	Total Sand 2.0-0.05	Silt 0.05-0.002	Clay 0.002	AVERAGE CLAY MINERALOGY (%< 0.002 mm) MT	MI	KL	GI	QZ
Adamsville, fine sand Aquic Quartzipsamment, Hyperthermic, coated	0-203	0.1	4.7	37.5	45.3	6.9	94.5	3.0	2.5			3.6		35.9
Arredondo, fine sand Grossarenic Paleudult Siliceous Hyperthermic	0-218	0.0	1.4	17.3	49.6	16.2	85.7	4.7	9.7	1.0		22.0		12.2
Astatula, fine sand Typic quartzipsamments Uncoated, hyperthermic	0-216	0.0	0.5	22.6	68.8	6.2	98.0	1.2	0.8	0.3		17.0	8.3	7.8
Blanton, fine sand Grossarenic Paleudult, Siliceous, Thermic	0-206	0.1	1.4	8.0	64.2	12.3	86.0	5.2	8.8		1.4	11.4		17.5
Fort Meade, fine sand Quartzipsammentic Haplumbrepts, Siliceous, Hyperthermic	0-216	0.1	2.6	27.0	53.0	6.9	91.0	6.0	3.4			6.7		23.7
Gainesville sand Typic Quartzipsamments Hyperthermic, coated	0-208	0.1	3.6	30.1	45.4	8.7	87.9	6.3	5.8			16.0		20.6

Table 3 continued.

Soil name and classification	Depth	AVERAGE PARTICLE SIZE DISTRIBUTION (mm) (percent) Sand Fractions VC 2.0-1.0	C 1.0-0.5	M 0.5-0.25	F 0.25-0.10	VF 0.10-0.05	Total Sand 2.0-0.05	Silt 0.05-0.002	Clay 0.002	AVERAGE CLAY MINERALOGY (%<0.002 mm) MT	MI	KL	GI	QZ
Immokalee, fine sand Arenic Haploquod, Siliceous, Hyperthermic	0-201	0.2	5.3	39.3	51.7	0.9	96.5	1.1	2.4	1.1	0.9	7.6	4.4	27.4
Lakeland sand Typic Quartzipsamments, Thermic, coated	0-208	1.4	11.7	51.7	25.1	4.2	94.0	2.9	3.1			4.0	9.8	6.7
Leon, fine sand Aeric Haplaquod, Siliceous, Thermic	0-203	0.0	2.5	1.3	90.7	3.3	95.4	2.4	2.2	4.1		3.4		26.3
Myakka, fine sand Aeric Haplaquod, Siliceous, Hyperthermic	0-208	0.1	1.5	14.9	71.5	5.7	93.7	3.0	3.3	11.1		2.5		18.3
Plummer, fine sand Grossarenic Paleaquults, Siliceous, Thermic	0-203	2.5	10.6	22.7	36.9	12.5	85.2	6.9	7.9	1.9	0.5	8.9	1.5	17
Pomello, fine sand Arenic Haplohumod, Siliceous Hyperthermic	0-203	0.1	1.8	13.2	71.7	10.5	97.5	1.9	0.6	2.1		7.7	3.0	15.3

Table 3 continued.

Soil name and classification	Depth	AVERAGE PARTICLE SIZE DISTRIBUTION (mm) (percent) Sand Fractions VC 2.0-1.0	C 1.0-0.5	M 0.5-0.25	F 0.25-0.10	VF 0.10-0.05	Total Sand 2.0-0.05	Silt 0.05-0.002	Clay 0.002	AVERAGE CLAY MINERALOGY (%< 0.002 mm) MT	MI	KL	GI	QZ
Rutledge loamy fine sand Typic Humaquepts, Siliceous, Thermic	0-208	0.9	5.9	18.3	48.2	16.0	89.2	6.9	4.0			8.5		28.8
St. Lucie sand Typic Quartzipsamments Hyperthermic, uncoated	0-203	0.1	6.9	66.9	24.4	0.6	98.8	0.9	0.3	6.0		1.7		13.7
Tavares fine sand Typic Quartzipsamments Hyperthermic, uncoated	0-216	0.0	1.4	17.4	72.9	6.5	98.4	0.5	1.1			5.0		9.5
Wabasso, fine sand Alfic Haplaquod, Siliceous, Hyperthermic	0-203	0.0	0.3	3.7	54.7	25.3	83.9	5.9	10.2	6.7		12.7		16.5

LEGEND: MT - montmorilonite; MI - mica; KL - kaolinite; GI - Gibbsite; QZ - quartz.

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THE MINERAL RESOURCES OF TAMPA BAY

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The Tampa Bay region, including Pinellas, Hillsborough and western Manatee counties is located in west-central peninsular Florida. This highly industrialized region produces and utilizes large quantities of mineral products. The region is, however, by no means self-sufficient.

Phosphate, uranium, portland cement, limestone, peat, shell, and unclassified sand are presently being produced within the region. Glass sand and bloating clay deposits are among those which, although they are known to exist, require additional exploration before the deposits could be exploited.

Phosphate. Phosphate rock is a mineral commodity of great importance to the Tampa Bay region. Phosphatic sediments are common throughout the region; however, the deposits of economic importance are located in eastern Hillsborough County where several companies are engaged in mining. The majority of the present production from the Central Florida Phosphate District, however, is from Polk County. In 1981 Florida produced 83% of the total U.S. phosphate production (U.S. Bureau of Mines 1982), essentially all of which was shipped through the Port of Tampa either as raw phosphate rock or as phosphate products. In 1979 this accounted for 93% of all exports from the port (Boyle and Henry 1981).

Uranium. Uranium is a by-product resource which can be recovered from the phosphoric acid produced by the acidulation of phosphate rock. The phosphate deposits in the Central Florida Phosphate district contain an average of .015% U_3O_8 (Sweeney and Windham 1979). With present technology, approximately one pound of U_3O_8 is recoverable from a ton of P_2O_5 from the central Florida phosphates. In 1978 three companies (2 in Florida, one in Louisiana) began operation of recovery facilities and three others had started construction on facilities. The 1980 capacity was projected at more than 2100 short tons, an amount which would provide approximately 15% of U.S. requirements (Sweeney and Windham 1979). A significant amount of this resource will be recovered from facilities in the Tampa Bay region.

Portland Cement. Portland cement, although not strictly a mineral, is considered as a mineral resource. The Tampa Bay region has plants operating in Hillsborough and Manatee counties. Cement is composed of limestone or lime, plus minor amounts of silica, alumina and iron. The final composition is determined by the product specifications but generally ranges from Ca_3SiO_5 to $Ca_4Al_2Fe_2O_{12}$ (Lefond 1975). If the minor constituents needed are not present in the limestone, they are added by introducing materials which contain the desired components. Silica sand, staurolite (iron and alumina) and clay (silica, alumina and iron) are commonly added. Fly ash and slag are man-made substances which may be utilized for this purpose.

In the Tampa Bay region, the clay necessary has been mined in Citrus and Hernando counties. In the past, the limestone necessary to feed these plants was mined in Citrus and Hernando counties; however, aragonitic oolite is now being imported from the Bahamas for that purpose (Wright 1973).

Limestone and Dolomite. Limestone resources are limited in the Tampa Bay region. Although extensive limestone deposits are present, the

impure nature of the limestone, coupled with excessive overburden thickness, prevent economic utilization throughout much of the region (Wright 1974). Areas in northeast Hillsborough, northwest Pinellas and western Manatee counties may present viable future mining options (Schmidt et al. 1979). Dolomite from the Hawthorn Formation has been mined from its outcrop belt along the Manatee River and has been quarried for building stone (May 1973).

Peat. Several peat mining operations are active in the Mango - Seffner area of Hillsborough County. The majority of this product is utilized locally to improve soil conditions and for nursery and potting soils. (Wright 1974).

Shell. Shell is or has been produced from several areas in and around Tampa Bay. The Pleistocene shell beds provide good road material and are extensively used for that purpose (May 1973; Wright 1973).

Sand. Sand pits for fill dirt are common throughout the Tampa Bay region; however, most area sands are too fine for many construction purposes. The majority of the high quality construction sands needed in the Tampa Bay region is shipped from the Lake Wales Ridge area of Polk County.

Glass sands (usually 99% pure SiO_2) were mined from the Plant City area of Hillsborough County in recent years. This deposit was of sufficient quality that beneficiation was not required. Deposits similar to the Plant City deposit are present in the region (Wright 1974), but further exploration is necessary.

Clay. Clay deposits and clayey sands are abundant throughout the Tampa Bay region. The majority of these clays, however, are of a noncommercial nature. Wahl and Timmons (1972) reported on the exploration and testing of a commercially valuable clay deposit east of Palm Harbor in northern Pinellas County. This deposit, of primarily montmorillonite and palygorskite composition is a bloating clay with good characteristics for light weight aggregate. Wahl and Timmons also speculated on the locations of similar deposits in other parts of Pinellas County based on the information gained in their study.

SUMMARY

The Tampa Bay region has an active mineral industry which contributes greatly to the regional and state-wide economy. Some deposits are not now economically mineable (some limestone and phosphate deposits) while others require more exploration to delineate profitable deposits (clay, specialty sands).

Several avenues present themselves with regard to fruitful future studies. Exploration for incompletely studied commodities should be undertaken. Research which would result in direct acidulation of phosphate ore, increasing the magnesium tolerance of the beneficiation process, and processes to extract the phosphate from phosphatic clay wastes would all result in an increase in recovered phosphate. Discovery of feasible uses for phosphogypsum would turn a mineral liability into a mineral resource.

It is of critical importance not to let urban spread negate the utilization of valuable mineral resources. With coordination and cooperation between mining and exploration concerns and local and regional planning and zoning officials, this can be avoided.

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COASTAL MORPHODYNAMICS OF THE TAMPA BAY AREA WITH EMPHASIS ON THE BARRIER ISLAND SYSTEM

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ABSTRACT

The Tampa Bay area is dominated by two major coastal depositional systems: a large estuary, and an extensive barrier island complex which borders the open Gulf adjacent to the estuary. The estuary is characterized by low-energy shorelines with prograding salt marshes and mangrove swamps. Natural and man-made beaches are locally present in areas exposed to relatively high wave energy. The barrier island system of west peninsular Florida represents one of the most diverse and unusual coasts in North America. The barriers range widely in size, shape, and age. Related inlets also tend to show a variety of configurations. The combination of a broad, shallow shoreface, irregular distribution of sediment and low mean annual wave height contribute to this diversity. The littoral sediment transport system diverges at Indian Rocks Beach (Pinellas Co.) although there are local reversals. The combination of small waves, small tidal range and large tidal prisms produces numerous tide-dominated inlets within the barrier system. This phenomenon, combined with the drumstick configuration of several barriers, produces an enigmatic coastal morphology.

Although there is much development along the shore in Tampa Bay itself, the most critical areas of development are in portions of the barrier island complex along the adjacent Gulf Coast. Considerable dredge and fill in the bays, construction of causeways, structuring of the shoreline and extensive construction of various residential buildings all have severe impacts on the natural dynamics of the barrier system. Many of these developmental elements have already caused problems which have resulted in considerable expenditure for maintenance. A severe tropical storm or hurricane would have a disastrous effect on such a highly developed barrier complex.

INTRODUCTION

The Tampa Bay area contains a broad range of coastal sedimentary environments. All major types are present except for riverine deltas. Extensive salt marshes, mangrove swamps, some tidal flats, beaches, dunes, tidal inlets, barrier islands and various types of coastal bays are present. These numerous and widely distributed sedimentary environments can conveniently be combined into two coastal depositional systems: an estuarine complex (Tampa Bay) and a barrier island system. Tampa Bay and related adjacent water bodies comprise a large estuarine system with complex morphology and circulation. Adjacent to this estuary is an extensive barrier island system which borders the open Gulf of Mexico.

As a region of rapid and intense development, the Tampa Bay area is experiencing considerable impact on the various sedimentary environments, some of which are quite fragile. Such man-related activities as causeway construction, dredging of ship channels, and extensive construction on barriers can greatly affect the sedimentary processes in the various environments and as a consequence, their morphology as well. In order to make responsible

decisions for proper coastal management it is necessary to have geologic-based data on the natural coastal environments. Such data will provide baseline information for design of appropriate development, if any, and for comparison with areas already developed. The Tampa Bay area has a broad spectrum of situations ranging from pristine coasts to those which are totally developed and greatly modified.

The following discussion will consider some general aspects of the natural coastal sedimentary environments emphasizing the barriers along the Gulf. Comparisons will then be made between the natural morphodynamics of the system and that which takes place after it has been severely impacted by man. Some site-specific examples will be used.

GENERAL SETTING AND CONDITIONS

The geologic age of Tampa Bay is not specifically known. The Bay may have originated from erosion during low stands of sea level during glacial advances of the Pleistocene. Some geologists feel that the morphology of Tampa Bay may be inherited from the Tertiary Period, as long as 10-15 million years before present.

Tampa Bay is a large, rather low energy estuary with a constricted opening to the Gulf of Mexico. Runoff of surface water and sediment is largely restricted to the eastern margin of the bay where the Hillsborough, Palm, Alafia, Little Manatee and Manatee Rivers enter the bay. Actually there is little terrigenous sediment being carried to the estuary by these rivers. Similarly there does not seem to be much sediment entering Tampa Bay from the Gulf.

Tides in the entire area are in the microtidal range with spring tides generally less than 80 cm. Such conditions do not result in extensive tidal flats but salt marshes and mangrove swamps are widespread. The size of Tampa Bay and its single, constricted entrance produces a large tidal prism with swift currents in the mouth of Egmont Channel. Similarly, the tidal inlets in the barrier island system serve a large area between the islands and the mainland, thus producing rapid currents in the inlets.

Waves in the Bay rarely exceed 50 cm. Prominent directions of wave propagation are from the southwest and north with largest waves associated with the passage of frontal weather systems in the winter months. Limited fetch for most of the shoreline results in only minimal wave-generated erosion although local effects may be significant, especially where reflection from seawalls takes place. Northerly winds tend to be the strongest and may cause abnormally low tides due to the frictional effect of wind pushing water out of the bay.

Waves on the Gulf barrier system may exceed a meter in height during passage of frontal weather systems during winter. Although some beach erosion is common during these conditions, there is typically a recovery period of beach accretion between storms or for a prolonged period during the summer months.

Intense storms such as hurricanes are infrequent on the west coast of the Florida peninsula. In fact, the last one of any consequence was in 1960 and little damage was incurred. Much of the development on the barrier systems has taken place since that time; consequently, the Pinellas County coast as we now see it has not experienced a hurricane. In some ways this circumstance has created a false sense of security among coastal residents.

TAMPA BAY SHORELINE

The shoreline of the Tampa Bay estuary spans a complete spectrum from the pristine areas of southern Hillsborough County such as Cockroach Bay to totally developed industrial areas along the northern part of Hillsborough Bay. Virtually all types of development are included: municipal utilities, residential, military, heavy industry including deep-water ports, and recreational areas.

The distribution is somewhat spotty, although most general development is along the Pinellas County shore and on the Interbay Peninsula and related metropolitan Tampa. The northern end of Old Tampa Bay and much of the shore in southeastern Hillborough County is relatively undeveloped but with locally intense development. Included in the latter would be the Port of Manatee and the Big Bend power station. Seawalls, groins, breakwaters and other coastal structures are prevalent and typically are associated with areas of development.

The unstructured natural shoreline consists of marshes, swamps or beaches. Marshes and swamps have developed along protected coasts where incident wave energy is low. Some narrow sandy shores may border these areas. Beaches and related sandy nearshore areas tend to be associated with areas where fetch is long and wave energy is relatively high. Some occurrences of sandy beaches may be associated with waves produced by passing vessels; the southeast side of Davis Island is an example. Numerous shore-parallel and closely spaced sand bars occur along various sandy shores of Tampa Bay. The number and size of the bars varies from site to site. Although their origin is not well understood it is probably related to wave parameters and slope of the bottom. Such sand bars are common in coastal bays throughout the world.

Modifications of the Tampa Bay shoreline also include the construction of causeways, of which there are four, and the formation of new islands from dredge spoil. Although the islands are distinctly separated from the mainland shore they have some impact on it because of effects on waves and currents. Refraction of waves around islands may result in either an increase or a decrease in wave energy at various mainland shoreline locations. These islands may also cause perturbations of tidal currents which could change sediment transport patterns along the shore. It is not likely however that either of these effects would be severe.

Causeways, on the other hand, may have great impact on the dynamics of the bay system. There are typically two styles of causeway construction, one built on pilings and one where fill is dominant. The latter is the type that can cause problems. Causeways built on pilings have minimal interference with tidal circulation but those where the road is on fill cause severe restrictions on circulation. The Courtney Campbell Causeway and the Sunshine Causeway have much of their extent on fill. This inhibits tidal flushing which can lead to water quality problems. It also causes locally intense tidal currents which will scour the bottom, change sediment transport and distribution patterns, and may modify the shoreline locally.

In general, the shoreline of Tampa Bay is stable except for man-related modification. No natural areas are experiencing severe erosion, nor are any accreting sediment rapidly. Most sediment movement along the shore is local and related to waves, wave-generated currents and tidal currents.

PINELLAS BARRIER ISLAND SYSTEM

The barrier islands along the coasts adjacent to the entrance of Tampa Bay form one of the most expensive sections of real estate in all of Florida. These barriers are the northernmost portion of a barrier island chain that extends from the Pinellas - Pasco County line to Cape Romano near Marco Island. Although the barriers in Manatee County are also adjacent to Tampa Bay, the emphasis in this discussion will be on Pinellas County. More is known about this area; it provides excellent contrasts, and it has many examples to consider.

Although barrier systems are commonly rather straight, the Pinellas County complex displays a marked deviation from this trend because of the protruding mainland coast centered near Indian Rocks Beach (Figure 1). The presence of totally developed barriers such as Sand Key and Clearwater Beach Island provides a marked contrast with nearly pristine examples such as Mullet

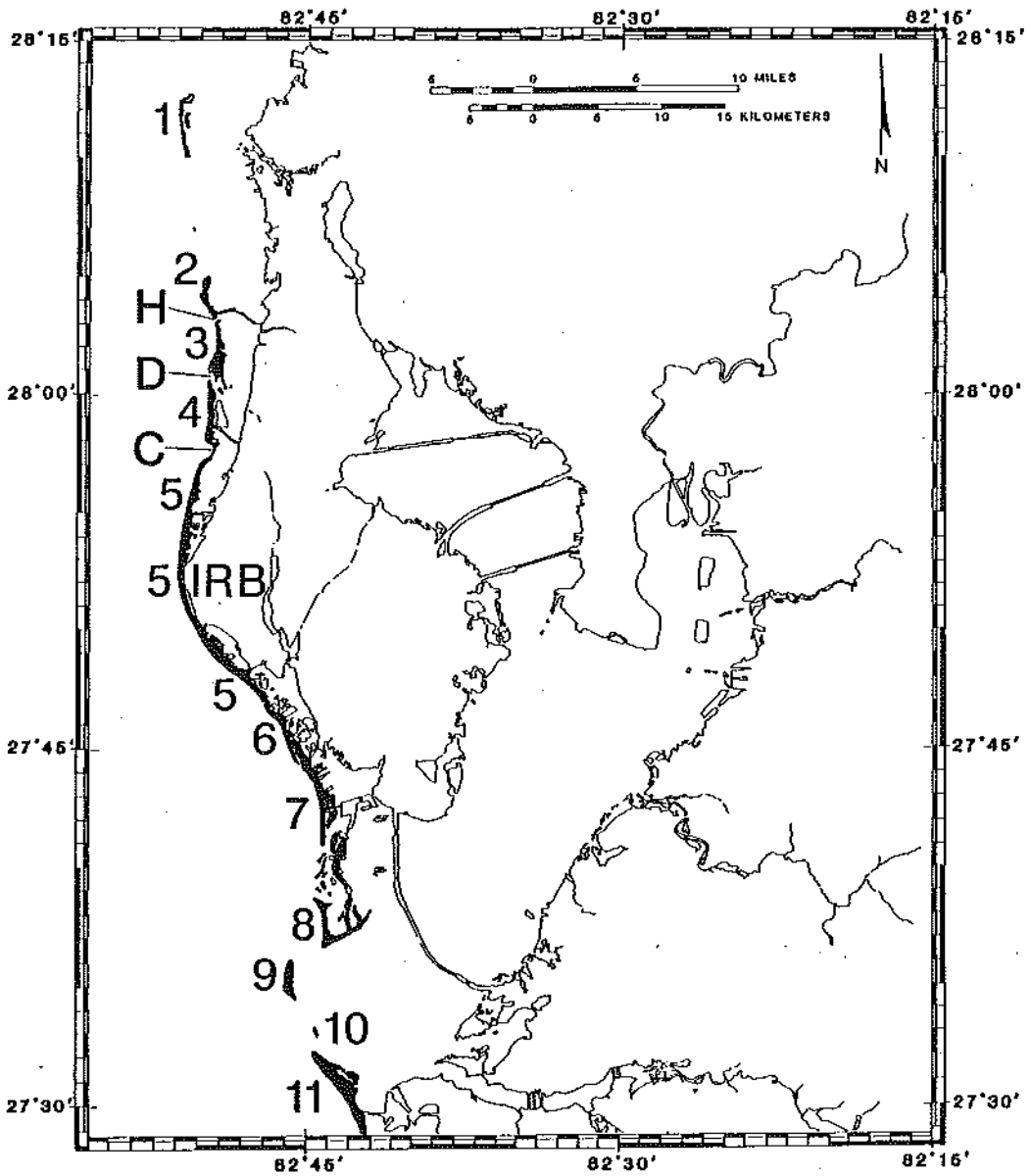

Figure 1. The Tampa Bay area, showing the estuary system and the Gulf Coast barrier island complex.

Key, Caladesi Island and Anclote Key which are used exclusively as recreational barriers. In order to grasp the impact of development on the Pinellas County barriers it is necessary to consider the natural process-response system which operates on coastal barriers.

Barrier Island Dynamics. Although barriers may result from any or a combination of three styles of origin, once they have formed, the morphology and processes to which they are subjected are rather uniform. The major components of the barrier system include the nearshore and surf zone, beach, dunes, washover apron, and the coastal bays which separate the islands from the mainland. Inlets typically interrupt the continuity of the barriers and provide for tidal circulation as well as pathways for vessels and migration of animals.

Most of the microtidal Gulf Coast contains long, rather straight barriers with widely spaced inlets; however, the Pinellas County barriers display a morphology which is similar to mesotidal coasts (Hayes and Kana 1976). The barriers are short with a "drumstick" shape and numerous inlets are present.

Although tidal range and wave energy are low, the barriers do exhibit considerable change over short periods of time in response to these processes. The inlets have well-developed tidal deltas, especially the ebb deltas. These large protruding sediment bodies produce wave refraction patterns which cause local reversal of the littoral drift system and lead to the drumstick configuration (Figure 2). The result is a downdrift offset of the inlets which is common throughout barrier systems of the world (Goldsmith and Colonell 1970).

One of the best examples of the dynamics of a natural barrier is that of Caladesi Island. This island is rotating clockwise and migrating northward, which is the direction of net littoral drift (Lynch-Blosse and Davis 1977). The inlet at its southern end, Dunedin Pass, is an ebb-dominated inlet with a large ebb delta. The inlet is eroding rapidly on its north side and the spit on the north end of Clearwater Beach Island is migrating rapidly to the north. This spit has been extended about one kilometer in the past century (Figure 3). In addition the spit

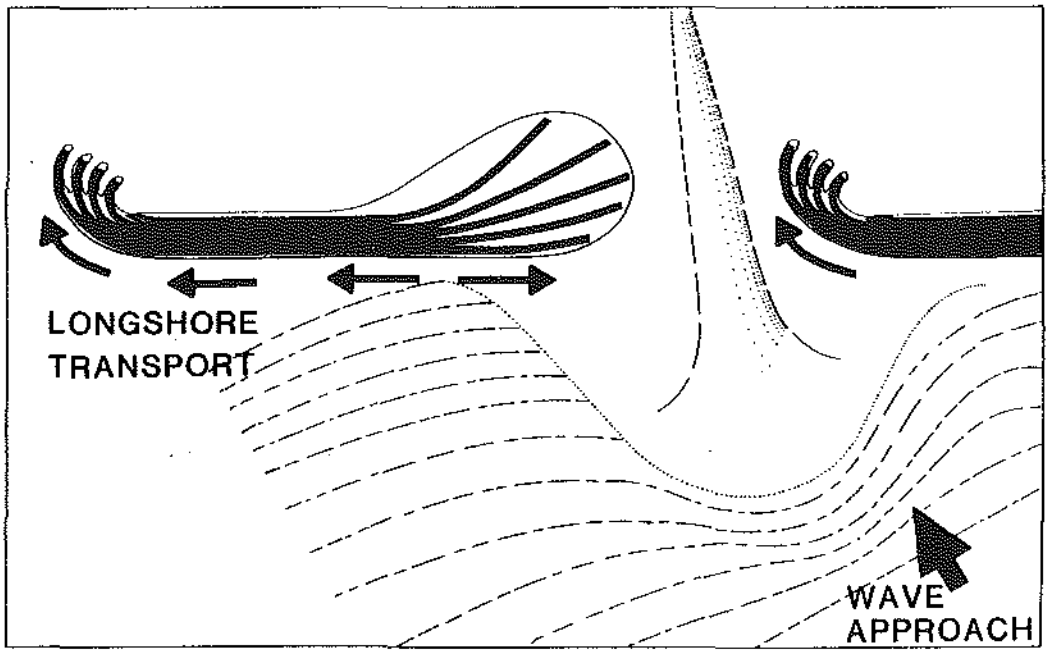

Figure 2. Drumstick model barrier island showing major open water processes and general morphology (after Hayes and Kana 1976).

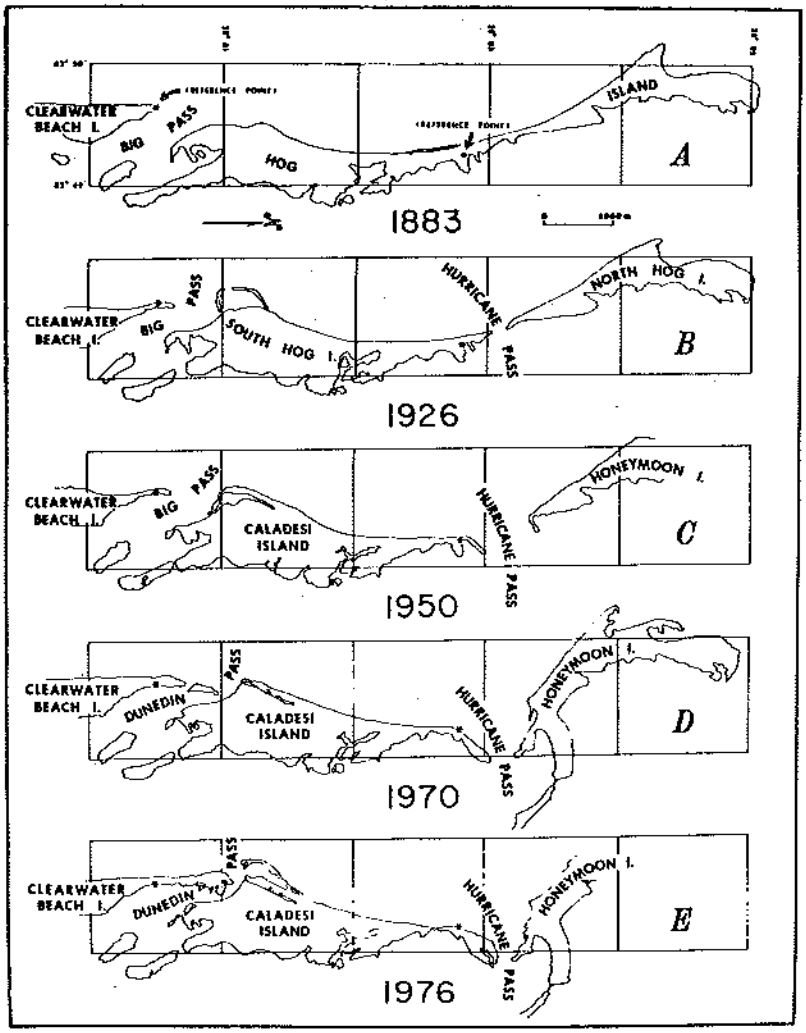

Figure 3. Coastal changes during the past century on Caladesi Island and adjacent tidal inlets. Hurricane Pass was generated by the 1921 hurricane. Note the location of reference points (from Lynch-Blosse and Davis 1977).

at the north end of Caladesi Island is growing northward. The result is a northward migration of Dunedin Pass and of Caladesi Island.

Caladesi Island is rotating clockwise with rapid Gulfward progradation in the southern part and landward migration due to erosion and washover on the northern part. This rotation has reoriented the axis of the island about 13^{o} in the last century (Lynch-Blosse 1977). The combination of these process-response systems has caused the island to change both its configuration and location in a rather short period of time.

One of the important natural processes that takes place on barriers, especially those areas with little or no development of dunes, is the washover of sediment during storm conditions. This process is the primary agent whereby barriers migrate landward. The combination of large waves and elevated water level caused by onshore winds (storm tide or storm surge) causes water to overtop low lying portions of islands and carry sediment from the beach or dunes to the back of the island or even into the bay. These fan-shaped accumulations of sediment are called washover fans. They are common along most Gulf Coast barriers and may be both widespread and large after tropical storms or hurricanes. Washover fans can be generated by minor frontal systems especially if the passage of the weather system is coincident with high tide.

Impact of Development on Tampa Bay Barriers. Numerous modifications of barriers that are associated with man have detrimental effects on the natural dynamics of the system. These include construction of seawalls, jetties, buildings, causeways, and the dredge and fill which is common along coastal bays. All of these tend to interfere with the natural dynamics of the barrier system and tend to create problems which may become very costly.

Structures such as seawalls, jetties, groins and buildings inhibit or may prevent the transport of sediment along the Gulf side of barriers. Jetties and groins are typically perpendicular to the shore and as a result act as dams to the littoral drift system. Consequently the "river of sand" that moves along the beach and surf zone may be interrupted. Locations downcurrent from such structures may be deprived of sediment and thus are more susceptible to erosion than would otherwise be the case. Jetties may cause modifications to ebb tidal deltas and thus change wave refraction patterns or incident wave energy. This may also produce local erosion problems. Seawalls and buildings provide another impairment to normal sediment transport phenomena. Both impact the ability of sediment to be carried across the barrier by washover processes. Seawalls inhibit or may prevent waves from breaking at the shore and washing onto or over the beach. In many cases, they also cause waves to be reflected and scour at the base of the seawall. The result may be both expensive and unsightly. Buildings which are not elevated on stilts or pilings also act as barriers to washover. Even those buildings that are elevated can cause scour depressions from washover during severe storms. A visit to a developed barrier such as Sand Key or the Pass-a-Grille area after even a modest storm will provide ample evidence of these situations. Not only are streets and yards covered with sand but seawalls and residences may be damaged or destroyed.

Tidal fluctuations and the currents associated with these tides also play an important role in the dynamics of the barrier island system. The dredge and fill in Boca Ciega Bay, Clearwater Bay and St. Joseph Sound has drastically altered the area of the coastal bay system. For example, Boca Ciega Bay has incurred a 20% reduction in area as the result of this type of development (Simon 1974). This causes a corresponding reduction in tidal prism which then destroys the equilibrium conditions of inlets that service this bay, i.e. Blind Pass and Johns Pass. The result is that the inlets tend to decrease their cross-sectional area by shoaling,

narrowing or a combination of both.

Related to this situation is the construction of causeways which are dominated by fill. This results in considerable change in circulation within the bay system and may also cause related changes to the nearby inlets. Data show that construction of the Clearwater Causeway in 1921 had an impact on Clearwater Pass and that the Dunedin Causeway, built in 1963-64, probably affected Dunedin Pass (Coastal and Oceanographic Engineering Laboratory 1973; Lynch-Blosse and Davis 1977). In both situations a drastic and rapid narrowing of the inlet followed causeway construction (Fig. 4).

Another activity of man which causes problems in the inlets of the barrier system is the dredging of inlets. Each inlet carries a certain volume of water as tides flood and ebb. There is also a tendency for adjacent inlets within a barrier system to have some interdependency of tidal circulation. For example, one inlet may be flood dominated and the adjacent one ebb dominated. When causeways segment the bay system this interdependency becomes even more pronounced. If an inlet is dredged, one of two things typically happens in response: 1) the inlet accumulates sediment rapidly and achieves or approaches its pre-dredging state, or 2) the adjacent inlet will accumulate sediment and may result in other problems.

In summary, any type of development activity which interferes with the normal process-response mechanisms of a coastal system will have deleterious effects. Most of these problems will result in very high maintenance or repair expenditures. This is not to say that all development will cause or has caused problems for the barrier system. It is critical, however, to plan properly and to avoid interference with the natural dynamics of barrier and other coastal systems. Change on the coast is normal and to be expected; it must be accomodated.

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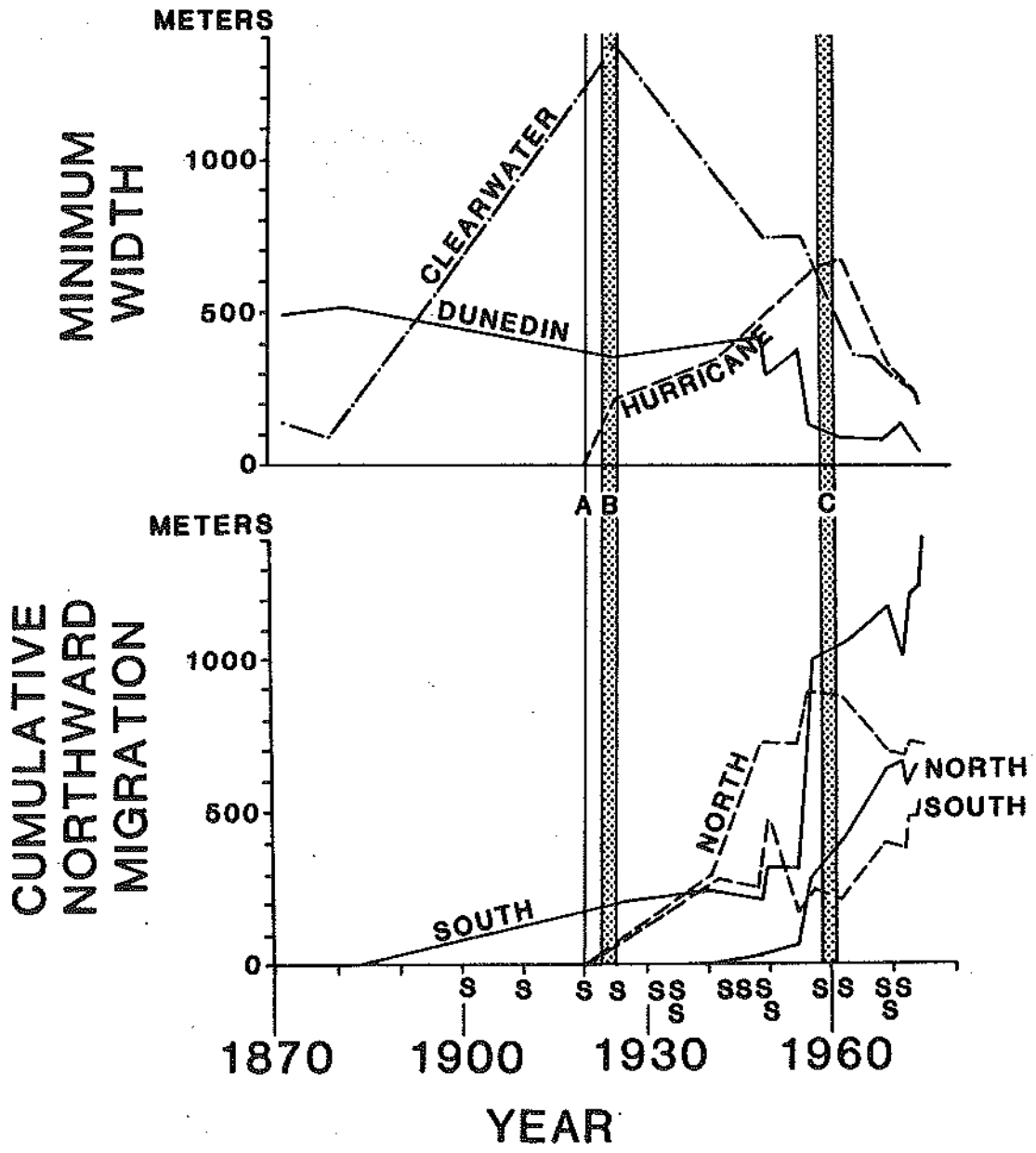

Figure 4. Changes in minimum width and cumulative migration of northern Pinellas County inlets: A is formation of Hurricane Pass; B is the construction of Clearwater Causeway; and C is the construction of Dunedin Causeway. Major storms are denoted by S (from Lynch-Blosse and Davis 1977).

STRUCTURAL FRAMEWORK AND MOVEMENT OF REGIONAL GROUNDWATERS

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ABSTRACT

The geologic units underlying the Tampa Bay area can be divided into three principle hydrostratigraphic units. The first unit, the semi-confined aquifer (Floridan Aquifer), was formed before mid-Miocene time and consists of limestone and dolostone. The second unit, the semi-confining layer, was deposited during the mid- to late Miocene. The material is interfingered phosphatic sands, clays, and limestones. The uppermost unit is unconsolidated Pliocene and Pleistocene sands, silts, and clays. These units dip and thicken toward the southwest. The regional groundwater movement is towards Tampa Bay. The flow net and flow directions vary due to seasonal changes in the potentiometric surface caused by pumping centers. The degree of interconnection between the semi-confined aquifer and Tampa Bay is not well known. The amount of groundwater flow into the Bay is influenced by the relationship between the water table and potentiometric surface, the thickness of the semi-confining layer, and the position of the saltwater interface. A rough estimate of the quantity of flow would be possible if adequate information were available for aquifer characteristics such as transmissivity, storativity, specific yield, and the position of the saltwater interface.

INTRODUCTION

In the period from 1960 to 1980, the area comprising Pinellas, Hillsborough, and Manatee Counties experienced an 81% population increase from 841,600 in 1960 to 1,523,800 in 1980 (U.S. Census 1970; University of Florida 1981). This rapid growth has increased the demand for fresh (potable) water which is used to serve domestic, industrial, and agricultural needs. A projected growth of about 300,000 people by the year 2,000, along with an increase in the number of industries, will further increase the demand for potable water.

Growth may be beneficial for the local economy, but can have adverse effects on the supply of fresh water. Two of the more serious effects are infiltration of pollutants into the groundwater supply, and induced saltwater encroachment.

As storm water runoff and/or discharges from industries infiltrate into the groundwater supply, the water may carry with it pollutants harmful to plants and animals or may encourage the reproduction of harmful bacteria. Industrial and municipal pollution from seepage lagoons, "midnight dumpers," landfills, and unregulated industrial discharges constitute a serious hazard to groundwater quality in an urban area.

Saltwater may also be considered a pollutant. As water is pumped from an aquifer, water moves towards the pumping center. In coastal areas, this movement may include saltwater, thus increasing the chloride content of the groundwater. Saltwater encroachment has long been a problem in south Florida, but more recently has become a major concern in the Tampa Bay area. Due to a lack of potable water and saltwater

encroachment, the city of St. Petersburg and Pinellas County developed well fields in Pasco and Hillsborough Counties beginning in the 1950s. The development of other well fields in the future is likely, as are conflicts between water importers and exporters.

The increased demand has made potable water an increasingly important natural resource. As with any natural resource, over-exploitation and mismanagement can yield unwanted consequences. Therefore, a thorough understanding of this natural resource is necessary by those involved in planning and management decisions concerning growth and development in the Tampa Bay area. This paper summarizes the geologic framework and hydrogeology of the Tampa Bay area and examines the groundwater flow patterns and areas of discharge.

GEOLOGIC FRAMEWORK

The Tampa Bay area rests on a sequence of sedimentary rocks overlying a basement rock of Pre-Mesozoic igneous and metamorphic rocks. These igneous rocks consist of a probably time-related group of diabases, basalts, and rhyolites that extend from the Florida state line and continue as far south as Lake Okeechobee (Milton 1972). Overlying this basement is a sequence of interbedded shale, limestone, and anhydrite (Peek 1958). Above this basal section of the sedimentary sequence is a carbonate platform that underlies all of Florida and Georgia, extending northwestward through Georgia and South Carolina into North Carolina (Stringfield and LeGrand 1966). The carbonate platform can be divided into several sequences based on changes in lithology, fossils, and the occurrence of unconformities. Often these divisions represent a change in the depositional environment. The formal nomenclature and boundaries of the sequences are the basis of many unresolved controversies. In general, the carbonate sequence includes in ascending order: the Cedar Keys Formation, the Lake City Limestone, the Avon Park Limestone, the Ocala Group, the Suwannee Limestone, and the Tampa Formation (Peek 1958). The following general descriptions of the hydrologically important sequences are compiled from the following sources: Carr and Alverson (1959); Cherry et al. (1970); Heath and Smith (1954); Menke et al. (1961); Peek (1958); Puri (1957). See Figure 1.

Avon Park Limestone: middle Eocene; ranges from white or tan, soft, coquinoid or granular limestone, to dark brown, hard, crystalline dolomite; very fossiliferous, containing bryozoans, corals, echinoids, mollusks and foraminifera; generally very permeable due to the development of solution channels; thickness ranges from 200 feet to 700 feet.

Ocala Group: late Eocene; cream, tan, and grayish-tan, soft, chalky limestone; highly fossiliferous containing ostracods, other crustaceans, foraminifera, mollusks and echinoids; limestone consists mostly of foraminiferal coquinas in a pasty limestone matrix; foraminifera and ostracods are important as stratigraphic indicators; the lower part contains beds of brown and tan, hard, crystalline dolomite and dolomitic limestone; lies unconformably on underlying formations; thickness ranges from 80 feet to 500 feet.

Suwannee Limestone: includes all deposits of Oligocene age and lies unconformably on underlying formations; is generally a creamy-white to tan, soft to hard granular porous limestone, with some beds of crystalline and dolomitic limestone; contains only a small percentage of very fine grained quartz sand, but contains abundant fossil detritus and organic structures including casts, molds, and borings of mollusks and tests of foraminifera and bryozoa; echinoids are also abundant; the lower part of the formation is generally tan to gray, and it is harder, more crystalline, more dolomitic, and less fossiliferous than the upper part; porosity is high; thickness ranges from about 50 feet to 300 feet.

Tampa Formation: early Miocene; lies unconformably on the Suwannee

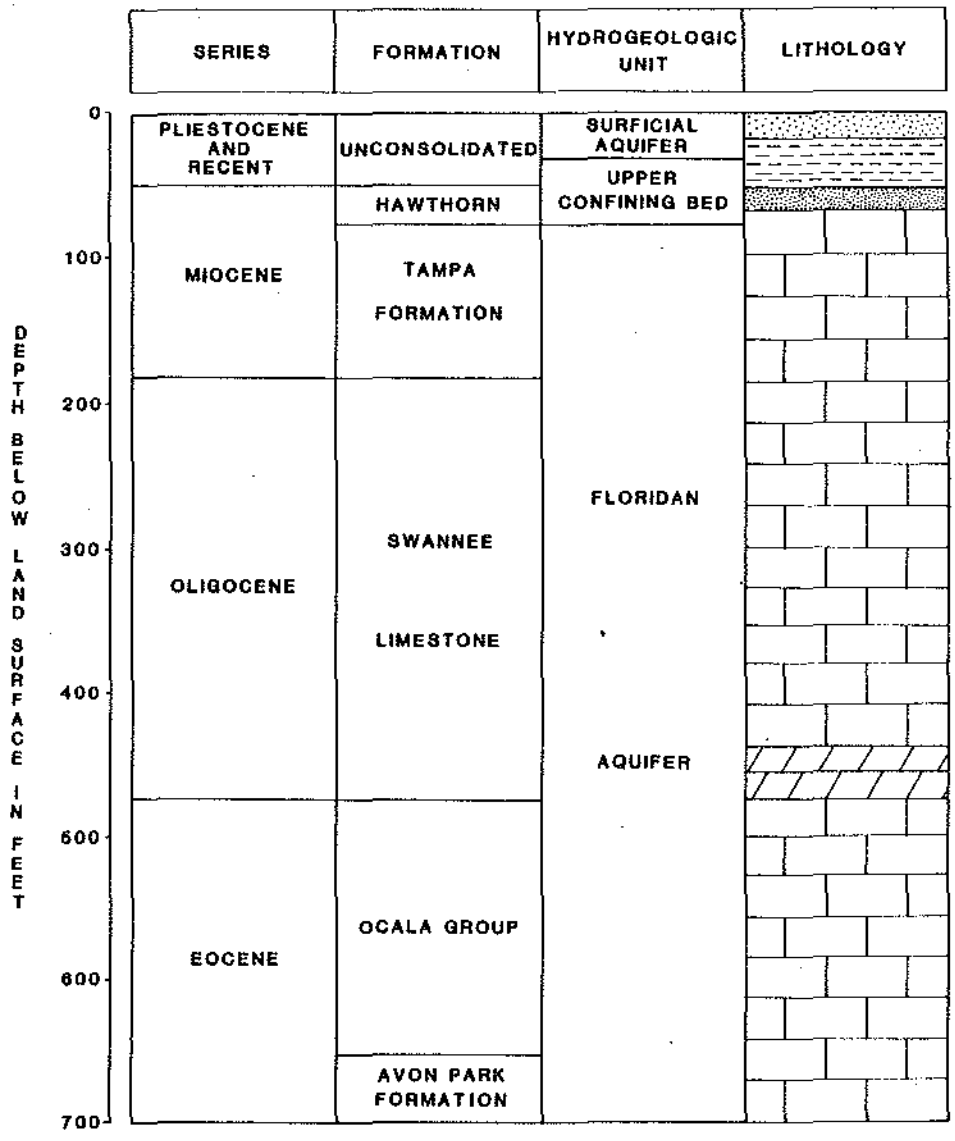

Figure 1. Stratigraphic and hydrogeologic section, upper 700' of well 1669.

Limestone; white to light yellow to gray, soft to hard, moderately sandy and clayey limestone; contains fine grained phosphorite in some places; and is crystalline and dolomitic in part; contains thin beds of chert. Both fresh water and marine limestone are present. Fossil remains constitute up to 90% of the rock in places. Fossil molds give this rock a high porosity. Fossils include echinoids, mollusks, ostracods, foraminifera, and corals; thickness ranges from about 50 feet to 200 feet.

Overlying this carbonate sequence is a sequence of sands and clays interbedded with limestones and dolostones. This sequence, the Hawthorn Formation, is the most extensive upper Tertiary formation in Florida extending into southeastern Georgia and southern South Carolina (Carr and Alverson 1959). The Hawthorn Formation must have been deposited by several depositional environments. In peninsular Florida, Reynolds (1962) showed that the Hawthorn is more clastic towards the east and more calcareous towards the west. Almost any combination of sand, silt, clay, limestone, dolomite, and phosphate can be found in this formation (Eddy et al. 1981). Carr and Alverson (1959) recognize four major lithologic divisions of the Hawthorn in west-central Florida: 1) lower limestone unit - yellow to white, soft, sandy and clayey massive dolomitic limestone and calcitic dolomite; 2) upper limestone unit - gray to white, slightly sandy and clayey, soft, massive dolomitic limestone and calcitic dolomite; 3) phosphorite unit - calcareous gray-green to tan sand and clay with abundant phosphate nodules; 4) sand unit - gray to red and orange-brown sand and clay. Fossils include mollusks, crustaceans, sharks' teeth and vertebrate fossils. The Hawthorn ranges in thickness from 0 to about 300 feet.

Overlying the Hawthorn and other formations is an irregular deposit of sand, clay and marl deposited during the Pliocene and Pleistocene (Menke et al. 1961). The irregularity of these deposits reflects various stands of sea level during the Pleistocene, with sub-areal erosion modifying these terraces.

HYDROGEOLOGY OF THE TAMPA BAY AREA

An aquifer is any water-bearing zone consisting of one or more geologic units which can transmit and store water in significant amounts and will yield water in economic quantities. There are three basic types of aquifers: confined, semi-confined, and surficial. A confining layer consists of a geologic unit or units that restrict(s) the vertical movement of water between aquifers. The degree of restriction may vary from a layer which allows little vertical movement to a layer that allows a large amount of vertical movement of water (Fig. 2).

A confined aquifer (Fig. 2) is one in which there is little vertical movement of water through the confining layer. It is bounded both top and bottom by confining layers. Therefore, recharge to the aquifer is from some distant source. The most diagnostic characteristic of a confined aquifer is the lack of a water table. Instead, confined aquifers have a potentiometric surface, which is the level to which water rises in a well open only to the confined aquifer.

Another type of aquifer is a semi-confined aquifer. It is bounded top and bottom by a semi-confining layer and does not have a water table. The difference between the confined and semi-confined aquifers is that in the semi-confined aquifer, water may move through the semi-confining layer into and/or out of the aquifer. Water may also enter the aquifer through sinkholes and fractures. This type of aquifer may also be called a leaky aquifer.

The third type of aquifer is the surficial aquifer, also known as a water table aquifer or an unconfined aquifer. The surficial aquifer overlies a confining layer but is in free communication with the atmosphere; that is, the recharge area is close by, if not immediately above it, versus a distant recharge area for confined aquifers. The most characteristic feature of the surficial

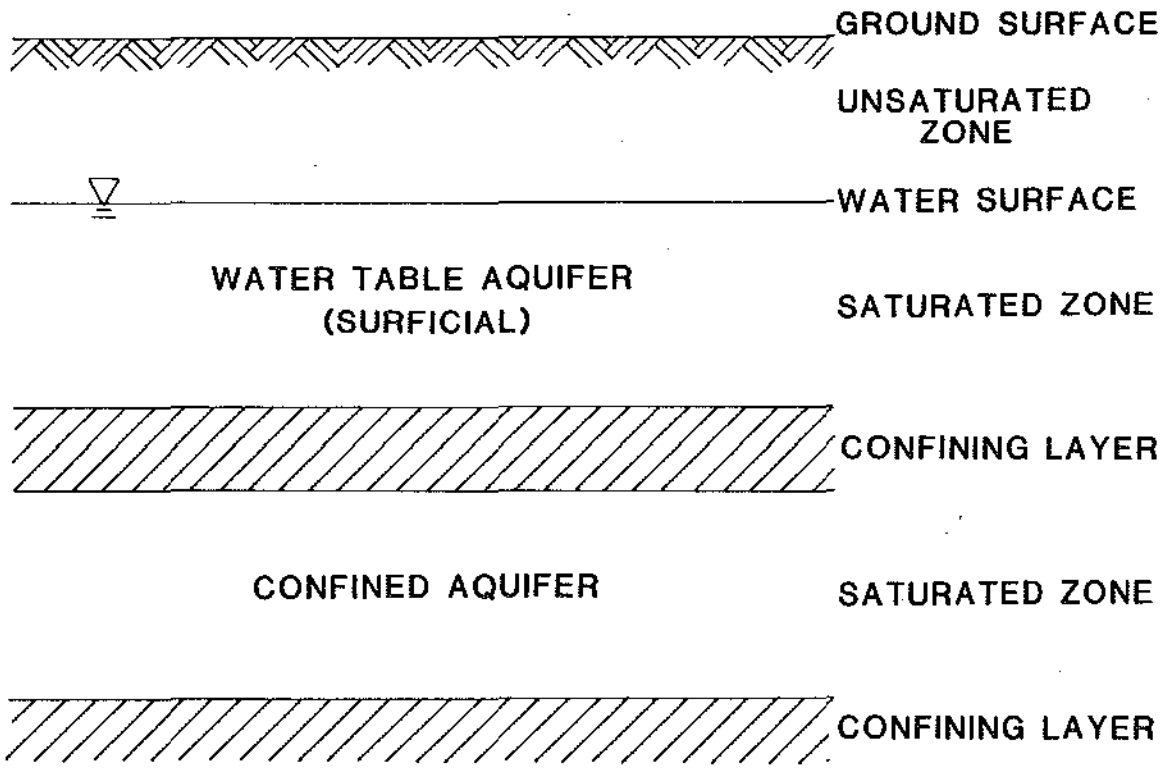

Figure 2. Generalized aquifers.

aquifer is the presence of a water table, which is the boundary between the saturated and unsaturated zones. Below the water table the geologic units are saturated and under hydrostatic pressure; above the water table, water is held as capillary films (Fig. 2).

The sedimentary sequence previously described can be divided into three hydrostratigraphic units. The first unit is the thickest, consisting of the upper 1,000 feet to 1,400 feet of the carbonate series. This unit makes up the semi-confined to confined Floridan Aquifer, which is one of the most productive aquifer systems in the United States (Stringfield and LeGrand 1966). The upper 500 feet to 700 feet of the Floridan Aquifer is the region where most of the water used for domestic, industrial, and agricultural uses is obtained. In coastal areas the Avon Park Limestone and the Ocala Group cannot be used as a source of potable water due to high chloride concentrations. The Floridan Aquifer thickens toward the south as can be seen in Figure 3. This hydrostratigraphic unit is the same as Stringfield and LeGrand's (1966) hydrologic unit 3. Hickey (1981) recognizes three and possibly four widespread and readily identified permeable zones that occur within the Floridan Aquifer in the Tampa Bay area. The two most important occur in the Tampa Limestone (and, in places, parts of the Hawthorn Formation and Suwannee Limestone), and in the dolomitized sequence in the lower part of the aquifer, which is very dense and has been fractured (this includes the Avon Park Limestone and possibly parts of the Ocala Group).

The next hydrostratigraphic unit, which overlies the Floridan Aquifer, is the sand, silt, clay, and carbonate unit which confines the Floridan Aquifer. This unit is comprised of the Hawthorn Formation and, in places, clays of the top of the Tampa Formation. The

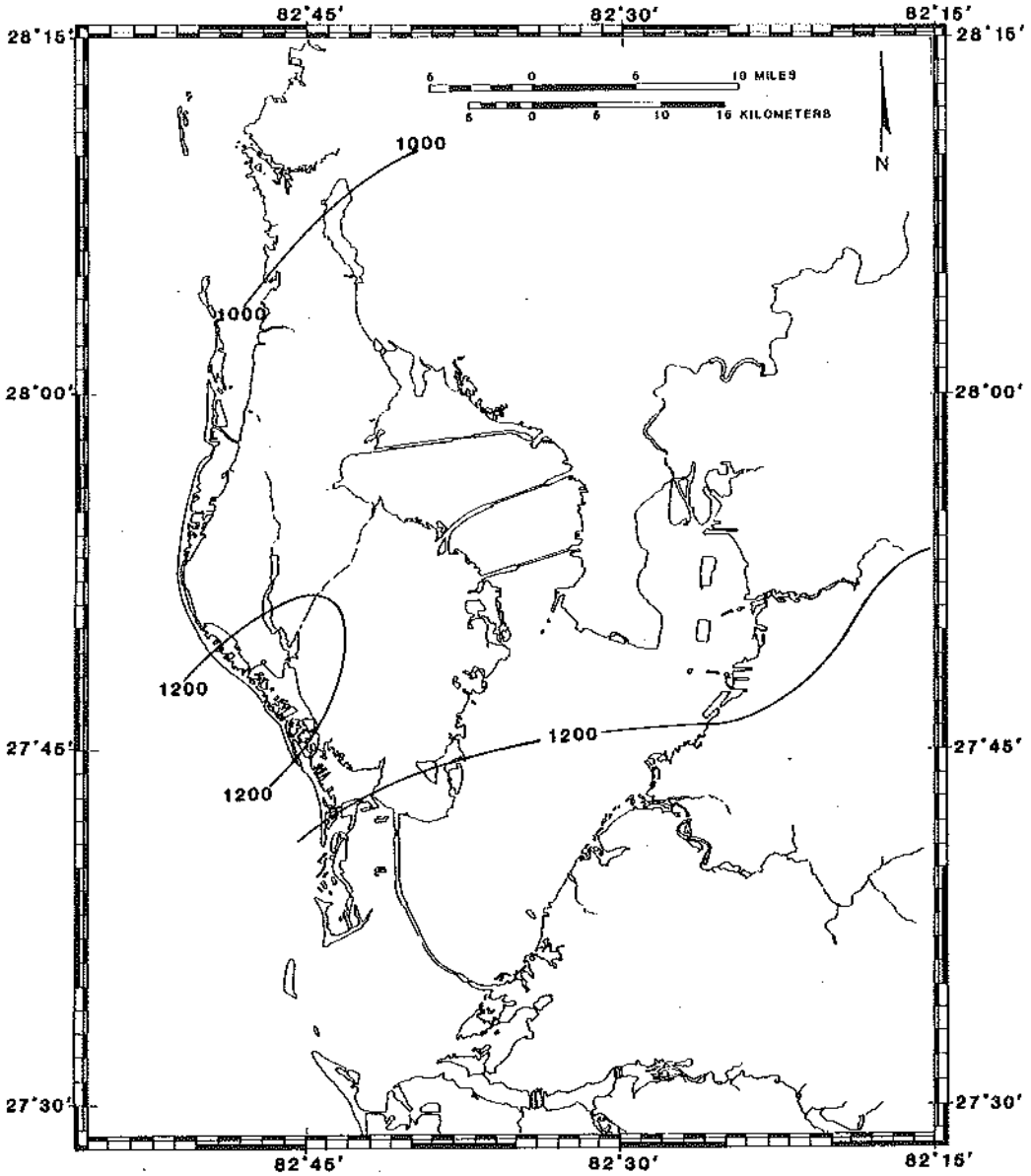

Figure 3. Generalized thickness of the Floridan Aquifer. From Wolansky and Garbade 1981.

varying depositional environments of the Miocene are largely responsible for the confining properties of this unit.

During the early Miocene, the depositional marine environment was one of varied and shifting conditions. In general it is represented by islands, lagoons, and freshwater lakes. During the late Miocene, the depositional environment changed toward a more shallow, open marine environment. As the sea advanced, calcareous sand and clay was deposited near shore and at higher elevations on the sea floor, while limestone was deposited elsewhere (Carr and Alverson 1959). Evidence also shows that part of this Hawthorn may have been deposited in a deltaic environment (Scott 1980).

The confining properties come from the clays and clayey materials which restrict the vertical movement of water through the Hawthorn Formation. This unit is equivalent to Stringfield and LeGrand's (1966) hydrologic unit 2. Figure 4 shows that the confining layer thickens toward the south. Figures 6 and 7 show that the confining layer also dips toward the south. In the northern parts of the Tampa Bay area the confining layer is discontinuous, thus leaving the Floridan Aquifer in direct contact with the overlying surficial aquifer or exposed at the surface (Fig. 9). In this region the Floridan Aquifer is semi-confined to unconfined since water can migrate between the Floridan and surficial aquifer. In the southern part of Tampa Bay the confining layer thickens to about 200 feet, thus making the Floridan Aquifer a semi-confined to a confined aquifer.

The last hydrostratigraphic unit consists of the undifferentiated sands, silts, and clays of the Pliocene and Pleistocene. This relatively permeable unit acts as a surficial aquifer throughout the Tampa Bay area. A dense, plastic clay underlies the sand and silt unit throughout most of the area. The clay, a weathering product of the underlying limestone, forms a confining layer which may be one of the most important factors in restricting movement of water from the surficial to the Floridan Aquifer (Sinclair 1974). Figure 5 shows the irregular thickness of these surficial deposits.

Figures 6, 7 and 8 show the relationship of these hydrostratigraphic units. Figure 6 shows a cross-section through Pinellas County. It shows the thickening trend of the confining layer and the dipping trend of the Floridan Aquifer southward. Figure 7 shows a cross-section through Hillsborough and Manatee Counties. It shows the same thickening and dipping trends as Figure 5. Figure 8 shows a cross-section across Tampa Bay and shows the correlation of the units across the Bay. These cross-sections were compiled from information from well logs around the Bay.

MOVEMENT OF REGIONAL GROUNDWATERS

Movement of all waters can be shown in a hydrologic cycle (Fig. 10). From any open body of water, evaporation takes place. As it rises, it cools and condenses to form clouds. Transpiration from plants also aids in the formation of clouds. The clouds then release the water as precipitation. Next, one of three things happens. First, the water may be intercepted by plants and animals; second, the water may run off into a body of water; and third, the water may infiltrate into the ground. When infiltration occurs, two things can happen: the water may be intercepted by roots, or the water may be incorporated into a groundwater flow system. It is this flow system that will be examined for the Tampa Bay area.

Note in Figure 10 that the water table shows some relief. A contour map of the water table elevations is called a water table map. The same idea is applicable to potentiometric surfaces, the result being a potentiometric surface map. Upon examination of water table and potentiometric surface maps of the Bay area, and knowing water flows from higher elevations to lower elevations, it is possible to determine groundwater flow directions in the Bay area.

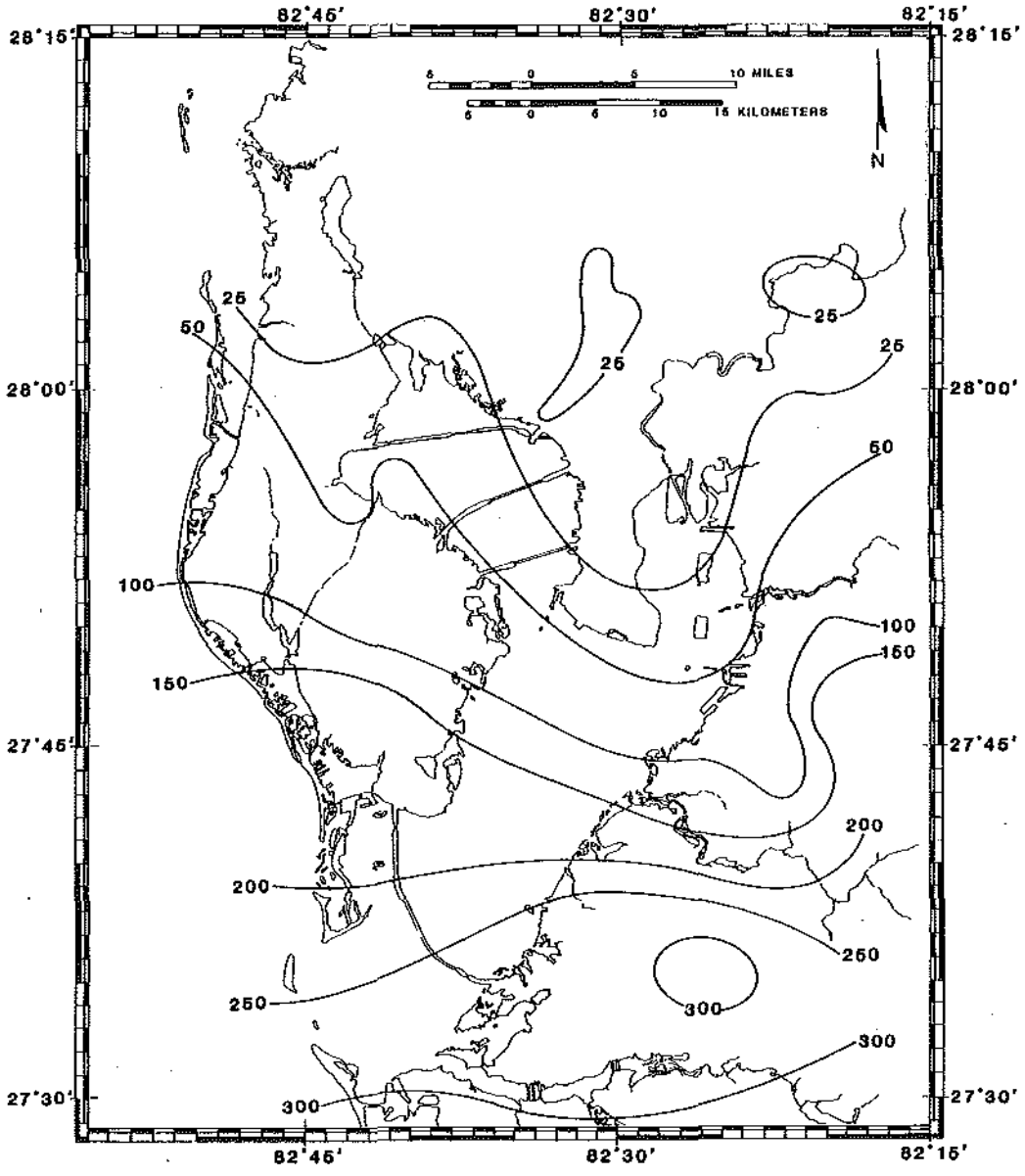

Figure 4. Generalized thickness of the confining bed. From Buono et al. 1979.

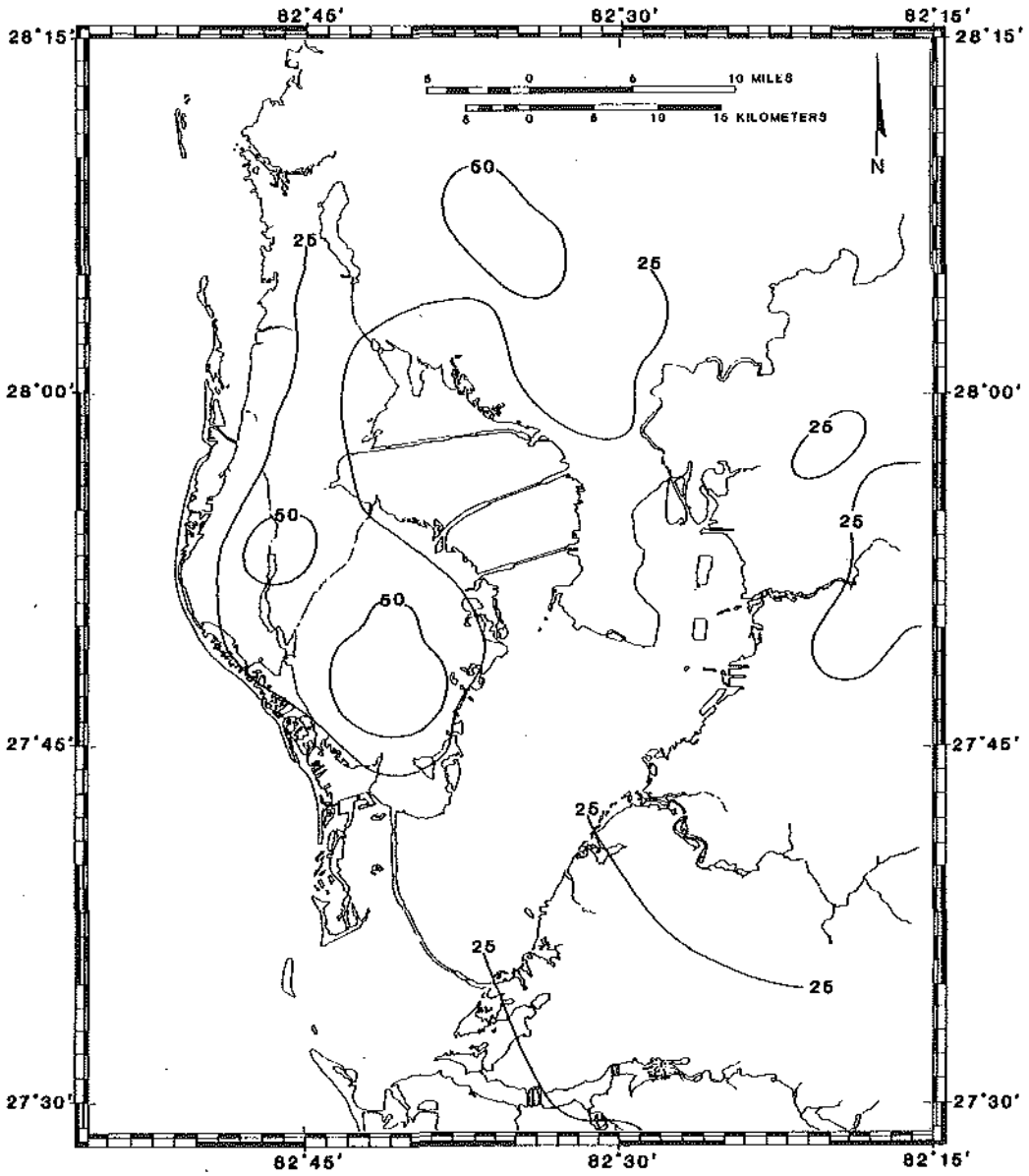

Figure 5. Generalized thickness of the surficial deposits. From Wolansky et al. 1979.

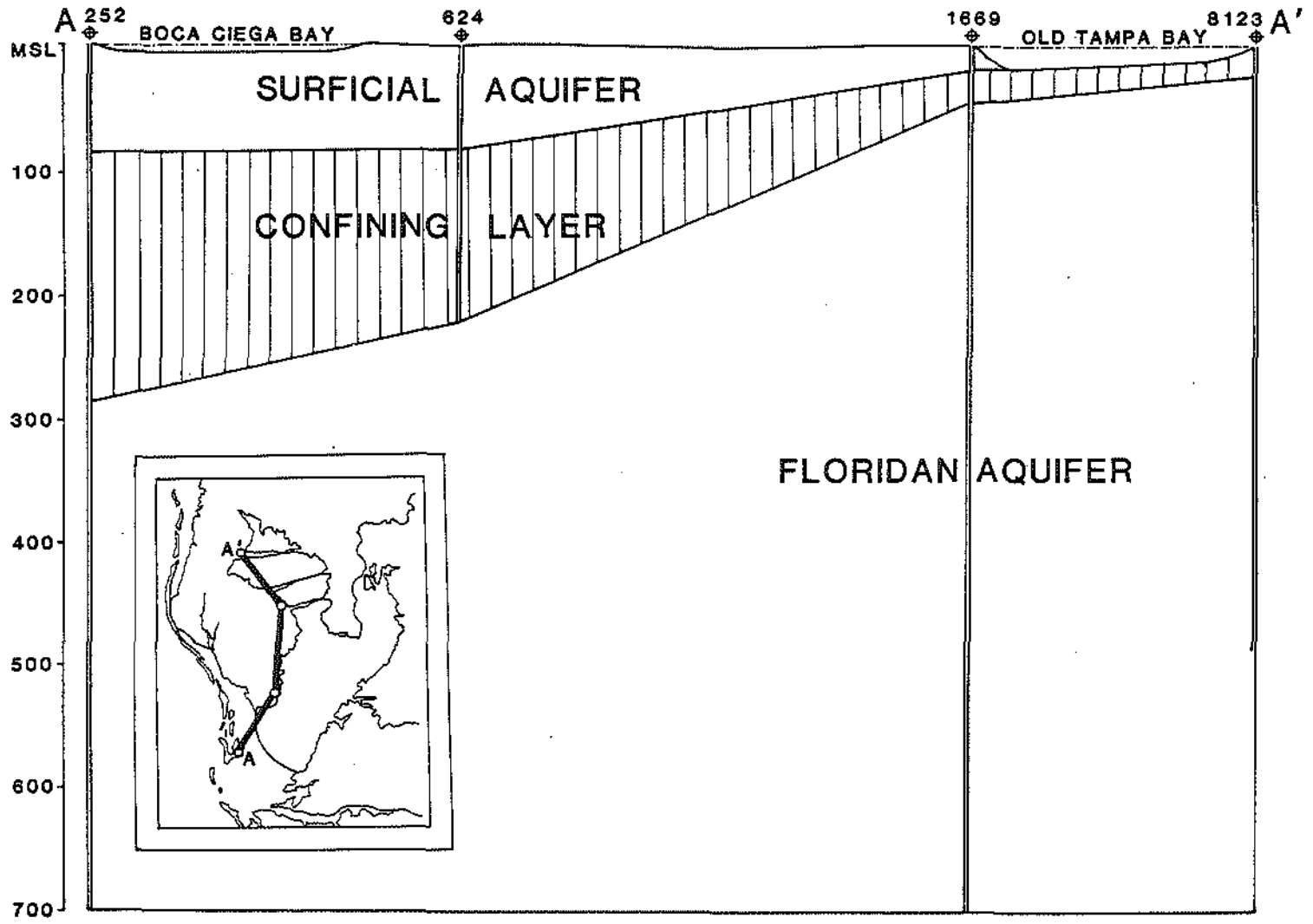

Figure 6. Cross section through A-A' (Pinellas County). Inset shows data points for A-A'.

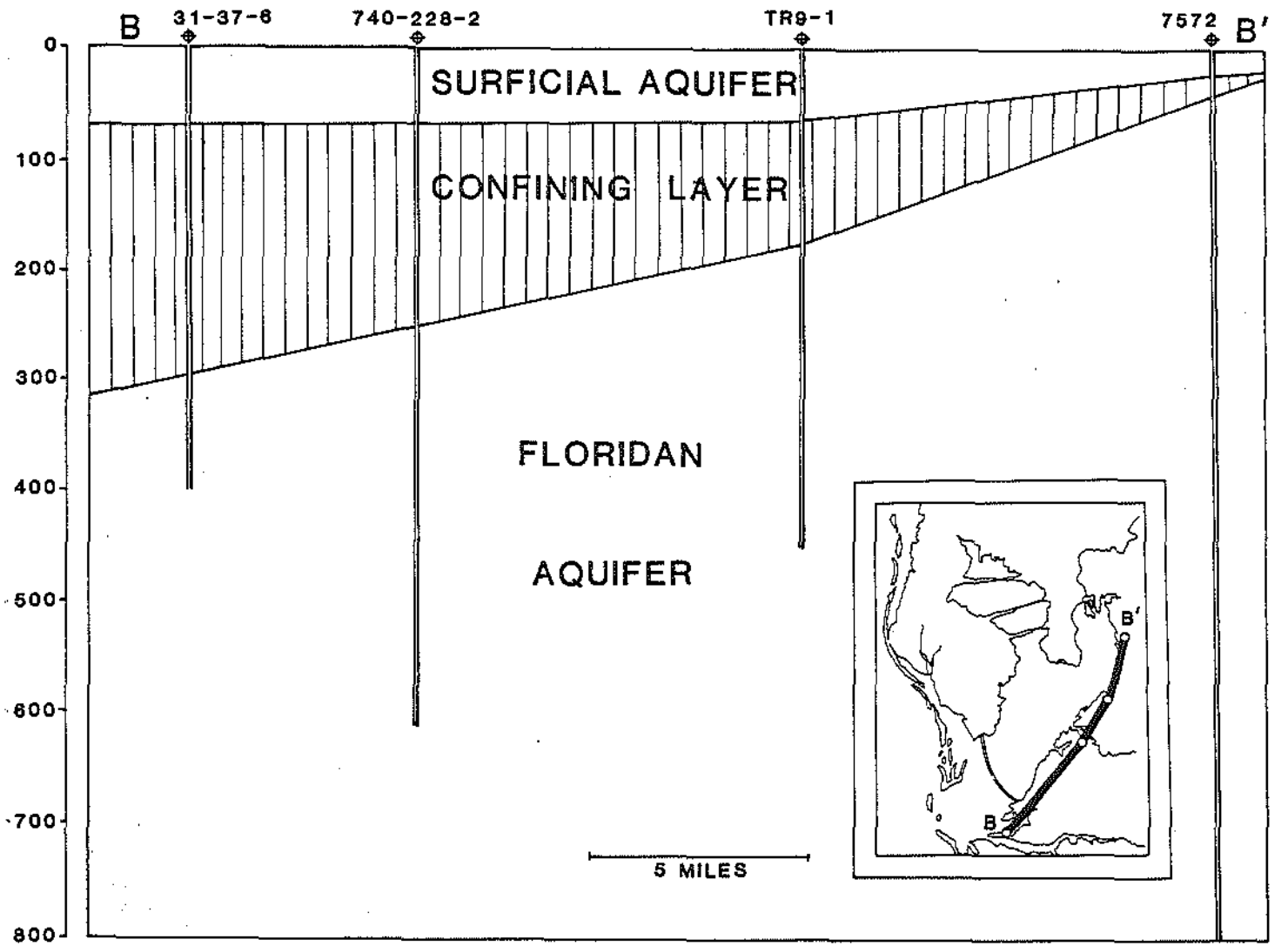

Figure 7. Cross section through B-B' (Manatee County - Hillsborough County). Inset shows data points for B-B'.

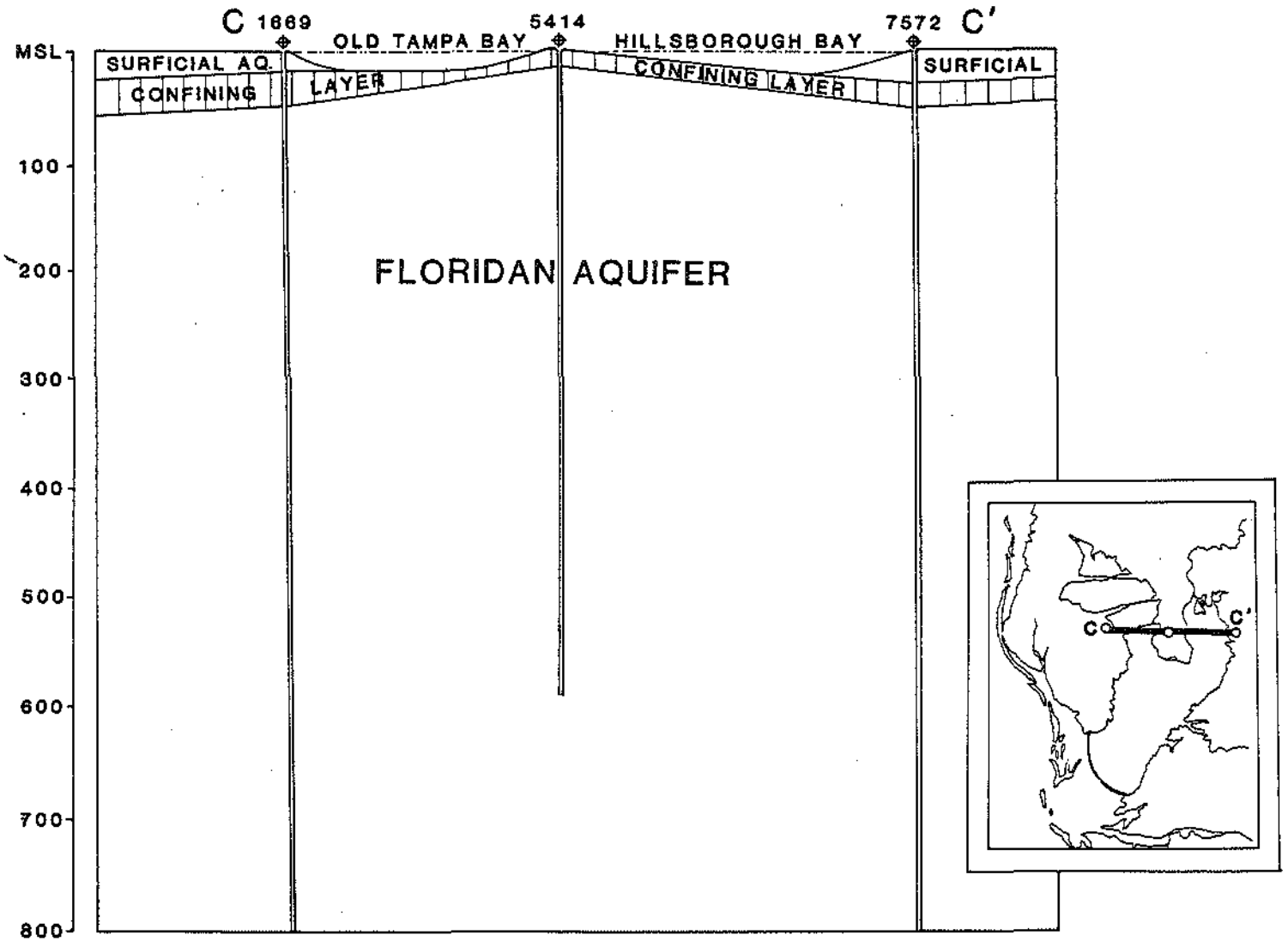

Figure 8. Cross section through C-C' (Tampa Bay). Inset shows data points for C-C'.

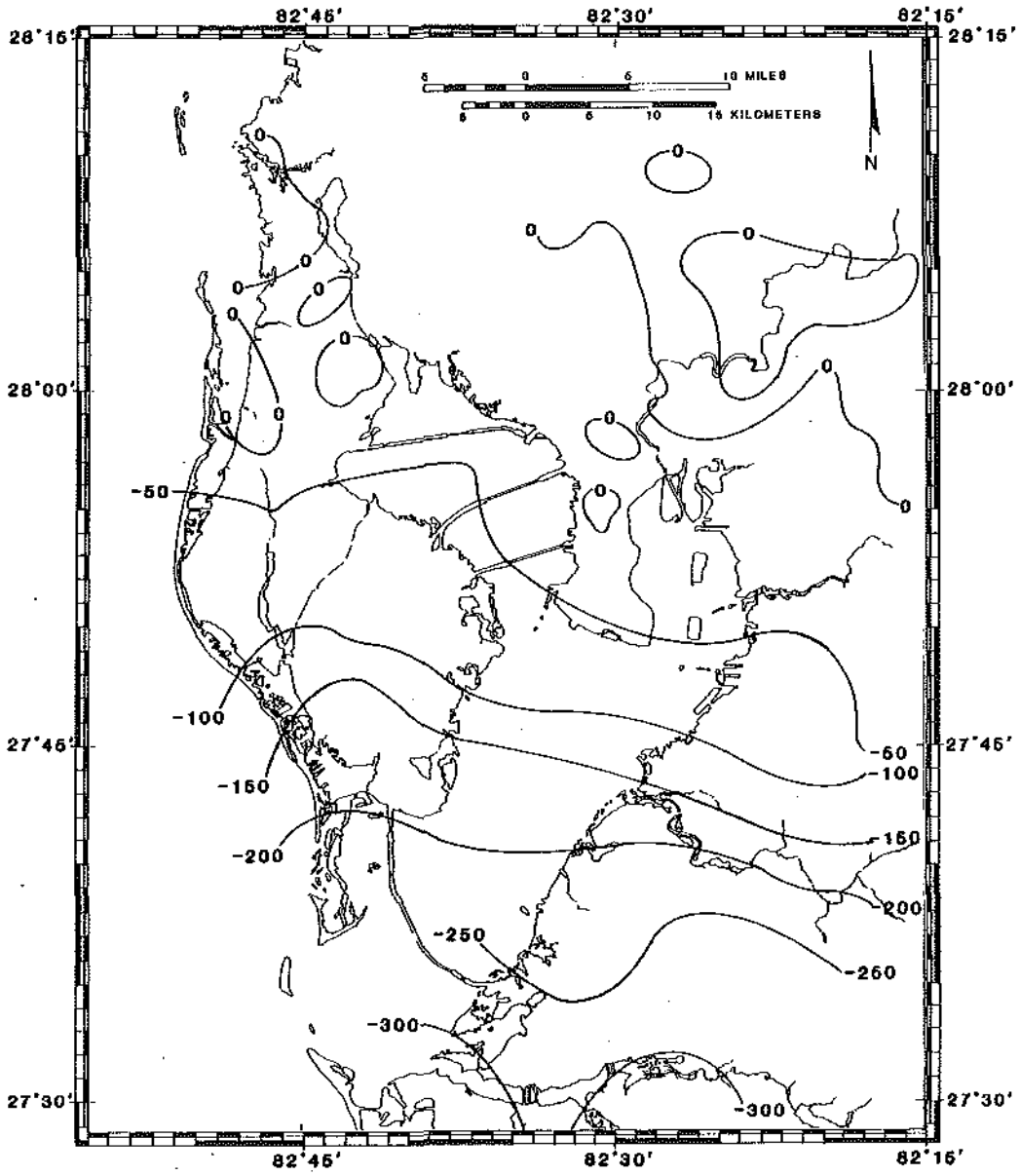

Figure 9. Configuration of the top of the Floridan Aquifer.

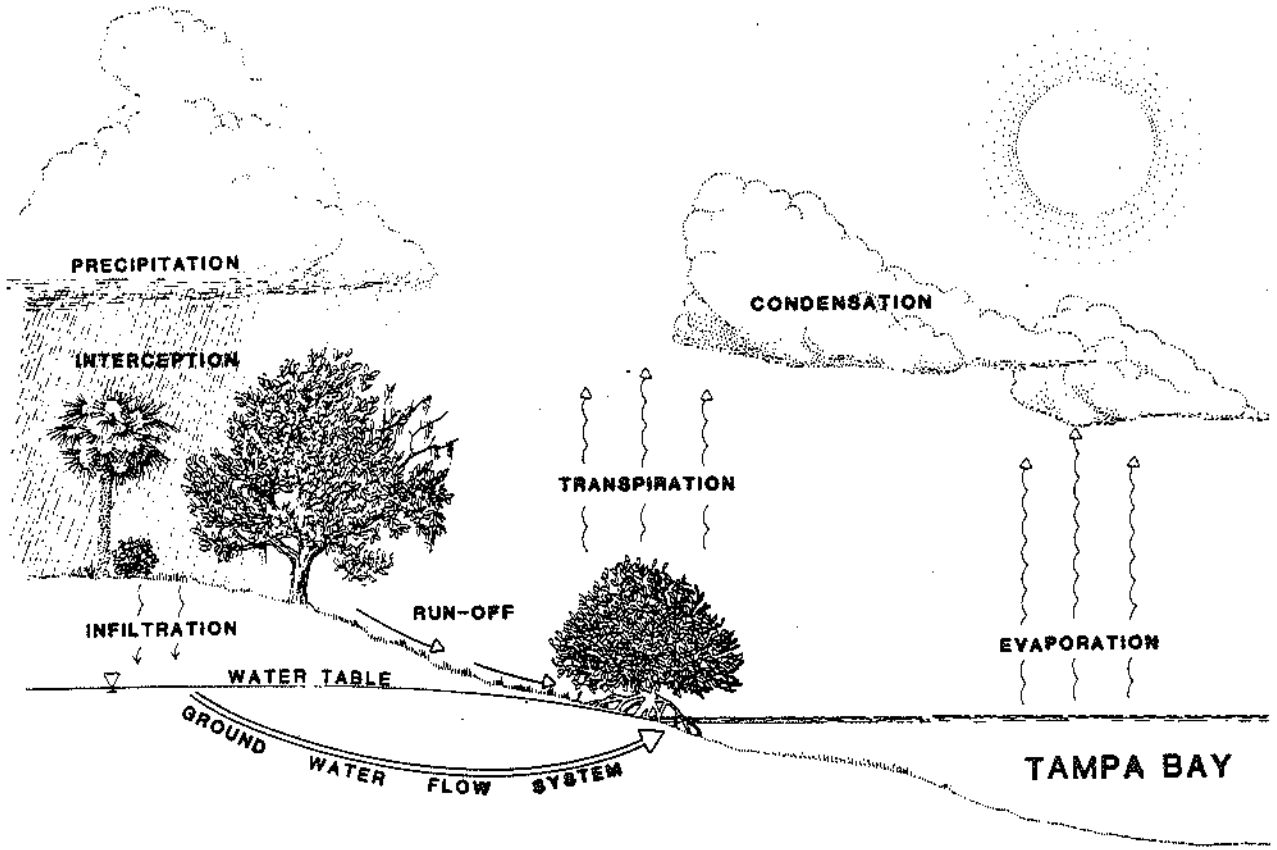

Figure 10. Generalized hydrologic cycle.

Figure 11 shows the flow directions in the surficial aquifer. It is important to note that flow in the surficial aquifer is greatly affected by topographic features such as lakes and rivers. Flow is toward the Bay, Gulf, and rivers. A lack of data prohibited the extension of the flow lines into Manatee County, but they are expected to behave similarly to other flow lines around the Bay.

A comparison of Figures 11 and 12 shows that flow in the Floridan Aquifer is not greatly affected by minor topographic features. There are several important things to note in Figure 12. First, a comparison of the water table and potentiometric contours shows a striking similarity north of Old Tampa Bay. This is due to the thinning of the confining bed, resulting in the unconfined and semi-confined behavior of the Floridan Aquifer. Secondly, note the cone of depression off the mouth of the Alafia River. This is due to withdrawals of groundwater by a phosphate chemical plant. The well is not discharging freshwater and is not harming the potable water supply.

A comparison of Figures 12 and 13 shows the differences in flow patterns in the Floridan Aquifer at different times of the year. The major differences are the large cones of depression near the Little Manatee River. These are due to agricultural withdrawals in the area. These large cones tend to pull saltwater from the aquifer inland. Because of the seasonality of the withdrawals, the saltwater interface will not move permanently inland. Instead, a wide zone of mixing of fresh and saltwater will develop.

It is obvious that groundwater moves toward the Bay, but does it enter the Bay, and if so, where and how much? To answer these questions, the vertical flow of water through the confining layer must be examined.

The degree of connection between the Floridan Aquifer and Tampa Bay is not well understood. The complex nature of the confining layer makes it difficult to calculate how water will flow through it. Recalling that the confining layer is leaky in places, the areas of potential upward leakance were determined. This was accomplished by comparing water table and potentiometric surface contours. In areas where the potentiometric surface contour is higher than the water table, there is a potential for upward leakance (Fig. 14). The shaded region in Figure 15 is the area in which there is potential for upward leakance and discharge from the Floridan Aquifer. Because the confining layer thins in the northern part of the Bay, discharge from the aquifer systems to the Bay is greater in the north than it is toward the south. In Manatee County discharge is from the surficial aquifer and possibly from some of the limestones of the confining layer. Dredging in the Bay would increase the likelihood of leakance into the Bay, particularly where the confining layer is breached and the limestones of the upper Tampa and lower Hawthorn Formations are exposed.

The amount of water flowing into the Bay is unknown. This is because many poorly known factors influence flow toward the Bay. Two of these factors are position of the saltwater interface and interception by pumping wells. Other factors concerning the properties of the aquifer material are considered in a basic equation for discharge. This equation, known as Darcy's Law, states:

$$Q = -KA\,(dh/dl)$$

where Q = discharge; K = hydraulic conductivity (the ability of aquifer material to transmit water); A = area perpendicular to flow; and dh/dl represents the slope of the water table or potentiometric surface (hydraulic gradient). By breaking the area into its components, thickness (b) of saturated zone and width (W), and letting i = the hydraulic gradient, we have:

$$Q = KbWi$$

Kb = transmissivity, which is a property of the aquifer that measures the ability of water to flow through the aquifer. The resulting equation,

$$Q = TWi$$

is desirable because transmissivity can be obtained from analytical analysis of

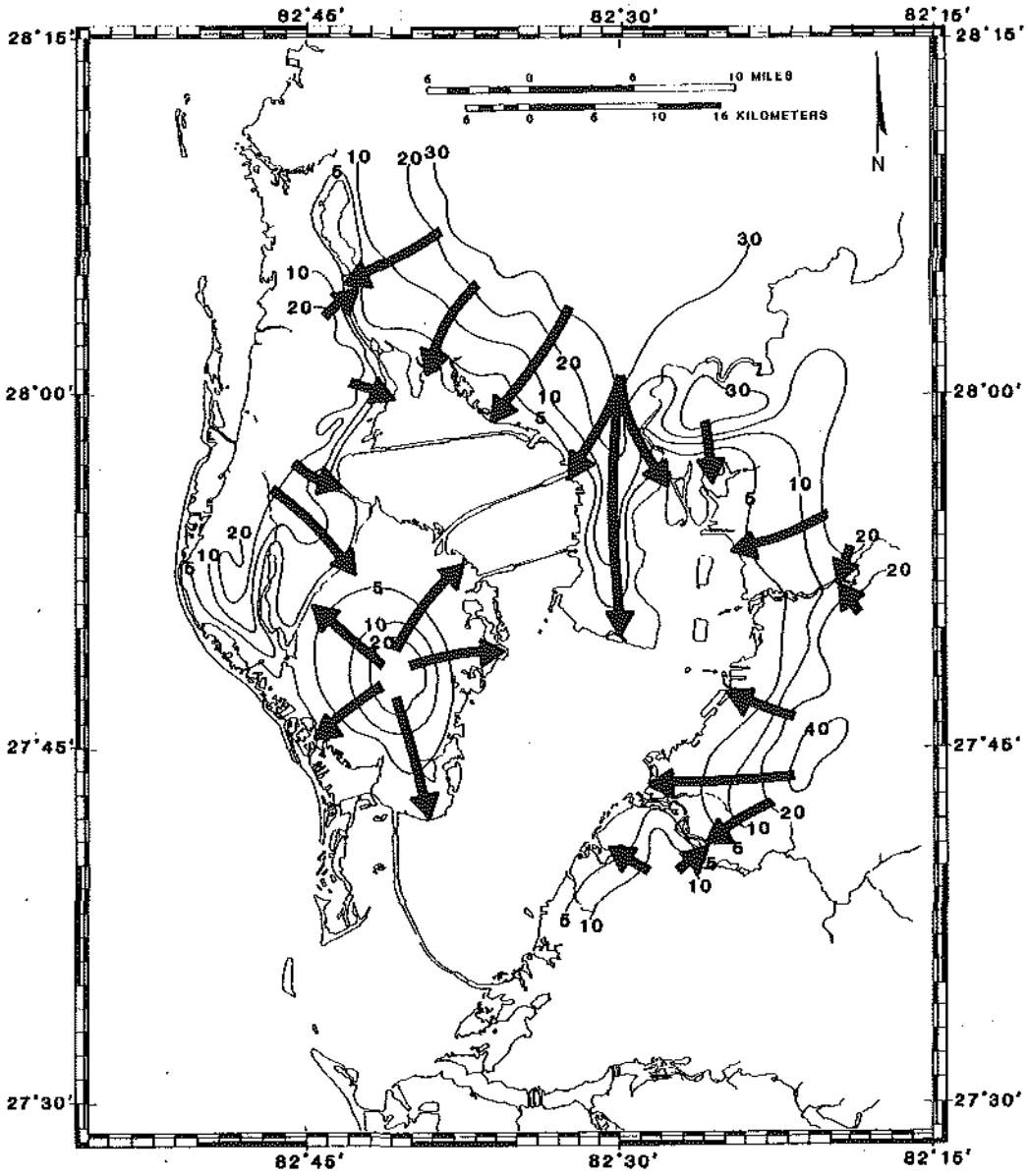

Figure 11. Generalized flow in the surficial aquifer, September 1980.

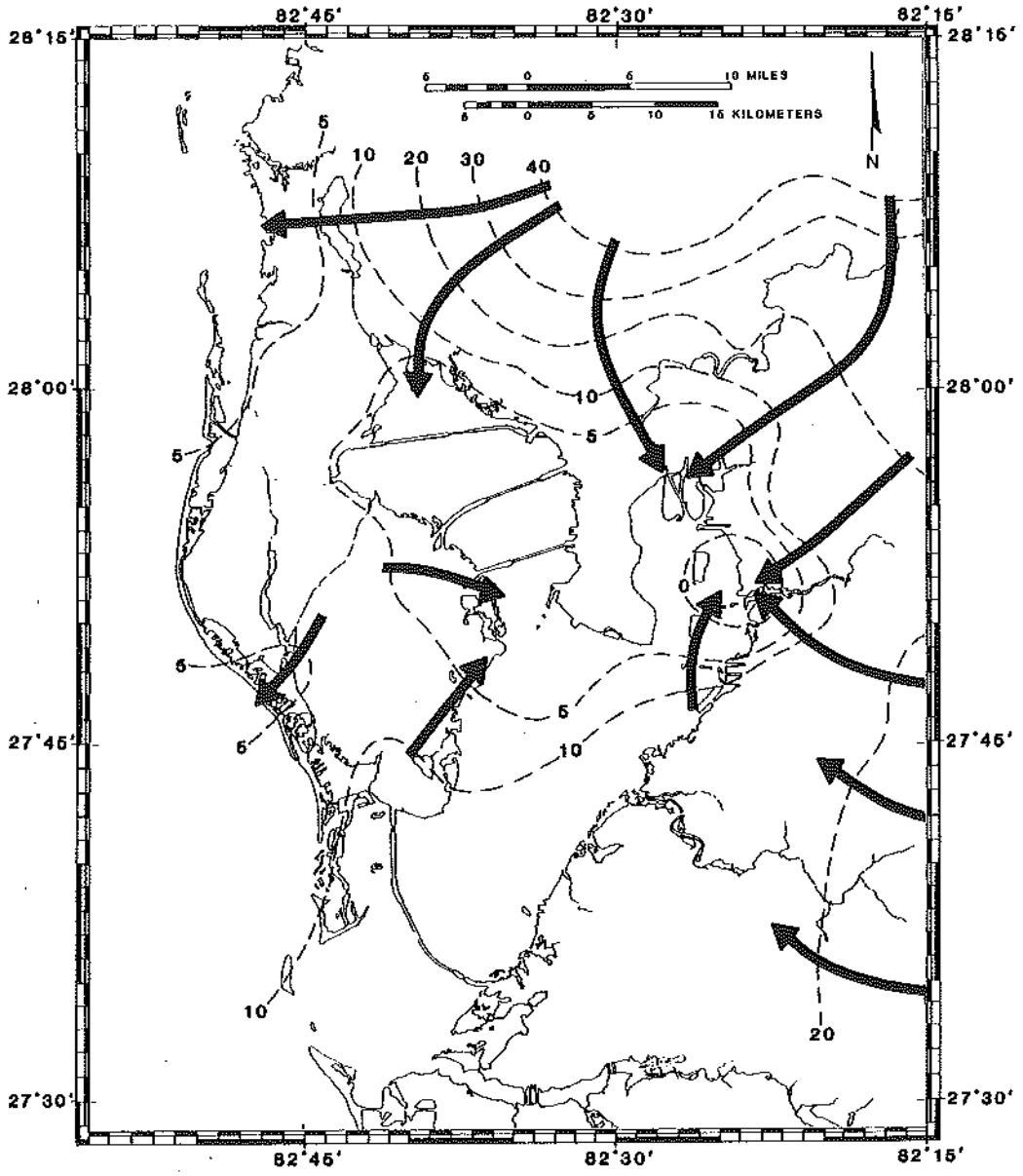

Figure 12. Generalized flow in the Floridan Aquifer, September 1980.

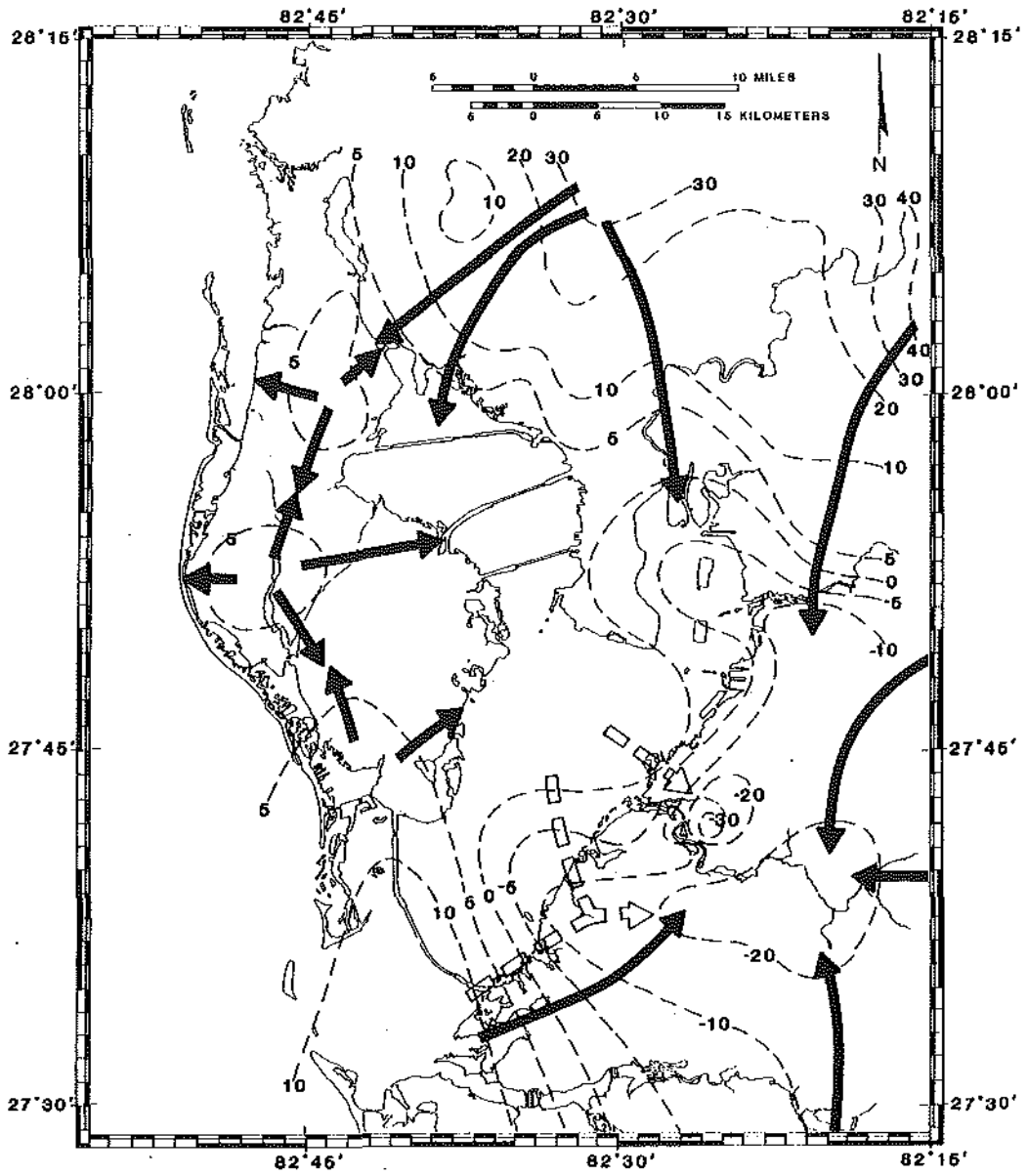

Figure 13. Generalized flow in the Floridan Aquifer, May 1981.

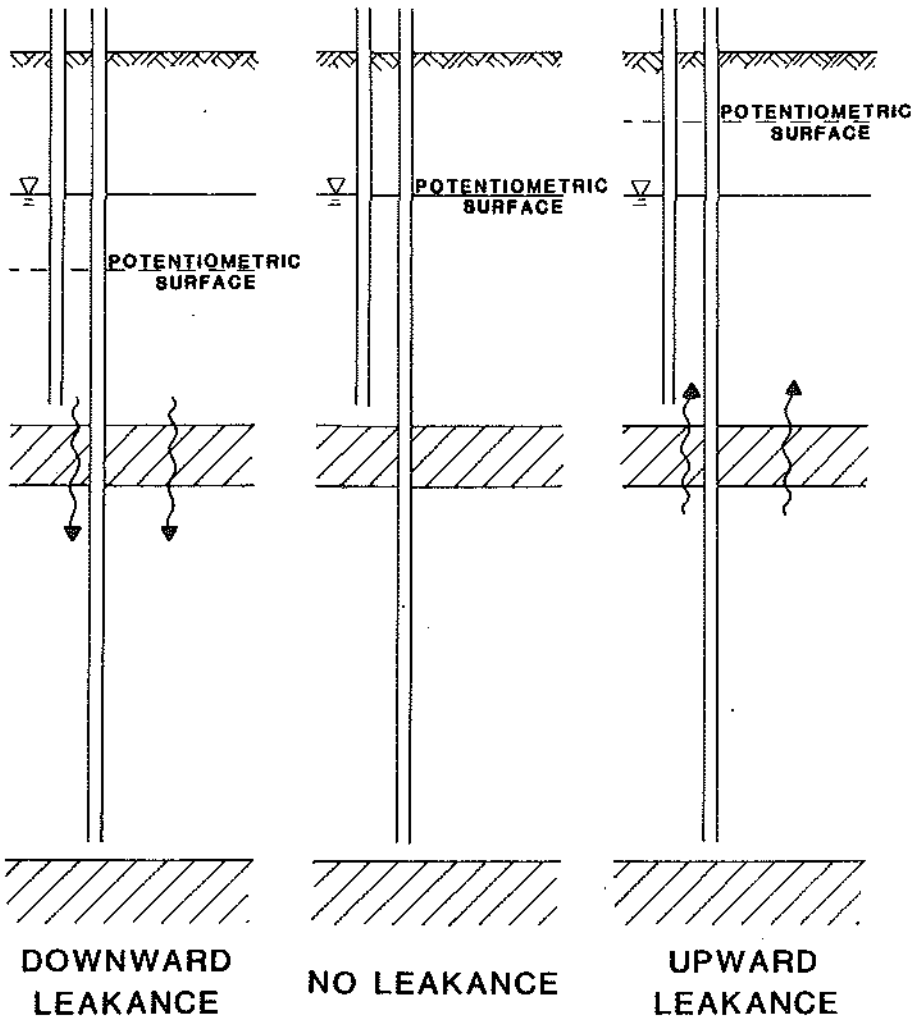

Figure 14. Leakance.

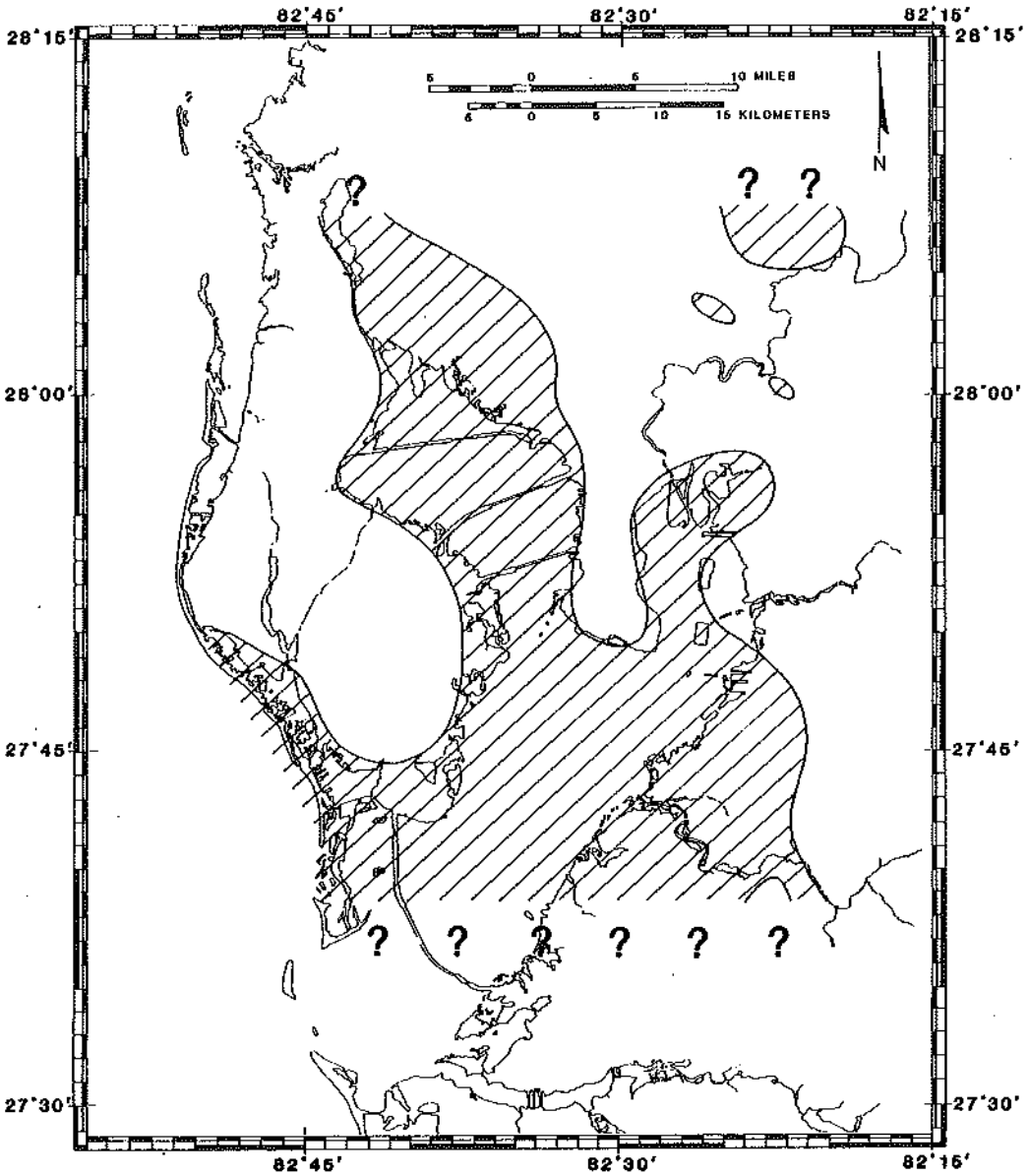

Figure 15. Region of potential discharge from the Floridan aquifer, September 1980. From Yobbi et al. 1981b.

pumping tests. However, extensive pumping test data are not available around the Bay, and those data that are available show a wide range of values.

SUMMARY

The Tampa Bay area is underlain by three hydrostratigraphic units: a confined aquifer, a confining layer, and a surficial aquifer. Changing depositional environments are responsible for the differences among the properties of these units. Most of the water used for domestic, industrial, and agricultural needs is withdrawn from the upper 500 to 700 feet of the Floridan Aquifer.

It can be shown that water flows toward Tampa Bay in the confined and surficial aquifers, but it may also be intercepted in the surficial aquifer by lakes and rivers. Water from the confined aquifer probably flows into the Bay in the northern regions and in other places where the confining layer is thin or has been breached. The amount of water flowing into the Bay is unknown and best estimates are not very accurate. The principal data needed to estimate flow into the Bay are more extensive transmissivity measurements, information on agricultural withdrawals, and the position of the saltwater interface.

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CHEMISTRY OF GROUND WATER DISCHARGING INTO TAMPA BAY, FLORIDA

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ABSTRACT

The chemical quality of ground water discharging into Tampa Bay is affected by three principal processes. The most ubiquitous process is dissolution of aquifer materials inland as ground water flows to the bay. Concentrations of calcium, magnesium, bicarbonate, and other materials increase gradually seaward as a result of this dissolution. The zone of mixing of salt and fresh ground water near the coast is complex and depends on aquifer properties and water flow paths. This mixing zone, the saltwater interface, is poorly understood in the bay area. Numerous conceptual models have been proposed for regional ground water flow and discharge at the saltwater interface. However, lack of knowledge of aquifer properties and flow dynamics, and inability to handle complex systems, render these models inadequate to predict saltwater interface behavior around the bay. Thus, there are minimal predictive data as to water quality under the bay and interactions of the bay with the ground water system. Waste disposal is the third process of concern. Waste discharge to the aquifer system in distal portions of the drainage basin of the bay probably has little impact on ground water quality near the bay. Dilution, dispersion, chemical reaction with aquifer materials, and interaction with saltwater reduce any threat to quality of water flowing to the bay. There are, however, several waste disposal sites on the margins of the bay that may have localized impacts on ground water quality at the bay margin. Again, meager data do not indicate widespread problems owing to coastal ground water pollution. This is largely because of 1) circulation and large buffering capacity in the bay; 2) insignificant waste inputs in ground water as compared with surface water; and 3) inability to recognize problems. Inability to recognize problems is because protection of salty, non-potable water is not a priority in ground water management and no connection has been made between quality of bay water or health of bay biota and discharge of contaminated ground water. On-going Federal, State, and local ground water monitoring programs, which are now being implemented, allow identification of potential waste sources and recognition of regional ground water quality problems near the coast. These programs will not be sensitive to localized problems that arise at the coast or in the bay.

SURFACE FLOWS TO TAMPA BAY: QUANTITY AND QUALITY ASPECTS

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INTRODUCTION

The quality of water in Tampa Bay is influenced by a number of factors, not the least of which are the quality, timing and magnitude of surface flows entering the Bay. In this paper, the streams discharging to the Bay will be discussed with respect to their flow characteristics and chemical quality. Emphasis will be placed on well-defined surface water-bodies, leaving other flows such as sewage plant effluent and stormwater runoff to be discussed by others.

There are twenty named rivers and streams which discharge to Tampa Bay (Table 1), and the data available on their chemical and flow characteristics vary considerably. For some, such as the Hillsborough, Alafia, and Little Manatee Rivers, long-term data on both discharge and chemical quality can be obtained. For others, particularly those streams entering the Bay from Pinellas County, data are scanty or non-existent. The period of record for which discharge and quality data are available for each of the twenty streams is indicated in Table 1.

Most of the data referred to in this paper were obtained from the U.S. Geological Survey's (USGS) WATSTORE files or from the files of the Hillsborough County Environmental Protection Commission (HCEPC) and the Florida Department of Environmental Regulation (FDER) as accessed through STORET. Data from several other sources were also reviewed. These sources included reports by governmental agencies, universities, and technical consulting firms. The primary sources consulted are described in an annotated List of References.

For the most part, only the data collected by USGS, FDER and HCEPC are suitable for use in characterizing streams and identifying trends in chemical quality. These agencies have conducted regular water sampling over a long period of time and the samples have been collected and tested according to acceptable procedures. Original information contained in agency or company reports can be used in describing specific reaches of streams during a particular time, but care must be taken in the interpretation of data in these reports, especially in cases in which no explanation is provided concerning the methods of water sample collection, handling, and analysis.

The interpretation of data for streams entering the Bay must be judicious for other reasons as well. Many of the surface inflows have been altered or affected in ways which would influence the data collected from some of the sampling stations. Such alterations include unusually heavy effluent loadings, water control structures, salinity barriers, watershed disturbance, artificial drainage, and others. None of the streams can be considered unaffected by artificial outside influences. These factors will be mentioned when applicable in the discussion of the stream data.

Table 1. Available discharge and chemical quality data for streams and rivers entering Tampa Bay. Periods of record are given for routine monitoring only. All discharge stations are USGS stations, while quality stations may be USGS, FDER, County or City stations

	Stream/River	Discharge, Period of Record	Quality, Sampling Agencies
1	Alafia River - at Lithia	1932-current	USGS, FDER, HCEPC
	Allen's Creek	none	none
	Alligator Creek	none	none
	Bishop Creek	none	none
5	Bullfrog Creek - at Wimauma	1956-current	USGS, HCEPC
	Channel "A"	none	HCEPC
	Cross Bayou Canal	none	none
	Delaney Creek	none	none
	Double Branch Creek	none	HCEPC
10	Hillsborough River - stations	1938-current (at Tampa)	City of Tampa USGS, FDER, HCEPC
	Lake Tarpon Outfall Canal	1971-current	USGS
	Little Manatee River - 2 stations	1939-current (near Wimauma)	USGS, HCEPC
	Long Branch	none	none
	Manatee River - near Myakka Head	1966-current	USGS, Manatee Co.
15	Mullet Creek	none	none
	Rocky Creek - near Sulphur Springs	1953-current	USGS, HCEPC
	Salt Creek	none	USGS
	Sweetwater Creek	none	HCEPC
	Tampa Bypass Canal - 2 stations	1974-current (at S-160)	USGS, HCEPC
20	Turner Creek	none	none

CHARACTERIZATION OF THE QUALITY OF SELECTED STREAMS

This subject will be addressed only on streams having data on selected parameters which were determined to be sufficient for characterization purposes. For that reason, information will be presented only on some parameters.

Conductivity. The conductivity of streams entering Tampa Bay varies considerably (Fig. 1). The highest readings, at or above 10^4 umho/cm, were observed in those streams in which the sampling station was most influenced by tidal surge. These include Channel "A", Double Branch Creek, Rocky Creek, and Sweetwater Creek, all located in Hillsborough County. It should be noted here that both Channel "A" and Rocky Creek have salinity barriers which were constructed in 1977-78. The Manatee River, with a water supply reservoir miles upstream of the mouth, and the Tarpon Outfall Canal, which has a salinity barrier/control structure downstream of Lake Tarpon, had intermediate values around 10^3 umho/cm. The remaining streams had average conductivity values between 450 and 550 umho/cm.

pH. Most streams in the study area are slightly alkaline (Fig. 2). The highest average pH value of 7.7 was recorded in Channel "A". The Tarpon Outfall Canal was neutral while the only streams having an average pH below 7 were the Alafia River, the Manatee River, and Sweetwater Creek with a pH value of approximately 6.7.

Dissolved Oxygen (DO). Three streams entering the Bay had average DO concentrations between 7.0 and 8.0 mg/l: the Little Manatee River, the Tarpon Outfall Canal and the Tampa Bypass Canal (Fig. 2). Three streams fell below the FDER 5.0 mg/l requirement for Class III waters: Double Branch Creek, Rocky Creek and Sweetwater Creek. These streams pass through heavily populated areas, and the depressed DO values were due, in part, to large volumes of stormwater runoff and sewage plant effluent.

Total Phosphorus (P_{tot}). One stream stands apart from the rest in total phosphorus concentrations, the Alafia (Fig. 2). This river, with an average concentration of 4.7 mg/l, drains an area of intense phosphate mining. The Manatee River had a total phosphorus concentration of 1.7 mg/l, while the remaining streams fell at or below 1.0 mg/l.

Nitrate-Nitrogen (NO_3-N). The highest NO_3-N concentration is found in Sweetwater Creek (Fig. 2). This stream averaged 1.83 mg/l which is slightly more than twice the concentration of NO_3-N found in the stream having the next highest concentration, the Alafia River (0.9 mg/l). The Manatee River averaged 0.36 mg/l, while the remaining streams were at or below 0.2 mg/l. The lowest average NO_3-N concentration (0.02 mg/l) was recorded from Tarpon Outfall Canal.

Ammonia-Nitrogen (NH_3-N). Of the streams observed, the Alafia River had the highest average concentrations of NH_3-N (.4 mg/l) (Fig. 2). While Sweetwater Creek might have been expected to have high NH_3-N concentrations as well, there were little data available for this parameter. Three Hillsborough County streams, Channel "A", Double Branch Creek and Rocky Creek, also had fairly high NH_3-N concentrations ranging between 2.2 and 3.1 mg/l. The lowest average concentration of NH_3-N was recorded at the Tarpon Outfall Canal.

Total Organic Nitrogen (N_{org}-Total). Five streams were found to have relatively high concentrations of N_{org}-Total (Fig. 2). The highest concentration, approaching 1.2 mg/l, was found in Sweetwater Creek. The Manatee River had the second highest concentration at almost 1.0 mg/l, followed by the Tarpon Outfall Canal, Tampa Bypass Canal and the Alafia River. The remaining streams were all below 0.3 mg/l N_{org}-Total.

Total Organic Carbon (TOC). Sweetwater Creek had the highest average concentration of TOC, approximately 16 mg/l (Fig. 3). Double

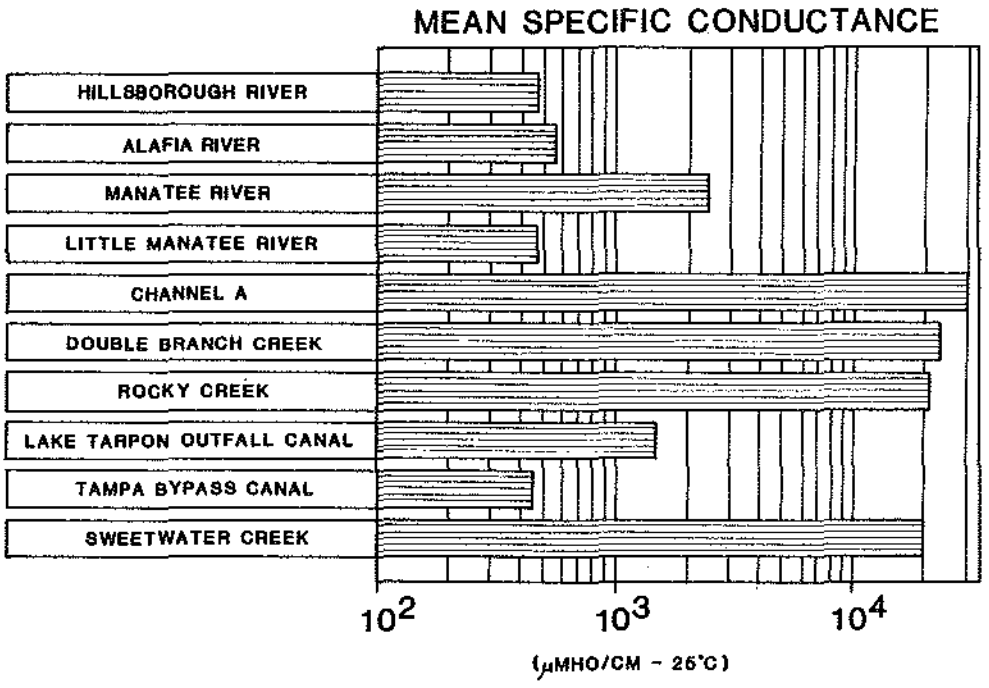

Figure 1. Conductance (means for period of record) of selected streams entering Tampa Bay.

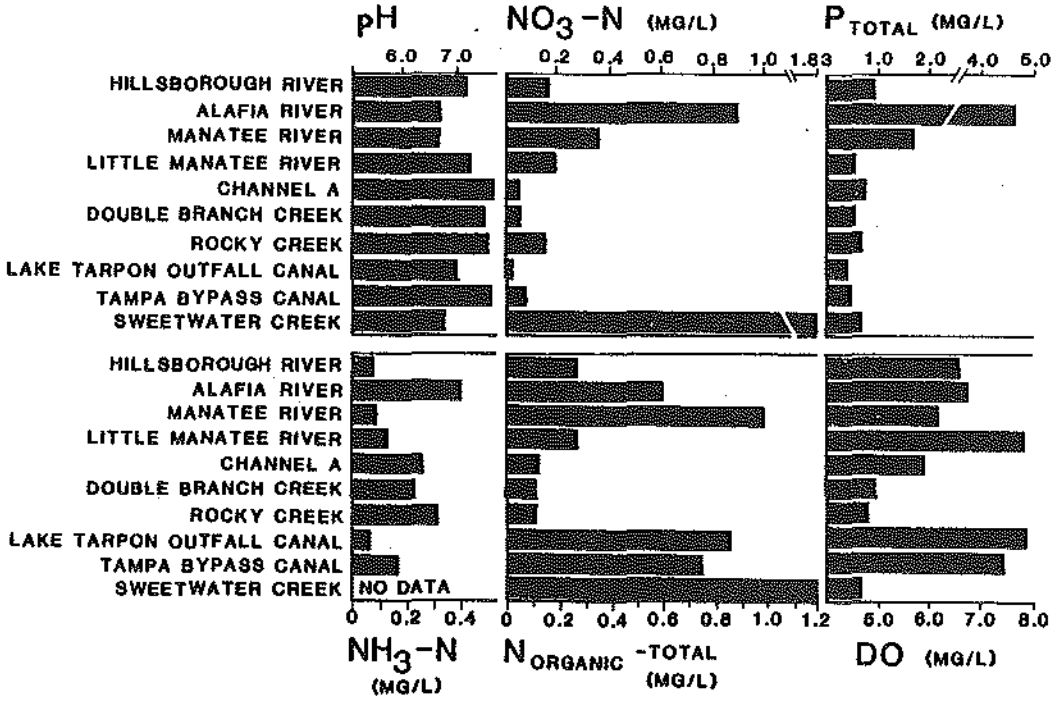

Figure 2. Data for selected chemical parameters for streams entering Tampa Bay. Values are means for period of record.

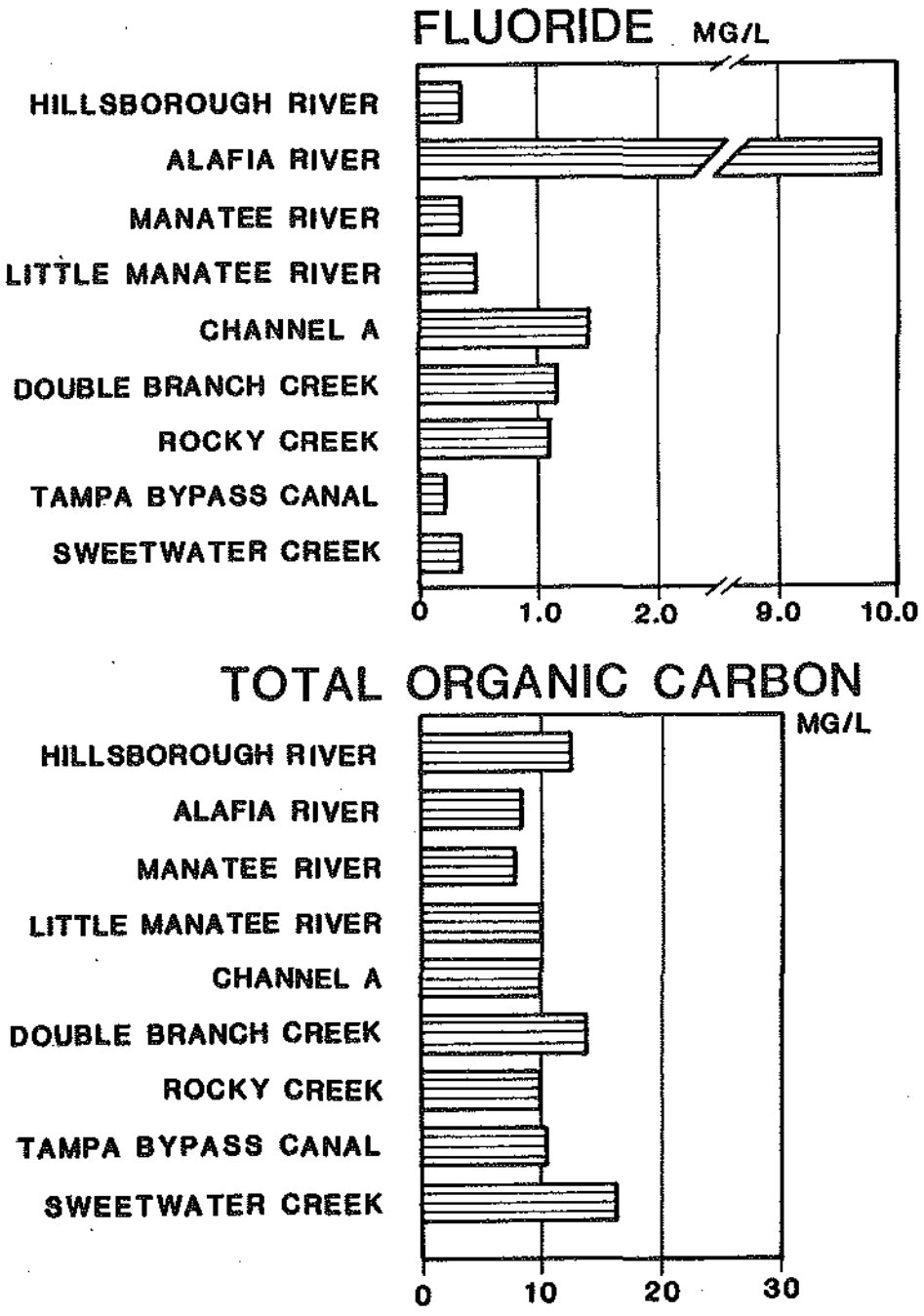

Figure 3. Mean concentrations of fluoride and total organic carbon for streams entering Tampa Bay.

Branch Creek had the second highest concentration, at 14 mg/l. The remaining streams group closely together with average concentrations ranging between 8.0 and 11.0 mg/l TOC.

Fluoride (F^-). The Alafia River stands by itself in the concentration of fluoride reported. With an average concentration of approximately 9.85 mg/l, it posessed more than six times the concentration of F^- reported from the second highest stream, Channel "A" (Fig. 3). Channel "A", Double Branch Creek and Rocky Creek group together at 1.1 to 1.4 mg/l. The remaining streams are all at or below 0.5 mg/l. While the data presented for the Alafia River may cause concern, evidence will be presented later in this paper indicating a recent decline in fluoride concentration in this river.

TEMPORAL TRENDS IN WATER QUALITY

The discussion of temporal patterns must necessarily be restricted to only a few parameters. Long-term data are not available for all parameters which would be of interest.

Conductivity. Over the period of record, the average conductivities of Channel "A" and the Tampa Bypass Canal have changed little, while the conductivities of Double Branch Creek and Sweetwater Creek have shown a slight decline (Fig. 4). In Rocky Creek, conductivity has shown a more dramatic decline which had followed a peak in 1977.

The Little Manatee River showed marked differences in the trends observed at the Highway 41 and Highway 301 stations. At the Highway 301 stations, conductivity has remained relatively stable, fluctuating generally less than 500 umho/cm on an annual basis. An exception to this observation was the fluctuation between 1979 and 1980 and between 1980 and 1981, when high average conductivity in 1980, approximately 1900 umho/cm, produced annual fluctuations of about 1600 umho/cm. As expected, at the Highway 41 station the usual annual fluctuation was about 2000 umho/cm; however, a range of as much as 15,000 umho/cm (between 1977 and 1978) was observed.

A similar pattern is observed for the two Alafia River stations (Fig. 4). The average conductivity of the Hillsborough River has varied over the period of record, showing a slight increasing trend in 1981 which may have been related to the lower-than-average rainfall for that year (Fig. 4).

Total Phosphorus (P_{tot}). Average P_{tot} concentrations are highest in the Alafia River but have been decreasing from about 8 mg/l in 1974 to 3.4 mg/l in 1979 (Fig. 5). The other streams studied, the Hillsborough and Little Manatee Rivers, have exhibited for the most part decreasing P_{tot} concentrations during the same time period. There was, however, a sharp increase in average P_{tot} concentration in the Little Manatee River from 1978 through 1980.

Fluoride and other parameters. Because reliable, long-term data were available, the Alafia River was studied more closely with respect to F^- trends, the relationship of discharge and selected chemical parameters.

Figure 6 shows the relationship between discharge and three chemical parameters. As might be expected there is an inverse relationship between the rate of discharge and conductance. There is a steady decline in both total phosphorus and fluoride concentrations. This decline in fluoride concentration is not a short time phenomenon as can be seen in Figure 7. Fluoride concentrations have declined from a high of almost 36 mg/l in 1958 to approximately 2.5 mg/l in 1979. This decline is significant with a correlation coefficient of -.52.

SEASONAL VARIATION IN DISCHARGE RATES

The average monthly flows for the larger streams entering Tampa Bay are depicted in Figure 8. Discharges for all of these streams generally follow the same pattern, with lowest discharge in the dry months of May and again in November, and the the highest discharge rates during the months of highest

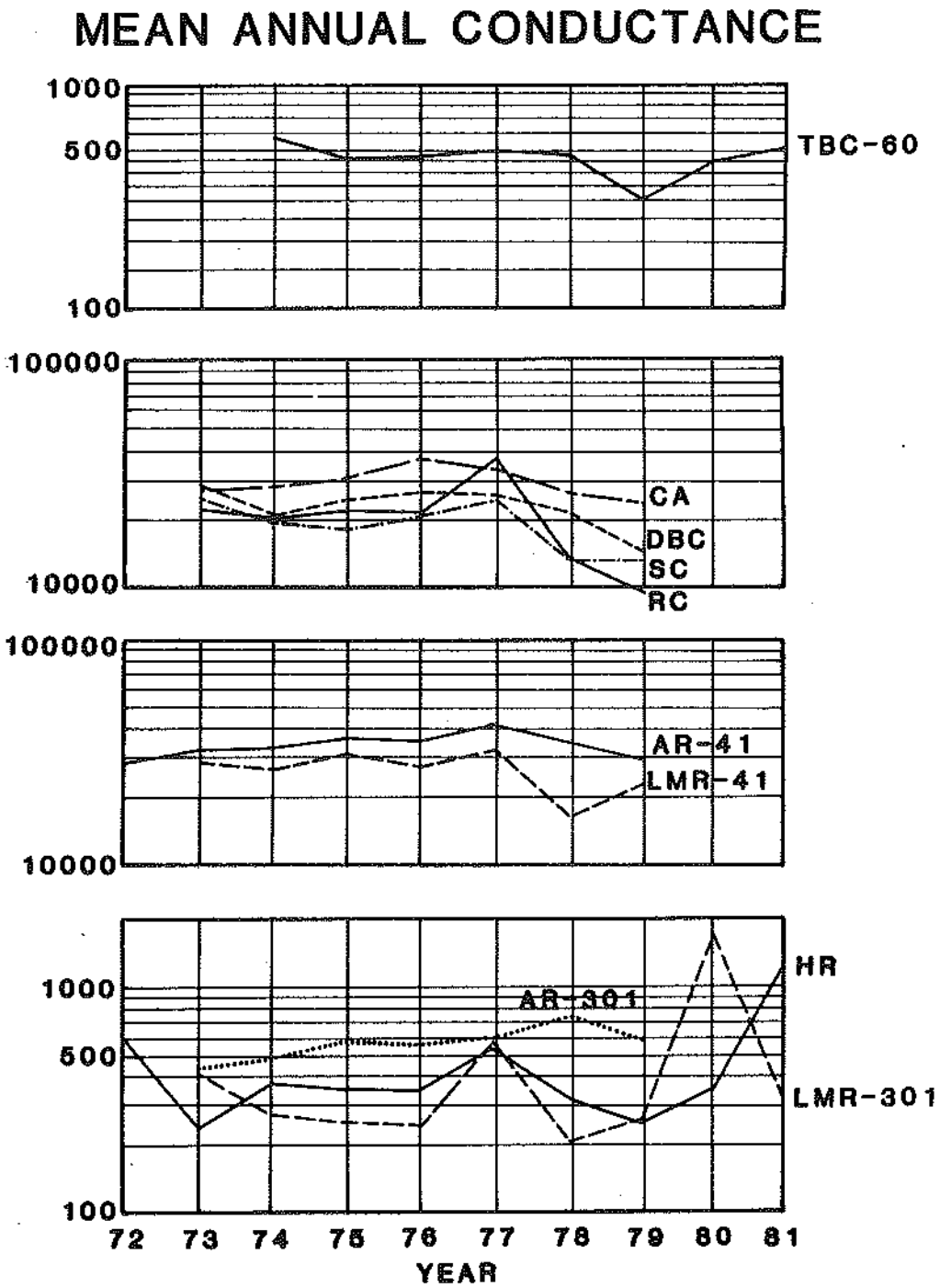

Figure 4. Mean annual conductance for streams entering Tampa Bay.

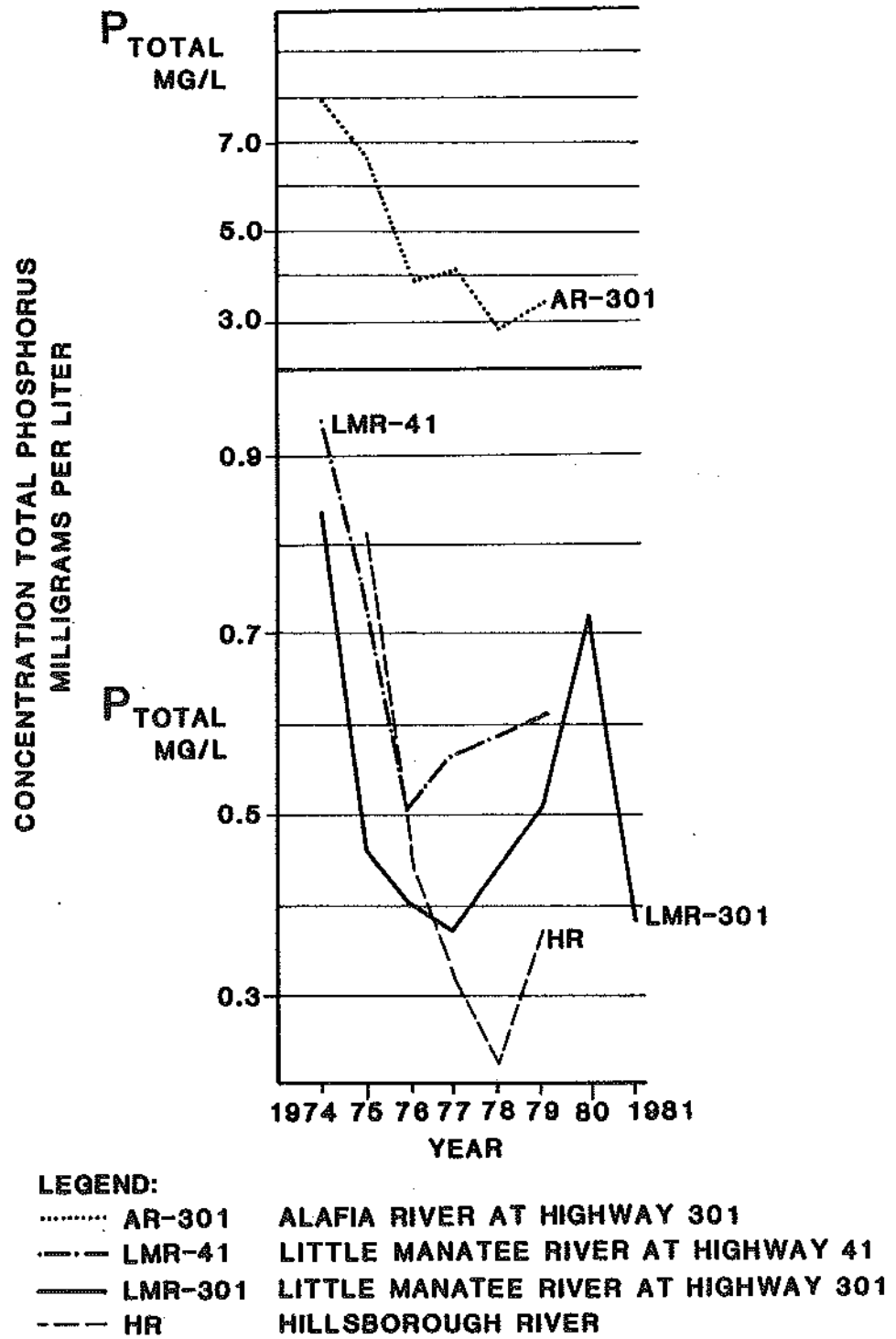

Figure 5. Mean annual total phosphorus concentrations for the Hillsborough River, Little Manatee River, and the Alafia River.

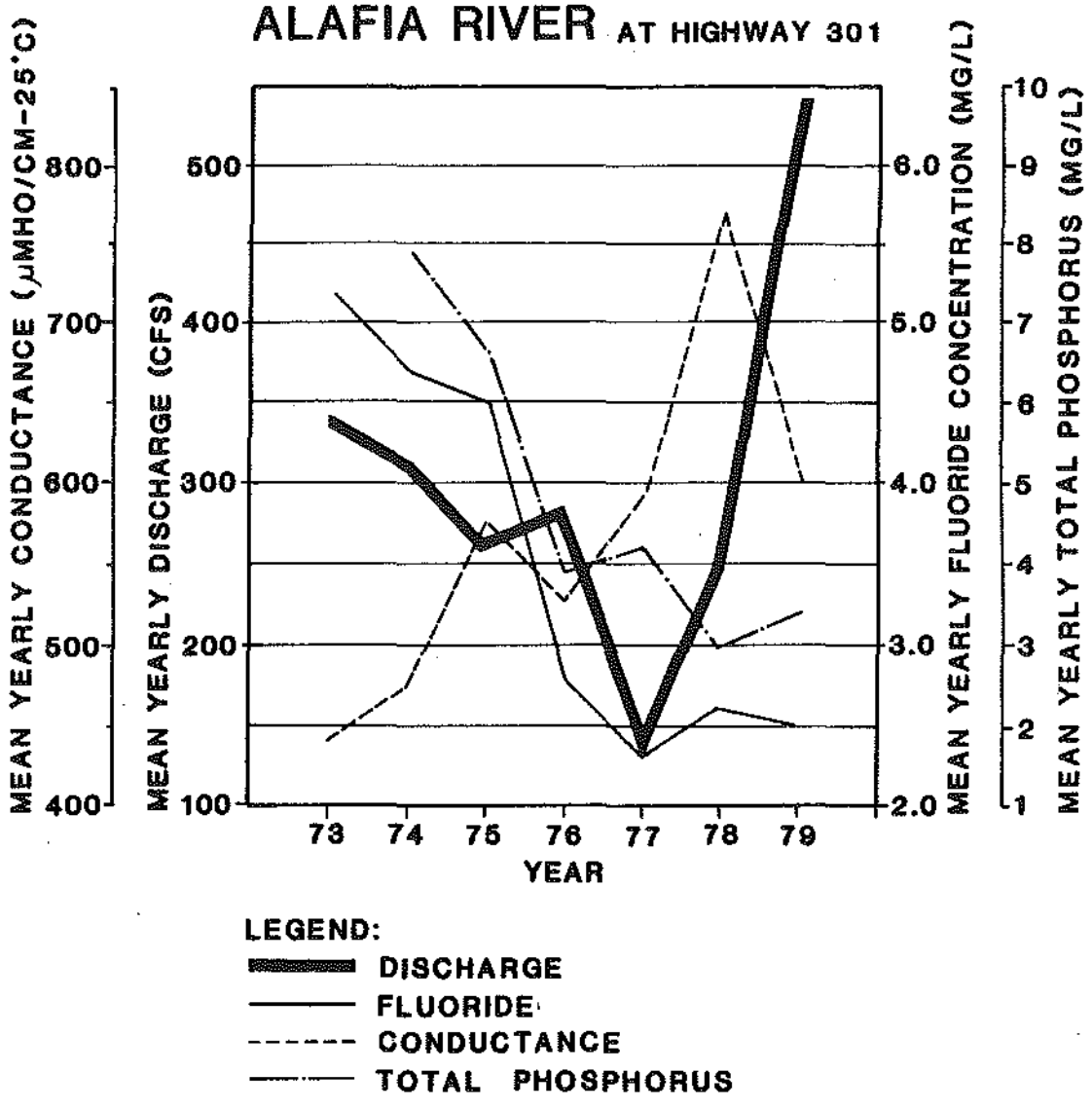

Figure 6. Comparison of mean annual conductance, discharge, fluoride concentration, and phosphorus concentrations for the Alafia River, 1973-1979.

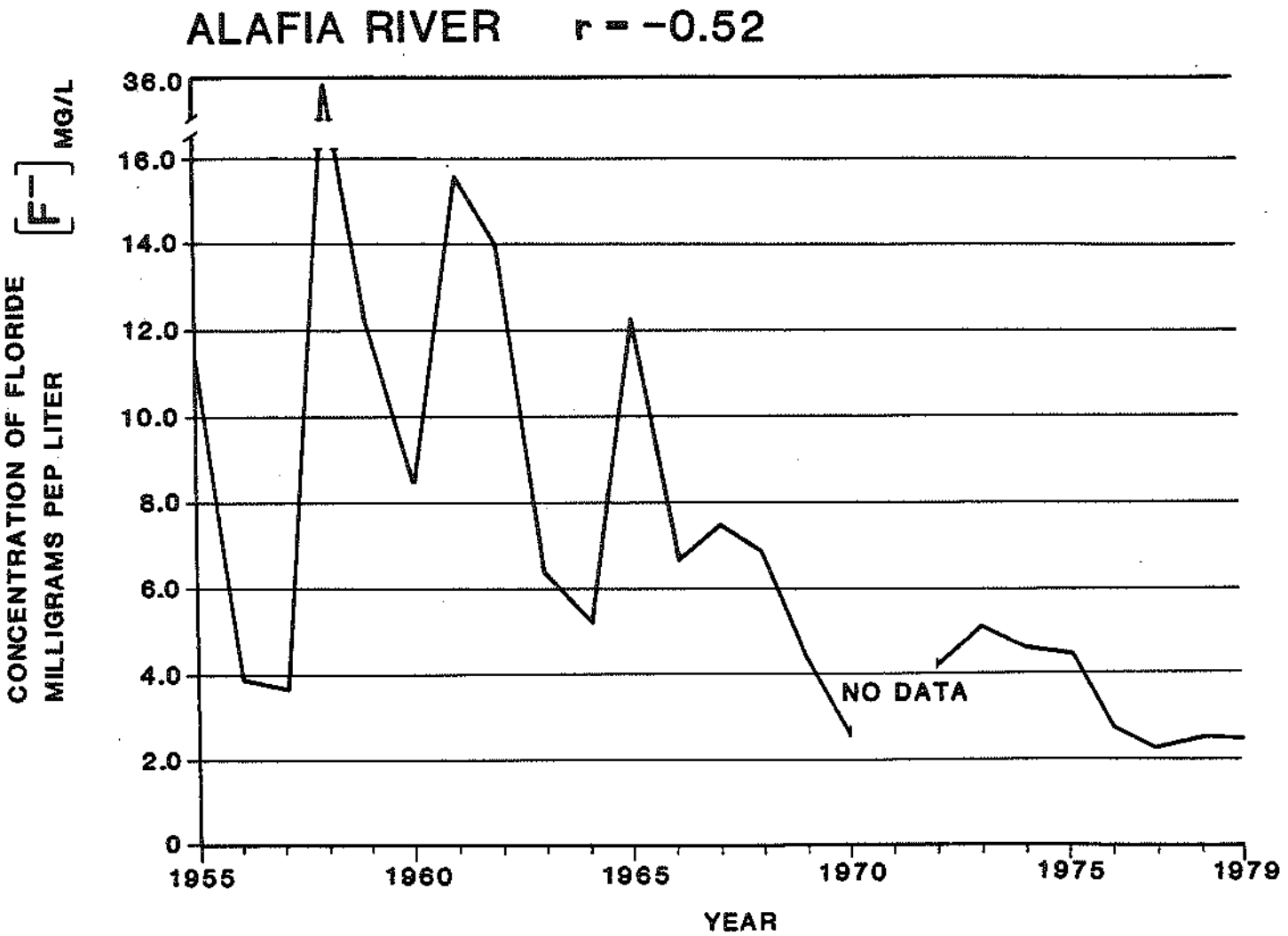

Figure 7. Mean annual fluoride concentrations for the Alafia River, 1955-1979.

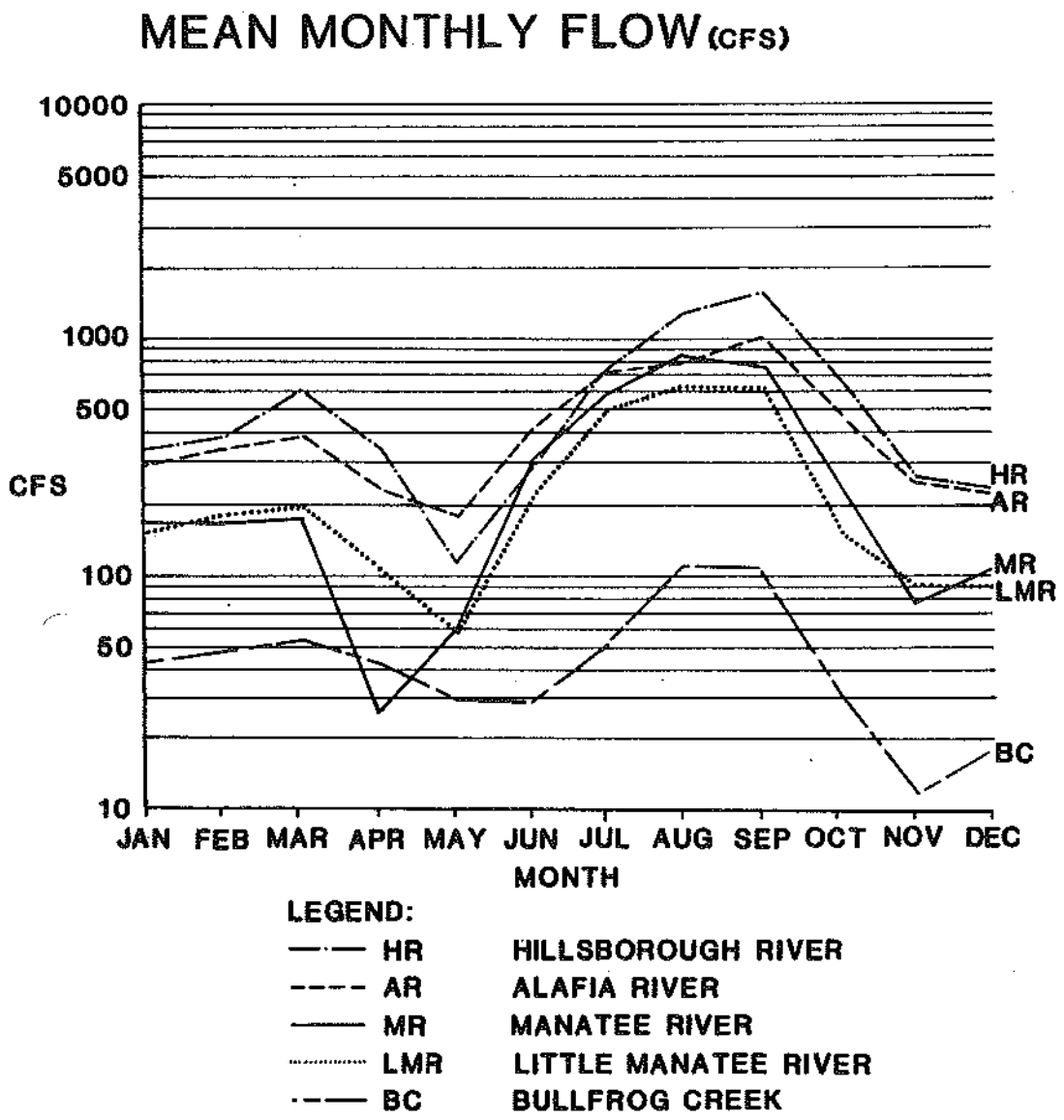

Figure 8. Mean monthly flow for period of record for larger streams entering Tampa Bay.

rainfall, August and September. A slight departure from the general pattern occurs on the Manatee River which has lowest flows in April rather than in May. The same pattern is exhibited by most of the smaller streams entering the Bay (Fig. 9). The exceptions are the Tampa Bypass Canal and the Tarpon Outfall Canal. Both of these have control structures and peaks of discharge during the dry season reflect release of water to increase storage capacity prior to the wet season.

As previously mentioned, the Alafia River was investigated in more detail with respect to its discharge characteristics. The estimated average discharge for the river at the Highway 301 station is 449 cfs. From an examination of Figure 10, it can be seen that the flow rate was exceeded in 4 years out of the 27 years of record shown. While a statistical analysis was not performed to determine the relationship between discharge and rainfall, it appears that flow on the Alafia is strongly related to total annual rainfall. Low discharge years (i.e., 1961, 1971, 1972, 1977, 1981) were coincident with low rainfall years, and years of higher discharge (1959, 1960, 1974, 1979) occurred during years of higher-than-average rainfall.

ANNUAL FRESHWATER VOLUME TO TAMPA BAY

The annual freshwater contribution to Tampa Bay by gaged streams can be seen in Figure 11. The Hillsborough River has the largest annual flow, contributing approximately 5.8×10^{11} l/yr to the Bay. It is followed by the Alafia, Manatee, Little Manatee and Tampa Bypass Canal, all with flows exceeding 10^{11} l/yr. The flow from all gaged streams exceeds 1.6×10^{12} l/yr.

ANNUAL CHEMICAL LOADS TO TAMPA BAY

Nitrate-Nitrogen. The Alafia River delivers the greatest amount of NO_3-N to Tampa Bay, approximately 3.9×10^5 kg/yr (Fig. 12). The Manatee and Hillsborough Rivers both contribute about 9×10^4 kg/yr. The Tarpon Outfall Canal adds approximately 6×10^2 kg/yr.

Total Organic Nitrogen. The Manatee and Alafia Rivers contribute nearly equal quantities of N_{org}-Tot to the Bay, about 2.5×10^5 kg/yr (Fig. 12). The Hillsborough River again was in third place despite having the largest discharge. Rocky Creek delivered the lowest amount of N_{org}-Tot of the streams studied (3.5×10^3 kg/yr).

Fluoride. As mentioned in previous discussions, the Alafia River, contributes, by far, the largest quantity of fluoride to Tampa Bay, approximately 4.3×10^6 kg/yr (Fig. 13). The Hillsborough River is a distant second at just in excess of 2×10^5 kg/yr. The Little Manatee and Manatee Rivers group closely together at about 10^5 kg/yr. Sweetwater Creek contributes least of the studied streams at 2.1×10^3 kg/yr fluoride.

Total Phosphorus. The Alafia River contributes the largest amounts of P_{tot} to the Bay, just over 2×10^6 kg/yr (Fig. 13). The Hillsborough River was second with approximately 5×10^5 kg/yr followed by the Manatee River at 4×10^5 kg/yr. Sweetwater Creek was again the smallest contributor at 3.8×10^3 kg/yr P_{tot}.

FUTURE DIRECTION

There is an enormous amount of information available on surface waters discharging to the Bay. Nevertheless, several streams remain without any routine data collection program for discharge or water quality. Other streams are sampled, but the number of stations is inadequate for the generation of an accurate picture of the character of the resource. This situation becomes more critical as time goes by because the demand on the water resources of the State, particularly in west central Florida, grows daily. This demand creates a prodigious need for technical information which, as just mentioned, is frequently insufficient or totally lacking. The answer to this problem is, of course, an expanded data network; however, the network must be the result

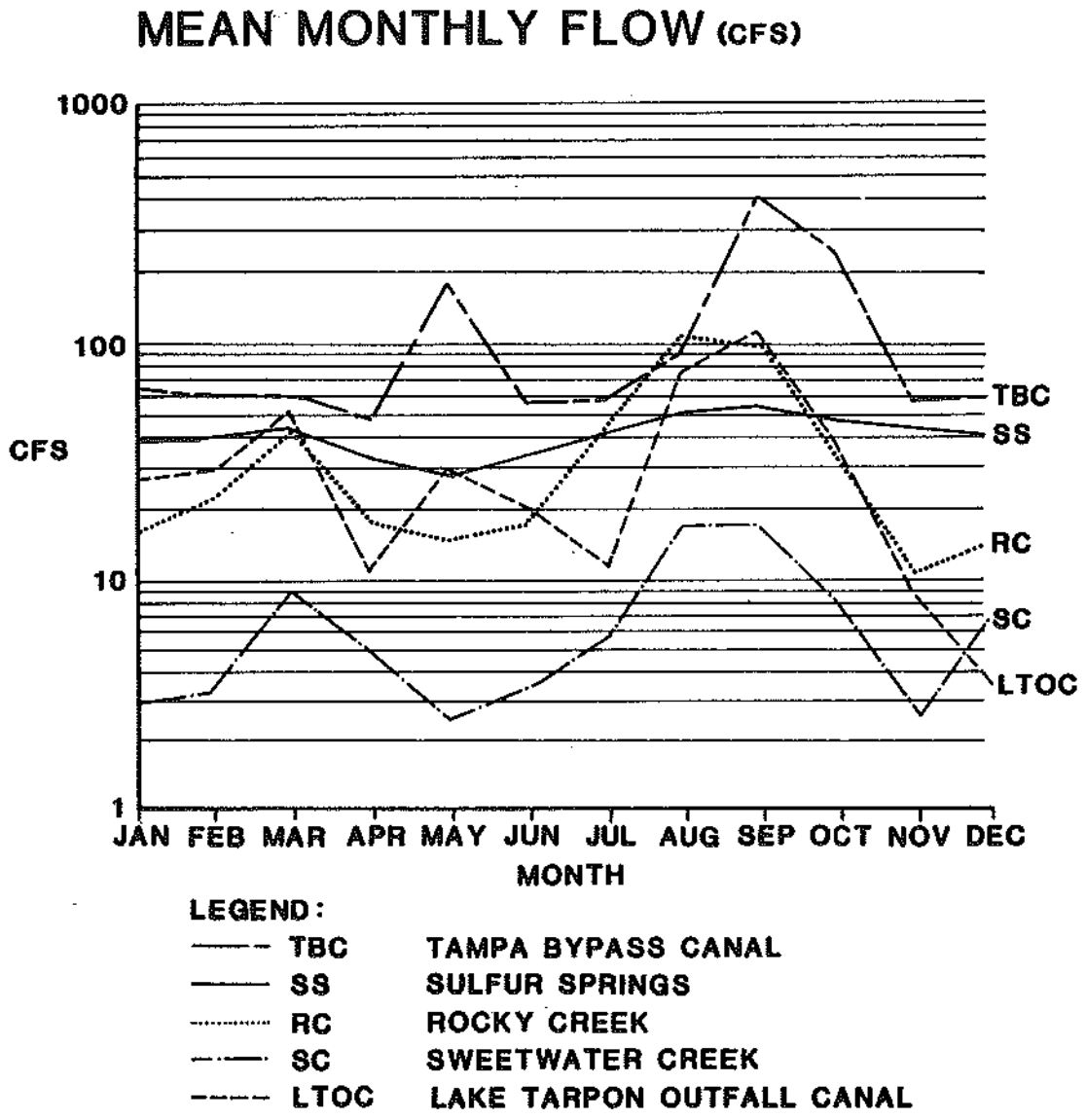

Figure 9. Mean monthly flow for period of record for smaller streams entering Tampa Bay.

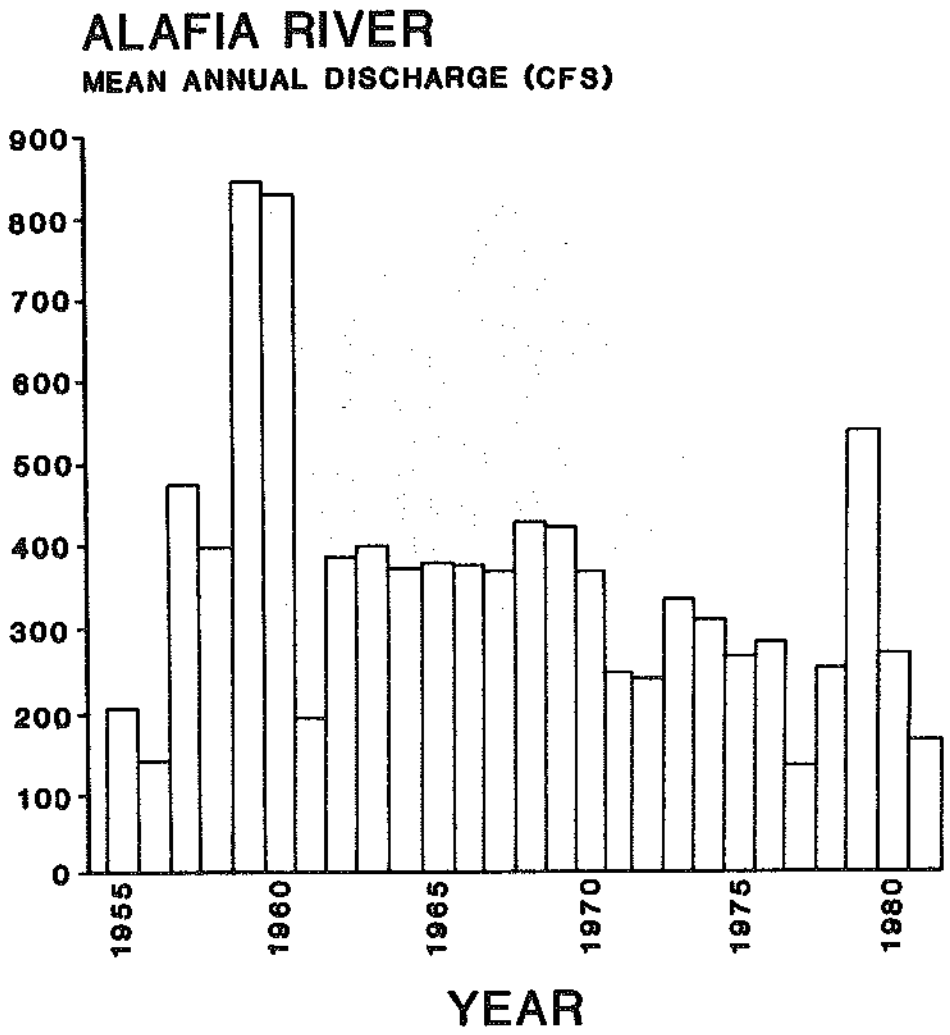

Figure 10. Mean annual discharge for the Alafia River, 1955-1981.

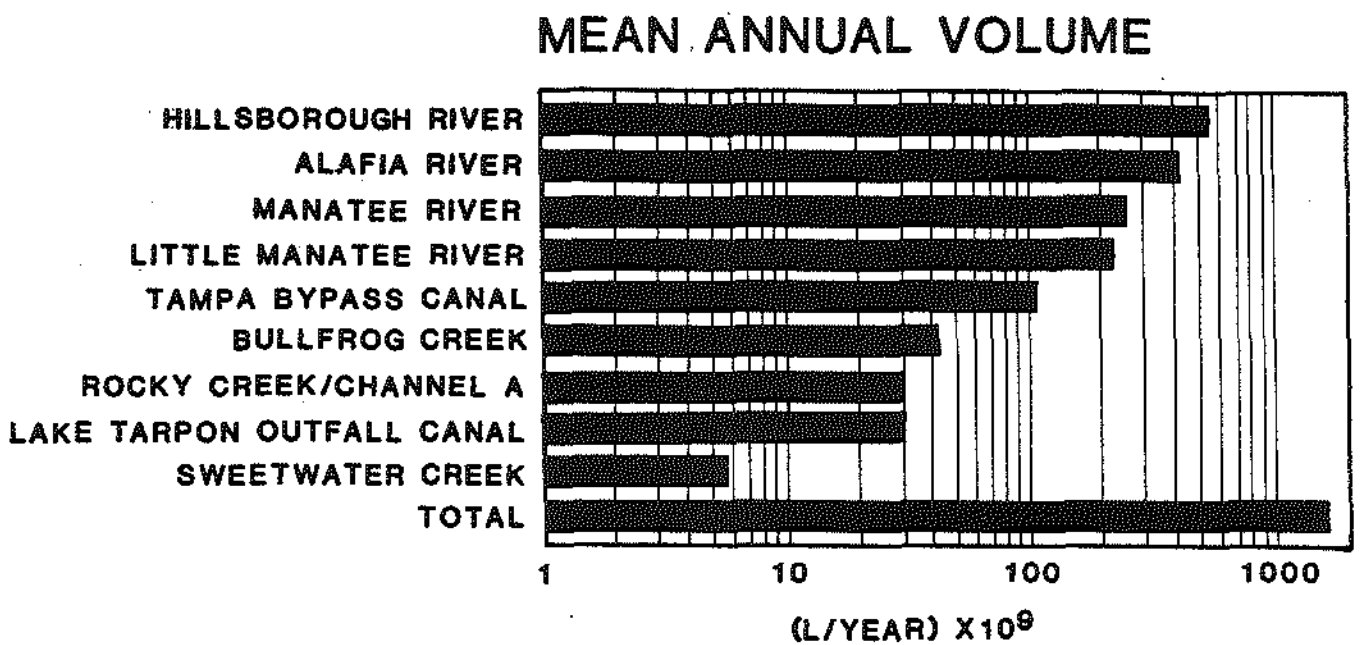

Figure 11. Mean annual volume of water entering Tampa Bay from gaged streams.

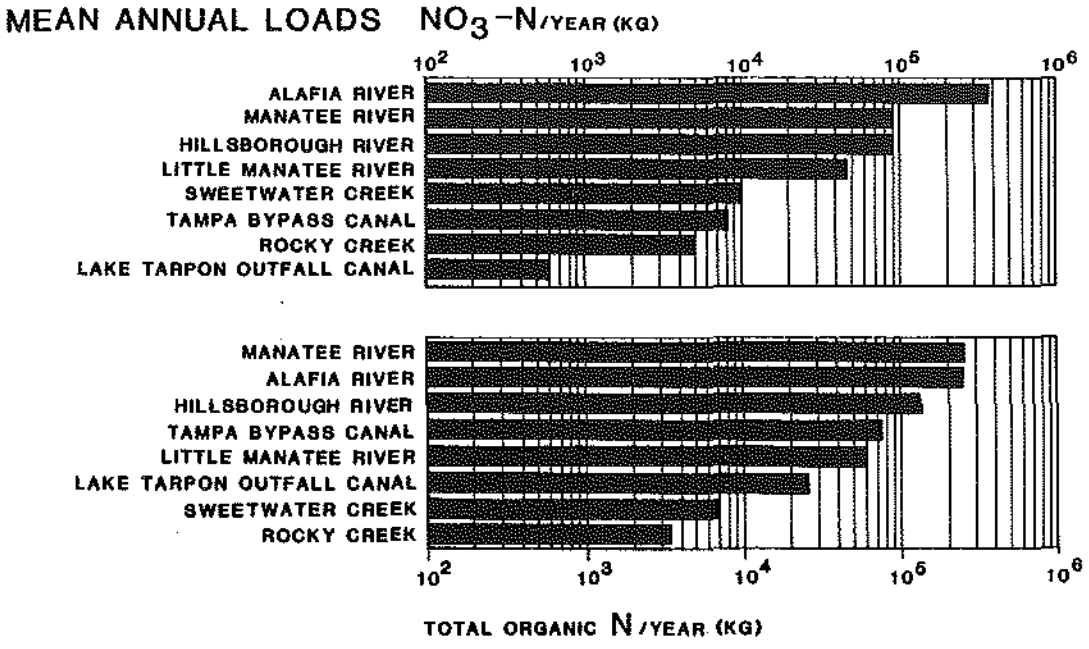

Figure 12. Mean annual loads (kg) of ammonia nitrogen and total organic nitrogen entering Tampa Bay from gaged streams.

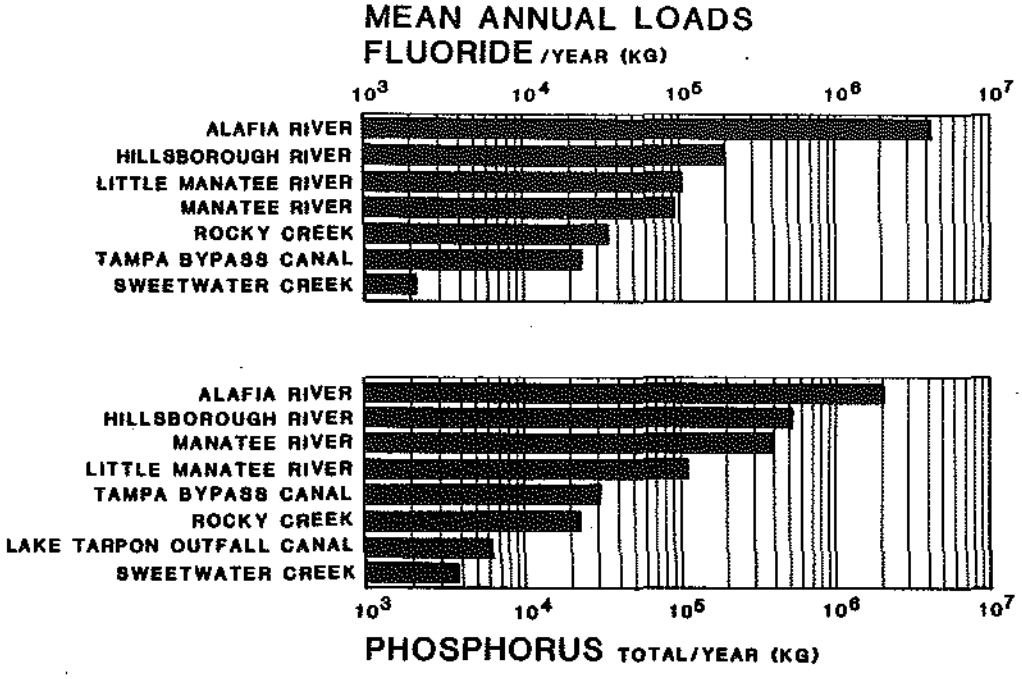

Figure 13. Mean annual loads (kg) of fluoride and total phosphorus entering Tampa Bay from gaged streams.

of a well coordinated effort among the Federal, State, regional, and local agencies involved with Florida's water resources.

ACKNOWLEDGMENTS

The authors would like to thank the organizers of BASIS for providing an opportunity for all local scientists to discover how much is not known about Tampa Bay. Also, the authors would like to express appreciation for the support of Mr. Bill Tatum, Executive Director of the Southwest Florida Water Management District and the assistance of the Administration of Saint Leo College. Our special thanks go to Dorothea Cole, Interagency Coordinator at Southwest Florida Water Management District, for her extremely able assistance.

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THE CIRCULATION AND FLUSHING OF SURFACE WATER IN TAMPA BAY

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ABSTRACT

This paper presents a chronological listing of projects undertaken regarding Tampa Bay which resulted in knowledge of the stages, currents, circulation and flushing of Tampa Bay. The performing agency or individual is recognized and the pertinent data from each study is enumerated and evaluated. The subject matter ranges from data gathering experiences from the year 1900 to the present time, and discusses measured physical data as well as data derived from mathematical and physical models of Tampa Bay. Subject matter includes references to hurricanes and oil spills, as well as major man-made changes to the Bay. This paper points out areas of need for more data regarding tide stages and currents immediately exterior to the mouth of Tampa Bay. A need also exists for studies of wave refractions and fundamental seiche nodes for Tampa Bay.

WATER QUALITY MONITORING IN TAMPA BAY

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ABSTRACT

The Hillsborough County Environmental Protection Commission has operated an extensive water quality monitoring network throughout Tampa Bay and its tributaries since January 1972. The network involves monthly sampling of about 75 locations with analyses of about 40 parameters. To provide a spatial comparison of water quality in Tampa Bay, the 1981 data is presented by SYMAP, a computer mapping of each parameter measured; a temporal comparison is depicted by graphs of each parameter from 1972 through 1981. Climatic and pollutional causes of water quality variations are discussed.

NUTRIENTS IN TAMPA BAY

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INTRODUCTION

There are many sources of the fertility of estuaries. Runoff from the land, influx from the surrounding sea, and remineralization processes in the water column and sediments can all contribute to the supply of estuarine nutrients (Nixon 1981). Circulation and rapid nutrient turnover facilitate the trapping of nutrients in estuaries. As we shall see, these processes in Tampa Bay seem to give it a few characteristics peculiar among estuaries. However, the deficiencies in knowledge about Tampa Bay prevent us from answering some of the most important questions that can be asked about nutrients in an estuary.

Several nutrients will be considered in this review. They were chosen because they are necessary for growth of most autotrophs or heterotrophs and because they might occasionally be in short supply. Members of the nitrogen system are the most interesting in the Bay, particularly ammonia (NH_3). We will also consider nitrate (NO_3^-) and nitrite (NO_2^-). Phosphate (PO_4^{3-}) must be discussed because of its abundance in the Bay. Dissolved silica ($Si(OH)_4$) is found in the Bay, as in many estuaries, although there is little evidence that it is ever limiting. However, diatoms are significant components of the Bay phytoplankton (see Steidinger and Gardiner, this volume). We also briefly will consider dissolved organic nitrogen (DON). Although there is little evidence for its importance to bay organisms, it could be a significant indicator of the ultimate impact of the Bay on the Gulf of Mexico. In some coastal waters, nutrients such as nitrate accumulate, are converted to dissolved organic form, and are then exported to the surrounding ocean (Nixon and Lee 1981). Future studies may show that Tampa Bay is performing a similar function.

For the purposes of this review, Tampa Bay was divided into six zones (Fig. 1): Zone 1, Old Tampa Bay; Zone 2, Hillsborough Bay; Zone 3, Middle Tampa Bay; Zone 4, South Tampa Bay (extends to just east of Egmont Key and from Mullet Key to Anna Maria Island); Zone 5, Boca Ciega Bay; and Zone 6, the Manatee River. Boundaries between these zones were selected roughly in accordance with the zones used by United States Geological Survey (Goetz and Goodwin 1980). Our zones are also similar to those proposed by Lewis and Whitman (this volume).

The review is organized in the following sections:

- Data Available
- Characteristics of Tampa Bay Nutrients
- The Importance of Sediments in Tampa Bay
- Summary of Recommendations

DATA AVAILABLE

Sources. Most of the long-term data available on nutrients in Tampa Bay is from state or Federal agencies -- Florida Department of Environmental Regulation (FDER), EPA and USGS -- or from our own laboratory at USF. The FDER, EPA and USGS have gathered some water-column information on Tampa Bay for at least 20 years, but until the 1970s sampling was neither very frequent nor comprehensive. Our chemistry lab at USF's Department of Marine Science has been doing nutrient analyses of Hillsborough Bay for the City of Tampa since 1976. The Hillsborough County Environmental Protection Commission (HCEPC) has computer-

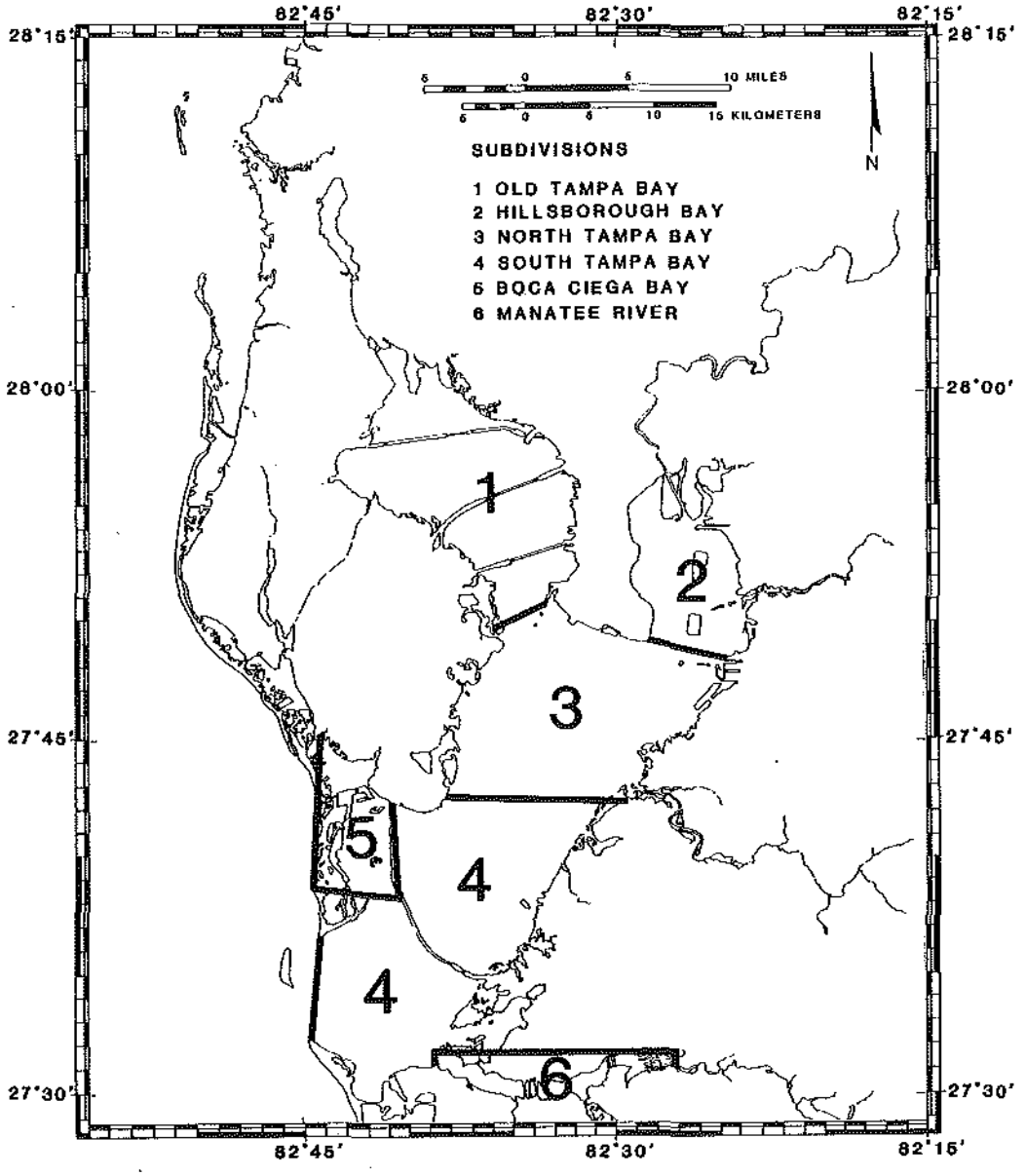

Figure 1. Zones sampled for nutrients in Tampa Bay.

generated graphs of nutrients in Tampa Bay from 1974 to 1982. Many of the analytical results of FDER and USGS, and those of other governmental agencies, are entered in EPA's data bank, STORET, which can be accessed through FDER in Tallahassee.

Through the cooperation of FDER, we retrieved data from STORET by zone for the six areas plotted in Figure 1. Most of the work of USGS in Tampa Bay is presented for four areas closely corresponding to our zones 1-4 (see Figure 1 in Goetz and Goodwin 1980). The four sections of Tampa Bay used for HCEPC results follow the natural divisions adopted by USGS and adapted by us for this report. Thus, intercomparisons by area are relatively straightforward.

The City of Tampa program began in 1976 by sampling 12 stations in Hillsborough Bay (Zone 2). In 1980, the number of stations was reduced to two (Stations 4 and 12) which were considered to be representative of Hillsborough Bay. To confirm this approach, we calculated the average concentrations for nutrients in Hillsborough Bay at different times during 1976-80 using all 12 stations and then plotted the results against the average concentration calculated using only stations 4 and 12. The regressions fit straight lines very well with the following correlation coefficients: SiO_2, r = .99; PO_4, r = .95; NH_3, r = .86; dissolved organic N, r = .95. This test showed that stations 4 and 12 of our City of Tampa data could be used to calculate annual average concentrations in Hillsborough Bay. In 1980, the City of Tampa also began sampling a station in the middle of North Tampa Bay, supplying additional information for Zone 3.

Figure 2 is a record of the sampling programs for nutrients in Tampa Bay. It shows that the most comprehensive coverage was from 1974 to 1979, both in terms of zones sampled and the number of agencies involved. So far, 1976 remains the year for which we have the most nutrient information.

The data for this report came mainly from four sources: USGS, FDER, the analyses our lab performed for the City of Tampa, and analyses done at the Department of Marine Science for other Florida west coast estuaries. Three USGS Open File Reports were used extensively: FL-74026 (1974), FL-7505 (1975) and #80-12 (Goetz and Goodwin 1980). The first two were comparisons of wet and dry conditions in 1971 which provided much of what little synoptic data we could find. The third was a thorough four-year study of the Bay that furnished seasonal data. For 1960 to 1982 and for all six areas of the Bay, we obtained results of FDER analyses plus additional USGS data from STORET. Results of EPA analyses were also available through STORET, but lack of time prevented our using them for this report as the data require multiple retrievals and compilations. HCEPC reports were used for comparison.

Problems. Several problems became apparent as we worked to gather and assess nutrient data on Tampa Bay. First, there is insufficient long-term coordinated coverage of the Bay. City of Tampa analyses continue for their seventh year, but they provide results for Hillsborough Bay and one mid-bay station in Zone 3. The data retrieved from STORET indicate that little is being done in Zones 5 and 6, and fewer analyses are reported for Zones 1-4 since 1980. The comprehensive studies of USGS apparently ended in 1976. The profile of nutrient analyses in Figure 2 has an obvious bulge which begins and ends in the 1970s.

The second problem is the lack of synopticity. Only the dry-wet season reports of USGS (1974, 1975) and the HCEPC data approach simultaneous sampling.

Third is the confusion and problems associated with organic-nitrogen analyses. Two methods are commonly used. Most frequently used is the "total Kjeldahl" method in which the amine nitrogen in organic matter is freed by acid hydrolysis and measured as ammonia. If ammonia is already in the

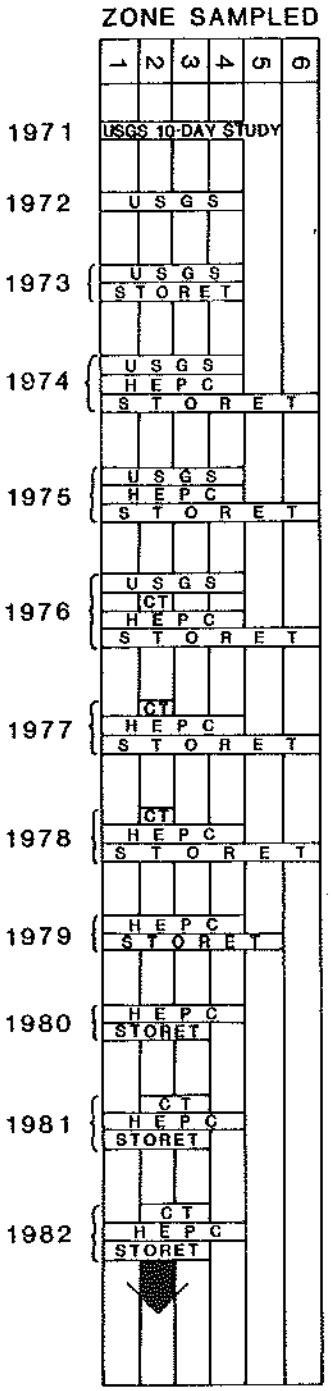

Figure 2. Record of sampling programs in Tampa Bay.

sample, then the hydrolyzed nitrogen is added to it. Thus, calculation of the amount of organic nitrogen in the samples requires that the ammonia initially present be subtracted from the "total Kjeldahl nitrogen", and it is not always clear if that subtraction has been carried out before data were compiled. Oxidation by ultraviolet light is a newer technique for determining organic nitrogen. The technique frees the reduced nitrogen in organic matter and oxidizes it to nitrate. At the same time, any ammonia and nitrite in the sample are also converted to nitrate and detected in the colorimetric reaction used for the oxidized organic nitrogen. Thus, a subtraction of nitrate, nitrite and ammonia initially present is required for the UV method. Another, and perhaps more serious, concern is the possibility that the two methods do not detect the same kinds of organic nitrogen compounds: i.e., some compounds may be more susceptible to one technique than the other. This question is currently being studied (e.g., Solorazano and Sharp 1980) and is somewhat controversial because we cannot be certain which technique gives the most "complete" analysis of organic nitrogen and which technique is better at detecting organic nitrogen compounds that are more reactive in the marine environment. The final outcome of organic-nitrogen measurements could be very important because of the possibility that the Bay may export them to the Gulf of Mexico.

The fourth problem is that of intercomparison. Even though there is adequate agreement about the major zones of Tampa Bay, the stations sampled within each zone differ between sampling programs -- and sometimes differ from one time to another within sampling programs. As far as we know, no inter-laboratory or inter-agency comparisons have been attempted other than those done for this report. Quality control tests such as EPA's (1979) are not uniformly used, further complicating attempts to share and compare nutrient data from the Bay.

Last, it is difficult to assess variability, given the available data. The graph of phosphate values from HCEPC (Fig. 3) shows the large variability that can exist even with fairly straightforward analyses. Because of the

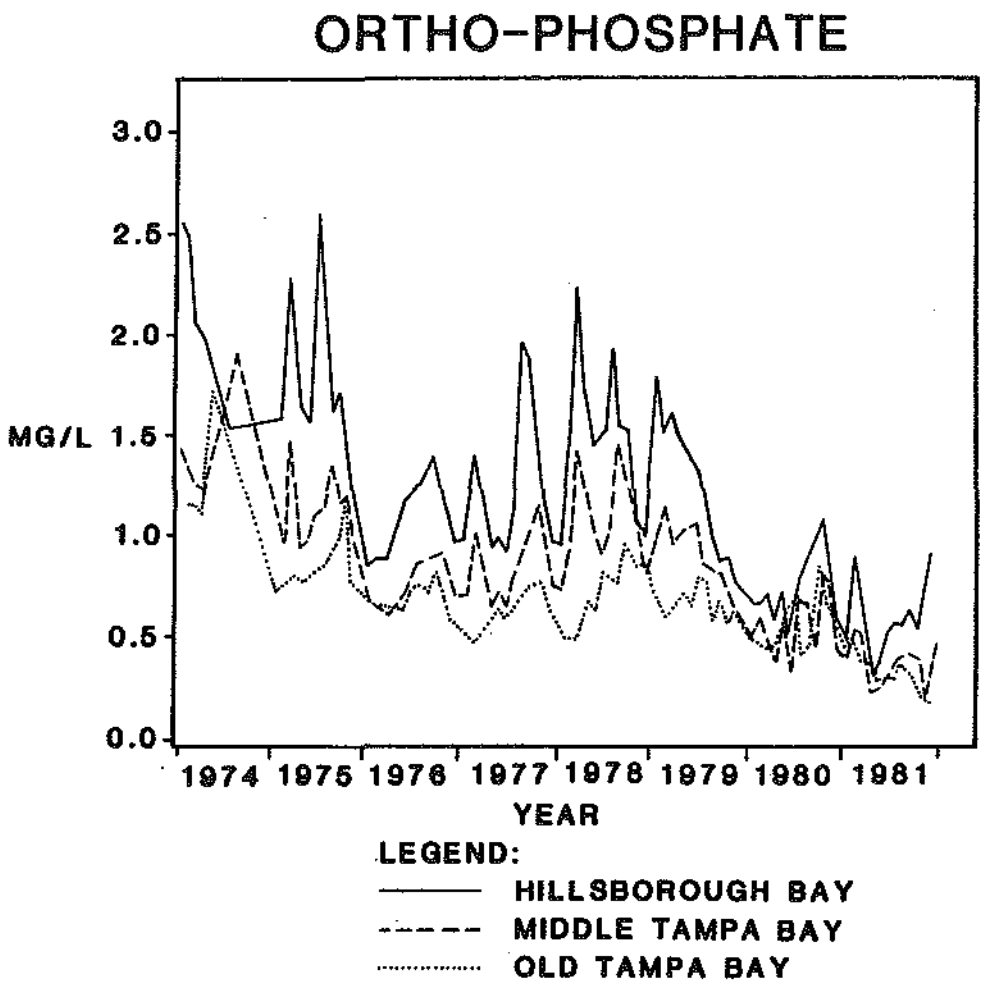

Figure 3. Phosphate values, HCEPC data.

difficulties mentioned, evaluation of such variability is currently impossible.

CHARACTERISTICS OF TAMPA BAY NUTRIENTS

Phosphate. Compared to other estuaries and coastal waters, Tampa Bay is considerably enriched in phosphate (Table 1). In fact, no other major estuarine or coastal area we know of even comes close to having as high a phosphate concentration. Charlotte Harbor south of Tampa Bay is fairly rich in phosphate, with an average concentration of 7 uM in 1980 when Tampa Bay had an average concentration of 14 uM (Fig. 4). Rookery Bay in southwestern Florida has an average phosphate concentration more in keeping with those of estuaries outside Florida. The explanation of the high phosphate concentrations in the Bay could be rather complex, involving leaching of Florida's phosphate beds, drainage of fertilizer from adjacent agricultural lands, industrial and sewage inputs, etc.

Figure 4 presents annual average phosphate concentrations in the Bay from 1972 to 1981, both for the whole Bay and its major zones. Data used in preparing the figure came from USGS work in 1972-1976 (Goetz and Goodwin 1980), from USGS and FDER studies after 1976, and from our own data on Hillsborough Bay. For calculating annual average concentrations, only stations where data from all four quarters of any given year were available were used.

Table 1. Phosphate concentrations in estuaries and coastal waters.

AREA	PO_4^{3-} (uM)
West Florida Coast:	
Tampa Bay	9-40 (annual averages, 1972-1981)
Charlotte Harbor (Squires 1982)	7 (annual average, 1980)
Rookery Bay (Naples, Florida)	1 (annual average, 1981)
Elsewhere:	
Chesapeake Bay (Taft et al. 1975)	0-0.2
Narragansett Bay, Rhode Island (Nixon et al. 1981)	0.5-2.0
Rhode Island coastal lagoons (Nixon and Lee 1981)	0.1-1.0
Bahia de Mochima and Laguna Grande, Venezuela (Okuda 1981)	0.2-0.4

The overall average for the whole Bay in any one year was obtained by combining the area-weighted averages of zones 1-4. Not enough data on Boca Ciega Bay or the Manatee River are available for inclusion in the averages; however, some values are shown in Figure 4.

The ranking in terms of phosphate concentration for 1972-1981 shows that Hillsborough Bay always had the highest annual average concentration, possibly due to the discharge of the Alafia River and the Tampa sewage plant at Hookers Point. Next highest was North Tampa Bay (Zone 3 in Figure 1). Zone 3 was followed by Old Tampa Bay (Zone 2), South Tampa Bay (Zone 4), and Boca Ceiga Bay (Zone 5). All of Tampa Bay is much higher in phosphate than the nearby Gulf waters; we have found typical values for PO_4 concentrations just west of the Sunshine Skyway Bridge are less than 1.0 uM.

Between 1972 and 1981, several interesting trends appeared (Fig. 4). Throughout the Bay, phosphate concentrations decreased dramatically; overall average phosphate concentration fell three- to four-fold. Average annual concentrations for Zones 1-4 followed the same trend, with Hillsborough Bay showing the largest decrease (80 uM in 1973 to 16 uM in 1981). The two largest decreases occurred in 1973-76 and 1978-81, and were 50-60% both times. There was a 20-30% increase in average annual concentrations from 1976-1978, but between 1972 and 1981 the spread in the average annual concentrations for Zones 1-4 decreased from 65 uM to 10 uM, or a six-fold decline. Why phosphate concentrations decreased is not known, although it is tempting to suggest that the input of pollutant phosphate to Hillsborough Bay was significantly reduced during those years. Without a much greater understanding of the rates of the various processes affecting phosphate in the Bay (uptake by plants, remineralization, deposition of organic

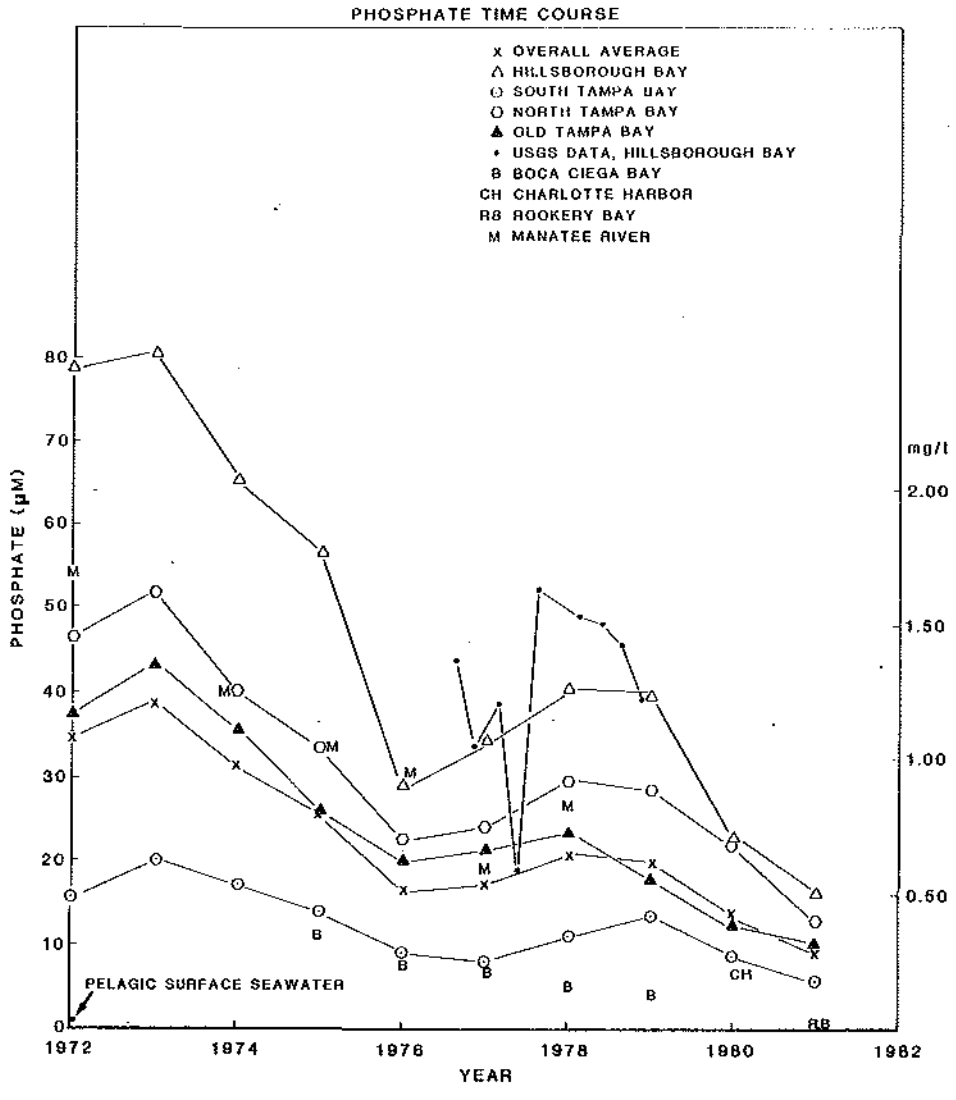

Figure 4. Phosphate time course, 1972-1981.

matter, flushing, etc.), details of curves like those in Figure 4 are difficult to interpret.

Figure 4 is misleading in one sense because its curves imply a smoothness in the time course of phosphate concentrations in the Bay which does not exist. The smoothness is an artifact of the averaging process. A better idea of the temporal variability of phosphate in the Bay is provided by the USGS data on Hillsborough Bay displayed in Figure 4 along with the average annual concentrations. The locations of the USGS data points along the time axis correspond to the actual times of sampling; they are not annual averages as are the other points. The HCEPC phosphate data in Figure 3 also demonstrate considerable temporal variability. That kind of scatter points out the need for many synoptic samples throughout the Bay in order to achieve better estimates of average nutrient concentrations.

Nitrogen. The nitrogen system in Tampa Bay is rather intriguing. Some comparisons between inorganic forms of nutrient nitrogen in the Bay and elsewhere are given in Table 2. The data indicate that estuaries and coastal lagoons often have quite variable concentrations of both oxidized forms (NO_3^- and NO_2^-) and ammonia. However, the concentrations of both (NO_3^- and NO_2^-) and NH_3 in Tampa Bay reach values that appear to be slightly higher than found elsewhere. What is more interesting is (the third column of numbers in Table 2), the ratio of ammonia to total inorganic nitrogen ($NO_3^- + NO_2^- + NH_3$). From the average of 91 samplings of portions of the Bay for 1971-1981, we conclude that the Bay has a distinctly larger fraction of its inorganic nutrient nitrogen present as ammonia -- 0.84 -- than do many other estuaries. Only Caminada Bay in Louisiana and some Venezuelan bays come close to being as ammonia-rich as Tampa Bay. The range of NH_3:total inorganic nitrogen ratios in the whole Bay or parts of the Bay was 0.54 to 0.99; we could discern no clear trends in the ratio with year or season. Why the Bay should have so much ammonia relative to nitrate and nitrite is unclear at present. Perhaps the supply of ammonia in river runoff or street runoff is quite high, or perhaps the shallowness of the Bay (average depth 3-4 m) means that ammonia release from sediment is much more important than in other estuaries (see below). The ammonia question is one that definitely needs to be pursued, both with the idea of confirming the ammonia-rich character of the Bay and of discovering the reason(s).

Figure 5 gives the long-term trends in ammonia concentrations in parts of the Bay from 1972-1981 and a few estimates of the annual average concentration for the whole Bay taken as Zones 1-4. The data are quite scattered and do not seem to demonstrate any strong trend with time as phosphate does. Old Tampa Bay may have had an increase in annual average ammonia concentration since 1979. The best we can say is that Tampa Bay seems to have had about 10 uM NH_3 on the average for the last 10 years. Obviously, ammonia should be carefully studied in the Bay because of its high concentration relative to other nitrogenous nutrients and because it is sometimes preferred as a nitrogen source by estuarine phytoplankton and macroalgae (McCarthy et al. 1977). Discussions during this symposium suggested that the relative importance of phytoplankton and seagrasses as primary producers in the Bay may be changing. If that is true, ammonia abundance compared to other nitrogenous nutrients, or to phosphate, may play a role in the change. Any ammonia studies should be conducted using very careful methods, with great care to avoid contamination of blank solutions or standard solutions, because the techniques used (e.g., Grasshoff and Johannsen 1972) can be very susceptible to such problems.

Nitrogen:Phosphate Ratio. If we assume that the average ammonia concentration in the Bay for the last 10 years is 10 uM and that the ratio of ammonia to total inorganic nutrient

Table 2. Forms of nutrient nitrogen in estuaries and coastal waters.

AREA	Concentrations (uM) $(NO_3^-)+(NO_2^-)$	(NH_3)	$NH_3:(NO_3^-)+(NO_2^-)+(NH_3)$
West Florida coast:			
Tampa Bay	0.1-20	1-20	0.84 (±0.12)
Rookery Bay	2.4	1.1	0.31
Elsewhere:			
Wadden Sea, Neth. (Van der Eijk 1979)	9-19	6-8	0.3-0.4
Caminada Bay, Louisiana (Ho and Barrett 1977)	0-9	1-6	0.4-1
Barataria Bay, Louisiana (Ho and Barrett 1977)	2-19	2-5	0.2-0.5
Narragansett Bay (Nixon et al. 1976)	0-15	0-15	0.5
Rhode Island coastal lagoons (Nixon and Lee 1981)	0-9	0-4	0.31
Bahia de Mochima and Laguna Grande, Venez. (Okuda 1981)	1.7	2.5	0.60

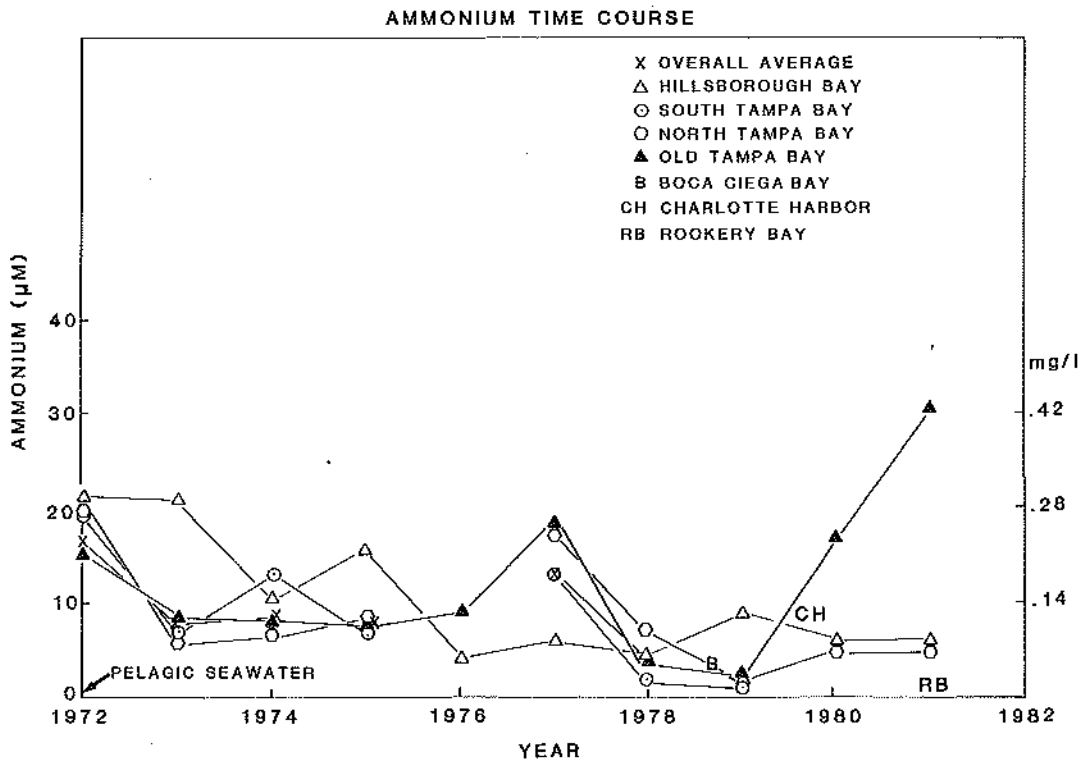

Figure 5. Ammonium time course, 1972-1981.

nitrogen is 0.84 (Table 2), then we can estimate the nitrogen:phosphate ratio in the Bay. The total inorganic nitrogen is estimated to have been 12 uM for the last ten years while the inorganic phosphate concentration decreased from 40 uM to 9 uM. Thus, the N:P ratio has increased from 0.3 in 1972 to 1.3 in 1981. If the Redfield ratios (N:P = 16:1 by atoms) have been approximately followed by primary producers in the Bay, as suggested for estuarine phytoplankton elsewhere (Nixon 1981), then the Bay has been nitrogen-limited at least since 1972. The ten year rise in the N:P ratio in the Bay might be taken to imply that the Bay is not as nitrogen-limited as it once was. One could suggest that primary productivity may have increased. However, our survey of the nitrogen data does not indicate any substantial increase in nitrogenous nutrients in the Bay since 1972. Therefore, it may be that the Bay is as nitrogen-limited now as it was in 1972, only now the plants consume a greater fraction of the available phosphate since less phosphate is present. Careful studies of the rates of processes affecting Bay nutrients must be made to provide knowledge vital to an understanding of the ecosystem. In particular, such studies must include assessment of the composition, growth rates, and production rates of the principal primary producers in the Bay (phytoplankton, macroalgae, seagrasses and associated epiphytes).

Variation with Depth. Our examination of the variation of nutrient concentrations with depth is somewhat meager, partly because of time constraints and partly because of a lack of measured depth distributions. There does not seem to be any substantial change in nutrient concentrations with depth in the Bay, based on the USGS surveys (Goetz and Goodwin 1980) and our own data for the City of Tampa. A lack of vertical variation would be expected. Freshwater is not very important in Tampa Bay's circulation,

which is dominated by tidal exchange (Goodell and Gorsline 1961). Thus, according to Bowden's (1967) criteria, the Bay should not show much vertical stratification.

Seasonal Cycles. A useful practice in studying estuarine nutrients is to examine their yearly cycles or variations (Nixon et al. 1976, 1981). For Tampa Bay, the most pronounced seasonal differences might be related to the dry winter season vs. the wet summer season. Our preliminary examination seems to support this idea. In 1971, two 5-day surveys of Bay nutrients were conducted, one in late spring before the rainy season, and one in early fall just after a period of very high rainfall (USGS 1974, 1975). Salinities were measured as well, and the regressions of nutrient concentrations against salinity showed some interesting differences (Fig. 6). The concentrations of total inorganic nitrogen (NO_3^- + NO_2^- + NH_3) decreased tremendously after the rainy season, but the concentrations of inorganic phosphate did not. These findings were true for Zones 1-5. Not surprisingly, salinities decreased 10-30% after the rainfall. We found evidence of a reduction in inorganic nitrogenous nutrients following the rainy season in other years in the USGS data report of Goetz and Goodwin (1981) and in our own data for the City of Tampa from Hillsborough Bay (Fig. 7). Apparently a loss of inorganic nitrogenous nutrients has occurred in several years during the rainy season, although not always in the same zone or to the same extent. The reason for this loss is unknown at present. Higher production, and therefore higher nutrient uptake rates during the rainy season, is a good possibility although chemical reactions in sediments may also be involved. Similar reductions in nitrate and ammonia concentrations have been found in Narragansett Bay in the summer (Nixon et al. 1976) while phosphate concentrations there tend to increase in the late summer (Nixon et al. 1981). However, the New England coast does not have the pronounced summer rainy season of the Tampa Bay area.

Examination of long-term phosphate data for the Bay does not show clear seasonal trends. In the USGS survey (Fig. 25 in Goetz and Goodwin 1980) no definite seasonality can be observed for Zones 1-4 in the years 1972-1976. However, HCEPC data for 1974 to present may indicate a tendency for phosphate concentrations in the Bay to be lower in the winter (Fig. 3) at the same time when oxygen concentrations appear to be high (Fig. 8).

One curious discovery from comparing Figures 6 and 7 is that the average total concentration of NO_3^- + NO_2^- + NH_3 in the Bay in the dry season seems to have fallen considerably between 1971 and subsequent years (from about 180 uM to about 20 uM). Why there should have been such a change is a puzzle, assuming that the sampling and analytical techniques are comparable. Continued monitoring of the Bay combined with a well designed research program is required to expain such substantial changes.

Figure 9 shows our somewhat intermittent data from different times in Hillsborough Bay as analyzed for the City of Tampa. The data plotted show the average concentrations for all of Hillsborough Bay. In keeping with much of the data for the rest of Tampa Bay, no regular seasonal variations were found for phosphate in Hillsborough Bay. However, in 1977, 1978, 1979, and 1981, ammonia in Hillsborough Bay seemed to reach a maximum in the late winter and spring. There was no seasonality in dissolved organic nitrogen (DON), either when measured by the Kjeldahl method or by UV oxidation. The DON concentrations usually ranged from 0-40 uM, only slightly higher that reported for Rhode Island coastal lagoons (0-30 uM; Nixon and Lee 1981) but much higher than reported for Venezuelan bays (0-10 uM; Okuda 1981). DON may be a useful indicator of the potential impact of Tampa Bay on adjacent coastal waters and should therefore be studied.

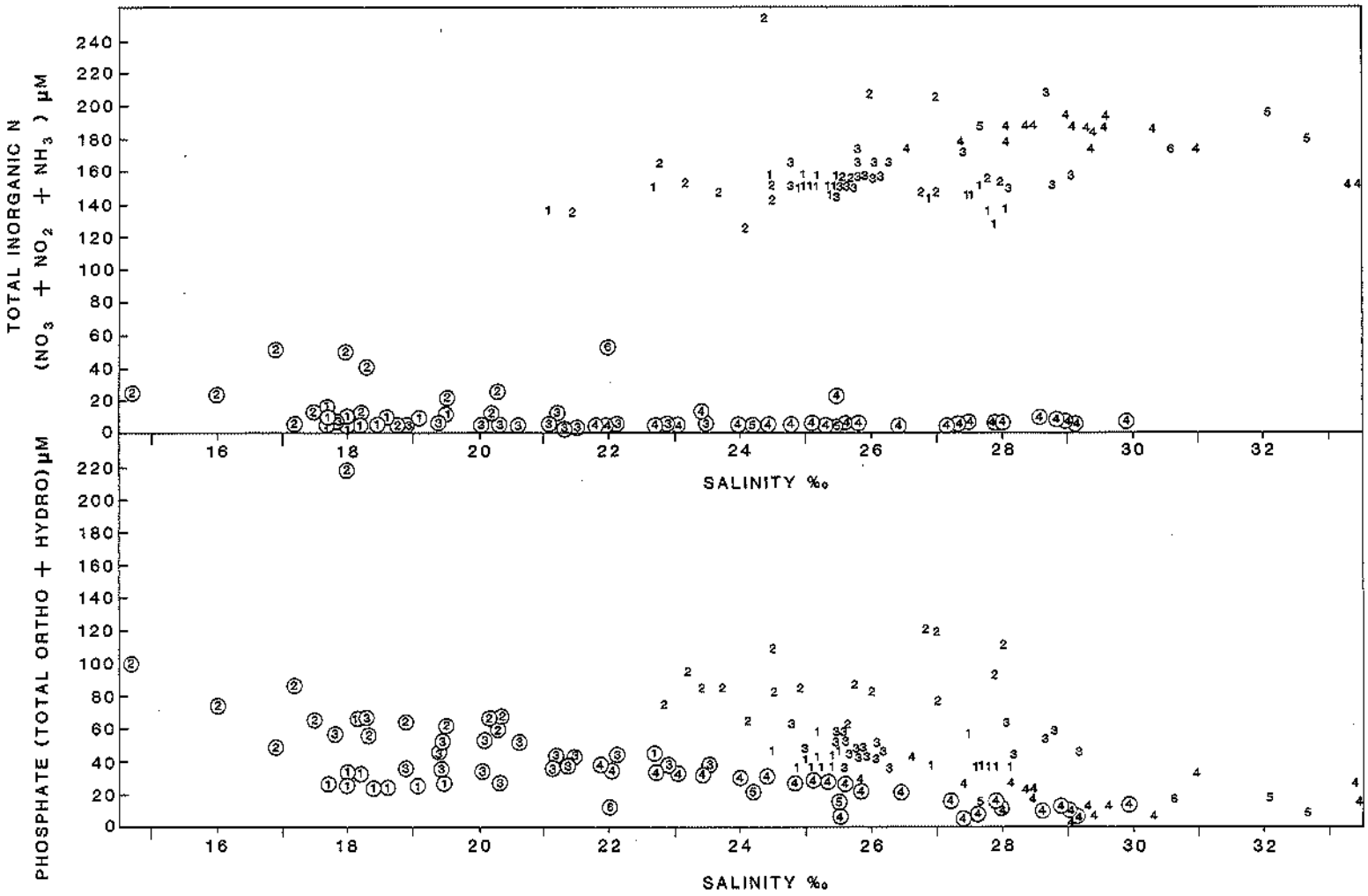

Figure 6. Regressions of nutrient concentrations against salinity.

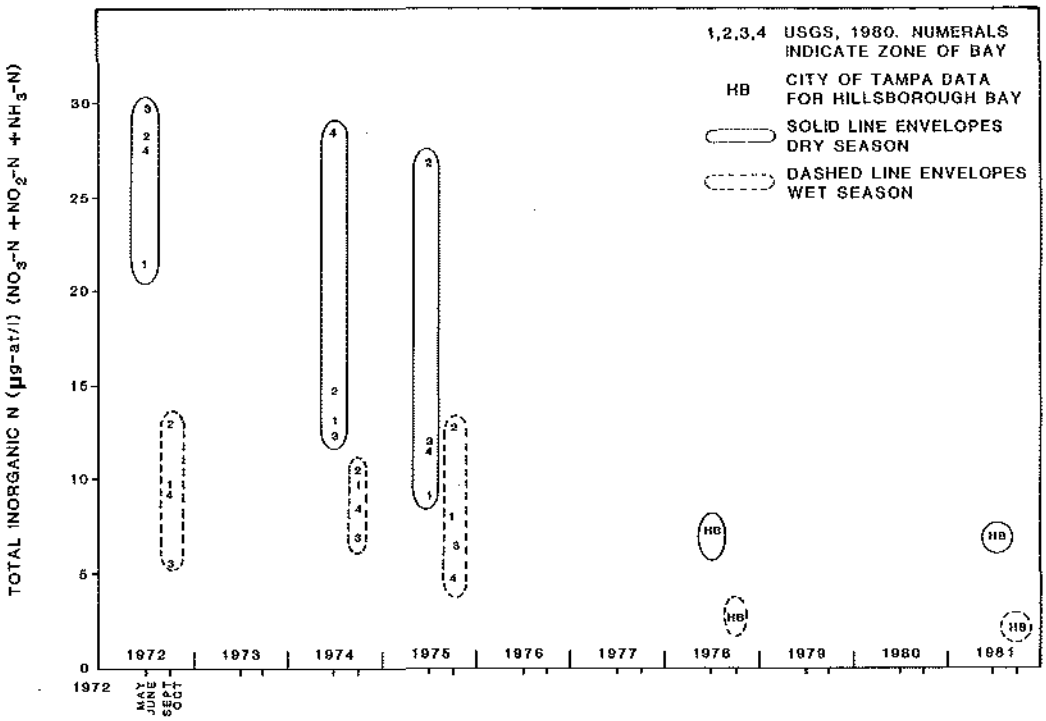

Figure 7. Total inorganic nitrogenous nutrients, 1972-1981.

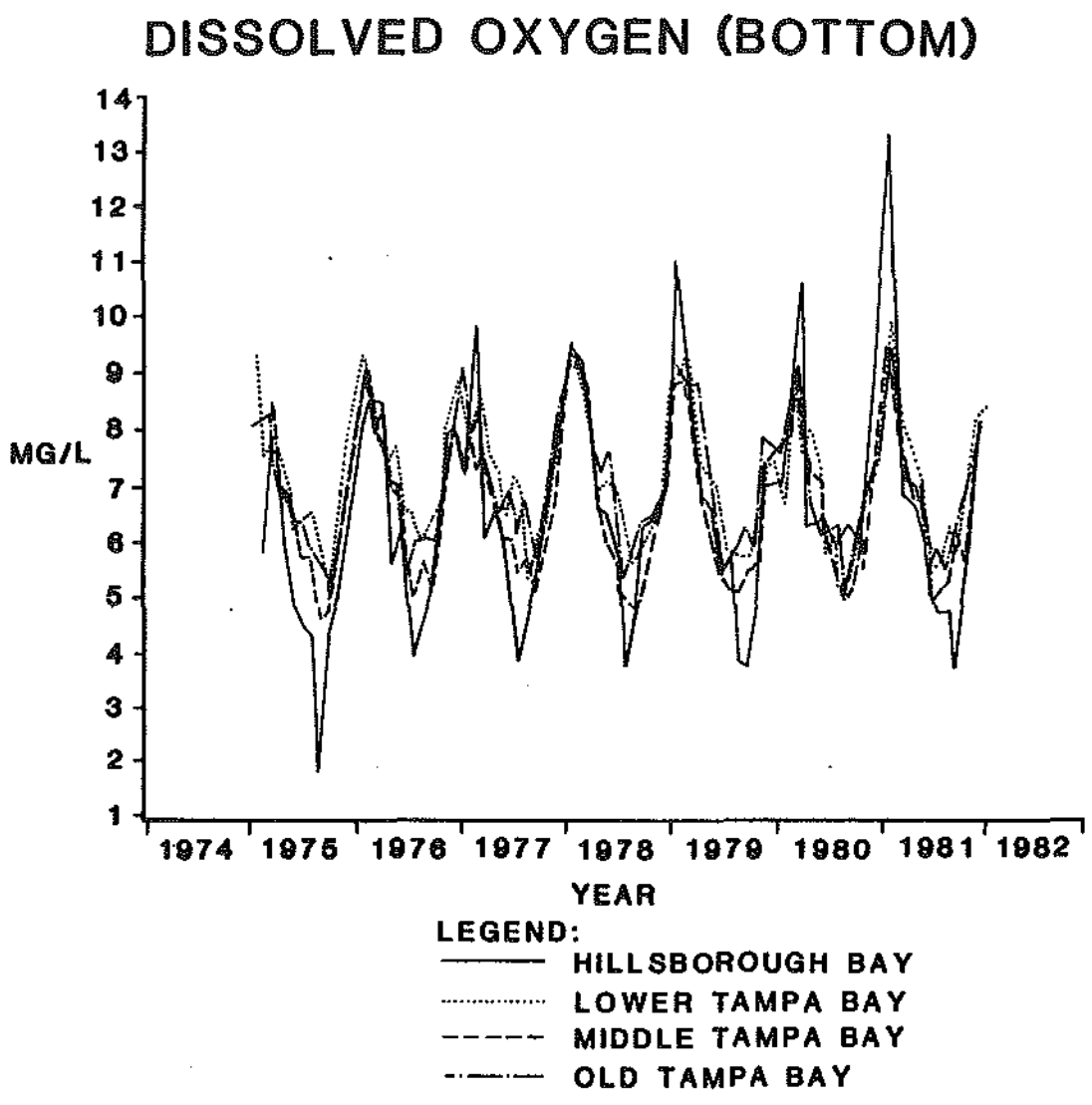

Figure 8. Dissolved oxygen, 1975-1981.

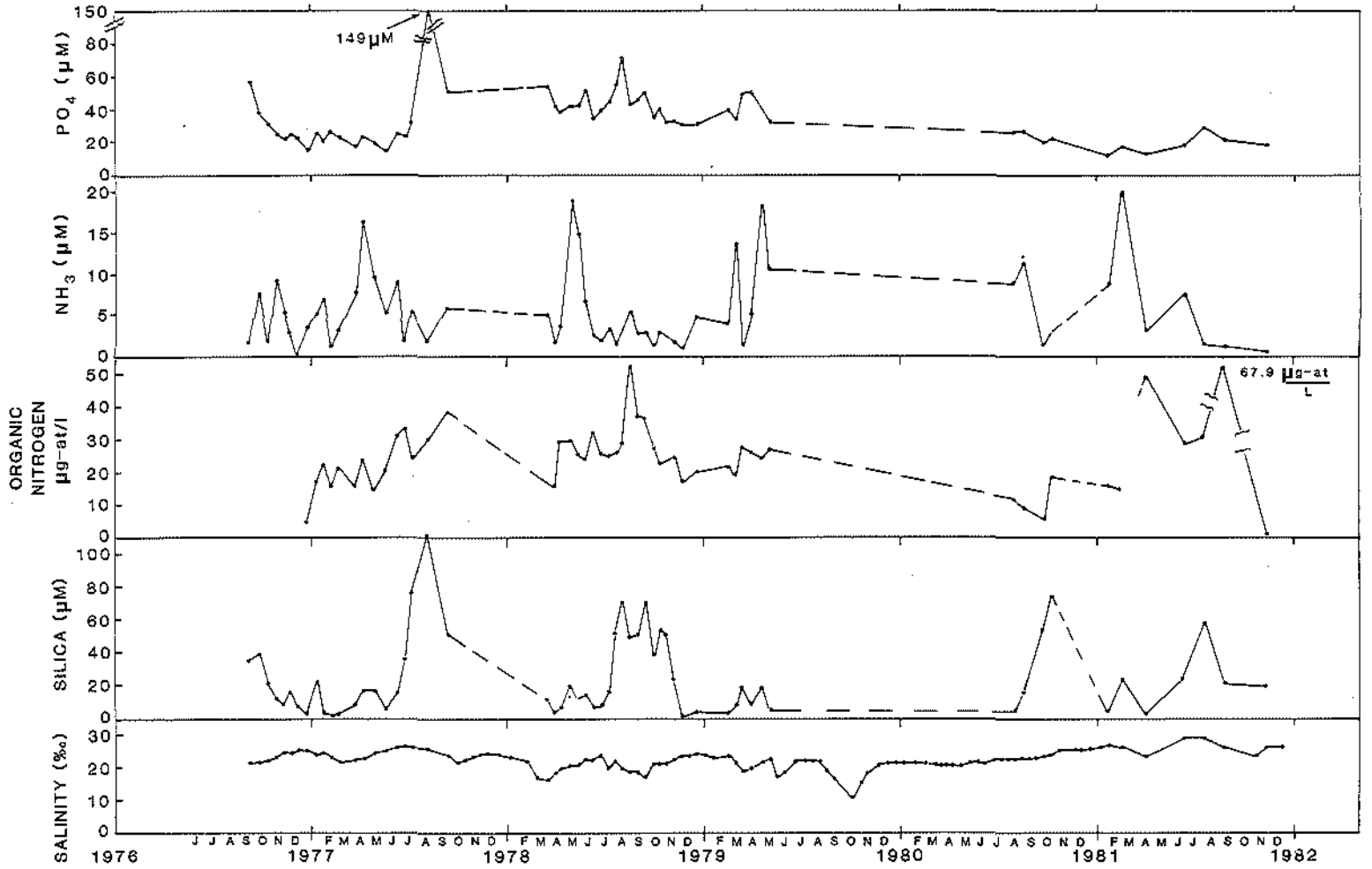

Figure 9. Average concentrations of nutrients over time, Hillsborough Bay.

Silica. Dissolved silica in Hillsborough Bay showed a curious tendency to increase in concentration in the summer. Since freshwater runoff often has much higher silica concentrations than seawater, increased runoff during the rainy season could be a factor. However, the salinity record does not show decreases that correspond to silica increases, so we must look for another explanation (see below).

Nutrient Transport. Calculations based on the nutrient data given in this report suggest that the natural processes in Tampa Bay are transporting nutrients through the Bay system rather quickly. For instance, river studies by Dooris and Dooris (this volume) indicate that the major streams discharging into the Bay deliver 3.2×10^{14} ug-at P/yr. This input is the same order of magnitude as riverine inputs estimated by Ross (1973): 2.7×10^{14} ug-at P/yr for 1968 and 1.2×10^{14} ug-at P/yr for 1972. If we take the average depth of the Bay to be 3.4 m and its area to be 910 km^2 (Goetz and Goodwin 1980), then the Bay's volume is 3.1×10^{12} liters. We estimated the average PO_4^{3-} concentration of the Bay to be 9 uM in 1981 (Fig. 4); therefore, the total amount of phosphate in the Bay in 1981 was 2.78×10^{13} umoles. Division of this number by the riverine input of total phosphorus given by Dooris and Dooris (this volume) yields the estimate that the phosphorus in the streams entering the Bay could replace the phosphate in the Bay in about one month. However, if that replacement were to happen, all of the riverine phosphorus (phosphate, dissolved organic phosphate, particulate phosphorus, etc.) would have to be present as phosphate, which is the form most usable by phytoplankton (Riley and Chester 1971). Thus, other forms of phosphorus delivered in rivers would have to be converted to phosphate. In addition to riverine inputs there are phosphorus inputs from industries, street runoff, sewage plants, etc., all of which have the potential to become converted to phosphate. Thus, the impact and flow of phosphorus through the biological system of the Bay could be tremendous. One month or less is a very short residence time. Research on the forms of phosphorus delivered and the extents and rates of their conversions is paramount to understanding the significance of phosphorus to the Bay.

A similar calculation can be made for nitrate, and perhaps for other nitrogenous nutrients. Dooris and Dooris (this volume) estimate that the major streams entering the Bay deliver 5×10^{13} umoles NO_3^-/yr. If the Bay's average ammonia concentration is 10 uM, and the average NH_3:(NO_3^- + NO_2^- + NH_3) ratio is 0.84, then the total amount of (NO_3^- + NO_2^-) in the Bay is about 5.9×10^{12} umoles, and the rivers could replace that amount in about 1.4 months. The nitrogen system as it interacts with the marine food web is even more complex than the phosphorus system. Thus, the true importance of nitrogen in the Bay as it relates to fertility, species composition and succession, etc. cannot be predicted without extensive study of the forms of nutrient nitrogen and the processes which influence them.

THE POTENTIAL IMPORTANCE OF TAMPA BAY SEDIMENTS

In the pelagic ocean, there is so much water between the sediments and the euphotic zone that a direct connection between them is difficult to establish. However, as one moves closer to shore there is a greater possibility that biologically reactive materials solubilized and released from the sea bed will reach the euphotic zone and affect its biota. Indeed, in estuaries, much of the sediment may lie within the euphotic zone, and Tampa Bay may be especially responsive to fluxes from sediments because its water column is quite shallow -- 3.4 m on the average (Goetz and Goodwin 1980).

A thorough treatment of the impact of estuarine sediments on the biochemistry of estuarine waters is provided in the excellent review of Nixon (1981). He demonstrates that the recycling of nutrients within many

estuaries can be just as important or more important than external inputs of nutrients, and he presents data and calculations suggesting that nutrient fluxes from sediments are major contributors to nutrient recycling within estuaries. Some of that benthic flux work was published in greater detail earlier (Nixon et al. 1976, 1981). Ammonia fluxes from the bottom can be large in portions of the nitrogen cycle in estuaries, and benthic fluxes of nitrate and phosphate also have an effect. However, perhaps Nixon's most interesting conclusion concerns the role of sedimentary denitrification on nitrogenous nutrients in estuarine water columns. He begins by asking why estuaries are considered to be nitrogen-limited when N:P ratios in runoff and in estuarine plankton are close to the Redfield ratio of 16 atoms N to 1 atom P. As mentioned above, estuarine waters like those of Tampa Bay often have N:P ratios less than 5. Nixon shows that the ratio of the benthic flux of ammonia and nitrate to that of phosphate is 5:1 or less in Narragansett Bay, and thus the sediments are implicated. He then proposed that denitrification in the sediments converts nitrate and nitrite to elemental nitrogen which escapes from sediment to water and then to the atmosphere. Elemental nitrogen cannot be used by estuarine biota that are not nitrogen fixers and is not normally measured by people studying benthic fluxes. Nixon found the missing nitrogen in Narragansett Bay because he has succeeded in measuring fluxes of nitrogen gas from cores. He has also provided a very plausible explanation for nitrogen limitation in any estuary, including Tampa Bay.

Our attempt to find out what is known about nutrient processes in sediments of Tampa Bay produced very little information. To our knowledge, there have been no measurements of benthic respiration or of benthic fluxes of nutrients back into the water column of the Bay. Such studies are crucial to an understanding of nutrient cycles in an estuary, and their application to the Bay may explain its apparent nitrogen deficiencies (N:P less than 2, see above). Data from our laboratory at USF relate to the rate of nutrient return from Bay sediments. In 1974, phosphate concentrations of 1870 uM were measured in the interstitial water of the top centimeter of sediment in Hillsborough Bay off the Alafia River while the overlying water had 15 uM PO_4^{3-}. In 1981, the interstitial water in the top centimeter of Bayboro Harbor sediment had a phosphate concentration of 208 uM. If we assume a 3.4 meter water column over the "typical" Bay sediment, a phosphate concentration of 15 uM at the sediment-water interface, and use a diffusion coefficient of 1×10^{-6} cm^2/sec for interstitial phosphate (Li and Gregory 1974), we can calculate that molecular diffusion of phosphate out of typical Bay sediment should replace the phosphate in the overlying water in 30 to 300 days, depending on which interstitial phosphate concentration is used. Obviously, a serious survey of interstitial phosphate in Tampa Bay should be undertaken in order to estimate what the diffusive flux might actually be. It is also possible that agitation of sediment by organisms or currents might enhance the phosphate release from the bottom; diffusive-flux calculations do not include that transport. There is evidence from the Florida continental shelf that near-bottom currents can cause nutrient release (Fanning et al. 1982), and similar processes could occur within Tampa Bay. For example, disturbances of the sediment in Hillsborough Bay may explain its sharp summertime silica increases (see above and Figure 9). Hillsborough Bay sediment is finer grained and possibly more easily resuspended than the rest of the Bay sediment (Goodell and Gorsline 1961; Doyle, this volume).

Sediment from Bayboro Harbor has about 2,700 uM NH_3 dissolved in pore water from its top centimeter. A diffusive flux calculation similar to that for phosphate can be made assuming 10 uM NH_3 in the water column just at the

sediment-water interface of the Bay. The results suggest that an ammonia flux from Bay sediment could replace the overlying ammonia in only 14 days. Thus, just as Nixon (1981) reported for Narragansett Bay and other estuaries, the sediment of Tampa Bay could play a large role in the nitrogen cycle of Bay waters.

SUMMARY OF RECOMMENDATIONS

Knowledge of nutrients in Tampa Bay has progessed to a rather fortunate stage. Enough work has been done in recent years that we no longer have to ask only basic questions about what nutrients are present in greatest abundance in the Bay. We have learned that the Bay appears to be rich in phosphate but is less so as time passes, and that a surprising amount of ammonia seems to be present. The situation is fortunate because future research can thus be adequately directed toward identification and quantification of the most important processes affecting nutrients and biota in the Bay. Our recommendations for future work follow.

The first aspect to be studied is that the Bay seems to be capable of extensive and rapid changes in its complement of nutrients. An excellent demonstration is the large decrease in phosphate concentration in the last 10 years. In addition to longer term changes in nutrients, there are seasonal cycles or changes such as found in other estuaries. The annual summer increase in silica in Hillsborough Bay is an example. There are good reasons why the Bay should be susceptible to change. First, it is quite shallow, meaning that there is not a large buffer of water column to resist change. Next, inputs of nutrients in runoff are quite large relative to the standing stocks in the water column, and thus the potential replacement times calculated for phosphorus and nitrate were quite low. Third, the human population around the shores of the Bay is growing, and with rapid urbanization the amounts and character of inputs could change quickly.

Thus, the Bay is far from static in its nutrient composition, and conclusions based on past data might be obsolete almost as soon as drawn. To keep abreast of such variability, permanent long-term monitoring of the nutrients in the Bay is needed. Our evaluation of past nutrient studies indicates that no single effort has been sufficient. There has not been enough synoptic geographic coverage to permit the most meaningful estimates of trends in overall nutrient averages. Comparisons of nutrient data for the same locations within the Bay are very hard to make because information on analytical quality control in various laboratories is not readily available, and different laboratories do not perform nutrient analyses on the same water samples. Therefore, all of the laboratories now making nutrient surveys in the Bay or interested in making future surveys should plan a long-range coordinated effort so that all parts of the Bay are adequately sampled in the future and that nutrient data from all sources can be reliably compared. Then the changes in nutrient concentrations or ratios in the Bay would be documented beyond a reasonable doubt.

Another very significant study which can now be undertaken concerns the pathways and rates of nutrient transformation within the Bay system. This effort would involve intense studies of the first two levels of the Bay's food web -- primary producers and grazers. Seagrass beds in Tampa Bay are decreasing (Lewis et al., this volume), theoretically due in part to competition with phytoplankton and macroalgae for available light. If nutrient levels remain the same, then the production of water-column microflora and epibenthic microflora should increase due to decreased competition for available nutrients, or release of stored nutrients as seagrass biomass decreases. Such a change at the base of the food web would have profound effects on the higher trophic levels. Answers are needed to many questions. Are the very low N:P ratios in the water-column nutrients reflected in the N:P ratios of primary producers and grazers? If not, where is

the additional nitrogen coming from -- the sediments, more rapid turnover, etc.? What are the growth rates and nutrient uptake rates of the primary producers? What are the nutrient excretion rates of the grazers? What forms of nutrients are preferred by the primary producers? What forms of nutrients are excreted by the grazers? Which type of primary producer is more important? Hints or suggestions of answers to these questions can be obtained from work in other estuaries but are no substitute for studies on Tampa Bay itself.

A third investigation which compels interest concerns the interaction and exchanges between all the forms of Tampa Bay nutrients and the neighboring waters of the Gulf of Mexico. Since the Bay seems to be so nutrient-rich, one might expect an impact on the biota west of Egmont Key. Do biological processes inside the Bay convert inorganic nitrogen and phosphorus to dissolved and particulate organic forms which are then exported to the Gulf in outgoing tidal circulation? Such exportation has been reported for coastal lagoons and estuaries along the New England coast; does it occur here? Nutrient budgets in the Bay cannot be completed without good estimates of net losses (or maybe even gains) of all nutrients across the mouth.

The fourth area of study that must be considered is the impact of the sea bed on nutrients and related substances in the Bay. This study may prove to be indispensible to a complete understanding of the pathways, rates, and budgets of nutrients in the Bay. Is ammonia release from the sediment responsible for the apparently ammonia-rich character of Bay water? Denitrification must be occurring in Bay sediments as in most estuarine sediment, but is that process a major reason for the low N:P ratio in Bay water because it converts usable nitrate and nitrite to nitrogen gas which is then lost to the atmosphere? There is urgent need for measurements of oxygen consumption, nitrogen fixation, nutrient release, and nitrogen-gas release in Bay sediment, either in the form of cores or by installing benthic chambers on the Bay floor. There is also a need to investigate the effect of storms and water circulation in the Bay on the release of nutrients from sediments. Such studies should be conducted in several parts of the Bay because of differences in biota and sediment characteristics and the properties of the overlying water. Finally, we need to know if organic nutrients are being permanently removed from the water by sediment deposition in the Bay.

Other studies may suggest themselves in the future, but the four broad investigations just described seem the most important for understanding the flow and transformations of nutrients in Tampa Bay. If studies such as these can be implemented, we should be able to present far more vital knowledge about the Bay's nutrients than the cataloguing of concentrations which has been the focus of past work.

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HYDROCARBONS IN TAMPA BAY - A REVIEW

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INTRODUCTION

By definition, hydrocarbons are those organic molecules containing only the elements carbon and hydrogen. They are produced both biogenically and geochemically in terrestrial and marine systems. Geochemically produced hydrocarbons are most often considered as being related to fossil fuel compounds such as coal, shale, tar sands or petroleum. In addition to these naturally produced compounds, man has created a set of synthetic hydrocarbon derivatives which include herbicides, fungicides, insecticides, molluscicides and bacteriocides. These groups of compounds are collectively referred to as "pesticides". Many of the pesticides are readily degraded within a short time after their application and do not pose a threat to the marine environment. The longest-lived pesticides, and those which appear capable of accumulating in the marine environment, are the chlorinated derivatives of the hydrocarbons. Other synthetic chlorinated hydrocarbon derivatives, such as polychlorinated biphenyls (PCBs) are produced for industrial use and are not used as pesticides. For the purpose of this paper, the polychlorinated biphenyls will be included with pesticides under the general heading of "chlorinated hydrocarbons." This paper reviews the extent to which petroleum hydrocarbons and chlorinated hydrocarbons are impacting the marine environment of Tampa Bay, Florida.

BACKGROUND

Oil pollution is a direct consequence of the growing world demand for petroleum products. Research concerned with hydrocarbons in the marine environment has intensified over the past decade due to a global committment to understanding oil pollution problems. According to the latest National Academy of Sciences estimate, approximately 3.3 million metric tons per year (mta) of petroleum hydrocarbons are discharged to the oceans (NAS 1982). These hydrocarbons are released through such processes as oil production and tanker transportation (1.5 mta), municipal and industrial effluent discharges (1.2 mta), atmospheric deposition (0.3 mta), and natural marine seeps (0.2 mta). The input of petroleum hydrocarbons is not uniform over entire oceans, however, with most of the hydrocarbon inputs occurring in coastal environments near major urban centers. The degree to which the oceans and its estuaries are capable of absorbing continual low level stresses, or occasional large scale stresses, due to petroleum inputs, is uncertain.

Petroleum hydrocarbons can have both lethal and sublethal effects on a wide variety of marine organisms. Sublethal effects which have been reported for petroleum hydrocarbons include interference with the chemotactic response of bacteria resulting in the inhibition of organic matter decomposition in seawater (Chet and Mitchell 1976); depressed photosynthetic rate in algae (Parker and Menzel 1974); interference with reproduction in sand dollars (Parker and Menzel 1974); abnormal development and hatching of barnacle embryos (Donahue et al. 1977); and inhibited molting, alteration of sex ratios, and reduced resistance to environmental stress in crabs (Parker and Menzel 1974; Krebs and Burns 1977). Many shellfish including clams and oysters are capable of accumulating these hydrocarbons and hence are able to transfer the toxic

compounds to higher trophic levels, including man (Stegeman and Teal 1973; Boehm and Quinn 1977).

One of the most critical problems in detecting hydrocarbon pollution in marine samples is the ability to differentiate petroleum hydrocarbons from biosynthesized hydrocarbons. The differences in these suites of compounds have been thoroughly reviewed by Farrington and Meyers (1975) and Farrington et al. (1976). In general, the occurrence of fossil fuel hydrocarbons will be apparent by the presence of a 1:1 ratio of n-alkanes as well as by the presence of an unresolved complex mixture of hydrocarbons when analyzed by gas-liquid chromatography. The unresolved complex mixture is comprised of cycloalkanes, naphthenoaromatic, and aromatic compounds. Biologically produced hydrocarbons are expected to show a much simpler distribution of hydrocarbons with an odd carbon preference of about 4 or 5.

Once released into the marine environment, there are several biological, chemical, and physical fates which the hydrocarbons can encounter. The relative importance of these processes depends upon the hydrocarbon or mixture of hydrocarbons in question. Dissolution and evaporation effects can remove from 50 to 70% of a crude oil that is spilled into the oceans or estuaries. Low molecular weight hydrocarbons (C_1 to C_{10}) are influenced to the greatest extent by these processes (Farrington and Meyers 1975). Heavier molecular weight hydrocarbons (C_{10} to greater than C_{40}) can become adsorbed onto particulates, ingested into organisms, or physically broken down into smaller particles in the water column. These hydrocarbons can then become incorporated into the sediments by sinking of particulate material and fecal pellets. Once deposited in the sediments, the hydrocarbons become available to the deposit or filter feeding organisms. Hydrocarbons that are not taken up by benthic organisms are subjected to microbial degradation processes before being permanently buried. Due to the relatively refractory nature of petroleum hydrocarbons, many of these compounds are not readily degraded by bacteria and can remain intact in the sediments for several years (Blumer et al. 1970; Blumer and Sass 1972; Sanders et al. 1980).

Many chlorinated hydrocarbon compounds are also extremely resistant to environmental degradation. Polychlorinated biphenyls and DDT, plus its breakdown products, are perhaps the most persistent and environmentally damaging of the chlorinated hydrocarbons (Risebrough 1971). The pioneering work of Woodwell et al. (1967) and Ratcliffe (1967) demonstrated for the first time that biological magnification of DDT up to 10^7 times in a marine food chain resulted in reproductive failures in birds living on a marine food source. Other sublethal effects of chlorinated hydrocarbons reported for marine organisms include decreased phytoplankton productivity, inhibited shell growth in oysters, alteration of the metal composition of clams, deleterious alteration of blood chemistry and tissue metabolism in fishes, disruption of the schooling and feeding behavior of fishes, and abnormal ovary development in molluscs and teleosts (Eisler 1968). Chlorinated hydrocarbons have also been shown to be lethal to a number of adult and larval forms of marine species (Eisler 1968).

Many of the pesticides, including Malathion and Parathion, belong to a group of organophosphorus compounds that contain no chlorine atoms. These molecules may be just as toxic as the chlorinated hydrocarbons, but are generally less stable in the environment and are much more rapidly degraded than their chlorinated analogs. Hence, they generally do not represent as great an environmental threat to the marine environment as the chlorinated pesticides such as DDT, Dieldrin, Chlordane and Heptachlor.

Polychlorinated biphenyls were first manufactured in the 1930s for commercial use in such products as electrical equipment, paints, and inks

(Paulson 1978). Concern over the possible environmental damage being caused by these compounds arose when declining bird populations were found to contain high PCB levels (Holmes et al. 1967). Further research has shown that PCBs have both lethal and sublethal effects that are similar to the effects induced by pesticides.

Since chlorinated hydrocarbons and petroleum hydrocarbons can both cause significant environmental stress in the marine environment, it is imperative that we understand the nature and extent to which these compounds are impacting the ecosystems of Tampa Bay. Without this information, the health and future of the Tampa Bay environment cannot be realized.

CHLORINATED HYDROCARBONS

Between 1971 and 1973, chlorinated hydrocarbons were analyzed by the U.S. Geological Survey (USGS) prior to the Tampa Harbor Deepening Project. Dr. John L. Taylor of the USGS was subcontracted by the U.S. Army Corps of Engineers to determine heavy metal and pesticide concentrations in sediments, water, and selected groups of benthic organisms at several locations throughout the Tampa Bay estuary (U.S. Army Engineer District Jacksonville 1974). Water quality data was collected at approximately 100 sites along 14 transects throughout the Bay (Fig. 1). Once a year, samples were obtained for analysis of herbicides, pesticides, and PCBs. Table 1 shows a list of the chlorinated compounds which were investigated as well as the concentrations of those compounds detected in sediments of the Tampa Bay shipping channel. The results of these studies have been briefly reviewed by Simon (1974). The major pesticides detected in the sediments during this study were DDT and its breakdown products DDD and DDE. These compounds were generally present at concentrations of less than 1 ppb (ng g^{-1}). The maximum DDD concentration of 7.7 ppb was observed in transect 12. The decrease in DDD concentration at stations 11 and 13 indicate that the high DDD concentration in transect 12 was a localized condition and was not representative of the rest of the Bay. The only other pesticide detected in these sediments was Dieldrin and was observed only in transect 10 at a concentration of 0.4 ppb. In addition to the pesticide compounds, polychlorinated biphenyls (PCBs) were detected in transects 11 through 14 at concentrations averaging about 10 ppb (Table 1). These concentrations are generally similar to, or less than, chlorinated hydrocarbon concentrations reported for other areas in the Gulf of Mexico (Duke et al. 1970; Giam et al. 1978a, b).

In contrast to these relatively low levels of pesticides and PCBs found in the main shipping channel, much higher concentrations of these compounds were found in East Bay (Table 1). Concentrations were generally 10 to 100 times higher in East Bay than in the main shipping channel. East Bay apparently acts as a settling basin for most of the pesticides which enter East Bay from anthropogenic sources such as municipal and industrial wastes. The pesticides appear to accumulate in the bottom sediments and are not rapidly flushed out into Hillsborough Bay and Tampa Bay. Although pesticides have also been found in rainwater in the Tampa Bay area (U.S. Army Engineer District Jacksonville 1974), this does not appear to be a major transport mechanism to the Bay since the high concentrations of pesticides in the sediments were restricted to East Bay.

In addition to the sediments analyzed in the above study, the USGS analyzed pesticides in water and benthic organisms at selected sites throughout Tampa Bay (Table 2). Of the thirteen compounds for which the organisms were tested, six (Aldrin, Endrin, Heptachlor, Lindane, Silvex and 2,4,5-T) were not detected in the organisms. The authors of the study (U.S. Army Engineer District Jacksonville 1974) suggest that the highest pesticide concentrations were observed in oysters taken from

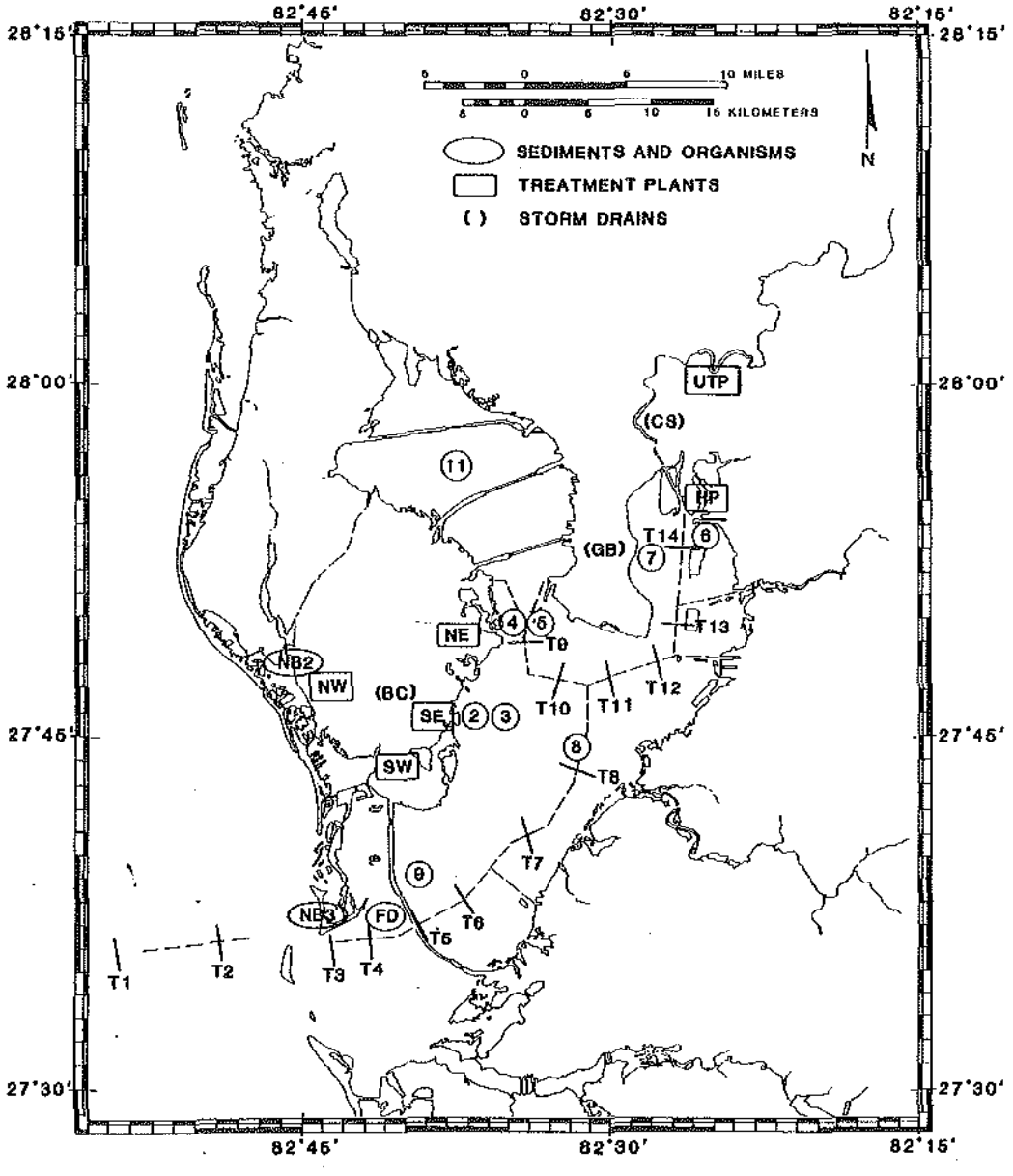

Figure 1. Sampling locations for chlorinated hydrocarbons and petroleum hydrocarbons in and around Tampa Bay. Transects for the USGS pesticide study (U.S. Army Engineer District Jacksonville 1974) are designated T1 through T14. Petroleum hydrocarbon sampling sites (Van Vleet and Reinhardt 1982) are represented by the remaining designations.

Table 1. Concentrations of pesticides and polychlorinated biphenyls (PCBs) in sediments from the Tampa Bay shipping channel and East Bay.

Tampa Bay Shipping Channel

Compunds not detected in sediments:

Aldrin	Heptachlor	Parathion
Chlordane	Lindane	Silvex
Diazinon	Malathion	Trithion
Endrin	Methyl Parathion	2,4-D
Ethion	Methyl Trithion	2,4,5-T

Compounds detected in sediments:

Compound	Transect	Average Concentration (ppb)
DDD	11, 14	less than 1
	12	7.7
DDE	11, 14	less than 1
	12	0.5
DDT	11, 14	less than 1
	12	none detected
PCB	11, 12, 13, 14	10

East Bay

Compounds detected in sediments:

Compound	Concentration Range (ppb)
Chlordane	5-13
DDD	3-92
DDE	4-43
DDT	2-100
PCB	50-60

Table 2. Pesticide levels in organisms and water at selected stations in Tampa Bay (from U.S. Army Engineer District Jacksonville 1974).

Station & Organisms	Aldrin	DDD	DDE	DDT	Dieldrin	Endrin	Heptachlor
			ORGANISMS (ppm)				
Buoy #8							
Starfish	.00	.00	.00	.00	.00	.00	.00
Stone Crabs	.00	.0067	.02	.0029	.00	.00	.00
Tunicates	.00	.00	.00	.00	.00	.00	.00
Oysters	.00	.0025	.0034	.00	.0005	.00	.00
Buoy #1A							
Tunicates	.00	.00	.0002	.00	.00	.00	.00
Crown Conchs	.00	.0003	.0009	.0003	.00	.00	.00
Buoy #1D							
Stone Crabs	.00	.0006	.0061	.0005	.00	.00	.00
Buoy #1							
Stone Crabs	.00	.0015	.021	.00	.00	.00	.00
Tunicates	.00	.00	.0007	.0001	.00	.00	.00
Crown Conchs	.00	.0001	.0021	.0002	.00	.00	.00
Buoy #2K							
Oysters	.00	.0057	.0067	.00	.0004	.00	.00
Tunicates	.00	.00	.00	.00	.00	.00	.00
Crown Conchs	.00	.015	.019	.00	.00	.00	.00
Stone Crabs	.00	.00	.0027	.00	.0013	.00	.00
Buoy #16							
Oysters	.00	.017	.0048	.0017	.00	.00	.00
Buoy #2							
Tunicates	.00	.00	.0003	.0003	.00	.00	.00
Blue Crabs	.00	.017	.038	.00	.00	.00	.00
			WATER (ppb)				
Transect -Station							
7-3					0.1		
11-5		0.5			0.1		
12-3							
13-3							
14-3	0.9						
48 hr TLM*	40				300		
EPA limit**	0.003			0.001	0.003	0.004	0.001

*48 hr Median Tolerance Limit for shrimp as presented in the FWPCA "Green Book" (from U.S. Army Engineer District Jacksonville 1974)
**EPA (1976) water quality criteria for marine waters

Table 2 continued.

ORGANISMS (ppm)

Station & Organisms	Lindane	Chlordane	PCBs	Heptachlor Epoxide	2-4-5 T	Silvex	Total
Buoy #8							
Starfish	.00	.00	.002	.00	.00	.00	0.002
Stone Crabs	.00	.00	.04	.00	.00	.00	0.070
Tunicates	.00	.00	.00	.00	.00	.00	0.000
Oysters	.00	.003	.005	.0001	.00	.00	0.015
Buoy #1A							
Tunicates	.00	.00	.00	.00	.00	.00	0.000
Crown Conchs	.00	.001	.005	.00	.00	.00	0.008
Buoy #1D							
Stone Crabs	.00	.0001	.02	.00	.00	.00	0.027
Buoy #1							
Stone Crabs	.00	.00	.065	.0004	.00	.00	0.088
Tunicates	.00	.0001	.0003	.00	.00	.00	0.001
Crown Conchs	.00	.00	.0005	.002	.00	.00	0.005
Buoy #2K							
Oysters	.00	.006	.015	.0003	.00	.00	0.034
Tunicates	.00	.0001	.002	.00	.00	.00	0.002
Crown Conchs	.00	.065	.033	.0004	.00	.00	0.132
Stone Crabs	.00	.00	.007	.0004	.00	.00	0.011
Buoy #16							
Oysters	.00	.004	.014	.00	.00	.00	0.057
Buoy #2							
Tunicates	.00	.001	.010	.00	.00	.00	0.012
Blue Crabs	.00	.031	.130	.00	.00	.00	0.216

WATER (ppb)

Transect -Station			
7-3			
11-5			
12-3		0.1	
13-3		0.1	
14-3			
48 hr TLM*		2.000	
EPA limit**	0.004	0.004	0.001

around Buoys 8, 2K, and 16 in the Bay, although the data (Table 2) only weakly supports this contention.

The same pesticides were analyzed in water collected from five stations around Tampa Bay (Table 2). The most abundant pesticide observed in the water column was Aldrin, being present in transect 14 at a concentration of 0.0009 ppm (mg l^{-1}). All of the pesticide levels observed in the water column are below the 48 hr Median Tolerance Limit (TLM) for shrimp as presented in the Federal Water Pollution Control Administration "Green Book" of the Committee on Water Quality Criteria (U.S. Army Engineer District Jacksonville 1974) but are 300 times the EPA acceptable levels in marine waters for Aldrin (Table 2). In a separate study of wet and dry weather water quality conditions in Tampa Bay, Goodwin et al. (1975) reported pesticide concentrations in five water column stations for all of the pesticides listed in Table 2 except Heptachlor Epoxide. In addition, these authors analyzed for Diazinon, Ethion, Malathion, Parathion, Methyl Parathion, Trithion, Methyl Trithion, and 2,4-D. The only pesticide observed in this study was 2,4-D which had a concentraton of 0.001 ppm at a station located in Safety Harbor (Old Tampa Bay). No other pesticides were detected in this study.

In 1971 and 1972, the Tampa Electric Company (TECO) analyzed pesticides in sediments and organisms from several stations around Tampa Bay (U.S. Army Engineer District Jacksonville 1974). "Moderate to high levels" of Toxaphene, Trithion, DDE, 2,4-D, Ronnel, and Methyl Parathion were found in sediment samples collected at both their Big Bend and Beacon Key sampling areas. Pesticides which were analyzed but not found in these samples included PCBs, DDT, Dilan-I, Endrin, Heptachlor, Lindane, Malathion, and Parathion. Evidence of pesticide levels in biological systems was also reported for the TECO study. Oysters collected from Cockroach Bay (Fig. 1) exhibited the following pesticide levels: DDE = 5 ppb (ng g^{-1}); Dilan-I = 20 ppb, and Heptachlor plus Heptachlor Epoxide 387 ppb. DDT and Endrin were also found in tissues of a laughing gull that was sacrificed for analysis in the TECO study.

Currently, the Marine Research Laboratory of the Florida Department of Natural Resources is conducting a study of chlorinated compounds in shellfish from selected sites in Tampa Bay. Oyster samples collected near Weedon Island contained total chlordane concentrations of about 40 ppb (ng g^{-1}) (Patrice Krug, pers. comm.). These concentrations are approximately the same magnitude as the levels reported in the earlier Tampa Bay studies (Table 2).

PETROLEUM HYDROCARBONS

The port of Tampa is the seventh largest sea-port in the U.S. and handles more gross tonnage annually than the next four largest Florida ports combined (Maynard 1981). Among the consumables brought into Tampa Bay in 1979, 12.1 million tons of petroleum were imported, having an economic impact value of approximately $50,000,000 (Tampa Port Authority 1980). This shipping traffic results in some leakage of petroleum hydrocarbons into the Tampa Bay environment. In addition to direct shipping losses, other sources which may contribute petroleum hydrocarbons directly to the Bay include industrial losses, municipal wastewater treatment plant discharges, and stormwater runoff. Although there have been no direct measurements of petroleum hydrocarbon discharges in industrial effluents into Tampa Bay, possible industrial sources of petroleum and other types of contaminants have been reviewed by Wilkins (1980). The contribution of petroleum hydrocarbon contamination to Tampa Bay from industrial sources is presently uncertain.

Although direct measurements of petroleum hydrocarbon discharges from shipping losses have not been published for Tampa Bay, indirect evidence can be used to estimate the importance of shipping losses relative to other types of hydrocarbon inputs. In 1980, 12.3 million

tons of petroleum products were brought in Tampa Bay while only 0.002×10^6 tons were exported (Tampa Port Authority, pers. comm.). The inbound hydrocarbon products consisted mostly of gasoline (5.8×10^6 tons), #6 (Bunker C) fuel oil (3.1×10^6 tons), diesel fuel (1.6×10^6 tons), and jet fuel (1.1×10^6 tons). Several major oil spills have occurred in Tampa Bay as a result of these and other types of shipping operations. The largest spill reported to date occurred in February 1970 when the oil tanker Delion Apollon spilled 1.6×10^7 liters (4,200,000 gallons) of Bunker C oil into upper Tampa Bay, covering an area of 260 km^2 (100 mi^2). On January 9 1977, the 155 m oil barge New York crashed into a Tampa Electric Company dock and spilled 3.1×10^5 liters (81,270 gallons) of light diesel fuel into Tampa Harbor. The next day approximately 7.6×10^3 liters (2,000) gallons of light diesel fuel escaped into the Ybor shipping channel when a tug sank and released its cargo (Clendening 1977). In October 1978, the oil tanker Howard Star accidently pumped 1.5×10^5 liters (40,000 gallons) of a mixture of 80% Bunker C fuel oil and 20% diesel fuel into a harbor in upper Tampa ay (Lewis 1981), resulting in a clean-up cost of over $950,000 (U.S. Coast Guard 1978). This is perhaps the most extensively documented oil spill in Tampa Bay history. Finally, in June 1980, the barge Domar 118 ran aground outside the entrance to Tampa Bay and released 9.5×10^3 liters (2,500 gallons) of #6 fuel oil into the surface waters. Portions of this oil soon washed up on the Gulf beaches and fouled approximately 16 km of beach at Ft. DeSoto Park.

Although these types of major spills attract the most public attention and result in the most immediate economic and ecological damage, smaller spills occur much more frequently in Tampa Bay. Between January 1980 and March 1982, approximately 450 oil spills were reported for Tampa Bay (U.S. Coast Guard 1980, 1981, 1982). Of these reported spills, approximately 90% were less than 50 gallons, 5% were 50-100 gallons, 4% were 100-500 gallons and less than 1% were over 500 gallons. The only two spills over 500 gallons were the Howard Star and the Domar 118. Using these figures, it is possible to estimate the average input of petroleum hydrocarbons to Tampa Bay from direct shipping losses over this two year period. This calculation results in an average of approximately 7.8×10^4 liters (20.6×10^3 gallons) of oil per year discharged into Tampa Bay. The Howard Star incident accounted for about 86% of this input. Although major spills may only occur in Tampa Bay every 5 to 10 years, these spills still represent the largest contributor of petroleum hydrocarbons to Tampa Bay from shipping losses.

An extensive investigation of the ecological effects of the Howard Star oil spill was conducted by several cooperating groups including Mangrove Systems, Inc., Mote Marine Laboratory, Bowdoin College Hydrocarbon Research Center, and Research Planning Institute (Gundlach et al. 1979; Getter et al. 1980; Lewis 1979, 1980, 1981, 1983; Snedaker et al. 1981). Comparison of several of the biological studies indicates that the benthic community data showed no distinct pattern in number of individuals, population densities, or species diversity in the oiled versus non-oiled sites (Lewis 1981). In addition, very few of the mangrove trees observed over the two year study died or were stressed beyond recovery. Dr. David S. Page of the Bowdoin College Hydrocarbon Research Center analyzed eight sediment samples for petroleum hydrocarbon contamination that had been impacted by the Howard Star spill. The samples were collected approximately 18 months following the spill incident. Hydrocarbon values ranged from a low of 177 ppm (ug g^{-1}) at the control station in McKay Bay to a maximum value near Hookers Point of 56,800 ppm (Lewis 1980b). Dr. Page suggests that these hydrocarbons are relatively unweathered oil that was closely related to oil spilled by the Howard Star.

A second method of redistributing and remobilizing petroleum hydrocarbons

in Bay sediments is through dredging of sediments in which hydrocarbons have previously been deposited. During the past 100 years, four major types of dredging have impacted Tampa Bay (Lewis 1976): 1) channel deepening, resulting in large scale resuspension of sediments; 2) maintenance dredging, in which large amounts of dredged sediment have been stored in diked areas within the Bay; 3) shell dredging, in which 18 x 10^6 tons of shell material have been removed causing silt plumes with suspended load concentrations substantially above background levels, and 4) dredging for landfill which resulted in substantial loss of wetland habitats. The major dredging operation which has taken place in Tampa Bay is the Tampa Harbor Deepening Project which began in October 1975. In this project, 55 x 10^6 m^3 of material was dredged from a 65 km (40 mile) stretch of Tampa Bay and the dredge spoils redeposited in the open waters of the Bay as submerged or emergent islands. Although no hydrocarbon studies were reported in preparation for, or during, these dredging operations, it is apparent that any hydrocarbons existing in the sediments could be resuspended in the water column and made available to suspension or filter feeding organisms. The environmental damage caused by resuspension of petroleum compounds (or chlorinated hydrocarbons) during these dredging operations is uncertain.

The most recent study of petroleum hydrocarbons in Tampa Bay has been conducted in the Department of Marine Science at the University of South Florida (Van Vleet and Reinhardt 1982). In this study, the authors investigated the recycling of petroleum compounds in Tampa Bay by analyzing samples from selected input sources and benthic sinks (Fig. 1). Inputs were measured both from secondary and tertiary municipal wastewater treatment plants and from urban runoff areas draining watersheds of diverse characteristics. The fates of petroleum hydrocarbons were investigated by analyzing sediments and benthic organisms from selected areas around the Bay. The concentrations of total petroleum hydrocarbons entering the municipal wastewater treatment plants ranged from 11 to 194 ppb (ug l^{-1}) while no hydrocarbons were detected in the plant effluents (Table 3), indicating essentially a 100% removal of these compounds by each treatment plant. Studies of wastewater treatment plant effluents in temperate environments around the U.S. indicate hydrocarbon levels ranging from 1,490 to 21,800 ppb (Whipple et al. 1976; Van Vleet and Quinn 1977; Tanacredi 1977; Eganhouse and Kaplan 1982; Barrick 1982). In a study conducted by the Environmental Protection Agency for the Hookers Point Treatment Plant (Fig. 1, HP), conclusions similar to the Van Vleet and Reinhardt (1982) study were reached (EPA 1982). Over a six day sampling period in the EPA study, total EPA base-neutral aromatic hydrocarbon concentrations in the influent waters were less than 60 ppb while no aromatic hydrocarbons could be detected in the tertiary chlorinated effluents.

Van Vleet and Reinhardt (1982) also analyzed petroleum hydrocarbons in three stormwater drains in the Tampa-St. Petersburg area (Fig. 1, Table 3). Measurable petroleum hydrocarbon concentrations were observed at only one of the storm drains (Gandy Boulevard = 70 ppb). These hydrocarbon concentrations are lower than stormwater runoff values reported for other parts of the country (Hunter et al. 1979; Eganhouse and Kaplan 1981; Hoffman et al. 1982). The samples analyzed in the Van Vleet and Reinhardt study, however, were collected following five days without rainfall. Therefore, these samples, at best, represent the hydrocarbons discharged under base flow conditions through the storm drains.

No measurements were conducted on the receiving waters in the above study (Van Vleet and Reinhardt 1982). The only available data on dissolved hydrocarbons in Tampa Bay comes from an unpublished report by Byrne (1975) in which fluorescence spectroscopy was

Table 3. Concentration of petroleum hydrocarbons in municipal wastewater treatment plant effluents and urban storm drains (ppb). From Van Vleet and Reinhardt 1982.

Treatment Plants:	St. Petersburg				Tampa	
	NE	NW	SE	SW	HP	UTP
Influent	11	78	186	128	194	47
Effluent	all less than 1					

Storm Drain:	Concentration
Booker's Creek (St. Petersburg)	less than 1
Cass Street (Tampa)	less than 1
Gandy Boulevard (Tampa)	70

used to estimate petroleum hydrocarbon contamination in surface waters. Elevated hydrocarbon levels were observed by Byrne at the northernmost point of the Tampa shipping channel (74.2 ppb). Slightly further south, near the Hookers Point (HP) Treatment plant discharge (Fig. 1), the dissolved hydrocarbon concentration had decreased to 7.8 ppb. Hydrocarbon levels decreased only slightly to levels of about 3-5 ppb throughout the remainder of the Bay. The relatively constant dissolved hydrocarbon concentrations are in good agreement with the uniform sediment hydrocarbon values reported by Van Vleet and Reinhardt (1982).

In the Van Vleet and Reinhardt (1982) study, the fate of petroleum hydrocarbons discharged into Tampa Bay was determined by investigating the accumulation of hydrocarbons in sediments and benthic organisms (Table 4). Total hydrocarbon concentrations in Tampa Bay sediments averaged 2.9 $\pm$ 3.2 ppm (ug g^{-1}). Elevated concentrations were seen only at Station 7 (Fig. 1) in Hillsborough ay. The sedimentary hydrocarbon concentrations reported in Table 4 are very similar to those reported by Gearing et al. (1976) for continental shelf sediments taken at ten stations located just outside Tampa Bay (average 4.1 $\pm$ 1.5 ppm). The hydrocarbon levels in Tampa Bay sediments, however, are much lower than values reported for other anthropogenically impacted estuarine surface sediments around the U.S. (Narragansett Bay: 27-5700 ppm total hydrocarbons, Van Vleet and Quinn 1978; Farrington and Quinn 1973; Wade and Quinn 1979; Hurtt and Quinn 1979; Boehm and Quinn 1978; Puget Sound: 4-350 ppm aliphatic hydrocarbons, Barrick et al. 1980; Buzzards Bay: 20-3040 ppm aromatic hydrocarbons, Teal et al. 1977). Although the Hookers Point Treatment Plant discharges its effluent directly into the Bay, only slightly elevated hydrocarbon values were observed in the sediments at this station (Fig. 1). This observation supports the earlier contention that wastewater treatment plants are not a major source of petroleum hydrocarbons to Tampa Bay.

In addition to the sediments analyzed in the Van Vleet and Reinhardt (1982) study, the authors also analyzed twenty-one pooled benthic organism samples (83 individuals, 8 species; Table 4). Petroleum hydrocarbons were not conspicuously present in any of the organisms sampled. All of the hydrocarbons reported for the organisms (Table 4) appeared to be of biogenic origin. The organisms collected near wastewater treatment plants did not

Table 4. Hydrocarbons in sediments and organisms from Tampa Bay (ppm). From Van Vleet and Reinhardt (1982).

	STATION												Avg. ±
	2	3	4	5	6	7	8	9	11	NB2	NB3	FD	Std. Dev
Sediment	0.3	1.1	3.3	< 1.0	5.2	10.5	2.4	0.7	1.3	-	-	1.0	2.9±3.2
Mercenaria campechiensis[a]	-	-	-	-	-	-	406	-	1,365	1,745	809	1,417	1,148±534
Astropectin duplicatus[b]	-	-	343	557	-	-	-	225	-	-	-	-	375±168
Luidia clathrata[b]	1,201	872	-	-	266	-	2,716	1,867	-	-	-	-	1,384±942
Mellita quinquiesperforata[c]	-	-	224	185	-	-	-	126	-	-	-	-	178±49
Busycon spiratum[d]	-	-	230	-	-	-	-	-	-	-	-	-	230
Atrina seminuda[e]	704	-	-	-	-	-	-	-	-	-	-	-	704
Melangina corona[f]	-	-	-	-	937	-	-	-	-	-	-	-	937
Polinices duplicatus[g]	-	-	-	-	182	573	-	-	-	-	-	-	378

[a]quahog; [b]starfish; [c]sand dollar; [d]whelk; [e]penshell; [f]crown conch; [g]moon snail.

exhibit significantly elevated hydrocarbon concentrations.

The Van Vleet and Reinhardt (1982) study indicates that most of Tampa Bay is relatively pristine with respect to petroleum hydrocarbon contamination. Since it is unlikely that the anthropogenic input of hydrocarbons to this estuary is significantly lower than in other urbanized areas, the authors have suggested that elevated mean temperatures in this subtropical system result in increased metabolic rates of microorganisms and more rapid degradation or metabolism of the petroleum hydrocarbons. This increased microbial activity would result in higher municipal wastewater treatment plant efficiencies and lower hydrocarbon discharges than in temperate climates. The low input from wastewater treatment plants is reflected in the low concentrations of petroleum hydrocarbons found in sediments and organisms collected in the vicinity of the treatment plants, as well as throughout Tampa Bay.

In another recent study, Young et al. (unpublished data) examined a sediment core from Bayboro Harbor obtained prior to the Bayboro Harbor dredging operations of 1980-81. This core consisted primarily of an organic rich anoxic mud and contained much higher petroleum hydrocarbon levels than sediments collected from other areas of Tampa Bay. Surface concentrations (0-5 cm) of 317 ppm were observed. These concentrations increased down core to a maximum value of 1876 ppm at a depth of 37-45 cm. The concentrations then decreased down core to a value of 623 ppm at 70-77 cm. The cause of the subsurface maximum is not known but reflects a major change in hydrocarbon inputs to Bayboro Harbor approximately 10 to 15 years ago. The hydrocarbon levels in the surface layers of this core are comparable to relatively clean surface sediments in Narragansett Bay, Rhode Island (Van Vleet and Quinn 1978; Hurtt and Quinn 1979), but are still two orders of magnitude higher than levels reported in the Van Vleet and Reinhardt (1982) study for most of Tampa Bay. The results of Young et al. suggest that petroleum hydrocarbons can remain intact in the sediments for a number of years and may later be remobilized or resuspended during dredging or similar operations.

SUMMARY AND CONCLUSIONS

Very little data is available on the occurrence of petroleum hydrocarbons and chlorinated hydrocarbons in the Tampa Bay environment. This is probably a reflection of the time, money, and training necessary for the hydrocarbon analyses. The sparse data presently available tends to indicate that most of Tampa Bay is still much cleaner with respect to petroleum and chlorinated hydrocarbon contamination than many other anthropogenically impacted estuaries around the U.S. Areas of unusually high concentrations of these compounds have been reported around Tampa Bay, however. Known "hot spots" for hydrocarbon contamination include Bayboro Harbor (prior to its dredging), the northernmost portions of the Tampa shipping channel around Seddon Island, and the Hillsborough River and East Bay. Local hot spots may also occur near specific industrial discharges. Although petroleum hydrocarbons and chlorinated hydrocarbons have not both been reported in the same studies for Tampa Bay, their chemical and physical properties would suggest their coexistence in anthropogenically impacted areas. Further investigation is needed to confirm the concentrations and trends reported in this paper. If the majority of Tampa ay is, indeed, as pristine as previous studies suggest, it is in the best interest of the Tampa Bay community to try and preserve the environmental health of this ecosystem through both conservation and legislative efforts. Without these efforts, the ecological health of Tampa Bay can certainly decline.

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PHYTOPLANKTON OF TAMPA BAY - A REVIEW

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INTRODUCTION

Phytoplankton in brackish and marine habitats, such as estuaries, consists of four principal microalgal groups: phytomicroflagellates (7 or more classes), diatoms, dinoflagellates, and blue-green algae. These groups are representative of several size classes: picoplankton (0.2 to 2 um), ultraplankton (less than 5 um), nannoplankton (5 to 20 um or less than 20 um), and microplankton (20 to 200 um). Occasionally, there are larger species such as Noctiluca, which can be 1-2 mm in diameter. These algal groups can be found in both the water column and sediments of estuaries, yet specific species are usually planktonic or benthic in the prevailing vegetative stage. Benthic microalgal communities (epi- and endolithic, episammic, epiphytic) can be significant components of an estuary in diversity and biomass. Hustedt (1955) described 89 new species out of 319 species identified in just two mud samples from North Carolina. Bader and Roessler (1971) gave a biomass figure of 50-630 mgC/m^2 for a Florida bay (based on chlorophyll conversions) and Round (1971), in a benthic diatom review, gave 420 mg Chl a/m^2. Benthic microalgae can serve as food sources for a variety of heterotrophs, act as sediment stabilizers, and often become tychoplanktonic in turbulent events.

Phytoplankton less than 20 um often dominate the water column, particularly in temperate and subtropical waters; dominance can be both numerical and by biomass, and/or productivity (Fogg 1965; Loftus et al. 1972; Tundisi 1971, Herbland and Bouteiller 1981, and others). Photosynthetic microorganisms less than 20 um, even less than 2 um, can account for 20-90% of the planktonic inorganic C uptake, but at the same time they can have high respiration rates and function in remineralization cycles, thus being important in detrital food webs because of their dissolved organic uptake capabilities (Pomeroy 1974, Li et al. 1983). Number of species and associated abundance trends in estuaries usually reveal an inverse relationship horizontally with increasing salinity from the head to the mouth (Hulburt 1965; Kinne 1967, and others). Defelice and Lynts (1978) also noted an increase in benthic diatom diversity from terrestrial influences to open waters in upper Florida Bay. Many phytoplankters are cosmopolitan and endemic populations are rare, particularly in estuaries (Lackey 1967; Wood 1965; Steidinger 1973); however, brackish or marine microalgal assemblages (planktonic and benthic) may be distinct areally and seasonally. Most species are "neritic" and represent an estuarine/neritic grouping although there are periodic invasions of limnetic or oceanic/neritic species due to freshwater discharge or oceanic intrusions respectively (Wood 1965).

Estuaries are dynamic because of physical, chemical, and biological interactions. The system is a fluctuating, and at times unstable, environment. This affects which species are present as well as total production,

temporally and spatially. Such a system tends to limit planktonic and benthic populations to those that have wide ranges in physiological and reproductive strategies, e.g, most are euryhaline and eurythermal and have "regenerative" or "resting stage" cycles. Additionally, many species have varied nutritional requirements with adaptive assimilation rates, particularly nannoplankters.

Environmental factors limiting phytoplankton occurrence, diversity, and abundance interact synergistically and principally involve light (water clarity), temperature (metabolic processes, division rates), salinity (osmoregulation), micro- and macronutrients or growth factors, and circulation patterns. The influence of light intensity on primary production is simply demonstrated by the existence of productivity formulae involving solar radiation, extinction factors, and chlorophyll (Ryther and Yentsch 1957; Small et al. 1972; Bannister 1974, and others) which are still used today with some reservations. Although light is required, high levels can cause photoinhibition and bleaching of surface restricted organisms. High light intensities can also cause organisms to seek a lower level in the water column. Diatoms are light saturated at lower light intensities than dinoflagellates (Riley and Chester 1971), while blue-greens do best at highest light intensities. Therefore, adaptations to light intensity and wavelengths can effect competitive advantages. In addition, photosynthetic organisms have phased uptake and metabolic functions in both light and dark cycles (see Eppley 1981). Light also acts to concentrate positively phototactic flagellates in the euphotic zone so that there are diurnal or diel vertical migration patterns associated with time of day, light intensity and water clarity. Benthic microalgal communities are likewise affected by light, although the association may be indirect due to substrate preference and its cyclic availability, or circadian rhythms. Most photosynthetic benthic microflora can chromatically adapt to varying light intensities because of efficient accessory pigments.

Temperature has always been used as a primary factor in distribution and seasonal occurrence (Braarud 1961; Eppley 1972; Raymont 1980). Many pelagic marine plants and animals are classified geographically by temperature regimes, e.g. boreal, polar, temperate, and tropical, yet most estuarine phytoplankters appear to be cosmopolitan. Temperature extremes and daily differentials can affect division rates (doublings per day = $0.85c^{0.63T}$ at a Q_{10} of 1.88; Eppley 1972), nutrient availability and uptake, photosynthetic rates, respiration, assimilation numbers (mg C mg chl a^{-1} hr^{-1}) with the relationship being $An = 1.43e^{0.080T}$ at a Q_{10} of 2.23 (Smayda 1976), and consequently successional patterns because of interspecific competitive adaptations.

Phytoplankton dynamics, whether it be in the estuary or in neritic or oceanic waters, have historically been equated to availability of macronutrients. If nitrates, phosphates, silicates and the like are in insufficient amounts they are considered limiting, yet growth is a function of cellular nutrient pools and enzymatic capabilities and not necessarily external levels (Healey 1973). Also, ambient levels of basic nutrients such as NH_3-N, NO_3-N, and PO_4-P at specific times do not reflect turnover rates and cycling by bacteria, nannoplankters, and animals. Theoretically, macronutrients could be growth limiting, particularly during seasonal bloom periods, with nitrogen being considered the limiting macronutrient in temperate North Atlantic estuaries (Smayda 1976). However, phytoplankton have varied nutritional strategies and adaptations in relation to availability and uptake, stored resources, organic N and P utilization, and growth factor requirements, e.g., vitamins, trace metals, and chelators. Laws and Bannister (1980) stated "... phytoplankton have mechanisms for regulating uptake of each element and ... these

mechanisms are used to maintain composition and achieve balanced growth." Even in oligotrophic oceanic waters, nutrients appear to be nonlimiting (see Platt 1981; Hulburt 1970; McCarthy and Goldman 1979) with growth rates up to three or more doublings per day. In constrast, eu- and mesotrophic areas (e.g., Koblentz-Mishke and Vedernikos 1976; Redalje and Laws 1981) would appear to have lower growth (doublings per day), suggesting physiological saturation inefficiencies in relation to higher nutrient availability and "threshold" growth, or other factors. Smayda (1976), in discussing Narragansett Bay data, stated

> In 1974, 42% of the annual production of 310 g m^{-2} occurred during July and August when nitrogen remained at very low concentrations. Rapid nutrient recycling was necessary to sustain this production. That it must have ocurred is consistent with the elevated assimilation numbers found during the summer despite very low ambient nutrient concentrations ... phytoplankton dynamics during the summer in this bay, however, are not clearly limited physiologically by nutrient limitation or grazing. While nutrition levels and the recycling rate may set the magnitude (yield) of the population pulses, the underlying factors regulating the fluctuations in abundance remain unknown.

Smayda (1974) had demonstrated earlier that bioassays of natural waters would give more reliable data on limiting factors and successional dynamics; he concluded that "...natural phytoplankton growth conditioned the surface waters of Narragansett Bay" and that "...chemical changes in situ important to the occurrence, growth, and succession of phytoplankton species would not be detected by the routinely used nutrient and biological analyses."

Although there may be correlations between final yield and nitrogen and phosphorus levels as suggested by Margalef (1971) and shown for some studies, the macrocomponents do not regulate the fine structure of planktonic systems. As an example, Provasoli (1971) considered vitamin requirements an important regulatory agent in occurrence and succession of species. Since the 1960s it has been shown that various phytoplankters, besides bacteria, produce vitamins, e.g. B_{12}, thiamin and biotin, as well as vitamin inhibitors or binders. Recently, Messina and Baker (1982), using axenic cultures of Skeletonema costatum, Gonyaulax tamarensis and Cyclotella cryptica and their filtrates, showed that G. tamarensis and C. cryptica in the exponential growth phase produced high molecular weight ectocrines that inhibited S. costatum growth responses, thus effecting a competitive advantage. The growth response could be "normalized" by addition of excess vitamin B_{12} or by autoclaving the active filtrate prior to testing. Others, (Keating 1978, for freshwater; Freeberg et al. 1979 and Kayser 1981, for marine waters) also have used culture filtrates to demonstrate species succession patterns and that they were mediated by competitive inhibition. Provasoli (1979) pointed out that laboratory experiments with axenic cultures may produce biased results because marine bacteria are capable of enzymatically degrading binders. Provasoli (1979) also discussed nutrient competition and the importance of chelators, such as hydroxamates, and trace metals (e.g., ferric and cupric ions) in relation to species succession and preconditioning of water masses. Using S. costatum as an example again (it is the dominant diatom in temperate and tropical estuaries, including Tampa Bay), Morel et al. (1978) showed that this species was relatively insensitive to Cu^{++} activity, yet some other diatoms and phytoplankters are sensitive and trace metal availability or sequestering has been used to project species successions. Such potential species interactions are particularly significant in estuarine areas with poor flushing, confined water masses, or frontal boundaries where biological conditioning

and species interactions are accentuated.

Ketchum (1954), among others, first pointed out the association of estuarine circulation with phytoplankton accumulation and growth; where there is less exchange there can be higher standing stock because loss due to mixing and export is minimal. Casper (1967) also reported that plankton can remain in the same water mass for long periods because of low flushing and mixing - particularly in upper reaches of estuaries. Later observations and studies have emphasized the significance of circulation patterns in transport and/or concentration of phytoplankton at a density or tidal boundary, motility, and life history stages (e.g., Tyler and Seliger 1981; Tyler et al. 1982). Most of these studies deal with long estuaries (more than 100 miles) and vertically stratified events associated with pycnoclines. Wind and tidal action alone can concentrate surface organisms by accumulation at convergences; with wind direction and/or intensity changes and tidal changes, patches can be diluted by mixing and dispersion. Venrick (1978a) stated, "In general, one may expect greater phytoplankton heterogeneity in regions of rapid growth and high standing crop as well as in regions of environmental heterogeneity." Plankton patches can be on the scale of meters to hundreds of kilometers and are influenced by turbulence and other convective processes, growth rates versus diffusion, grazing, and community structure. Platt et al. (1977) suggested that patches less than 100 m diameter were controlled by turbulence.

The Tampa Bay Estuary

The Tampa Bay System is a shallow, vertically mixed, coastal plain estuary (about 400 mi^2) with a mean depth of 3.3 m (see Simon 1974 and this volume for reviews). The system consists of eight named subunits: Old Tampa Bay, Hillsborough Bay, McKay Bay, Middle and Lower Tampa Bay (more than 50% of the system area), Boca Ciega Bay, Terra Ceia Bay, and Manatee River (see Lewis and Whitman, this volume). Three of these geographic subunits connect directly to Lower Tampa Bay which opens to the Gulf of Mexico through barrier islands.

Major freshwater tributaries (Hillsborough, Alafia, Little Manatee, and Manatee Rivers) are located on the eastern side and have an average total discharge of about 1350 cfs with peak periods usually from June through September. Other freshwater drainage enters the bay system through creeks, streams, ditches, canals, effluent pipes, and excessive land runoff. Mean salinities for the system reflect lower runoff for Old Tampa Bay and the western side of the system with the greatest influence from the eastern side due to river discharge. Salinities increase from an average of 20.8 °/oo at the upper reaches (Hillsborough Bay) to 26.5 °/oo mid-bay to 32.2 °/oo inside of Egmont Key; Gulf salinities just outside the system average 34.1 °/oo (McNulty et al. 1972). Because of drainage in upper reaches and wind-induced sediment suspension in shallow waters, there are associated lower water clarity and higher turbidity values which increase or decrease, respectively, toward the bay mouth. Turbidity also can be due to plankton blooms.

Mixing of bay waters is tidal or wind-induced with a flushing time of months in upper reaches. The predominately diurnal tides, with occasional semi-diurnal cycles, create an average tidal range of 2.3 ft, yet because of natural and man-made constrictions such as bridges and causeways, circulation and mixing in upper reaches of the system, i.e. Old Tampa Bay and Hillsborough/McKay Bay, is poor. Poor circulation and slow mixing contribute to long residency times for water masses and the biota they support. For this reason, the upper reaches of the estuary often act as nutrient or particulate "sinks." Such conditions can lead to massive algal blooms, anoxia, and the release of H_2S.

HISTORICAL ACCOUNT OF PHYTOPLANKTON STUDIES

1. Marshall, N., 1952-1953. Marshall (1956) made some important preliminary observations regarding phytoplankton standing stock in Tampa Bay. "The greatest concentrations, toward the head of the estuaries studied, were probably associated with low dispersal rates and with mixing of benthic forms into the plankton of shallow water ... the retention of phytoplankton populations, permitting recruitment and growth, may be regarded as the more fundamental of these reasons for such contrasts in production." Although sampling of the bay was not synoptic and represented only several stations, one or two days during five months in 1952-53, there was a north to south trend towards higher salinities and lower chlorophyll a values which is substantiated in later, more comprehensive studies.

2. Pomeroy, L. R., 1958. Pomeroy (1960) assessed the "relative" contribution of seagrasses and their epiphytes, phytoplankton and benthic microflora in Boca Ciega Bay to primary production using the O_2 light-dark bottle method or changes in dissolved O_2 in a bell jar. Phytoplankton and benthic microflora were not identified or enumerated. Measurements were made on 5 different days in May and September, 1958; chlorophyll varied from 0.8 to 3.5 mg/m^3 for water column phytoplankton, and benthic microflora accounted for an average of 130 ± 30 mg O_2/m^2/hr. He concluded that in waters deeper than 2 m, only phytoplankton were important primary producers in Boca Ciega Bay.

3. U.S. Bureau of Commercial Fisheries (later National Marine Fisheries Service), St. Petersburg Beach, Florida, 1954 to 1973 (see Dragovich, Kelly, Finucane, Rounsefell, Proctor, Sykes and McNulty references). These coastal and estuarine studies were initiated in response to data needs for assessing Florida west coast red tides and physical, chemical, and biological correlations, both inshore and offshore. Number of stations ranged from 4 to 30 for the Tampa Bay system. Variables measured included salinity, temperature, major nutrients, D.O., pH, turbidity, chlorophyll, primary production (chlorophyll-light or O_2 light-dark bottle), Ptychodiscus brevis (= Gymnodinium breve) counts, and limited phytoplankton identifications and enumerations. Not all variables were measured at all times for all studies; most hydrologic collections were monthly. Their data showed higher standing stock as total chlorophyll a in upper bay reaches with bay system peaks in spring and summer. Taylor (1970) stated, "The overabundance of phytoplankton in Hillsborough Bay is a consequence of high nutrient levels, and is reflected in high figures for chlorophyll a and primary production. Actually, phytoplankters are the only important primary producers in Hillsborough Bay because turbidity has reduced light in the littoral zone to such a degree that seagrasses now survive only in small, scattered patches."

Dragovich and Kelly (1964; 1966) identified limited phytoplankton species during a 1963-64 study. Of the diatoms identified, Skeletonema costatum and Asterionella glacialis were dominant species with S. costatum prevalent from February to May. They also reported concurrent dinoflagellate blooms in the upper system during April 1963: Ceratium hircus (= C. furca var. hircus), P. brevis, Prorocentrum micans, and Gonyaulax diegensis (?). Dragovich and Kelly (1964) reported that microflagellates of less than 12 um dominated Tampa Bay collections during a portion of 1963. Later, Dragovich et al. (1965) noted 4-7 um flagellates in a 1964 Ceratium hircus bloom in Hillsborough Bay.

McNulty et al. (1970) associated spring phytoplankton peaks with temperature and nutrients and summer peaks with salinity and nutrients. Rounsefell and Dragovich (1966) found no statistical correlation with the occurrence of P. brevis (1954-1961) in Florida waters and NO_3-N, NO_2-N, NH_3-N, PO_4-P, TON and TPO_4-P, but did find

correlations with temperature, salinity, onshore winds (greater than 7 kts), and the previous months' P. brevis counts. Physicochemical variables in relationship to standing stock and primary productivity are presented by Johannson et al., this volume.

4. Florida Board of Conservation (later the Florida Department of Natural Resources), St. Petersburg, Florida, 1963 to present. These phytoplankton studies were also initiated in response to data needs for assessing Florida's west coast red tides and physical, chemical, and biological correlations. Eldred et al. (1964) reported on the 1963 Tampa Bay red tide and shellfish toxicity in relation to P. brevis counts and were the first to associate a cause-effect relationship which was later confirmed by McFarren (1965) using mouse bioassays.

Saunders et al. (1967) and Steidinger et al. (1967) studied diatoms and dinoflagellates from Tampa Bay to Caxambas Pass in 1963-1964 at 20 stations; four Tampa Bay stations were sampled monthly, three were sampled weekly and all stations but two were less than 2 m deep. Taxa lists included 43 diatom genera with 68 identified species, 21 dinoflagellate genera with 28 identified species, 5 blue-green genera and many unidentified forms. The most dominant component of these unpreserved samples were microflagellates less than 15 um. Diatoms usually were encountered at 1×10^6 cells/liter while dinoflagellates were less than 20,000/liter except during blooms. Skeletonema costatum numerically dominated except during late spring and summer. In these months, larger species of Rhizosolenia, Chaetoceros, and Bellerochea (B. horologicalis) dominated the biomass, particularly in lower reaches. El-Sayed et al. (1972) stated, "The Tampa Bay region has perhaps the most distinct diatom flora of the entire Gulf. Unusual members of the genera Cyclotella, Porosira, Amphipora, Chaetoceros and Bacteriastrum are known ... certain species dominate the phytoplankton communities regularly ... Hemidiscus hardmanianus and Bellerochea sp. at times constitute over 90% of total plankton surface area in the lower bay." As expected, recorded species (live specimens) tolerated wide temperature and salinity ranges. Comparison of weekly versus monthly collections showed dramatic weekly (and daily) dinoflagellate species composition changes. These data, plus offshore data, (Steidinger and Williams 1970) demonstrate that monthly phytoplankton collections smooth out or miss major short-term fluctuations and successional patterns.

Steidinger (1973) stated:

> ... assemblages that characterize eastern Gulf estuarine conditions including the diatoms Skeletonema costatum, Chaetoceros spp., Rhizosolenia stolterfothii, R. setigera, Cylindrotheca closterium, Cyclotella spp., Thalassiosira spp., Thalassionema nitzschioides, Cerataulina pelagica, Bacillaria paradoxa, Asterionella japonica, Paralia sulcata, Bacteriastrum spp., Nitzschia seriata (?), Leptocylindrus danicus, Bellerochea sp., and the dinoflagellates Ceratium hircus, Gymnodinium splendens, small Gymnodinium and Gyrodinium spp., Polykrikos spp., Peridinium spp., (e.g. P. quinquecorne), Gonyaulax spp. (e.g. G. spinifera), Torodinium spp., Prorocentrum micans, and P. gracile ... An overview of estuarine, coastal (continental shelf) and open Gulf phytoplankton reveals four broad types of assemblages: 1) estuarine, 2) estuarine and coastal, 3) coastal and open Gulf, and 4) open Gulf ... Many of the diatoms and dinoflagellates listed above for estuaries also occur in coastal waters but usually in lesser numbers and lower frequency ... No doubt if we were to carefully identify the small microflagellates, unarmored dinoflagellates, and diatoms, we would be better able to distinguish an estuarine assemblage; however, as Saville (1966) mentioned, estuaries have few endemic species and are influenced by freshwater and marine forms ... Tampa Bay is also rather

distinct in that at times it can have coincident dinoflagellate blooms, e.g. Gymnodinium breve, Gonyaulax monilata (both toxic species, one of coastal origin), Cochlodinium citron, Gymnodinium splendens, Gonyaulax spinifera and Peridinium quinquecorne.

To this list should be added: Ceratium hircus, Prorocentrum micans, P. gracile, Peridinium foliaceum, Amphidinium carterae, Gonyaulax diacantha, G. digitalis, Pyrodinium bahamense var. bahamense, and Noctiluca. Up to five species can be co-blooming in the Bay system with two to three in the same general area, particularly the upper reaches; blooms can be monospecific or mixed. Gonyaulax monilata typically blooms in August and September in Old Tampa Bay or mid-bay and is rarely found during the rest of the year because the species forms a benthic hypnozygote which "overwinters" in the upper 1-5 cm of sediment. This species and others that have dormant benthic stages form seed beds; consequently, water column blooms recur in the same area and are usually seasonal. Recently, Walker and Steidinger (1979a) were the first to induce and document the complete sexual life history of a marine dinoflagellate - G. monilata - using Tampa Bay vegetative and zygotic isolates. Steidinger and Ingle (1972) recounted the 1971 Tampa Bay red tide and Steidinger (1975a) stated,

> ... data from two of the three red tides that have established in Tampa Bay, Florida, indicate that the normally low salinity barrier of the Tampa Bay System was nonexistent at these times because of drought conditions ... salinites in upper bay reaches, e.g. Old Tampa Bay, during the summer of 1971 were as high as 31°/oo ... high salinity conditions in 1971 allowed G. breve blooms, once in the estuary, to penetrate and survive in upper reaches in Old Tampa Bay while salinities in 1974 were at the lower limit for G. breve.

Salinities of less than 25 °/oo are typically limiting to P. brevis (= G. breve). Steidinger (1975a) also pointed out that "Gymnodinium breve during these two outbreaks originally gained access to mid-Tampa Bay via the ship channel ... once in Tampa Bay ... winds and tides were instrumental in transporting and dispersing blooms."

Surface counts of P. brevis in several instances in back Boca Ciega canals were 10^7 cells/l due to southwest winds and incoming tides, then on the turn of the tide counts were 10^5/l throughout the water column. Prior to 1973, researchers believed that red tides started inshore near passes, e.g. off Egmont, and were initiated by previous freshwater drainage, but a reanalysis of offshore and inshore data suggested red tides started 10-40 miles offshore (Steidinger 1973, 1975a, b) and may be associated with offshore benthic seed beds in a discrete zone. Offshore initiation has since been demonstrated by Haddad and Carder (1979), Steidinger and Haddad (1981) and Haddad (1982), and has been associated with intrusions of oceanic water on the broad continental shelf. Walker (1982) recently documented the sexual cycle of P. brevis from gamete formation through planozygotes in culture and is working on induction of hypnozygotes. Other coastal bloom species, e.g. the blue-green alga Oscillatoria erythraea, can also be transported into inshore areas and bays. Most monospecific blooms in Tampa Bay are dinoflagellates or blue-greens (e.g. Schizothrix calcicola) that initiate in the bay itself.

Other studies by this agency on phytoplankton occurring in Tampa Bay include: taxonomic treatments (e.g. Pyrodinium bahamense, Steidinger et al. 1981; Scrippsiella, Steidinger and Balech 1977; Gonyaulax, Steidinger 1968, 1971); culture studies (e.g. Prorocentrum minimum (= P. marie-lebourae), Birnhak and Farrow 1965; Guinardia flaccida, Birnhak et al. 1967; Ceratulina pelagica, Saunders 1968; Chaetoceros galvestonensis, Britton and Farrow 1965; Rhodomonas baltica, Detweiler et al.

1965); documentation of dinoflagellate cyst or hypnozygote stages, particularly in bloom species (Walker, unpublished); and benthic microalgal production of gas bubbles that resuspend and transport sediment particles. Durako et al. (1982) demonstrated that dense populations of microalgae, e.g. Peridinium foliaceum and Gyrodinium fissum in Tampa Bay grass flat sediments produced 307.9 ml of gas/m^2/24 hrs with the highest production during daylight hours. At night, there was a 75% reduction in bubble production. During the day, oxygen constituted more than 90% of the gases; at night there was an increase in CO_2 composition. These bubbles of benthic origin were capable of resuspending sediments by adsorption of particles.

5. University of South Florida (Department of Marine Science, St. Petersburg), 1968 to present. Various thesis topics and contract work involving phytoplankton, standing stock, associated physicochemical variables, and/or primary productivity have been completed or are underway for the Tampa Bay area and other nearshore and coastal areas, e.g. Anclote basin, Crystal River, Charlotte Harbor, and Gulf waters. These are in addition to unpublished and uncirculated short-term class projects or laboratory reports, e.g. vertical stratification in Bayboro Harbor due to runoff and the associated temporary separation of freshwater and marine plankters; the effects of Tampa Bay power plant cooling systems on phytoplankton and standing stock and production; and others. Both the Department of Biology and the Department of Marine Science use Tampa Bay as a study site.

Phytoplankton thesis topics based on Tampa Bay and offshore Tampa Bay have included: description of a new species and distribution of Gonyaulax (Steidinger 1971); phytoplankton distribution, abundance and seasonality in relation to physicochemical variables (Turner 1972); oceanic intrusions in relation to offshore initiation of red tides (Haddad 1982), and vertical distribution of chlorophyll a and its degradation products in intertidal sediments (Buckley 1982). Of these, Turner's work was the most extensive as regards number of stations (55) and variables measured, but sampling was quarterly from fall 1969 to summer 1971, thus missing short-term fluctuations and masking seasonal trends. In addition, the samples were preserved in formalin, thus distorting or lysing most of the unarmored dinoflagellates and other fragile phytoflagellates. Turner measured species occurrence, cell counts, biomass, total chlorophyll a, salinity, temperature, turbidity, depth, water color, total seston, PO_4-P, NO_3-N, NH_3-N, and SiO_2-Si but found no consistent significant correlation among biological and physicochemical variables for most of the collections. Even for the fall 1971 synoptic samples of the bay system (66 samples) Turner stated, "The absence of significant correlation among factors in the synoptic data of fall 1971 indicates that synoptic sampling may not reduce many of the problems encountered in phytoplankton study." In total, 42 diatom and 23 dinoflagellate taxa were recorded. Skeletonema costatum was the most abundant diatom in fall and spring, particularly in upper reaches; diatoms predominated in spring both numerically and in biomass. Maximum cell counts were recorded in fall with a second maximum in winter. Summer 1970 had a dinoflagellate maximum. Phytoplankton abundance and nutrients generally decreased toward the mouth of the bay. Turner pointed out Platt et al.'s (1970) work on spatial heterogeneity of phytoplankton where they demonstrated up to a 70% coefficient of variation (CV) for chlorophyll values between closely spaced stations (0.5 n mi). The same has been reported for chlorophyll differences over one tidal cycle with higher CVs in other areas.

Turner's recording of oceanic Ornithocercus species at salinities of 16.7 to 26.9 °/oo and counts of up to 200,000 cells/l was in error (Turner, pers. comm.). The speculation that the Tampa

Bay system may be nitrogen limited solely based on NO_3:PO_4 ratios (Turner and Hopkins 1974) is beyond the data base as outlined in the Introduction because of unknown in situ turnover rates, use of other N sources, such as NH_3 and urea, and excess PO_4-P values due to natural phosphate beds and mining activities (Johannson et al., this symposium).

Buckley (1982) reported chlorophyll a values for 19 sediment samples from Lassing Park as 18.3-209.6 mg/m^2 and phaeopigments from 13.7-60.9 mg/m^2; little chlorophyll a was detected below 20 cm. Chlorophyll a peaked in early fall. Since most samples were from mud and the chlorophyll a values are less than some other areas, substrate type, e.g. firm sand vs. mud, no doubt could influence maxima obtained, as could sampling time in relation to tide and other factors, although Buckley found no distinct vertical migration with simulated tidal cycles.

More recently, Dr. Gabriel Vargo, a phytoplankton physiological ecologist, has been studying N and P metabolism in a Tampa Bay intruder - P. brevis. His interests are nitrate and urea uptake, phosphatases, photosynthetic capacity and efficiency, respiration, and vertical migration. He has conducted several laboratory and field trials to date and has verified varied N utilization as well as a population migration (partial) for this species.

6. University of South Florida (Department of Biology and Department of Chemistry), Tampa, 1967 to present. Various theses and contract work involving marine phytoplankton have been completed or are underway. Most of these studies have concentrated on toxic dinoflagellates causing red tides and have reported on ultrastructure (Davis 1969; Steidinger 1979), growth requirements (Olander 1968); growth and toxicity (e.g. Doig 1973; McCoy 1977; Eng-Wilmot 1978; Martin and Martin 1976), and ecological impacts (Smith 1978). One study, unrelated to red tides, documented the identity and occurrence of phytomicroflagellates in Tampa Bay (Gardiner 1982). The latter study is of the most interest to this review.

In a year-long nannoplankton flagellate study, Gardiner (1982) sampled five stations in Tampa Bay twice monthly; one of the stations, Cockroach Bay, was sampled for both water and sediment. Live samples were processed within 24 hours of collection and relative abundance of species was estimated.

At least 25 species were recorded including representatives of the following algal classes:

Chloromonadophyceae
Chlorophyceae
Chrysophyceae
Cryptophyceae
Dinophyceae
Euglenophyceae
Prasinophyceae
Prymnesiophyceae

This number is conservative, since many such species superficially resemble others when examined with light microscopy. Accordingly, many of the listed taxa, such as Pyramimonas disomata, may include two or more morphologically indistinguishable species. Six species were encountered year-round including Bipedinomonas rotunda, Calycomonas ovalis (non-photosynthetic), Chroomonas pluricocca, Amphidinium carterae (in sediments of Cockroach Bay), Pyramimonas disomata, Eutreptiella marina, Katodinium rotundatum, Gyrodinium estuariale and Prorocentrum minimum. Prymnesium parvum is reported to cause fish kills when it reaches densities exceeding 100,000/ml in England coastal waters (Holdway et al. 1978).

Other species of interest which were found include the chloromonad Horniella marina and the chrysophyte Olisthodiscus luteus which are morphologically similar bloom species. All species identified are between 5 and 20 um except for Horniella which is about 50 um, and larger Amphidinium carterae. In addition to the above work, two clones of Gyrodinium estuariale (spring and fall) were tested for growth

responses in relation to varied light, temperature, and salinity regimes. No substantial differences in growth rates were detected.

7. Tampa Electric Company, Big Bend site, (under contract to Conservation Consultants, Inc., Palmetto, Florida), 1970 to 1977. Monthly or more frequent (e.g. every 19 days) water samples for chlorophyll, phytoplankton occurrence and abundance, and certain physicochemical variables were collected from 1970-1977 using various field and laboratory techniques at several sites in Hillsborough Bay. From 1972-1975, 20 liter samples for phytoplankton were concentrated using a 135 um mesh net; later, a 35 um net was used. Net samples were preserved (glutaraldehyde) in one liter; live samples were additionally used in 1972-1975. In total, 46 dinoflagellate species and 17 genera, 137 diatom species and varieties and 61 genera, and 3 blue-green genera were identified (Hughes and Parks 1977). Using the 35 um data, diatoms had primary peaks in winter with secondary peaks in late summer/fall. Skeletonema costatum was common and dominant with peaks in fall and winter as was Rhizosolenia sp. cf. delicatula with peaks in early winter, late summer and late fall. Skeletonema costatum abundance biased the species diversity index (H'); highest diversity occurred at times of lowest S. costatum abundance. This was also demonstrated by Walker and Steidinger (1979b) for Florida east coast samples and would apply to monospecific phytoflagellate bloom events as well. Other dominants were Hemiaulus sinensis, Oscillatoria sp. (Schizothrix?), Ceratium hircus, Asterionella glacilis, Gonyaulax polygramma, Rhizosolenia setigera, Chaetoceros spp., and Nitzschia spp. This dominance for 15 months is not necessarily representative of the system since bloom events could influence maximum counts and dominance, and such events can represent different species during different years. Oscillatoria sp. (Schizothrix?) was abundant from late summer through fall which agrees with City of Tampa data for Schizothrix calcicola. Dinoflagellates dominated during spring and summer but were in low concentrations during the rest of the 15 month study; bloom species were Gonyaulax polygramma, G. balechii, Gymnodinium nelsonii (= G. splendens in part), and P. brevis.

8. Hillsborough County Environmental Protection Commission, (HCEPC) Tampa, 1972 to present. Hillsborough County personnel have been sampling the Tampa Bay system since 1972; their 50 to 54 stations in marine waters were sampled for up to 42 water quality parameters including salinity, temperature, basic nutrients, chlorophyll, turbidity, dissolved oxygen, light penetration, and algal blooms. Sampling has been monthly and since 1975, surface, mid-depth, and bottom samples have usually been collected. This data base is available through HCEPC and is summarized annually in reports; stored raw data is also available on computer tapes through the Department of Environmental Regulation. Although chlorophyll as chlorophyll a is available, the procedure followed does not include grinding and therefore data points may be underestimated, particularly during diatom peaks or blue-green algal blooms. Yet chlorophyll trends show north to south decreases. Typically upper Old Tampa Bay and Hillsborough/McKay Bay have chlorophyll a values greater than 20 mg/m^3 and some data points exceed 100 mg/m^3 during bloom events. The lower reaches of the system have less than 10 mg/m^3. The average chlorophyll a concentration for those stations sampled between 1972-79 was the highest in 1979 with a mean of 18 mg/m^3. The lowest for this period was a mean of about 10 mg/m^3 in 1972. The high chlorophyll a levels for upper reaches are often coincident with lower salinity/higher turbidity and lower light penetration levels. Algal blooms of dinoflagellates, blue-greens and occasionally diatoms are recorded, but in some instances taxa are only identified to genus or basic taxonomic grouping,

e.g. filamentous algae, diatom. Nutrients from this data base are discussed separately in this volume (Fanning and Bell).

9. City of Tampa, 1976 to present. The City of Tampa (CT) has been monitoring primary production and standing stock since 1976. The data from 1978 to present are used in J. O. R. Johannson et al. (this volume) and include ^{14}C for planktonic primary productivity, chlorophyll a, temperature, salinity, secchi depth, nutrients and dissolved oxygen. From 1978 to 1981 they occupied 2 stations in Hillsborough Bay and sampled surface and 3 m depths for phytoplankton occurrence and abundance (Lugol-preserved) and the variables listed above. From 1979 to 1981, another station in mid-Tampa Bay was added and sampling strategy was the same except subsurface depth was 4 m. In 1981, sampling changed to monthly collections. Seventy-five diatom species and 39 genera, 31 dinoflagellate species and 14 genera, 4 blue-green genera (including two Schizothrix species), 8 microflagellate species, and various unidentified forms have been recorded to date. Peak chlorophyll biomass is usually in fall which corresponds with Schizothrix blooms. Nannoplankters (less than 20 um) typically dominate except during monospecific blue-green or larger dinoflagellate blooms. There is a general decrease in standing stock seaward with increasing salinities. Schizothrix calcicola usually dominates Hillsborough Bay from July/August to October or later and represents high biomass but low productivity. The blooms are associated with anoxia and benthic fauna mortalities. These blooms also occur in parts of Old Tampa Bay, sometimes coincident with the Hillsborough Bay events. Previous studies (Saunders et al. 1976, HCEPC) list Oscillatoria or filamentous algae blooms for the same time period and these are assumed to be Schizothrix calcicola blooms. Other bloom events, e.g. Noctiluca, have also been documented with analysis of successive feeding strategies of this heterotroph underway. The City of Tampa data base is the most comprehensive available based on techniques and variables measured but it is limited to Hillsborough Bay and one station mid-bay.

In addition to their monitoring efforts, Johannson and Carpenter are conducting quarterly natural plankton enrichment studies to evaluate nitrogen and phosphorus limitation. Data to date show that PO_4-P is not limiting (all data provided by J. O. R. Johannson, pers. comm.).

DISCUSSION AND SUMMARY

Phytoplankton studies in the Tampa Bay system and surrounding coastal waters were initiated to determine the occurrence and distribution of the red tide organism Ptychodiscus brevis (= Gymnodinium breve) in relation to environmental variables, e.g. salinity, temperature, and major nutrients, following the 11 month 1946-47 red tide outbreak. Since then, a number of specific studies or theses have been pursued by federal, state, county, city, university, and private organizations as outlined above.

The findings of these studies can be summarized by seven major headings: north to south gradients in the system; dominance of nannoplankton; number of species and biogeographic classification; planktonic versus benthic assemblages; bloom events; short-term fluctuations and seasonality; and sampling strategy and analytical procedures.

North to South Gradients: Studies, even those of short duration, showed that a north to south, or head to mouth, gradient existed for salinity (lower to higher). They also showed increased water clarity, mixing of water, and species "diversity" from lower to higher salinities within the Old Tampa Bay, Hillsborough Bay/McKay Bay, Tampa Bay system. Contrarily, standing stock as chlorophyll a or cell counts and the location and frequency of bloom events (autochthonous) decreased from the head to the mouth of this large, shallow estuary. These trends are obvious regardless of sampling frequency (e.g.

weekly, monthly, quarterly, sporadic) or analytical techniques (e.g. chlorophyll a derived with or without grinding of the concentrated samples). Intuitively, these specific associations would be suspected because of freshwater inputs, the shallowness of the bay, and poor circulation and mixing in the upper reaches where residency of water masses may be months. These trends are classical associations as expressed by Hulburt (1965), Casper (1967), Kinne (1967), and others.

Dominance of Nannoplankton (5-20 um): As early as 1965, Fogg recognized that at least half of planktonic photosynthesis was due to microalgae that passed through a 35 um mesh net and that even though the smaller size classes were the most productive, they went unstudied. Since then there have been numerous studies showing the importance of pico-, ultra- and nannoplankters and their contributions to biomass and primary production in estuaries, coastal waters, and even open, oceanic waters, both in tropical and temperate regions. Smaller size classes have higher turnover and uptake rates and are metabolically very active.

Again, Tampa Bay is not an exception to the general rule of nannoplankters dominating microplanktonic microalgae, except seasonally when monospecific blooms of blue-greens (Schizothrix) or dinoflagellates (e.g. Gymnodinium nelsonii, Ceratium hircus, Prorocentrum micans, Gonyaulax spp., and others) dominate certain water masses in the upper or middle reaches of the system. Nannoplankters, such as small diatoms and microphytoflagellates, often less than 15 um, have been reported to dominate water samples since 1963. However, not until Gardiner's (1982) dissertation work has this group been studied in any quantitative detail. Prior to Johannson (pers. comm.) and Gardiner, few researchers attempted generic or species identification because of size and taxonomic difficulties.

Nannoplankters not only dominate the water column but can be a significant component of benthic populations, e.g. Amphidinium carterae, an unarmored dinoflagellate. No one has yet attempted quantitative benthic and epiphytic community studies of microalgae in Tampa Bay or other major estuaries in Florida even though biomass as chlorophyll a suggests high standing stocks, and casual personal observations suggest rich communities of diatoms, dinoflagellates and other flagellates.

Number of Species and Classification: In total, 272 taxa identified to species or varieties have been recorded from the Tampa Bay system (see Appendix). If unidentified forms were added, the list would exceed 300 taxa. Benthic studies would further increase the list and no doubt reveal new, undescribed taxa. Of the 272 species/varieties identified, 167 were diatoms, 78 were dinoflagellates, four were blue-greens, and 25 were microphytoflagellates (Table 1).

Table 1. Number of Tampa Bay system phytoplankton species/varieties and genera by major grouping (see Appendix for species lists and references).

Group	Species	Genera
diatoms	167	65
dinoflagellates	76	28
blue-greens	-	7
microflagellates*	25	18

*exclusive of dinoflagellates

Comparison of the Tampa Bay system assemblage to other geographic areas shows that 23.5% to 70% of the diatoms from 10 other studies, except two, were also recorded from the Tampa Bay area (Table 2). The lower the total number of species recorded, the higher the percentage in common. The two exceptions were a North Carolina estuary and Florida Bay where benthic diatoms dominated. Comparing dinoflagellates from nine of these same studies and another listing (Table 2), 11.3% to 38.1% of the dinoflagellates were in common. These lower percentages for dinoflagellates, as compared to diatoms, reflect differences in temperate versus tropical or subtropical assemblages. Tampa Bay is strongly influenced by a subtropical assemblage. In comparing Gulf of Mexico dinoflagellates (El Sayed et al. 1972), 56% of Japanese coastal dinoflagellates were recorded from Gulf waters whereas only 11.3% were in common for the Tampa Bay system. The 11 phytoplankton studies cited in Table 2 represent comprehensive studies of either long duration or intensive sampling effort, but techniques differed (e.g. live vs. preserved, different sized nets) as did sampling frequency and depth. Consequently, a direct comparison for similarity indices or association/matrix analyses was not possible nor warranted based on these differences and the lack of benthic sampling.

Smayda's (1978) biogeographical classification scheme based on records for 379 planktonic species outlined twelve proposed distribution types. Tampa Bay phytoplankton falls into two of his cosmopolitan classes - temperate and warm waters, and warm waters. Most species are cosmopolitan except for those that had been recently described in the last 10 years, e.g. Bellerochea horologicalis, Gonyaulax balechii, and Protoperidinium steidingerae. Even though many phytoplankters are cosmopolitan in distribution, most species represent different physiological strains with different environmental tolerances and growth responses. In at least one species complex (Crypthecodinium cohnii), Beam and Hines (1982) identified over 28 sibling species and the likelihood of other species complexes among cosmopolitan phytoplankters certainly exists.

Planktonic versus Benthic Assemblages: Planktonic phytoplankton have been well studied world-wide both taxonomically and as primary producers. However, benthic microalgal assemblages are not well known even though they represent a significant primary production component of an estimated 100-200 g C/m^2/yr. The lack of these data from a systems study approach represents a major gap in our knowledge of diversity, function, and energy flow. Diatoms, dinoflagellates, and microphytoflagellates can be epi- and endopelic, episammic, and epiphytic. Some can attach by stalks or filaments to a variety of substrates; others live in close association with various plant and inorganic materials. Hustedt (1955) identified 319 diatom species from just two North Carolina mud samples; 89 species were new to science. Diatoms, both vegetative and reproductive stages, can be found down to at least 5 cm as can dinoflagellates, and even down to 10 cm (Round 1971; Buckley 1982; D. Anderson, Woods Hole Oceanographic Institution, pers. comm.). Vertical distribution is associated with rhythmic migrations or biological and physical reworking of sediments. Benthic cryptomonads, chrysomonads, diatoms, and dinoflagellates can be significant components of estuarine phytoplankton as pointed out by Wood (1965), Saville (1966), Round (1971) and others. Benthic dinoflagellates, such as certain species of Prorocentrum, Amphidinium, Thecadinium, Polykrikos, Gymnodinium, Gyrodinium, Scrippsiella, Peridinium, Ostreopsis, and Protoperidinium, can be dense and metabolically active in their vegetative stages both in temperate and tropical areas. For example, Durako et al.'s (1982) study on benthic dinoflagellate gas production in a Tampa

Table 2. Number of species of diatoms and dinoflagellates in common between other geographical areas and the Tampa Bay system. Collection methods, handling methods, numbers of stations, frequency of sampling, and other factors variable.

	DIATOMS		DINOFLAGELLATES		
Study	# species	% (#) in Tampa Bay	# species	% (#) in Tampa Bay	Reference
Guadeloupe, West Indies (tropical)	196	23.5 (46)	28	35.7 (10)	Ricard & Delesalle 1979
India (tropical)	164	40.0 (66)	111	24.3 (27)	Subrahmanyan & Sarma 1960
Mozambique (tropical)	345	29.6 (102)	189	14.8 (28)	Sournia 1970
Lebanon (warm temperate)	100	54.0 (54)	148	16.9 (25)	Lakkis & Novel-Lakkis 1980
NW Atlantic (warm temperate/tropical)	81	63.0 (51)	31	32.3 (10)	Marshall 1971
North Carolina (temperate)	187	12.8 (24)	65	29.2 (19)	Campbell 1973
Narragansett Bay (cold temperate)	50	70.0 (35)	21	38.1 (8)	Pratt 1959
English Channel (temperate)	64	60.9 (39)	38	42.1 (16)	Maddock et al. 1981
Japan (temperate)	250	36.0 (90)	239	11.3 (27)	Yamaji 1966
Florida Bay (tropical)	160	13.8 (22)	-	-	Defelice & Lynts 1978
British Isles (cold temperate)	-	-	124	31.5 (39)	Dodge 1981

Bay seagrass bed suggests high diurnal metabolic activity that may indirectly influence sediment transport by resuspension via adsorption to bubbles.

In addition to benthic vegetative cells, this environment harbors a variety of resting stages of planktonic forms, e.g. hypnozygotes, hypnocysts, and resting cells that can influence the diversity and seasonality of planktonic diatoms, dinoflagellates and microphytoflagellates. These stages, under the right conditions, e.g. temperature and photoperiod, act as seed beds for future planktonic production, particularly in estuaries and coastal waters. These "resting" stages have lowered metabolic acitivity and often represent dimorphic life history stages. In essence, there are probably few truly holoplanktonic estuarine phytoplankton; most are probably meroplanktonic.

Even though benthic phytoplankton can be high in biomass, primary production and species diversity, they have principally been studied as tychoplankton, incidental in water column collections. This is an unfortunate oversight. On an areal basis, primary production of benthic microalgae could equal planktonic production values yearly, yet trophically, benthic microalgae may represent a more direct food source to herbivores such as ciliates, small crustaceans, and filter or other suspension feeders than phytoplankton or detritus from the water column. Not only are there few production values, but turnover rates, intra- and interspecific competition and interaction, food webs, morphological and physiological adaptations, habitat preference or tolerance, life histories, diversity, successional patterns and other factors remain relatively unknown. Such studies should be a high priority for phytoplanktonologists (or phycologists working with microalgae or systems ecologists if there is a conceptual problem with the term "plankton").

Short-term Fluctuations and Succession/Seasonality: The most dominant planktonic species is Skeletonema costatum, an estuarine and neritic chain-forming diatom, followed by Rhizosolenia spp., Chaetoceros spp. and seasonal dominants such as Bellerochea horologicalis, Schizothrix calcicola, and dinoflagellates. Skeletonema numerically dominates the water column in January to April/May and then again in fall. Bellerochea and Rhizosolenia can dominate in late spring and summer as can Chaetoceros. Dinoflagellate blooms, mixed or monospecific in water masses of long residency in upper and middle reaches of the bay, dominate in summer, fall and even late spring, depending on environmental factors such as salinity, light, temperature, micronutrients, and organics. These blooms and Schizothrix in upper reaches can lead to oxygen depletion in the shallow water column and cause fish and invertebrate mortalities. The broad successional pattern, and therefore seasonality, that emerges is small diatoms to larger diatoms to dinoflagellates to blue-greens. Margalef (1967) presented a temperate successional pattern of small diatoms and flagellates to Chaetoceros to Rhizosolenia (both larger diatom groups) to coccolithophorids and dinoflagellates. Even though there are year to year fluctuations in species occurrence and abundance, succession infers that major seasonal events, e.g. freshwater inputs, temperature, photoperiod, organic conditioning agents, and life history strategies (e.g. benthic resting stages), are more important than macronutrient regimes, at least in estuaries. Factors regulating succession, for example temperature, affect growth responses and maximum reproductive rate. A species that has a high division rate (e.g. 2-3 divisions per day or more), even at the extremes of its temperature tolerance or at a narrow band of high temperatures, can outcompete another species within a water mass. Such a productive advantage may explain the Schizothrix biomass. Blue-greens have the highest tolerance to high light and temperature, followed by dinoflagellates, then diatoms. Smayda's (1974) bioassay work suggests that microconstituents

produced as ectocrines and acting as either growth inhibitors or stimulators regulate succession rather than any measurable inorganic variable such as nitrate, nitrite, ammonia, and orthophosphates. It is also conceivable that light, temperature, and salinity influence the breaking of dormancy in benthic resting stages and that ectocrines and circulation patterns influence dominance and abundance of planktonic stages - at least for dinoflagellates. For example, Gonyaulax monilata can bloom July through September in Tampa Bay and elsewhere in the Gulf of Mexico; it is usually absent from the water column in other months. This species has known seed beds that inoculate the water column in Old Tampa Bay.

Weekly, monthly, quarterly or sporadic sampling misses short-term fluctuations that occur daily and tidally. As an example, sampling on an incoming tide in back shallow areas should reveal a higher composition of tychoplanktonic pennate diatoms. Seven to tenfold differences in biomass have been recorded within one tidal cycle and this may be due, at least in part, to turbulence and suspension of benthic microflora. Sampling at different times of the day, regardless of tidal cycle, may, at least in summer and fall, show different vertical distribution for flagellates because of light adaptations. Night sampling may even reveal migration patterns. Species composition differences occur at "stations" on a daily basis during nonbloom events because a station is a fixed location while plankton are transient and water masses are rarely tracked. In poorly flushed areas of long residency, such differences can be negligible. Because of daily and weekly differences, seasonality, abundance peaks, and successional patterns can be masked by sampling infrequency.

Auto- and Allochthonous Bloom Events: A phytoplankton bloom represents cell densities above background levels, usually greater than 50,000 cells/liter. Such blooms can be mixed and then monospecific by competitive inhibition or exclusion, or remain mixed. Those that become monospecific or almost monospecific often are associated with upper, poorly flushed areas and may last months, or at least several weeks. Blooms of Ceratium hircus, Prorocentrum micans, P. gracile, Gonyaulax digitalis, Ptychodiscus brevis, Schizothrix calcilcola, and others have lasted several months. Most bloom species are autochthonous and originate in the bay system either from a benthic or planktonic inoculum. Two exceptions are P. brevis and Oscillatoria erythreae which are oceanic/coastal "invaders" and of allochthonous origin. Blooms of the toxic dinoflagellate P. brevis originate 10-40 miles offshore, in association with oceanic events, not near passes as previously suspected, and can be transported shoreward by currents and winds. Between 1946 and 1982, various portions of the Tampa Bay system were exposed to this invader at least 12 times, usually in the lower reaches. In two outbreaks, 1963 and 1971, P. brevis penetrated the upper reaches and in one instance, this species dominated for over three months. The only reason P. brevis was able to establish itself in the upper portion of the system was because of higher than normal salinity regimes (up to 31 °/oo) due to drought conditions at the time of the outbreak. In 1963, with the lowering of salinities due to rainfall, the species quickly disappeared, but in 1971 there was no or minimal rainfall during its bloom duration. The species does not survive in waters of less than 25 °/oo.

There are several factors regulating bloom occurrence and duration; some are: seeding of an inoculum, salinity regimes, low mixing of bay waters, ectocrines, competitive growth rates, and lack of predators. These same factors probably account for the Schizothrix blooms, except that the importance of salinity is replaced by temperature and light. Again, monospecific blooms of photosynthetic microalgae, whether the species produces a toxin or not, can lead to oxygen depletion and animal mortalities,

particularly in early morning hours due to high respiration activity at night.

Sampling Strategy and Analytical Procedures: Each study should have a sound experimental design prior to initiation (see Venrick 1978a, b, c, d). This planning phase may involve preliminary sampling and analyses to establish minimal sample size in specific areas or under specific conditions and gear type. Sample size can relate to volume of field samples, number of field replicates, number of subsamples as replicates, and whether seawater volume or cell counts should serve as the sample in setting size limitations. When analyzing standing stock as chlorophyll or total cell volume, the initial sample size may be in ml or liters when unconcentrated, but it may be tens of m^3 if nets are used. When performing diversity or cluster analyses, then subsample size may relate to cell numbers, e.g. 400 cells per subsample or aliquot with a precision of $\pm$ 10% of the mean. Different techniques or approaches may even be used within this breakdown. The number of replicates when pooled, or total volume of subsample, can determine the lower level of detection if an entire sample is not analyzed, e.g. if ten one ml replicates (or 10 ml) are used, the limit of detection is 10^2 cell/liter or 10^5 cells/m^3. If only one ml is analyzed, the sensitivity is decreased to 10^3 cells/liter or 10^6 cells/m^3. Water column samples, in addition to being just "trapped" and not concentrated, can be sedimented, centrifuged, or filtered and the living or preserved concentrate subsampled. Again, pooled subsamples or total subsample size influences the level of detection and reported abundance or biomass. Turner's (1972) level of detection was 1 cell = 100,000 cells/liter. Lack of adequate sample or subsample size can obviously bias numerical data and presence or absence of less abundant forms that may be part of a characteristic assemblage. The advantage of individual replicates over a total subsample volume lies in being able to determine subsample variation, for example, with the coefficient of variation (CV) which does not require a normal distribution of data points around the mean.

Initial sample size and sampling techniques are important to any quantitative study because plankton distribution is not homogenous, rather it is "patchy" and among sample variation is very high (CV greater than 50%). Again, depending on the study goals and subsequent strategies, different gear types that represent continuous sampling, e.g. pumps or nets, may be warranted, or large volume point samples can be pooled and concentrated on board. In reviewing past Tampa Bay system studies, most programs probably had inadequate sample and subsample sizes for quantifying abundance or cell volume, and counts should have been expressed in orders of magnitude ranges for relative abundance for among area comparisons using nonparametric statistics.

Microscopic examination for identifications and abundance may require different volume subsamples because of magnification limitations. Many of the smaller forms have to be identified and counted under high dry or oil immersion with limited working distance, depending on available optics.

In addition to sample size and spatial heterogeneity of plankton, fixed station data can be misleading; the growth medium and the plankton are transitory. In essence, each collection, even at the same site, represents a new area or stations which would theoretically necessitate new sample size determinations. Only in a discrete water mass which was being tracked or a water mass that was physically retained, or even a small lake , would the concept of initial sample size have any carryover meaning for statistical reliablity. Another problem with sampling stations is whether they should be random or source/influence related, e.g. stratified random sampling. For example, in Tampa Bay: upper reaches and southern boundary areas have freshwater inputs; water mass residency in Old Tampa Bay

and Hillsborough Bay can be 5-27 months; shallow areas can contribute substantial tychoplanktonic components from tidal, wind or storm influence, etc. Should sampling be synoptic and at what depths? There are no simple answers to "station" locations, numer of stations, or sample and subsample sizes. There are other variables such as sampling frequency, gear type, plankton size categories, handling techniques and strata sampling that also need to be addressed depending on project goals and hypotheses being tested. The questions raised above not only apply to phytoplankton but to zooplankton, bacteria, nutrients, turbidity, suspended particles, and other aspects of water column investigations.

Sampling frequency and timing have historically been based on human and financial resources, sample processing time, and the convenience of the investigator. How many planktonologists do night sampling unless it is in relation to 24 hour, tidal, or limited cruise sampling? Should sampling be at a specific tidal phase, e.g. high tide, or can sampling be considered as random when tidal phases are ignored? Does sampling every second Monday of the month mask daily and weekly fluctuations; does it ignore rainfall and runoff events and system responses? Quarterly sampling for certain benthic sessile or infaunal populations may be adequate, but quarterly sampling for water column plankton is inadequate unless the investigator is looking at specific within-sample correlations and variables in a large enough data base.

From past and current Tampa Bay system phytoplankton studies, it is obvious that water column nannoplankton numerically dominate net plankton. Yet this fraction is usually ignored for its presence and contribution to standing stock as chlorophyll or primary production. Many of the nannoplankters are delicate phytomicroflagellates that do not fix well and therefore are lost to even baseline data. To understand phytoplankton "diversity", biomass, production, succession, and dynamics, the nannoplankton fraction between 5-20 um, as well as the pico- and ultraplankton fraction less than 5 um, must be studied quantitatively. Also, there are few investigators trained in the taxonomy of these small organisms. By definition, ecology is based on the study of biotic and abiotic system components; biotic aspects relate to communities and therefore populations. Populations are made up of individuals and consequently, systematics is the grassroots of ecology. It is an indispensable tool that unfortunately is looked upon as more of an art than a science. Systematic and taxonomic studies are receiving reduced funding at a time when species complexes and an expanded concept of "species" are just being realized.

Most phytoplanktonologists working in the Tampa Bay system and elsewhere have been preoccupied with water column microalgae and the dynamics of planktonic interactions and responses, ignoring the microalgal component in the benthos. Actually, the two realms are coupled through life histories, vertical migrations and sinking, and yet there are few even qualitative benthic analyses. Those benthic studies that are quantitative have been selective, concentrating on the diatom assemblage, the cyst or spore assemblage, or just biomass as chlorophyll in sediments. Such studies cannot be integrated into a plankton dynamics system approach because of missing compartments.

Quantitative sampling of benthic microalgae, vegetative or reproductive stages, usually follows techniques used for infauna, e.g. replicate core samples; sampling could be less frequent than water column collections, but it should take into account rhythms in response to tides, light, or other environmental cues. Analyses should be such that living and dead material can be differentiated quantitatively, e.g. by vital staining or fluorescence microscopy, since the benthos is a detrital reservoir, and fragile, unpreservable forms should be identified. This necessitates that samples be live and handled within a

short time frame to avoid decomposition and succession. Cores can be cut for different depths, weighed, sediments resuspended in filtered seawater letting the heavier particles settle out, and finally the supernatant size fractioned to remove larger inorganic fractions. This procedure would bias the data toward the removed episammic assemblage. Or, sediments from different depths can be resuspended in filtered seawater of a known volume from the site and subsampled with a wide bore pipette. Sampling water column phytoplankton with all the associated problems is technologically easier than sampling benthic populations. Round (1971), Round and Hickman (1971) and Dale (1979) gave benthic sampling techniques and strategies for diatoms and dinoflagellate cysts and there are several accounts for measuring chlorophyll in sediments. Even presence or absence without quantitative sampling would be meaningful data for associations, seasonality, and life history strategies since the data gap is so extensive, as would total standing stock as active chlorophyll. Recently, Moed and Hallegraeff (1978) and Riemann (1978) have emphasized pH problems with spectrophotometric determinations of phaeopigment concentrations in the water column. The same problems would apply to benthic samples, if not more so. Therefore, it may be best to use chromatographic separation techniques for benthic samples.

The above discussion on sampling strategy and analytical procedures is superficial at best because it does not recommend a final Tampa Bay system study design for phytoplankton or more appropriately, microalgae. Such a study would take a team effort of specialists and a variety of sampling strategies that should address stratified random sampling in the water column and benthos over a period of years at a frequency adequate to characterize natural fluctuations. Funding and human resources would necessarily restrict design and scope of such studies and thus limit the usefulness of the data base.

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APPENDIX
PHYTOPLANKTON SPECIES LIST FOR THE TAMPA BAY SYSTEM, FLORIDA

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DIATOMS (BACILLARIOPHYCEAE)	REFERENCES
Achnanthes longipes Agardh	1
A. spp.	1
Actinocyclus octdenarius Ehrenberg (= Actinoptychus splendens?)	1
*Actinoptychus senarius (Ehrenberg) Ehrenberg (= A. undulatus)	1,2,3,4
A. splendens (Shadbolt) Ralfs	1,3
Amphiprora gigantea var. sulcata (O'Meara) Cleve	1,3
A. spp.	1,2,3
Amphora marina Van Heurck	1,2.4
A. obtusa Gregory	1
A. spectabilis Gregory	1
A. A	1
A. spp.	1,2,3
Anomoeneis sphaerophora var. sculpta (Ehrenberg) Muller	1
*Asterionella glacialis Castracane (= A. japonica)	1,2,3,4
Asteromphalus flabellatus (de Brebisson) Greville	1
Aulacodiscus argus (Ehrenberg) A. Schmidt	1
A. sp.	1
Auliscus pruinosus Bailey	1
A. punctatus Bailey	1
A. sculptus (W. Smith) Ralfs	1
A. sp.	1
*Bacillaria paxillifer (O. F. Muller) Hendey (= Nitzchia paradoxa)	1,2,3,4
Bacteriastrum comosum Pavillard	1,4
B. delicatulum Cleve (= B. furcatum Shadb. sensu Fryxell)	2
B. elongatum Cleve	2
B. hyalinum Lauder	2,3
B. sp.	1,2
*Bellerochea horologicalis von Stosch (= B. malleus in part)	1,2,3,4,7
Biddulphia alternans (Bailey) van Heurck	1,2,3
B. dubia (Brightwell) Cleve	1
B. pulchella Gray	1,3
B. reticulata Roper	1

	REFERENCES
B. tuomeyi (Bailey) Roper	3
B. spp.	1,7
Caloneis westii (W. Smith) Hendey	1
Camplylodiscus echeneis Ehrenberg (= C. argus)	1
*Cerataulina pelagica (Cleve) Hendey (= C. bergonii)	1,2,3,4
Chaetoceros affine Lauder	1,2,3
C. affine var. willei (Gran) Hustedt	2
C. breve Schutt	2,4
C. compressum Lauder	1,2,3
C. crinitum Schutt	2
C. curvisetum Cleve	1,2
C. danicum Cleve	1
C. decipiens Cleve	4
C. didymum Ehrenberg	1,2,3
C. diversum Cleve	1,2
C. eibenii (Grunow) Meunier	1
C. galvestonensis Collier & Murphy	3
C. gracile Schutt	1,2
C. laciniosum Schutt	1,3
C. lauderi Ralfs	1
C. lorenzianum Grunow	1,3
C. pendulum Karsten (oceanic)	1
C. pelagicum Cleve	2
C. peruvianum Brightwell	1,2,3
C. sociale Lauder	1,3
C. subtile Cleve	1
C. teres Cleve	1
C. wighamii Brightwell	1
C. 'A' (3)	1,2,4
C. 'B'	1
C. 'C'	1
C. 'D'	1
C. spp.	1,2,3,4
Climacodium biconcavum Cleve	3
C. fraufeldianum Grunow	1,3
Cocconeis disculoides Hustedt	1
C. heteroidea Hantzsch	1
C. 'A'	1
C. spp.	1,2
Corethron criophilum Castracane	1,2
*Coscinodiscus centralis Ehrenberg	1,2,3,4
C. concinnus W. Smith	1
C. curvatulus Grunow	3
C. granii Gough	2
C. lineatus Ehrenberg	1,2
C. marginatus Ehrenberg	1
C. radiatus Ehrenberg	1,3,4
C. spp.	1,2,3,7
Coscinosira polychorda Gran	3
Cyclotella spp.	1,2,3,4
Dactyliosolen mediterraneus Peragallo	3
D. sp.	1

	REFERENCES
Diploneis crabro Ehrenberg (= Navicula crabro)	1
D. gruendleri (Schmidt) Cleve	1
D. obliqua (Brun) Hustedt	1
D. 'A'	1
D. 'B'	1
D. spp.	1,2
Ditylum brightwellii (West) Grunow	3
Donkinia recta (Donkin) Cleve	1
Epithemia sp.	1
Eucampia cornuta (Cleve) Grunow	3
E. zoodiacus Ehrenberg	1
Eunotogramma marina	3
Eupodiscus argus	2
E. radiatus Bailey	1,3
Fragilaria hyalina (Kutzing) Grunow ex Van Huerck	2
F. oceanica Cleve	2
*Grammatophora marina (Lyngbye) Kutzing	1,2,3
G. spp.	1,2
Guinardia flaccida (Castracane) Pergallo	1,2,3
G. spp.	1,2
Gyrosigma hummii Hustedt	1
G. wansheckii (Donkin) Cleve	1
Gyrosigma/Pleurosigma 'A'	2
Gyrosigma/Pleurosigma 'B'	2
G. spp.	1,2,3
Hantzschia virgata (Roper) Grunow	1,5
H. spp.	1
Haslea wawrikae (Hustedt) Simonsen	1,2,4
Hemiaulus hauckii Grunow	1,2
H. membranaceus Cleve	1,3
H. sinensis Greville	1,2,3
*Lauderia annulata Cleve (= L. borealis)	1,2,3,4
*Leptocylindrus danicus Cleve	1,2,3
L. minimus Gran	1,2
Licmophora abbreviata Agardh	2
L. spp.	1,2
Lithodesmium undulatum Ehrenberg	1,2,3
L. spp.	1
Mastigloia binotata (Grunow) Cleve	1
M. cribrosa Grunow	1
M. spp.	1
Melosira dubia Kutzing	3,5
M. granulata (Ehrenberg) Ralfs	1,5
M. nummuloides (Dillwyn) Agardh	1,2
M. 'A'	1,2,3
M. spp.	1
Navicula cancellata Donkin	1
N. clavata Gregory	1,4
N. forcipata Greville	1
N. lyra Ehrenberg	1
N. marina Ralfs in Pritchard	1
N. nummularia Greville	1

	REFERENCES
N. pelagica	4
N. pygmea Kutzing	1
N. 'A'	1
N. spp.	1,2,3
*Nitzschia closterium (Ehrenberg) W. Smith	1,2,3
N. constricta Ralfs	1
N. delicatissima? Cleve (= Pseudonitzschia delicatissima)	1,2,3
N. longissima (de Brebisson) Ralfs	1,2,3
*N. pungens var. atlanticum Cleve	1,2,3,4
N. sigma var. rigida Kutzing	2
N. 'A'	1
N. 'B'	1
N. spp.	1,2,3
Odontella aurita (Lyngbye) Agardh	1,2,3
O. aurita var. obtusa	1
O. chinensis Grunow (= Biddulphia sinensis)	1
O. mobiliensis Grunow (= Biddulphia mobiliensis)	1,2,3,4
O. obtusa Kutzing (= Biddulphia obtusa)	1,3
*O. regia Schultze (= Biddulphia regia)	1,2,3,4
O. rhombus Kutzing (= Biddulphia rhombus)	1,3
O. rhombus f. trigona (Cleve in Van Heurck) (= B. rhombus f. trigona)	1
*Palmeriana hardmanianus Greville (= Hemidiscus hardmanianus)	1,3
*Paralia sulcata (Ehrenberg) Cleve (= Melosira sulcata)	1,2,3,4
P. sulcata v. coronata (Ehrenberg) Grunow in Van Heurck	1
P. 'A'	1
Pinnularia rectangulata (Gregory) Cleve	1
P. 'A'	1
Plagiogramma staurophorum (Gregory) Heiberg	1
P. 'A'	1
P. spp.	1
Plagiogrammopsis vanheurkii (Grunow) Hasle, van Stosch & Syvertsen	3
Pleurosigma angulatum (Quekett) W. Smith	1,4
P. balticum (Ehrenberg) W. Smith (=Gyrosigma balticum)	1
P. fasciola (Ehrenberg) W. Smith (= Gyrosigma fasciola)	2
P. formosum W. Smith	4
P. rostoratum Hustedt	1
P. strigosum W. Smith	1,4
P. 'A'	1
P. spp.	1,2
Podosira stelliger (Bailey) Mann	1,3
Rhabdonema adriaticum Kutzing	1,5
R. spp.	1
Rhizosolenia alata Brightwell	1,2,3,4
R. calcar-avis Schultze	1,2,3,4

	REFERENCES
R. delicatula Cleve	1,2
R. fragilissima Bergon	1,2,3,4
R. hebatata f. semispina (Hensen) Gran	4
R. imbricata Brightwell	3,7
R. robusta Norman ex Pritchard	1,2,3,4
*R. setigera Brightwell	1,2,3,4,7
*R. stolterfothii Peragallo	1,2,3,4,7
*R. styliformis Brightwell	1,5
R. spp.	1,3,7
*Skeletonema costatum (Greville) Cleve	1,2,3,4,7
S. tropicum Cleve	1,2
Streptotheca tamesis Shrubsole	1,2,3
*Striatella unipunctata (Lyngbye) Agardh	1,2,3
S. interrupta (Ehrenberg) Heiberg	1
Surirella recedens A. Schmidt	1
S. gemma (Ehrenberg) Kutzing	1
S. ovata Kutzing	1
S. spp.	1
Synedra crystallina (Agardh) Kutzing	1
S. hennedyana Gregory	1
S. 'A'	1
S. spp.	1
*Thalassionema nitzschiodes Grunow	1,2,3,4
T. spp.	1
Thalassiosira aestivalis Gran & Angst	1,2,4
*T. decipiens (Grunow) Jorgensen	1,2,3
*T. eccentrica (Ehrenberg) Cleve (= Coscinodiscus excentricus)	1,2,3
T. subtilis (Ostenfeld) Gran	1
T. 'A' (2)	1,2
T. 'B'	1
T. spp.	1,2
*Thalassiothrix frauenfeldii (Grunow) Grunow in Cleve & Gran	1,2,5,7
T. mediterranea var. pacifica Cupp	1,2,4
T. 'A'	1
T. spp.	1,2
Trachyneis aspera (Ehrenberg) Cleve	1
T. spp.	1
Triceratium dubium Brightwell	3
T. favus Ehrenberg	1,2,3
Tropidoneis lepidoptera (Gregory) Cleve (= Plagiotropis lepidoptera)	1,2,4
DINOFLAGELLATES (DINOPHYCEAE)	
*Amphidinium carterae Hulburt	5,6
A. crassum Lohmann	2,5
A. klebsii Kofoid & Swezy	5
A. spp.	1,2,3
Ceratium furca (Ehrenberg) Claparede & Lachmann	2,3,4,7

	REFERENCES
*C. fusus (Ehrenberg) Dujardin	1,2,3,4,7
*C. hircus Schroder (= C. furca var. hircus)	1,2,3,4
C. massiliense (Gourret) Karsten	5
C. trichoceros (Ehrenberg) Kofoid	1,3,4
*C. tripos var. atlanticum (Ostenfeld) Paulsen	1,3,4,7
C. spp.	
Cochlodinium citron	
C. spp.	
Coolia monotis Meunier	5
Dinophysis caudata f. acutiformis Kofoid & Skogsberg	1,2
D. caudata var. pedunculata (Schmidt)	3
D. spp.	1,2
Diplopsalis lenticula Bergh	1,5
Fragilidium heterolobatum Balech ex Loeblich	5
F. spp.	1
Gonyaulax balechii Steidinger	1,4,5
G. diacantha (Meunier) Schiller	1,2,4,5,8
G. diegensis Kofoid	1,2,4,7
*G. digitalis (Pouchet) Kofoid	1,2,3,4,8
G. grindleyi Reinecke (= Protoceratium reticulatum	3
*G. monilata Howell	1,2,3,4
G. polygramma Stein	1,4,5
G. scrippsae Kofoid	1
*G. spinifera (Claparede & Lachmann) Diesing	1,2,3
G. 'A'	
*Gymnodinium nelsonii Martin (= G. splendens in part)	1,2,3,4,7,8
?G. aurantium Campbell n. sp.	2
G. spp.	1,2,3
Gyrodinium estuariale Hulburt	6
G. fissum (Levander) Kofoid & Swezy	1,3,8
G. spirale (Bergh) Kofoid & Swezy	1,3
G. spp.	1,2,3
Heterocapsa niei (Loeblich) Morrill & Loeblich (= Cachonina niei)	6
Katodinium rotundatum (Lohmann) Loeblich	1
K. glaucum (Lebour) Loeblich	1
Noctiluca scintillans (Macartney) Kofoid & Swezy	2,3,8
Oblea rotunda (Lebour) Balech ex Sournia (= Diplopsalis rotundum)	1
Oxyrrhis marina Dujardin	5
Oxytoxum scolopax Stein	1,2
O. spp.	2
Protoperidinium abei (Paulsen) Balech	2,3,4
*P. claudicans (Paulsen) Balech	1,2,3,4
P. conicum (Gran) Balech	1,3,4
P. crassipes (Kofoid) Balech	5
?P. deficiens Meunier	1
*P. depressum (Bailey) Balech	1,2,3
P. divergens (Ehrenberg) Balech	1,2,3
P. excentricum (Paulsen) Balech	1,3
P. nipponicum (Abe) Balech	1

	REFERENCES
*P. pellucidum Bergh	1,2,4,5
P. pentagonum (Gran) Balech	1
*P. quinquecorne (Abe) Balech	1,5
P. spiniferum (Schiller) Balech	4
*P. steidingerae Balech (= P. oblongum in part)	1,2,3,4
P. striatum (Bohm) (= P. leonis (Pavillard) Balech in part)	1,5
P. subinerme (Paulsen) Balech	1,2
P. tubum (Schiller) Balech	2,4
P. 'A'	1
P. spp.	1,2,3
Peridiniopsis asymmetrica Mangin	
Peridinium foliaceum (Stein) Biecheler	5
P. aciculiferum Lemmermann	2
P. 'A'	3
P. 'B'	3
P. 'E'	3
P. 'N'	3
*Polykrikos hartmannii Zimmermann	1,3
P. kofoidii Chatton	1
*P. schwartzii Butschlii	1,3
P. spp.	
Prorocentrum compressum (Ostenfeld) Abe	5
*P. gracile Schutt (= P. redfieldii in part)	1,2,3,8
P. mexicanum Tafall (= P. maximum in part)	1,5
*P. micans Ehrenberg	1,2,3,4,7
*P. minimum (Pavillard) Schiller (= P. marie-lebouriae in part)	1,2,5
P. oblongum (Pavillard) F. J. R. Taylor	
P. triestinum Schiller	8
Ptychodiscus brevis (Davis) Steidinger (= Gymnodinium breve)	1,3,7,8
Pyrodinium bahamense var. bahamense Plate	1,3,8
Pyrophacus horologium Stein	1,3
*P. steinii (Schiller) Wall & Dale	1,2,3
P. vancampoae (Rossignol) Wall & Dale	1,5
Scrippsiella subsalsa (Ostenfeld) Steidinger & Balech	5
*S. trochoidea (Stein) Loeblich	2,3
*Torodinium robustum Kofoid & Swezy	1
T. teredo (Pouchet) Kofoid & Swezy	3
Triadinium polyedricum (Pouchet) Dodge (= Goniodoma polyedricum)	3
Warnowia spp. (= Pouchetia spp.)	3
?Ornithocercus steinii Schutt (misidentified)	4
?O. thumii (Schmidt) Kofoid & Skogsberg (misidentified)	4

NANNOPLANKTON FLAGELLATES (exclusive of Dinophyceae)	REFERENCES
CHLOROPHYCEAE	
Dunaliella primolecta Butcher	6
CHRYSOPHYCEAE	
Apedinella spinifera (Throndsen) Throndsen	6
Dictyocha fibula Ehrenberg	6
Olisthodiscus luteus Carter	6
Olisthodiscus carterae Hulburt	6
Mallomonopsis elliptica Matwienko	2,6
CRYPTOPHYCEAE	
Chroomonas esopus (Conrad & Kuff) Butcher	6
Chroomonas pluricocca Butcher	6
Cryptomonas curvata (Ehrenberg) Penard	6
Hillea serpens (Conrad & Kuff) Butcher	6
EUGLENOPHYCEAE	
Eutreptia lanowii Steur	6
Eutreptiella marina da Cunha	6
E. gymnastica Throndsen	6
PRASINOPHYCEAE	
Bipedinomonas rotunda Carter	6
Pyramimonas amylifera Conrad	6
P. disomata Butcher	6
Tetraselmis apiculata (Butcher) Butcher	6
T. carteriiformis Butcher	6
T. gracilis (Kylin) Butcher	6
T. tetrahele (West) Butcher	6
PRYMNESIOPHYCEAE	
Chrysochromulina spp.	6
Pavlova salina (Carter) Green	6
Prymnesium parvum Carter	6
Hymenomonas carterae (Braarud and Faegerl.) Braarud	2,6
CHLOROMONADOPHYCEAE	
Horniella marina Subrahmanyam	5,6

BLUE GREENS	REFERENCES
Agmenellum spp. (= Merismopedia)	1,3,5
Anabaena spp.	1,2,3
Anacytis aeruginosa Drouet & Daily	5
Oscillatoria erythraea (Ehrenberg) Kutzing	2(?),3,5
Oscillatoria spp.	1,3
Schizothrix calcicola (Agardh) Gomont	2,3(?),6,8
S. mexicana Gomont	2
Spirulina spp.	3

ADDED IN PROOF: Dr. Grethe Hasle (pers. comm.) has identified the following additional diatoms from Tampa Bay: Nitzschia pseudodelicatissima Hasle, Cymatosira belgica Grunow, C. lorenziana Grunow, Skeletonema menzelii Guillard, Carpenter & Reimann, Thalssiosira tenera Proshkina & Laurenko, T. mala Takaro, T. allenii Takaro, and Minutocellus sp. In addition, Dr. Hasle pointed out the following synonymies: Thalassiosira leptopus (=Cascirodiscus lineatus), T. angustelineata (=Coscinosira polycorda), and Leptocylindrus mediterraneus (=Dactyliosolen mediterraneus).

MACROALGAE OF THE TAMPA BAY ESTUARINE SYSTEM

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ABSTRACT

Macroalgae, defined as multicellular macroscopic photosynthetic algae, are found in a wide variety of habitats in the Tampa Bay estuarine system. Intertidal habitats include the surface of the substrate and bases of mangroves and salt marsh plants, oyster shells, pilings, seawalls and limestone rubble. Subtidal habitats include seagrasses and submerged hard substrates. Psammophytic forms, especially tropical coenocytic green algae, are common in seagrass communities. Physiological studies on the intertidal and subtidal macroalgae have demonstrated their broad tolerances to a wide range in salinity (10-50 ppt), temperature (18-36°C), and light (200-2000+ ft-c). The photosynthetic and respiratory responses of Tampa Bay macroalgae suggest tropical affinities supporting the taxonomic evidence. Desiccation studies have shown that intertidal species such as the red alga Bostrychia binderi will carry on high rates of photosynthesis in the air even after 2-3 hours of exposure. Productivity and biomass figures for macroalgae are very limited although massive populations of red algae such as Gracilaria verrucosa offer the possibility of harvesting for phycocolloid extractions as well as methane production. A number of other economically important macroalgae are found in Tampa Bay in large numbers including Hypnea musciformis (kappa carrageenan), and other species of Gracilaria (agar). The macroalgal flora thus far identified for Tampa Bay and its estuarine system is 221 taxa including 23 blue-green, 68 green, 1 xanthophyte, 30 brown and 99 red algae. Sixty-nine of these taxa are primarily tropical in distribution suggesting that the macroalgal flora of Tampa Bay has strong tropical affinities.

INTRODUCTION

The macroalgal flora in the Tampa Bay estuarine system (28°40' N lat., 82°30' W long.) are important not only as a habitat and food source for benthic and small invertebrates, but may also prove economically important to man. In this review, the macroalgal flora is compared with floras reported for other estuarine systems in Florida and found to be the most luxuriant yet described. The term "macroalgae" is meant to separate the multicellular, usually attached (occasionally drift) macroscopic, photosynthetic algae from those that are unicellular, free-floating and microscopic (e.g. phytoplankton). The Tampa Bay estuarine system includes the roughly "Y" shaped Tampa Bay proper and adjacent bays (Fig. 1) as described by Simon (1974). The estuarine system can be divided into five sub-areas: 1) Old Tampa Bay, 2) Hillsborough and MacKay Bay, 3) Middle Tampa Bay, 4) Boca Ciega Bay, and 5) Terra Ceia Bay.

Previous studies of macroalgae in Tampa Bay are limited to Phillips (1960a) and Dawes (1967). Studies of macroalgae found directly offshore from Tampa Bay are of special interest in that they demonstrate the existence of a relatively stable offshore tropical flora in the eastern Gulf of Mexico (Phillips and Springer 1960; Dawes 1974; Mathieson and Dawes 1975; Cheney and Dyer 1976). In addition, studies have been carried out on estuaries on the west coast of Florida that have similar characteristics to Tampa Bay (Phillips 1960b; Steidinger and Van Breedveld

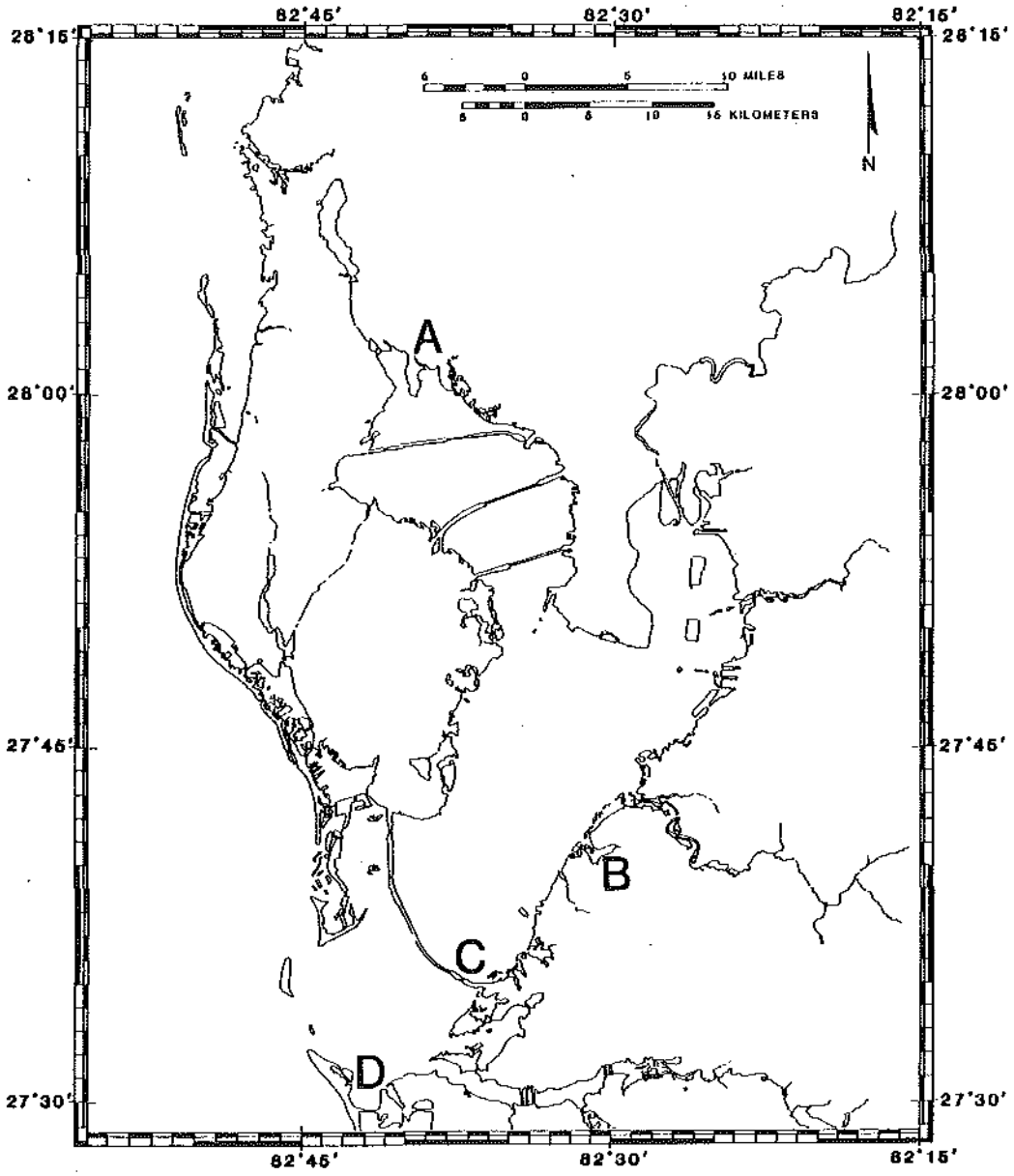

Figure 1. Map of the Tampa Bay estuarine system with various marine plant communities labeled. A - salt marshes; B - mangrove swamps at Cockroach Bay; C - rocky jetties on south end of Skyway (U.S. 19); D - seagrass communities at Anna Maria Island Sound.

1971; Dawes and Dudley 1975; Ballantine and Humm 1975; Hamm and Humm 1976) and on the east coast of Florida (Phillips 1961; Benz et al. 1979; Hall and Eiseman 1981). See Table 1.

Macroalgae occur both in the extensive intertidal and shallow (to 3 m depths) subtidal regions of Tampa Bay; as epiphytes on emergent (mangroves, salt marsh plants) and submergent (seagrasses) vegetation; as lithophytes on oyster shells, seawalls, limestone rubble, docks, pilings; and as psammophytes in seagrass beds, sand and mud flats. Because of the size of Tampa Bay (ca 56 km long, 6.2 km wide, 896 km^2) and its extensive coastline (341 km), a wide variety of intertidal and shallow subtidal habitats is available (Simon 1974).

The Tampa Bay system is truly estuarine in nature with various regions having larger or smaller fluctuations (after Simon 1974) in: 1) turbidity (mean = 9 JTU); 2) salinity (mean = 29 ppt); 3) temperature (seasonal mean = winter 16°C, spring 27°C, summer 30°C, fall 23°C); 4) nutrients (total nitrogen = 8 to 56 ug at/l, total phosphorus = 7 to 71 ug at/l); and 5) lack of wave action. The average tidal range is 0.7 m with a high of 1.1 m and a low of 0.1 m. Detailed discussions of the physical, chemical, and geological features of Tampa Bay are presented elsewhere in this volume. In this introduction to the macroalgae, ecological factors are considered only to emphasize the seasonal, subtropical aspect of the flora.

Tampa Bay has a humid, subtropical climate. The average annual rainfall is 125 cm and the mean daily temperatures range from 17.6°C to 1.1°C respectively with water temperatures following closely within this range (Dragovich and Kelly 1964). The maximum mean water temperature is as low as 10°C during December or January (U.S. Coast and Geodetic Survey 31-1 1960). The greatest temperature span is found in the intertidal zone where algae are exposed to direct air temperatures at low tide; the offshore water exhibits minimum variation in temperature ranges.

Generally, salinities range from a few parts per thousand in the upper regions of the Bay or adjacent estuarine units to that of normal seawater in the lower portions of the open Bay and in the adjacent Gulf (32 to 34 ppt). The seasonal salinity changes in the Bay and lagoons are associated with local rainfall and land run-off. The lowest salinities occur usually during the late summer-autumn, a period of high rainfall. During the periods of heavy rainfall, areas at river mouths display freshwater characteristics (Dragovich and May 1962).

The sediments of Tampa Bay consist of a mixture of terrigenous quartz sand and biogenic carbonate which form a homogenous mass due to shifting by tidal currents (Goodell and Gorsline 1960). In much of the shallow water regions such a substrate is stabilized subtidally by seagrass beds and intertidally by mangrove and salt marsh plants. The outer coastline consists of elongate barrier islands that mainly consist of sand with occasional coquina rock outcroppings. Jetties, submerged buildings, pilings, seawalls, and occasional limestone rubble offer a variety of firm substrates for algal lithophytes. North of Tampa Bay, subtidal limestone outcroppings become common and supply a continuous firm base for algal attachment. Wave action offshore has been described as moderate with average coastal wave height of 50 cm (Tanner 1960).

HABITATS OF MACROALGAE

The Tampa Bay estuarine system includes many small keys and islands including spoil banks created with the channelizaton of the Bay. At the mouth of the Bay a number of islands exist that are a portion of the general barrier island chain (Mullet Key, Anna Maria Island, Egmont Key) extending north to the Anclote River (Anclote Key) and south to Fort Myers (Sanibel Island). The overall depth of the Bay is less than 5 m although the numerous channels and passes, both natural and artificially maintained, may reach depths of 30 m.

Table 1. Studies of marine algae in Florida. *Blue-green names in these lists are synonyms of Drouet's taxonomy.

	Mode of Collection	Frequency of Collection	Blue-green	Green	Brown	Red	Other	Total
West Coast, offshore:								
Phillips and Springer 1960	SCUBA	12 in 1 yr.	17	31	18	89	-	128
Dawes and Van Breedveld 1969	Trinet	monthly, 3 yr.	5	38	29	85	-	157
Mathieson and Dawes 1975	SCUBA	monthly, 1 yr.	-	17	9	39	-	65
Cheney and Dyer 1974	SCUBA	4 in 1 yr.	7	22	9	53	-	92
West Coast, Crystal Bay:								
Phillips 1960	Dredge-trawl	3 in 1 yr.	5	7	8	26	-	46
Steidinger and Van Breedveld 1971	Trinet-trawl	monthly, 3 yr.	-	19	24	63	-	106
West Coast, Anclote Estuary:								
Ballantine and Humm 1975	Epiphytes on seagrasses	monthly, 6 months	21*	14	8	30	-	63
Hamm and Humm 1976	Free diving	irregular, 3 yr.	18*	39	17	50	2	126
West Coast, Donna and Robert's Bays:								
Dawes and Dudley 1975	Free diving	4 times, 1 yr.	16	13	6	15	-	50
West Coast, Tampa Bay:								
Phillips 1960	Free diving	irregular, 2 yr.	23	40	14	56	-	133
Dawes 1967	Free diving	irregular, 4 yr.	-	60	30	87	1	178
West Coast, general:								
Dawes 1974	SCUBA, free diving	irregular, 9 yr.	69*	85	45	140	1	340
East Coast, Indian River:								
Phillips 1961	Free diving	4 times, 1 yr.	8	31	20	63	-	123
Hall and Eiseman 1981	Epiphytes on seagrasses	bimonthly, 1 yr.	4	9	10	17	1	41
Benz et al. 1979	Free diving	monthly, 1 yr.	3	12	9	39	-	63

Several rivers, notably the Hillsborough, Alafia, and Little Manatee, and numerous freshwater streams flow into the Bay creating conditions favorable for the development of the extensive mangrove swamp in the southern portion (Fig. 1, B) and salt marshes in the northern portion (Fig. 1, A) that border much of the shoreline.

Macroalgal habitats in Tampa Bay can thus be considered with relation to tidal fluctuation (intertidal, subtidal) as well as the substrate the alga is adapted to (psammophytic, lithophytic, epiphytic). The most diverse (numbers of species) and abundant (number of individuals of a species) communities occur in the lower portions of Tampa Bay. Intertidal macroalgal species are similar to those reported for the northern portion of the west coast of Florida (Dawes 1974), probably because of the more extreme conditions characteristic of the habitat. Subtidal species show a strong relationship to subtropical and tropical floras although definite seasonal fluctuations have been noted in Tampa Bay.

Intertidal. Species adapted to the intertidal zone must tolerate both submerged and exposed conditions, and be able to withstand summer rains and freezing winter temperatures during periods of low tides. Physiological features of intertidal macroalgal species are presented in a separate section in this paper and demonstrate the wide range of tolerances. Intertidal species are found growing as psammophytes directly on mud and sand in mangrove and salt marsh swamps (Cladophora repens, Boodleopsis pusilla); as lithophytes on rocks and oyster shells (Ulva lactuca, Enteromorpha spp., Agardhiella tenera) as well as on pilings and jetties; and as epiphytes (e.g., Bostrychia binderi) growing on the pneumatophores of the black mangrove (Avicennia germinans, Fig. 2), the prop roots of the red mangrove (Rhizophora mangle), and the stalk bases of cordgrass (Spartina alterniflora) and black rush (Juncus roemerianus, Fig. 3).

Intertidal zonation of macroalgae is a common feature due to the effect of exposure, the less tolerant species being found in the lower regions of intertidal communities. The Cockroach Bay mangrove community (Fig. 1) is one example. Dawes (1974) described the zonation of algal epiphytes present in mangrove pneumatophores, prop roots, and bases of salt marsh grasses for Tampa Bay. The pneumatophores of the black mangrove mark the intertidal zone. The uppermost portion of the pneumatophores will typically have blue-green algae (corresponding to the upper intertidal zone). The intermediate region of the pneumatophore will have the green algae Rhizoclonium and Enteromorpha with the red algae Bostrychia and Caloglossa found in the lower intertidal region of the root. Filamentous algae (Cladophora, Chaetomorpha, Boodleopsis, Vaucheria, Centroceras) are usually found forming an entangled mat on the mud in a mangrove community.

The intertidal zone occupied by a salt marsh as found in Old Tampa Bay (Fig. 1) is quite similar with regard to the macroalgal component. Algae form a mat on the mud between the salt marsh plants and include the blue-green algae Anacystis, Microcoleus, Oscillatoria; the green algae Cladophora, Chaetomporpha, as well as the xanthophyte Vaucheria, and the red algae Centroceras. A similar but more limited zonation is seen with regard to the epiphytic algae on the salt marsh plant stalks and includes the red algal species Bostrychia, Catenella, and Polysiphonia. The lower intertidal region of a salt marsh is typically bare mud with only filamentous blue-green algae unless oyster shells or other firm substrates are present.

Intertidal lithophytic communities are best developed in the southern portions of Tampa Bay, especially on the limestone rubble found along the south end of the Skyway (U.S. 19) bridge (Fig. 1, C). The upper intertidal and limited spray zone region is black in color due to the presence of blue-green algae (Calothrix, Oscillatoria, Entophysalis). The upper major portion of the intertidal

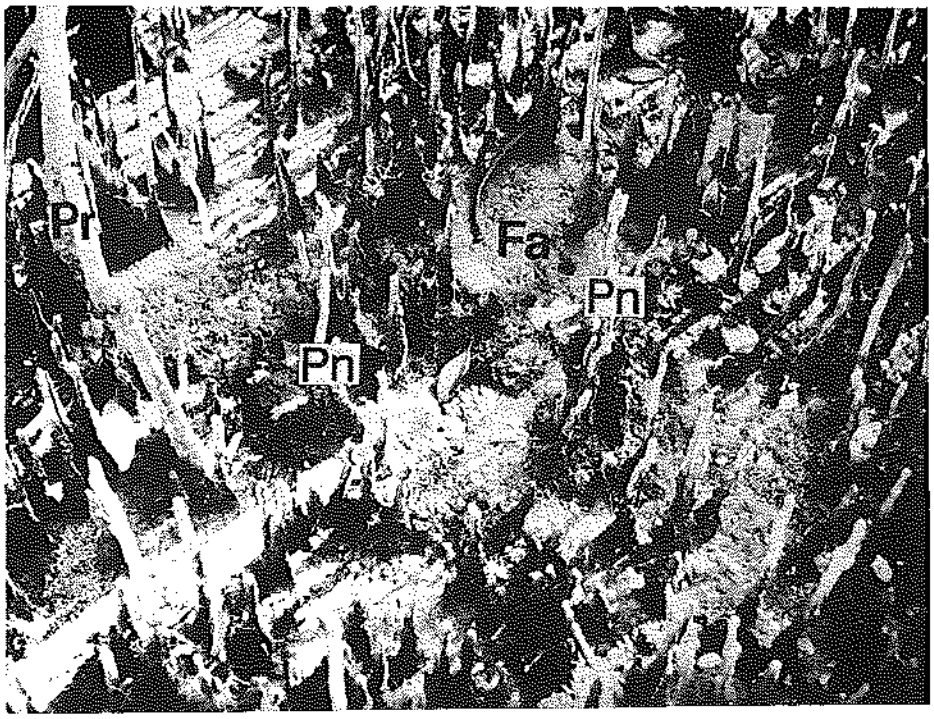

Figure 2. A view of the pneumatophores (Pn) of the black mangrove (Avicennia), proproots (Pr) of the red mangrove (Rhizophora), and the algal growth on these aerial roots. The substrate in the mangrove swamp is covered by a mat of filamentous algae (Fa).

Figure 3. A view of the cut bases of the black rush, Juncus in a salt marsh. The red alga, Bostrychia binderi (B), is growing on the lower portion of the stalks forming a fern-like mass.

zone is dominated by tufted algae such as species of Cladophora, Centroceras, Bryopsis, and Hypnea. The subtidal fringe is the richest zone in species diversity and contains the fleshy species of red algae such as Gracilaria spp. and Padina vickersiae.

Subtidal. In general, the water turbidity of the Tampa Bay system limits subtidal species to the upper 3 m. Lithophytic algae are especially common in areas where limestone rubble, oyster shells and man-made objects occur (Fig. 4). One such example is the rocky jetty along the south end of the Skyway. Usually a Caulerpa association can be found in the upper regions of the subtidal that consists of three species: C. prolifera, C. mexicana and C. racemosa. Other subtidal species common on the limestone rubble to about 3 meters are Hypnea, Cladophoropsis, Gracilaria, Chaetomorpha, Spyridia, Pterocladia, Padina, and Sargassum at the Skyway south end and at Bishop's Harbor.

Psammophytic algae such as Penicillus lamourouxii and Caulerpa spp. are common in the seagrass beds, especially in the extensive beds found in the lower portion of the Bay (Fig. 5). Dawes et al. (1979) reported that the biomass of psammophytic and drift algae in a seagrass bed adjacent to Tampa Bay was equal to that of the seagrasses. Johnston (1969) estimated the production of a mixed stand of Caulerpa prolifera and the seagrass Zostera marina in the Canary Islands to be 1.1 g C/m^2/day whereas individual stands of Caulerpa were only 0.1 g C/m^2/day and of Zostera 0.4 g C/m^2/day. Some of the more common algal epiphytes on the seagrasses include Champia, Lomentaria, Polysiphonia, Acrochaetium, Fosliella, Hypnea, Spyridia, Cladosiphon, Ectocarpus, and Cladophora. Some or all of these may be present at one time, but the brown algae epiphytes are typically found in the later winter months.

Epiphytism by benthic algae on seagrass leaves (turtle grass, Thalassia testudinum; manatee grass, Syringodium filiforme; shoal grass, Halodule wrightii) is probably the single most important site (Humm 1964; Ballantine and Humm 1975; Hall and Eiseman 1981) to find macroalgae in a seagrass community. Many seasonal species such as the spring growth of red and brown algae (Hall and Eiseman 1981) are found only as epiphytes. Nitrogen fixation by epiphytes of seagrasses common to Tampa Bay has been demonstrated and suggested to be an important source in the nitrogen economy of seagrass communities (Goering and Parker 1972). Penhale (1977) found that the summer biomass for algal epiphytes on eelgrass (Zostera marina) was 24.7 g dry/m^2. Productivity of the epiphytes on Zostera almost equaled that obtained for the seagrass, 0.65 mg C fixed per hour in a North Carolina seagrass bed. Working with turtle grass in Biscayne Bay (Miami, Florida), Jones (1968) found peak productivity of 0.9 g C/m^2/day in the summer and annual production by epiphytes was estimated as 200 g C/m^2/yr, or 20% of the estimated average net production of Thalassia in the area. As McRoy and McMillan (1977) point out, the contribution of the benthic algae in seagrass beds is poorly known and deserves further attention. This is true not only for epiphytes but also for the extensive populations of drift macroalgae that occur in seagrass beds of Tampa Bay.

PHYSIOLOGICAL ECOLOGY OF MACROALGAE

Estuarine systems, such as Tampa Bay, provide an excellent opportunity to study the acclimation (physiological range of tolerance) and adaptation (genetic limitation of tolerance) of marine algae to diverse ecological conditions of the fresh and marine water ecotones (Dawes et al. 1978). Some of the more apparent physical factors that fluctuate widely in estuaries include light, temperature, and exposure to desiccation while important chemical factors include oxygen level, salinity, and pH (due to anaerobic conditions in estuarine muds). Studies monitoring photosynthetic and respiratory rates can

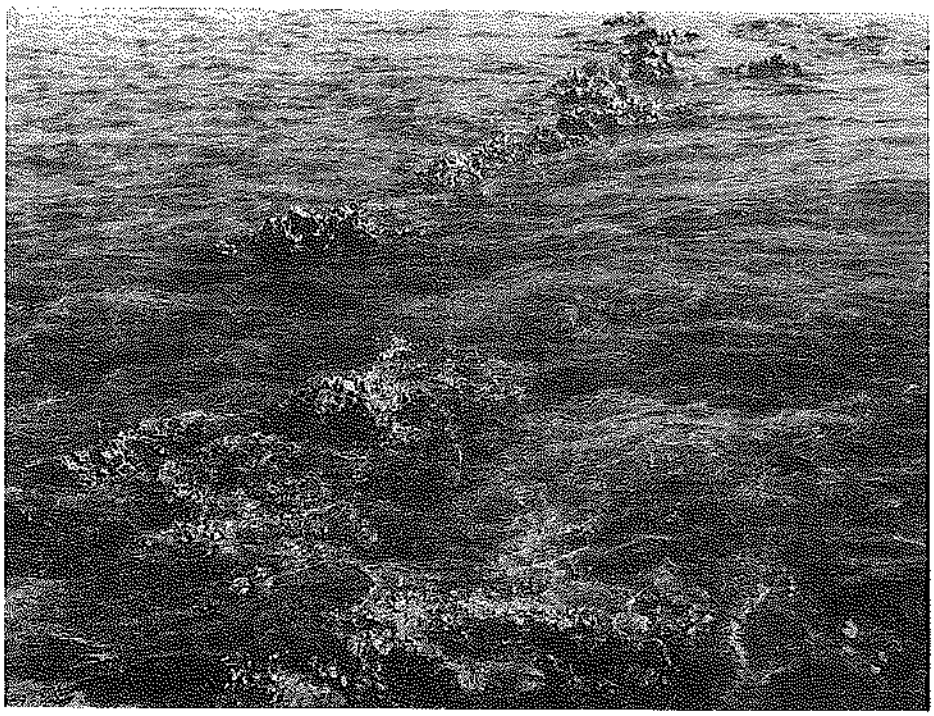

Figure 4. An oyster bar in Cockroach Bay. The oyster shells offer a hard substrate for larger lithophytic algae as well as blue-green algae.

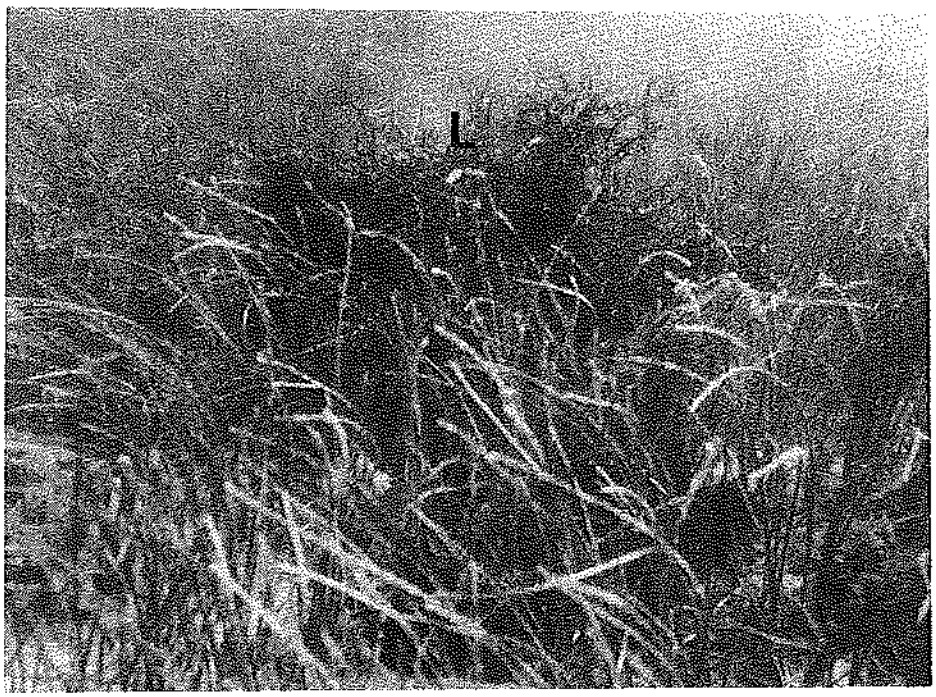

Figure 5. A seagrass community near Anna Maria Island Sound. Turtle grass (Thalassia testudinum) and manatee grass (Syringodium filiforme) predominate. A large mass of a drift red alga, Laurencia poitei (L) is visible in the upper center.

be used to follow the effects of changing physical and chemical factors on the marine algae. From such studies one can ascertain the tolerance of an alga and predict seasonal changes in algal growth.

Physiological studies of marine algae in Tampa Bay have included species found intertidally in mangrove and salt marshes (Dawes et al. 1978; Hoffman and Dawes 1980; Davis and Dawes 1981) and subtidally (Dawes et al. 1978; Hoffman and Dawes 1980; Bird et al. 1980, 1981). The intertidal red algal species, Bostrychia binderi, grows on the pneumatophores and proproots of mangroves as well as on the bases of salt marsh plants (Figs. 2 and 3). Another intertidal species, the green alga Cladophora repens, ocurs as a filamentous mat covering the mudflats in mangrove swamps (Fig. 2). Both of these species (Dawes et al. 1978) exhibited high photosynthetic rates to a range of salinites (5 to 45 ppt, Fig. 6a), at the higher temperatures (24-30°C, Fig. 6b) and showed peak photosynthetic response under low light (6000 uW/cm^2/sec, Fig. 6c). The plant shows typical estuarine adaptations and ability to acclimate to wide fluctuations while being tolerant only to low light levels typical of the marsh substrate. Furthermore, Bostrychia showed sustained, high photosynthetic rates and low respiration rates when held in the air, even after 6 hours of desiccation, while Cladophora could not tolerate even 2 hours of desiccation (Dawes et al. 1978, Fig. 7). Again, Bostrychia is adapted to an aerial site, growing on mangrove and salt marsh plant bases while Cladophora was found only directly on the mud flat where moisture levels are high even during low tide. Thus, one can use the physiological responses of macroalgae to determine the type of habitat they best occupy.

Seasonal changes in physiological responses can also be used to determine geographic distribution of macroalgae and their physiological affinities to more tropical and temperate populations (Davis and Dawes 1981, Fig. 8). In a study of Bostrychia binderi from Tampa Bay and the Weeki Wachee River salt marsh, about 150 km north, maximum photosynthetic rates were highest in the summer with regard to light and salinity and the plants had highest photosynthetic rates only in the higher temperatures, even in the winter months. In all studies, Tampa Bay macroalgae showed highest responses only at the summer temperatures of 24-30°C. Such responses suggest a physiological basis for the tropical affinity of the Tampa Bay flora when compared to temperate and tropical floras.

Subtidal species in Tampa Bay also show adaptations to the local environment (Dawes et al. 1976, 1978; Hoffman and Dawes 1980; Bird et al. 1980, 1981). The red algae, Hypnea musciformis, Gracilaria verrucosa, and Acanthophora spicifera, exhibited much smaller tolerance ranges to light, temperature and salinity (see Fig. 6a, b, c) but similar levels of net production (1.2 g C/m^2/day, Hoffman and Dawes 1980) when compared with the intertidal species from the same region (Dawes et al. 1976, 1978). When populations of Hypnea musciformis from an exposed Gulf Coast site were compared with those in Tampa Bay, distinct tolerance levels were visible (Dawes et al. 1976, Fig. 9). The responses of Hypnea from Cockroach Bay to forty-eight combinations of light, temperature, and salinity also demonstrated the importance of considering synergistic effects on plant physiology (Fig. 9). The estuarine populations from Cockroach Bay exhibited broad tolerances and high responses to various conditions with significantly higher responses occurring at lower salinities (10-20 ppt), higher temperatures (24-30°C), and highest light levels achieved in the laboratory (2000 ft-c).

The macroalgae of subtropical estuaries such as Tampa Bay are tolerant of a wide range of physical factors including exposures of fresh water and for intertidal species, desiccation without a drop in prductivity. Thus any calculations regarding productivity of intertidal species should consider that photosynthesis is continuous with

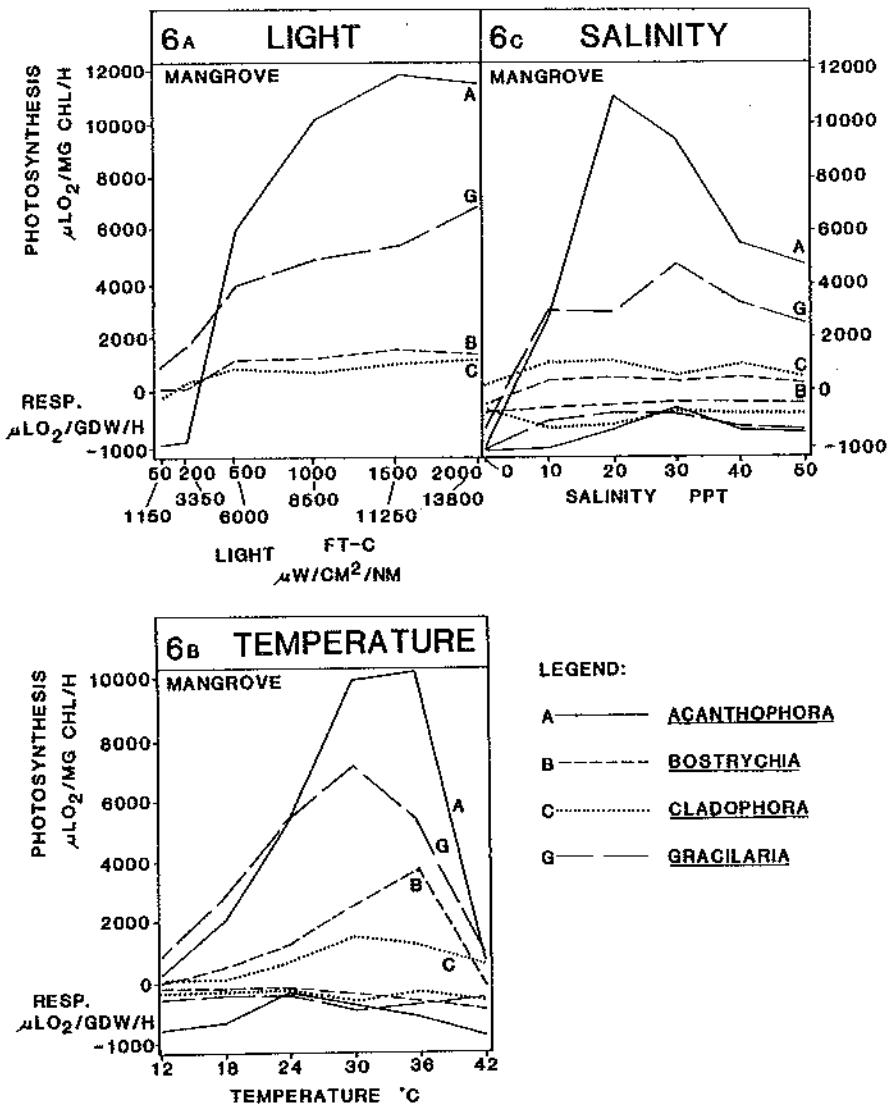

Figure 6. Solid lines represent subtidal species and dashed lines represent intertidal species. A - Photosynthetic responses of mangrove algae from Cockroach Bay vs. light intensity. Most species exhibited light saturation at the maximum light available (Dawes et al. 1977), showing adaptation to the low light conditions of a mangrove swamp. B - Net photosynthesis and respiration of mangrove algae vs. temperature. Note the high responses of all algae at 30 and 36°C, suggesting tropical affinities (Dawes et al. 1977). C - Net photosynthesis and respiration of mangrove algae vs. salinity. Species show broad tolerances to salinity, typical of estuarine algae (Dawes et al. 1977).

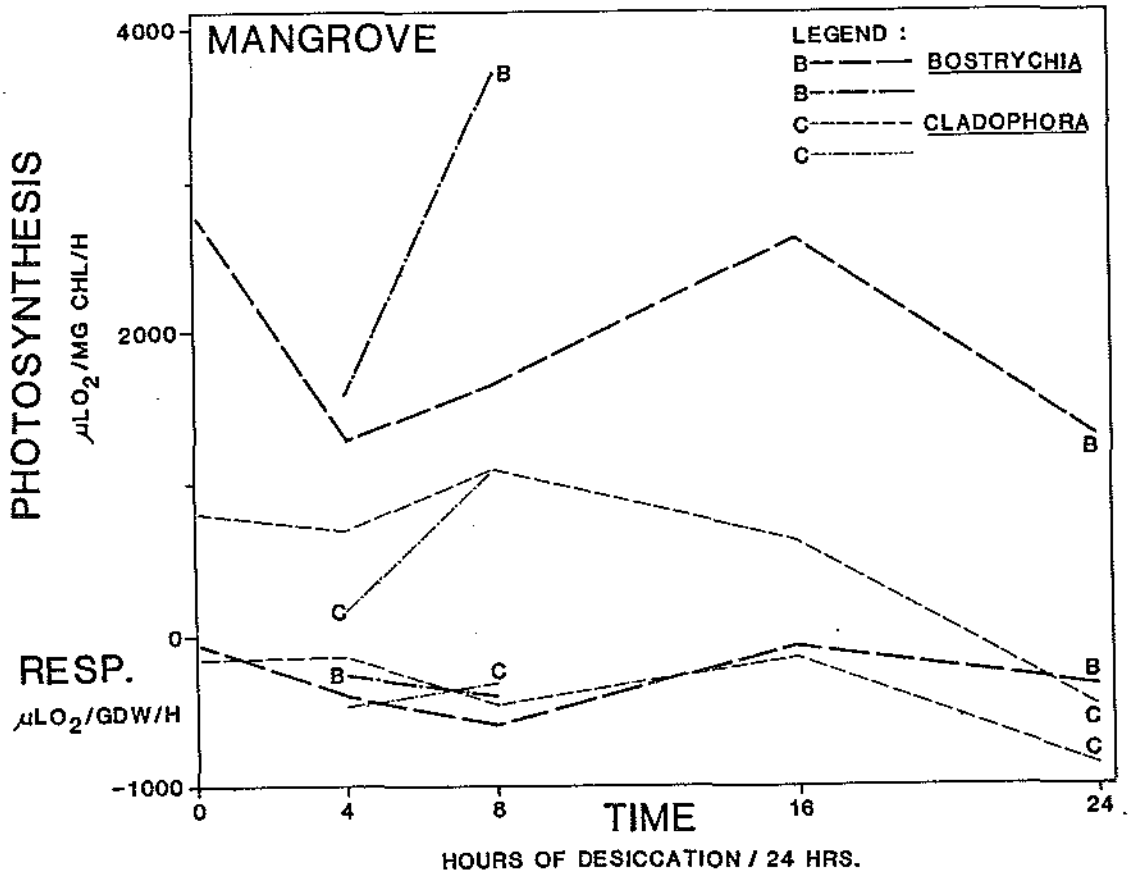

Figure 7. Net photosynthesis and respiration of intertidal algae from the mangrove swamp at Cockroach Bay. After growing the algae for 3 days under varying periods of desiccation (4, 8, 16 h) or continuous exposure or submergence (72 h), the algae were monitored and found to have high rates of photosynthesis. The short lines at 4 to 8 h desiccation indicated the responses of algae monitored in the air after exposure, the other lines represent algae submerged (Dawes et al. 1977). It is evident that the intertidal species Bostrychia is well adapted to aerial conditions while the filamentous green alga Cladophora that grows directly on the moist substrate is not.

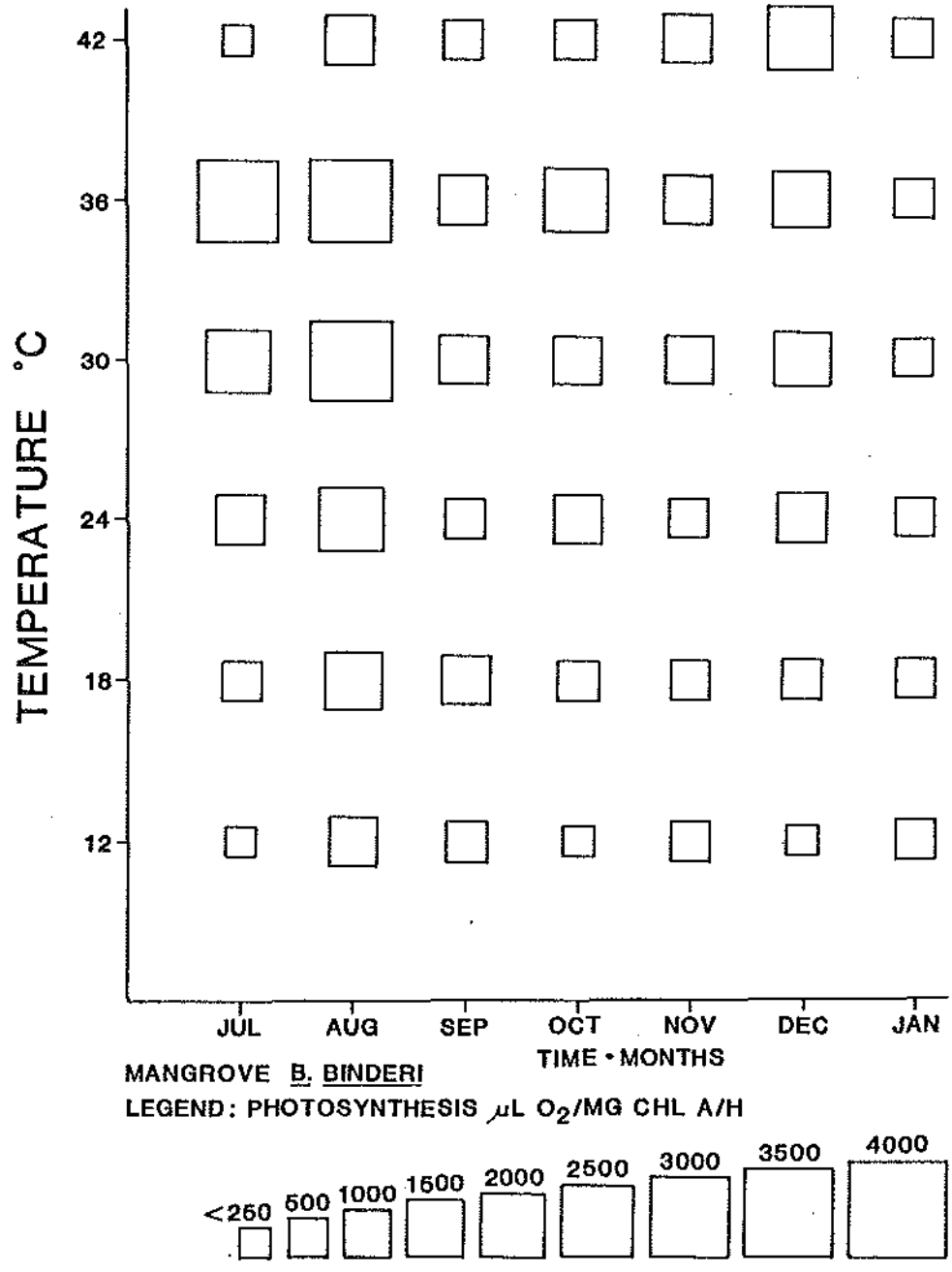

Figure 8. A seasonal summary of the mean photosynthetic responses to variations in temperature (T) for Cockroach Bay Bostrychia binderi (Davis and Dawes 1981). Note the peak responses (largest squares) occurred in the months of July (J) and August (A) as well as only at the warmer temperatures af 24-36°C regardless of the month of the year. This suggests a physiological tropical affinity for the estuarine algae.

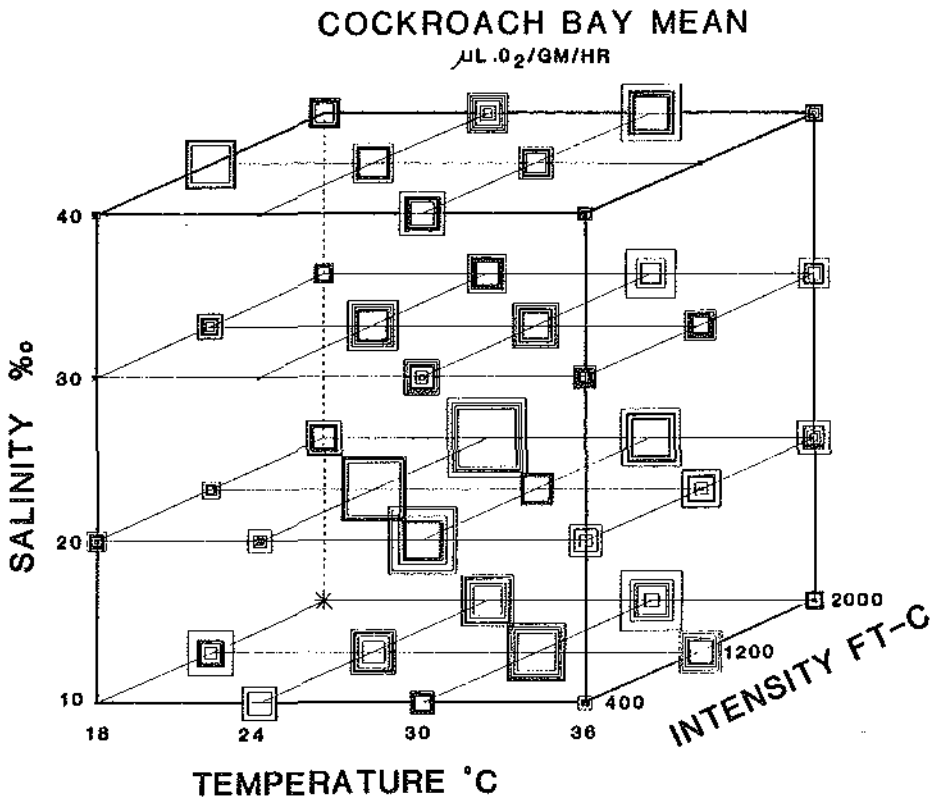

Figure 9. A study of the synergistic effects of light intensity (400-2,000 ft-c), temperatures (18-36°C), and salinity (10-40 ppt), on the mean net (n = 5) photosynthetic responses of the red alga Hypnea musciformis from the mangrove swamps at Cockroach Bay. After exposure for 3 days to the 48 combinations of light, temperature, and salinity, a computer-drawn graph was produced which shows peak responses (largest squares = 5,000 ul O_2/g dry wt/h) occurred under low to mid salinities, light and temperatures (Dawes et al. 1976).

concurrent low respiratory rates throughout the photoperiod regardless of tidal levels (Dawes et al. 1978). Furthermore, these seasonal changes in physiological responses will result in a decrease in productivity during the winter (Davis and Dawes 1981).

ENVIRONMENTAL AND ECONOMIC FEATURES

Macroalgae are primary producers and thus are an important food source in food webs, although little is known for the macroalgal contribution in Tampa Bay. Data regarding the amount of carbon fixed per square meter in Tampa Bay by macroalgae are very limited. Hoffman and Dawes (1980) found that the red algae Bostrychia binderi (intertidal) and Gracilaria verrucosa (subtidal) each produce 1.2 g C/m^2/day in Cockroach Bay during the summer. They also found that a diel fluctuation in the photosynthetic rate occurred with a peak occurring at about 9 A.M. in Cockroach Bay plants held in the laboratory (Fig. 10).

Macroalgal biomass and the energy available (g protein, carbohydrate, kilocalories) is essentially unknown for Tampa Bay or the Gulf Coast of Florida, although biomass can be very high, especially for drift algae. In connection with a manatee feeding study, Lewis (letter, unpublished) reported 1,804.5 g dry wt of algae per square meter at a

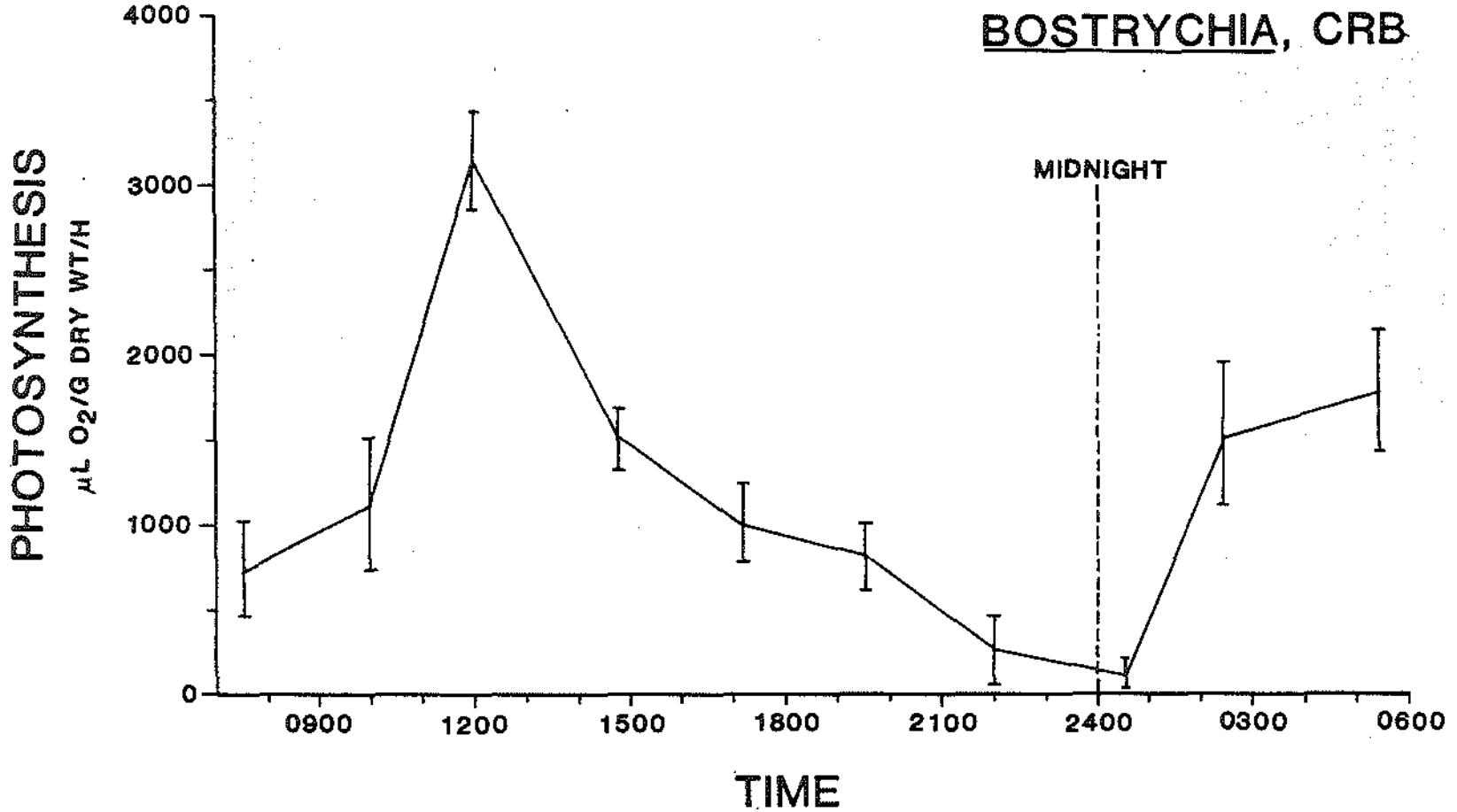

Figure 10. The net photosynthetic determination of Bostrychia binderi from Cockroach Bay grown in the laboratory under constant conditions including continuous light (Hoffman and Dawes 1980). A 1200 h peak can be seen in photosynthetic rates (n = 6; vertical lines are one standard deviation) showing a rhythm in photosynthetic activity.

site off the mouth of the Alafia River. Ninety-five percent of that biomass was determined to be one species, the agar-producing red alga Gracilaria verrucosa. Standing crop and biomass as well as energetic information is needed before an understanding of the productivity of Tampa Bay is available.

In reviewing the species list (Appendix) of macroalgae present in Tampa Bay, two species stand out as possible sources of economically valuable phycocolloids. Gracilaria verrucosa is a common drift species that contains agar while Hypnea musciformis is a commercial source of kappa carrageenan and is very common in Tampa Bay. Both phycocolloids are of major economic importance and both species are presently harvested in other parts of the world (Dawes 1981). The successful mariculture and high yields of phycocolloids from Gracilaria verrucosa (Bird et al. 1981) and Hypnea musciformis (LaPointe et al. 1976; Guist et al., in press) have been demonstrated for populations in Florida.

In addition, the harvesting of algal biomass for anaerobic digestion and subsequent methane production is a very likely possibility for the marine algal biomass present in the seagrass beds of the Bay. Drift red seaweeds such as Gracilaria spp., Laurencia spp., Hypnea musciformis, Acanthophora spicifera and Spyridia filamentosa as well as seasonal growth of green algae (Ulva lactuca, Enteromorpha intestinalis) and brown algae (Sargassum filipendula) offer nonlignified (therefore 100% biodegradable) biomass that is abundant in Tampa Bay. Anaerobic digestion and methane production from Gracilaria biomass has been studied and reported to be feasible for Florida (Hanisak 1981).

Another aspect of macroalgal use in Tampa Bay is removal of organics from secondary treated waste water. Both Gracilaria and Hypnea have been used in studies of waste water treatment in Florida (LaPointe et al. 1976; LaPointe and Ryther 1979). Large standing crops of the macroalgae were maintained in experimental ponds using diluted waste water, the biomass then harvested. Although macroalgae are not presently being harvested in Tampa Bay, there is every reason to believe such an industry could be initiated, removing the sometimes awesome and odiferous (when anaerobic conditions develop) biomass of algal material that accumulates at various times during the year (FWPCA 1969).

ALGAL TAXONOMY

Three hundred and forty taxa of blue-green (69), green (85), brown (45) and red (140) algae have been listed by Dawes (1974) for the west coast of Florida including Tampa Bay. Specific areas studied on the west coast (Table 1) include the offshore deep water flora (28 species, Phillips and Springer 1960; 157 species, Dawes and Van Breedveld 1969; 92 species, Cheney and Dyer 1974; 65 species, Mathieson and Dawes 1975) that has been described as being primarily tropical in nature. Coastal sites include estuaries such as Crystal River Bay (46 species, Phillips 1960a; 106 species, Steidinger and Van Breedveld 1971), the Anclote River estuary (63 species epiphytic on seagrasses, Ballantine and Humm 1975; 126 benthic algal species, Hamm and Humm 1976), Donna and Roberts Bays (50 species, Dawes and Dudley 1975) and Tampa Bay (133 species, Phillips 1960a; 178 species, Dawes 1967).

The macroalgal flora, 221 taxa thus far identified for the Tampa Bay estuarine system, is both more luxuriant and diverse when compared to other estuaries on either the west or east coasts of Florida (Appendix). Because both stable, high salinities and fluctuating salinites occur in Tampa Bay, it is not surprising that both euryhaline species such as Cladophora repens, Bostrychia binderi and Gracilaria verrucosa and stenohaline forms such as Caulerpa spp., various species of Ectocarpus, and open coast red algae (e.g. Gracilaria blodgetti) can be collected in the Bay. Coupled with seasonal changes in temperature, the resulting flora shows both a seasonal

diversity as well as diversity with relation to salinity. The macroalgal flora is more limited in species in the northern regions of the Bay where salinity and temperature fluctuations as well as turbidity can be extreme. There is a high degree of species diversity in the southern portion with a tendency toward tropical forms, especially in the subtidal habitat.

Red and green algae dominate during most of the year in Tampa Bay, probably because most brown algae are seasonal, occurring during the spring period (Dawes 1974). Blue-green algae have been poorly studied; Dawes (1967) did not include them and Phillips (1960a) listed only 12 species for the Bay. Based on the limited collections (60 species) by Dawes (1974) for the west coast, the number of blue-green algae present in Tampa Bay is probably around 30 species.

The list of macroalgae for Tampa Bay (Appendix) is taken from the papers of Phillips (1960a) and Dawes (1967). A number of species names have been changed to reflect the more modern taxonomic treatments. Phillips (1960a) identified 23 blue-green algae. Phillips (1960a) and Dawes (1967) together have reported a total of 68 taxa of Chlorophyta, 1 Xanthophycean alga, 30 taxa of Phaeophyta and 99 taxa of Rhodophyta, for a total of 221 taxa (Appendix). A careful study of seagrass epiphytes would probably yield other species for Tampa Bay as well; this list is not considered to be complete. Evidence that the Tampa Bay flora is subtropical to tropical in nature can be seen in the list. Nineteen taxa of the green, 10 of the brown, and 40 of the red algae listed are predominantly subtropical to tropical in distribution and are common to the Florida Keys.

As pointed out by Sykes (1964) in relation to Boca Ciega Bay, radical changes in the Tampa Bay coastline and benthos have altered the water quality and biological habitats. Dredge and fill operations, channelization, seawall building and effects of sewage have all left their mark. In the years since 1970, we have observed better control and a drastic reduction in the destruction of the intertidal marshes and shallow seagrass beds as well as the reduction of nutrient enhancement from spillage at phosphate plants and sewage release. Dredged materials have been contained more effectively in spoil island formation and water quality of Tampa Bay has improved in this author's view. There is presently a better chance for the continued existence of a highly diverse macroalgal flora in Tampa Bay than this author visualized in earlier years (Dawes 1967). The maintenance of a diverse macroalgal population will, in turn, support a more varied food web and the highly varied fauna. It does appear that the macroalgal component in the Tampa Bay estuarine system has affinities with the tropical species, especially the subtidal populations. This is further supported in the physiological studies reported in this paper.

A better understanding of the physiological ecology of the macroalgae in Tampa Bay will permit us to interpret seasonal and distributional aspects of algal populations. Furthermore, such studies will allow us to harvest the massive drift algal biomasses, thus removing excess nutrients via the plants as well as obtaining a source for methane production. After all, the algal biomass is a renewable resource that in turn aids in maintaining the water quality of the Bay. Future studies should consider biomass energetic information as well as the importance of macroalgae in food chains.

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APPENDIX
A LIST OF MACROALGAE REPORTED FOR TAMPA BAY

KEY

1. Species identified by Phillips (1960a)
2. Species identified by Dawes (1967)
3. Species with tropical affinities
4. New record
5. May be renamed Agardhiella subsalta

(a) winter species
(b) spring species
(c) summer-fall species
(d) year-round species

CYANOPHYTA

Chlorocccales.

Anacystis aeruginosa Drouet et Daily 1. (d)
Entophysalis conferta (Kutzing) Drouet et Daily 1. (d)
Entophysalis deusta (Meneghini) Drouet et Daily 1. (d)

Oscillatoriales: Oscillatoriaceae.

Lyngbya aestuarii Gomont 1.
L. confervoides C. Agardh 1. (d)
L. gracilis (Meneghini) Rabenhorst 1.
L. majuscula Gomont 1. (d)
L. meneghiniana Zanardini 1.
L. mittsii Phillips 1.
L. rosea Taylor 1.
L. semiplena (C. Agardh) J. Agardh 1. (d)
L. sordida (Zanardini) Gomont 1.
Microcoleus chthonoplastes (Flora Danica) Thuret 1. (d)
Oscillatoria bonnemaisonii Crouan 1.
O. corallinae Gomont 1.
O. nigro-viridis Thwaites 1. (d)
O. subuliformis Kutzing 1.
Spirulina subsalsa Oersted var. oceanica (Crouan) Gomont 1. (d)

Oscillatoriales: Rivulariaceae.

Calothrix aeruginea (Kutzing) Thur. 1. (d)
C. confervicola (Roth) C. Agardh 1. (d)
C. pilosa Harvey 1. (d)

Oscillatoriales: Stigonemataceae.

Mastigocoleus testarum Lagerheim 1.
Plectonema nostocorum Bornet 1.

CHLOROPHYTA

Tetrasporales: Palmellaceae.

Pseudotetraspora antillarum Howe 2. (c)

Ulotrichales: Chaetophoraceae.

Endoderme viride (Reinke) Lagerheim 1.
Entocladia flustrae (Reinke) Batters (as Epicladia flustrae) 1.
Entocladia viridis Reinke 2. (d)
Phaeophila dendroides (Crouan) Batters 1. 2. (d)
Protoderma marina Reinke 1. 2.
Ulvella lens Crouan 1. 2. (d)

Ulotrichales: Gomontiaceae.
Gomontia polyrhiza (Lagerheim) Bornet & Flahault 1. 2. (d)

Ulotrichales: Ulotrichaceae.
Stichococcus marinus (Wille) Hazen 2. (b)

Ulvales: Ulvaceae.
Enteromorpha chaetomorphoides Borgesen 2. (b)
E. clathrata (Roth) J. Agardh 1. 2.
E. compressa (Linnaeus) Greville 2. (b)
E. crinita (Roth) J. Agardh 1.
E. flexuosa (Wulfen) J. Agardh 1. 2.
E. intestinalis (Linnaeus) Link 1. 2. (c)
E. lingulata J. Agardh 1. 2.
E. plumosa Kutzing 1. (c)
E. prolifera (Muller) J. Agardh 1. 2. (c)
E. ramulosa (Smith) Hooker 1. 2.
E. salina Kutzing var. polyclados Kutzing 1. 2.
Monostroma latissima (Kutzing) Wittrock 1. (a)
M. oxyspermum (Kutzing) Doty 2.
Ulva fasciata Delile 1. 2. (a, b)
U. lactuca Linnaeus 1. 2. (a, b)
U. lactuca Linnaeus var. rigida (C. Agardh) Le Jolis 1. 2.
U. lactuca Linnaeus var. latissima (Linnaeus) De Candolle 1. 2.

Cladophorales: Cladophoraceae.
Chaetomorpha aerea (Dillwyn) Kutzing 2. (a, b)
C. brachygona Harvey 1. 2. (b)
C. gracilis Kutzing 1. 3.
C. linum (Muller) Kutzing 1. 2. (d)
Cladophora delicatula Montagne 1. 2.
C. fascicularis (Mertens) Kutzing 1. 2. (d)
C. frascatii Collins and Hervey 2.
C. fuliginosa Kutzing 1. 2. 3. (c)
C. glaucescens (Griffiths) Harvey 1. 2.
C. gracilis (Griffiths) Kutzing 2. (a)
C. luteola Harvey 1.
C. repens (J. Agardh) Harvey 2. 3. (d)
Rhizoclonium hookeri Kutzing 2. (d)
R. kochianum Kutzing var. kerneri (Stockmayer) Hamel 1. 2. (d)
R. riparium (Roth) Harvey 1. 2.

Caulerpales: Bryopsidaceae.
Bryopsis hypnoides Lamouroux 1. 2. (a, b)
B. pennata Lamouroux 1. 2. (a, b)
B. plumosa (Hudson) C. Agardh 2. (a, b)
Dervesia vaucheriaeformis (Harvey) J. Agardh 1. 2. (b, c)

Caulerpales: Caulerpaceae.
Caulerpa ashmeadii Harvey 2. 3. (b, c)
C. cupressoides (West) C. Agardh 2. 3. (b, c)
C. cupressoides (West) C. Agardh var. cupessoides C. Agardh 1. 3.
C. mexicana (Sonder) J. Agardh 1. 2. 3. (b, c)
C. mexicana (Sonder) J. Agardh forma typica (Weber) Borgesen 1. 2. 3

C. mexicana (Sonder) J. Agardh forma mexicana (Sonder) J. Agardh 1. 2. 3.
C. prolifera (Forsskal) J. Agardh 1. 2. (d)
C. racemosa (Forsskal) J. Agardh 2. 3. (b, c)
C. sertularioides (Gmelin) Howe 1. 2. 3. (b, c)

Caluerpales: Codiaceae.
Avrainvillea nigricans Decaisne 2. 3. (d)
Boodleopsis pusilla (Collins) Taylor, Joly and Bernatowicz 2. 3. (d)
Codium decorticatum (Woodward) Howe 2. (d)
C. isthmocladum Vickers 2. 3. (d)
C. taylori Silva 1. 2. 3. (d)
Halimeda incrassata (Ellis) Lamouroux 2. 3. (b, c)
Udotea conglutinata (Ellis and Solander) Lamouroux 2. 3. (b, c)
U. flabellum (Ellis and Solander) Lamouroux 2. 3. (b, c)

Caulerpales: Phyllosiphonaceae.
Ostrebium quekettii Bornet and Flahault 2.

Siphonocladales: Valoniaceae.
Anadyomene stellata (Wulfen) C. Agardh 2. 3. (b, c)
Cladophorophsis membranceae (C. Agardh) Borgesen 2. 3. (c)

Dasycladales: Dasycladaceae.
Acetabularia crenulata Lamouroux 2. 3. (b, c)
Batophora oerstedi J. Agardh 2. 3. (b, c)

XANTHOPHYTA

Heterosiphonales: Vaucheriaceae.
Vaucheria thuretii Woronin 2. (d)

PHAEOPHYTA

Ectocarpales: Ectocarpaceae.
Acinetospora crinita (Carmichael) Kornmann 4. (b)
Bachelotia antillarum (Grunow) Gerloff 4. (b)
Bachelotia fulvescens (Bornet) Kuckuck (as Pyaliella antillarum) 2. (b)
Ectocarpus confervoides (Roth) Le Jollis 2. (b)
E. dasycarpus Kuckuck 2. (b)
E. elachistaeformis Heydrich 1. 2. (b)
E. siliculosus (Dillwyn) Lyngbye 1. 2. (b)
Giffordia conifera (Borgesen) Taylor (may not be a Giffordia) 2. (b)
G. indica (Sonder) Earle (as G. duchassaigniana) 1. 2. (b)
G. mitchelliae (Harvey) Hamel 1. 2. (b)
G. rallsiae (Vickers) Taylor 1. 2. (b)

Sphacelariales: Sphacelariaceae.
Sphacelaria furcigera Kutzing 1. 2. (b, c)
S. tribuloides Meneghini 2. (b, c)

Dictyotales: Dictyotaceae.
Dictyota cervicornis Kutzing 1. 2. 3. (c)
D. dentata Lamouroux 1. 2. 3. (c)
D. dichotoma (Hudson) Lamouroux 2. 3. (c)
D. divaricata Lamouroux 2. 3. (c)
D. linearis (C. Agardh) Greville 2. 3. (c)
Padina vickersiae Hoyt 2. 3. (b, c)

Chordariales: Chordariaceae.
Cladosiphon occidentalis Kylin 2. (d)
C. zosterae (J. Agardh) Kylin 1. 2. (d)

Chordariales: Myrionemataceae.
Ascocyclus orbicularis Magnus 2.
Myrionema strangulans Greville 1. 2. (b)

Dictyosiphonales: Stictyosiphonaceae.
Stictyosiphon subsimplex Holden 2. (diploid phase of Hummi onusta (Kutzing) Fiore) (b)

Dictyosiphonales: Punctariaceae.
Myriotrichia subcorymbosa (Holden) Blomquist 1. 2. (haploid phase of H. onusta) (b)
Rosenvingea intricata (J. Agardh) Borgesen 1. 2. 3. (b, c)

Fucales: Sagassaceae.
Sargassum filipendula C. Agardh 1. 2. 3. (d)
S. filipendula C. Agardh var. montagnei (Bailey) Grunow 1. 2. 3.
S. fluitans Borgesen 2. 3. (c)
S. natans (Linnaeus) J. Meyen 2. 3. (c)
S. pteropleuron Grunow 2. (d)

RHODOPHYTA

Bangiales: Bangiaceae.
Erythrocladia subintegra Rosenvinge 2.
Erythrotichia carnea (Dillwyn) J. Agardh 1.
Gonotrichium alsidii (Zanardini) Howe 1. 2. (d)

Nemalionales: Acrochaetiaceae.
Achrochaetium flexuosum Vickers 1.
A. sagraeanum (Montagne) Bornet 1. 3.
A. sargassi Borgesen 1. 2. 3. (d)
A. sancti-thomae Borgesen 1. 2. 3.
A. seriatum Borgesen 1. 2. (b)
Kylinia crassipes (Borgesen) Kylin 1. 2. 3.

Gelidiales: Gelidiaceae.
Gelidiella acerosa (Forsskal) Feldmann and Hamel 1. 2. (d)
Gelidium crinale (Turner) Lamouroux 1. 2.
G. corneum (Hudson) Lamouroux 1.
G. pusillum (Stackhouse) Le Jolis 2. 3. (d)
Pterocladia americana Taylor 2. 3. (d)

Wurdemannia miniata (Draparnaud) Feldmann and Hamel 1. 2. 3.

Cryptonemales: Squamariaceae.
Hildenbrandia prototypus Nardo 2.

Cryptonemales: Corallinaceae.
Amphoria fragilissima (Linnaeus) Lamouroux 2. (d)
Fosliella atlantica (Foslie) Taylor 2. 3. (d)
F. farinosa (Lamouroux) Howe 2. 3. (d)
F. lejolisii (Rosanoff) Howe 1. 2. 3.
Goniolithon decutescens (Heydrich) Foslie 2. (d)
Jania adherens Lamouroux 2. 3. (d)
J. capillacea Harvey 2. 3. (d)
J. pumila Lamouroux 2. 3. (d)

Cryptonemales: Grateloupiaceae.
Grateloupia filicina (Wulfen) C. Agardh 1. 2.

Gigartinales: Gracilariaceae.
Gracilaria blodgettii Harvey 1. 2. (d)
G. cervicornis (Turner) J. Agardh 2.
G. compressa (C. Agardh) Greville 2.
G. damaecornis J. Agardh 1.
G. foliifera (Forsskal) Borgesen 1. 2. (d)
G. foliifera (Forsskal) Borgesen var. angustissima (Harvey) Taylor 1. 2. (d)
G. mammillaris (Montagne) Howe 2.
G. verrucosa (Hudson) Pappenfuss (may be G. tikvahiae McLachlin) 1. 2. (d)
Gracilariopsis sjoestedtii (Kylin) Daweson 2. (d)

Gigartinales: Solieriaceae.
Agardhiella ramosissima (Harvey) Kylin (also known as Neoagardhiella ramossissima) 2. 3. 5. (a, b)
A. tenera (J. Agardh) Schmitz (also known as Soleria tenera) 1. 2. 5. (a, b)
Eucheuma isiforme (C. Agardh) J. Agardh 1. 2. 3. (b, c)

Gigartinales: Hypneaceae.
Hypnea cervicornis J. Agardh 1. 2. (d)
H. cornuta (Lamouroux) J. Agardh 1. 2. (d)
H. musciformis (Wulfen) Lamouroux 1. 2. (d)
H. spinella (C. Agardh) Kutzing 1. 2. (d)

Gigartinales: Rhabdoniaceae.
Rhabdonia ramosissima (Harvey) J. Agardh 1. (d)
Catenella repens (Lightfoot) Batters 4. (d)

Rhodymeniales: Champiaceae.
Champia parvula (C. Agardh) Harvey 1. 2. (b, c)
Lomentaria baileyana (Harvey) Farlow 1. 2. (b, c)
L. rawitscheri Joly 2.

Rhodymeniales: Rhodymeniaceae.
Chrysymenia enteromorpha Harvey 2. 3. (b)

Ceramiales: Ceramiaceae.

Callithamnion roseum (Roth) Harvey 2.
Centroceras clavulatum (C. Agardh) Montagne 1. 2. 3. (d)
Ceramium byssoideum Harvey 1. 2. (b, c)
C. codii (Richards) Feldmann-Mazoyer 2.
C. deslongchampsii Chauvm. 1.
C. diaphanum (Lightfoot) Roth 1.
C. fastigiatum (Roth) Harvey 2. 3. (d)
C. fastigiatum (Roth) Harvey forma flaccida Peterson 2. 3.
C. rubrum (Hudson) C. Agardh 1.
C. strictum (Kutzing) Harvey 2.
C. subtile J. Agardh 1. 2.
C. tenuissimum (Lyngbye) J. Agardh 1. (b, c)
Crouania attenuata (Bonnemaison) J. Agardh 2. 3.
Griffithsia globulifera Harvey 2. 3. (b, c)
G. tenuis C. Agardh 2. (b, c)
Spyridia filamentosa (Wulfen) Harvey 1. 2. (d)

Ceramiales: Delesseriaceae.

Caloglossa leprieurii (Montagne) J. Agardh 2. (d)
Cryptopleura fimbriata (Greville) Kutzing 2. 3.
Hypoglossum tenuifolium (Harvey) J. Agardh 2. 3. (d)
Taenioma macrourum Thuret 3. 4. (b, c)

Ceramiales: Rhodomelaceae.

Acanthophora muscoides (Linnaeus) Bory 1. 2. (d)
A. spicifera (Vahl) Borgesen 1. 2. (d)
Bostrychia binderi Harvey 2. (d)
B. montagnei Harvey 2. (d)
B. radicans Montagne 2. (d)
B. rivularis Harvey 2. (d)
B. tenella (Vahl) J. Agardh 2. (d)
Brongniartella mucronata (Harvey) Schmitz 2. 3.
Chondria cnicophylla (Melvill) De Toni 2. (b, c)
C. dasyphylla (Woodward) C. Agardh 1. 2.
C. leptacremon (Melvill) De Toni 1. 2.
C. littoralis Harvey 1. 2. 3. (b)
C. sedifolia Harvey 1. 2. 3. (b)
C. tenuissima (Goodenough and Woodward) C. Agardh 1. 2. 3. (d)
Digenia simplex (Wulfen) C. Agardh 2. 3. (d)
Herposiphonia secunda (C. Agardh) Ambron 2. 3. (d)
Herposiphonia tenella (C. Agardh) Ambron 1. 2. (d)
Laurencia intricata Lamouroux 2. 3. (d)
L. obtusa (Hudson) Lamouroux 2. 3. (d)
L. papillosa (Forsskal) Greville 1. 2. 3. (d)
L. poitei (Lamouroux) Howe 1. 2. 3. (d)
Lophosiphonia bermudensis Collins and Hervey 1. 3.
L. saccorhiza Collins and Hervey 2. 3.
Murrayella periclados (C. Agardh) Schmitz 3. 4. (d)
Polysiphonia binneyi Harvey 1.
P. denudata (Dillwyn) Kutzing 1. 2. 3. (d)
P. ferulacea Suhr 1. 2.
P. hapalacantha Harvey 2. 3. (d)
P. havenensis Montagne 1. 2.

P. howei Hollenberg 1. 2.
P. macrocarpa Harvey 1. 2.
P. ramentacea Harvey 1. 2. 3. (d)
P. subtilissima Montagne 1. 2. (d)
P. tepida Hollenberg 2. (d)

Ceramiales: Dasyaceae.
Dasya baillouviana (Gmelin) Montagne (as D. pedicellata) 1. 2. (b, c)

SEAGRASS MEADOWS OF TAMPA BAY - A REVIEW

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ABSTRACT

Seagrass meadows presently cover approximately 5,750 ha of the bottom of Tampa Bay, an 81% reduction from the historical coverage of approximately 30,970 ha. Five of the seven species of seagrass occurring in Florida are found in the estuary, typically in less than 2 m of water. These are: Thalassia testudinum Banks ex Konig (turtle grass); Syringodium filiforme Kutzing (manatee grass); Halodule wrightii Ascherson (shoal grass); Ruppia maritima L. (widgeon grass), and Halophila engelmannii Ascherson. The dominant species are turtle grass and shoal grass. The meadows are subdivided into five types: 1) mid-bay shoal perennial; 2) healthy fringe perennial; 3) stressed fringe perennial; 4) ephemeral; and 5) colonizing perennial. The general characteristics of these meadow types are discussed. In addition, the habitat values, physiological ecology, reproductive biology and on-going research work are summarized. Seagrasses in Tampa Bay reproduce primarily vegetatively. Sexual reproduction occurs in T. testudinum and R. maritima. Thalassia seed production is low, however, and confined to the southern part of the Bay. Seed quantities may be insufficient for significant colonization and restoration projects.

INTRODUCTION

Seagrass beds have long been recognized as a food source and habitat for benthic invertebrates and fish (Phillips 1960a; Randall 1965; Wood et al. 1969). Hutton et al. (1956) were among the first researchers to recognize the importance of seagrass beds as fish and wildlife habitats in Tampa Bay. They also recognized that development activities along the shore and associated effects on these areas conflicted with conservation, fishing and recreational interests. Indeed, the destruction of 1,100 metric tons of seagrasses by dredging and filling in Boca Ciega Bay resulted in the immediate loss of 1,800 metric tons of infauna, and the annual loss of approximately 73 metric tons of fisheries products and 1,100 metric tons of infauna (Taylor and Saloman 1968). The loss of this habitat represented an annual monetary loss of $1.4 million. Godcharles (1971) found that the use of a commercial hydraulic clam dredge in seagrass beds uprooted all vegetation and that no recolonization had occurred after more than a year. He recommended that

the use of these harvesters be prohibited in grassy areas because of the importance of such areas as nursery grounds for the majority of Florida's sport and commercial species. In this regard, Lewis and Phillips (1980) found that the loss of seagrass habitat in Tampa Bay coincided with a reduction in commercial landings of spotted seatrout.

Seagrass habitat value is best summarized by the scheme of Wood et al. (1969):

1. Seagrasses have high growth and production rates;
2. The leaves support large numbers of epiphytic organisms with biomass approaching that of the seagrasses themselves;
3. Although few organisms feed directly on them, seagrasses produce large quantities of detritus which serves as a major food source for many species;
4. Seagrasses bind sediments and prevent erosion, in turn providing a quiescent environment in which a great variety of organisms can grow;
5. Seagrasses provide organic matter which encourages sulfate reduction and an active sulfur cycle; and,
6. Seagrasses act as nutrient sinks and sources.

In addition, Ketchum (cited in Phillips 1978) has estimated that 80-90% of the commercial and sport fish species depend on estuaries during all or part of their life cycle, and estuaries typically support large seagrass beds.

Dense populations of bacteria and fungi are associated with seagrass beds (Burkholder et al. 1959; Klug 1980). These microorganisms form a major source of nutrition for detritus feeders including various polychaetes, crustaceans, mollusks and fish (Brook 1975; O'Gower and Wacasey 1967). Seagrass-derived detrital material is important in food webs within beds, and also in detrital food webs based on material exported from the system (Zieman 1981). Direct herbivory forms the basis for the third type of food web based on seagrasses. However, most of the productivity of seagrasses is believed to be channeled through detrital pathways (Fig. 1 in Ogden 1980).

Several studies dealing with Florida seagrass beds and their associated animal communities have included species lists and population densities (Voss and Voss 1955; Tabb and Manning 1961; Dragovich and Kelly 1964; Santos and Simon 1974; Brook 1975; Stoner 1980; Livingston 1982). These studies show that diversity and abundance of fish and invertebrates are usually higher in grass beds than in unvegetated habitats. Stoner (1980) found that abundances of epifauna, suspension feeders and carnivorous polychaetes were correlated with seagrass biomass. The increase in abundance of epifauna was related to increased surface area of leaf blades. Taylor et al. (1973) reported that for each square meter of bed area, Thalassia leaf blades have a total surface area of up to 18 m^2. This large surface area provides a correspondingly large amount of substrate for epiphytes.

Mobile invertebrate epifauna, including several species of echinoids, asteroids and gastropods, feed upon the seagrasses and epiphytes (Ogden 1980). Other invertebrates such as some crabs, shrimp and gastropods are carnivorous, feeding on smaller herbivores and detritus feeders. Some fish species within seagrass beds may follow developmental sequences that encompass various trophic levels from herbivory to carnivory (Livingston 1982). Many commercially important fish are present in grass beds as juveniles obtaining both food and shelter (Ogden 1980). The major vertebrate consumers of seagrasses are sea turtles and manatees (Zieman 1981). These animals "mow" or "root" when feeding and can have substantial localized impacts on grass beds (Packard 1981; Zieman 1981). Waterfowl also feed on seagrasses which can constitute a major food source for some species (McRoy 1966).

OCCURRENCE AND DISTRIBUTION

Eiseman (1980) notes the occurrence of seven species of

seagrasses in Florida:

1. Thalassia testudinum Banks ex Konig (turtle grass)
2. Syringodium filiforme Kutzing (manatee grass)
3. Halodule wrightii Ascherson (shoal grass)
4. Ruppia maritima Linnaeus (widgeon grass)
5. Halophila engelmannii Ascherson
6. Halophila decipiens Ostenfeld
7. Halophila johnsonii Eiseman

The last species is newly described (Eiseman and McMillan 1980) and historically has probably been confused with H. decipiens (Eiseman 1980).

Thorne (1954) mentioned the occurrence of five of these species in Tampa Bay: Thalassia testudinum, Syringodium filiforme, Halodule wrightii, Halophila engelmannii, and Ruppia maritima. Phillips (1962) conducted the first comprehensive field sampling for seagrasses in Tampa Bay during 1959-60 and reported the occurrence of all of these species except H. engelmannii. Taylor and Saloman (1969) summarized data for 773 benthic samples taken during 1961-65 along 18 transects within Tampa Bay and noted the occurrence of seagrasses in 217 (34%) of the samples. No R. maritima was reported, probably due to difficulty in distinguishing it from H. wrightii without close examination. H. engelmannii was reported at only 2 stations, both in Boca Ciega Bay. Taylor (1973) also reported its occurrence behind Egmont Key. More recently, it has been observed around Cockroach Bay in Middle Tampa Bay by Lewis and Phillips (1980) and Moffler and Durako (unpublished data). Thus five of the seven Florida species of seagrasses have been reported to occur in Tampa Bay.

Phillips (1962, p. 8), sampling at 98 stations between Pinellas Point and Terra Ceia Bay during 1959-60 (Fig. 1), noted that "all attached plants were limited to waters inshore of the one fathom curve". Also, "... Diplanthera (Halodule) is dominant in the southern portions of the bay while Ruppia is dominant in the most northerly portions".

Lewis and Phillips (1980) reported the results of 226 samples collected seasonally at 18 inshore stations during 1980-81, and found 42.5% of the samples contained Thalassia testudinum, 40.7% Halodule wrightii, 19.0% Syringodium filiforme, 15.5% Ruppia maritima, and none contained Halophila engelmannii (Table 1). Table 2 lists the seagrass associations found during the same sampling program. Single species were found in 83.3% of the samples. Four species associations occurred in the remainder of the samples, with H. wrightii/R. maritima being the most common (8.8%), followed by T. testudinum/S. filiforme (5.3%), T. testudinum/H. wrightii (2.2%) and T. testudinum/H. wrightii/S. filiforme (0.5%).

Based on the currently available aerial photography of Tampa Bay (1981), Figure 2 was prepared. It shows 5,750 ha (14,203 acres) of seagrass meadows in Tampa Bay. Similar working maps were prepared using vertical black and white aerial photography of Tampa Bay (secured from the National Archives, Washington, DC) that had been taken by

Table 1. Percent species occurrence, Tampa Bay (Lewis and Phillips 1980). Percent of samples in which species was collected, n = 226.

SPECIES	PERCENT
Thalassia testudinum	42.5
Halodule wrightii	40.7
Syringodium filiforme	19.0
Ruppia maritima	15.5
Halophila engelmannii	0.0

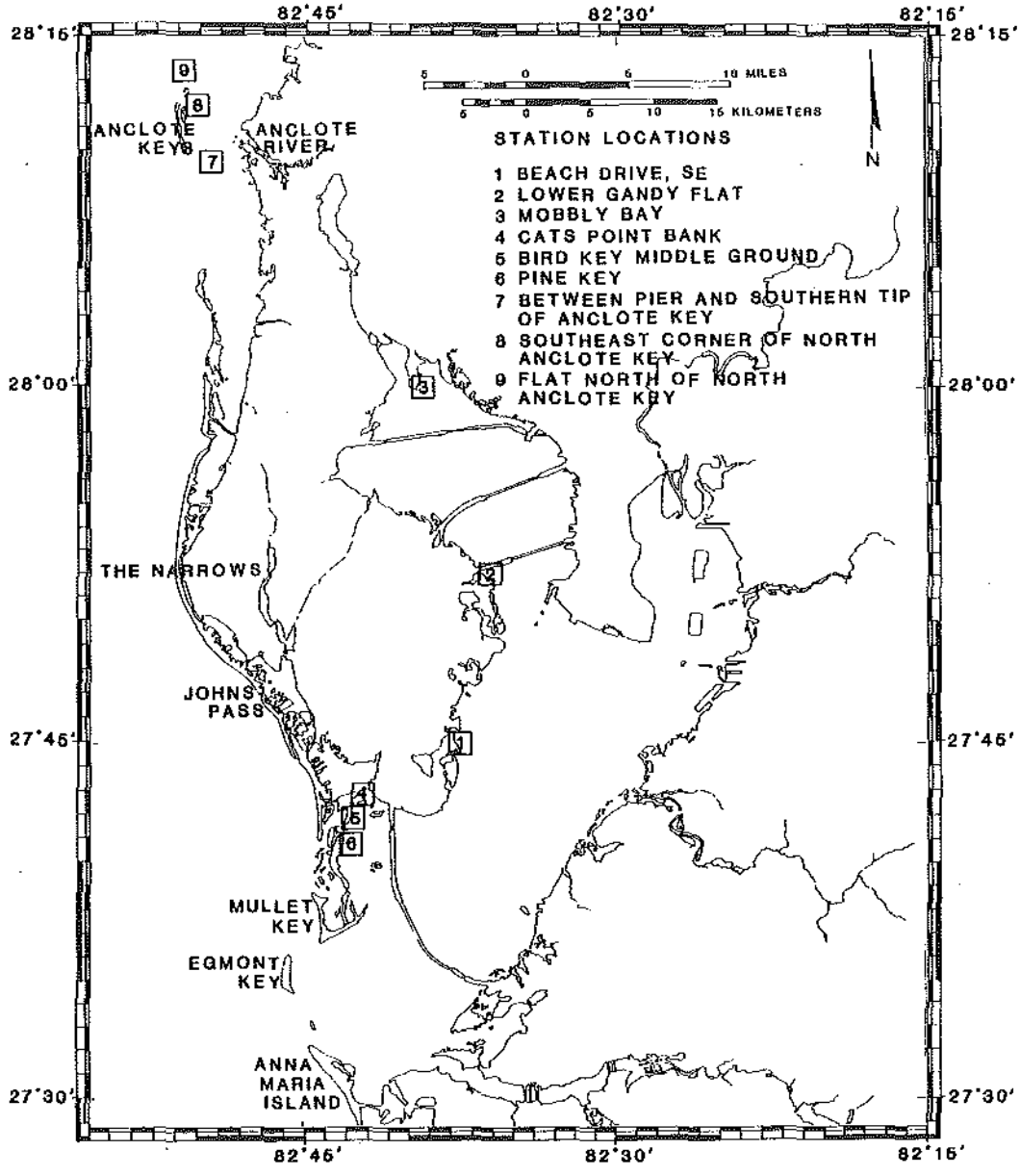

Figure 1. Location of station sites in Tampa Bay, Boca Ciega Bay, and at Tarpon Springs (from Phillips 1960a).

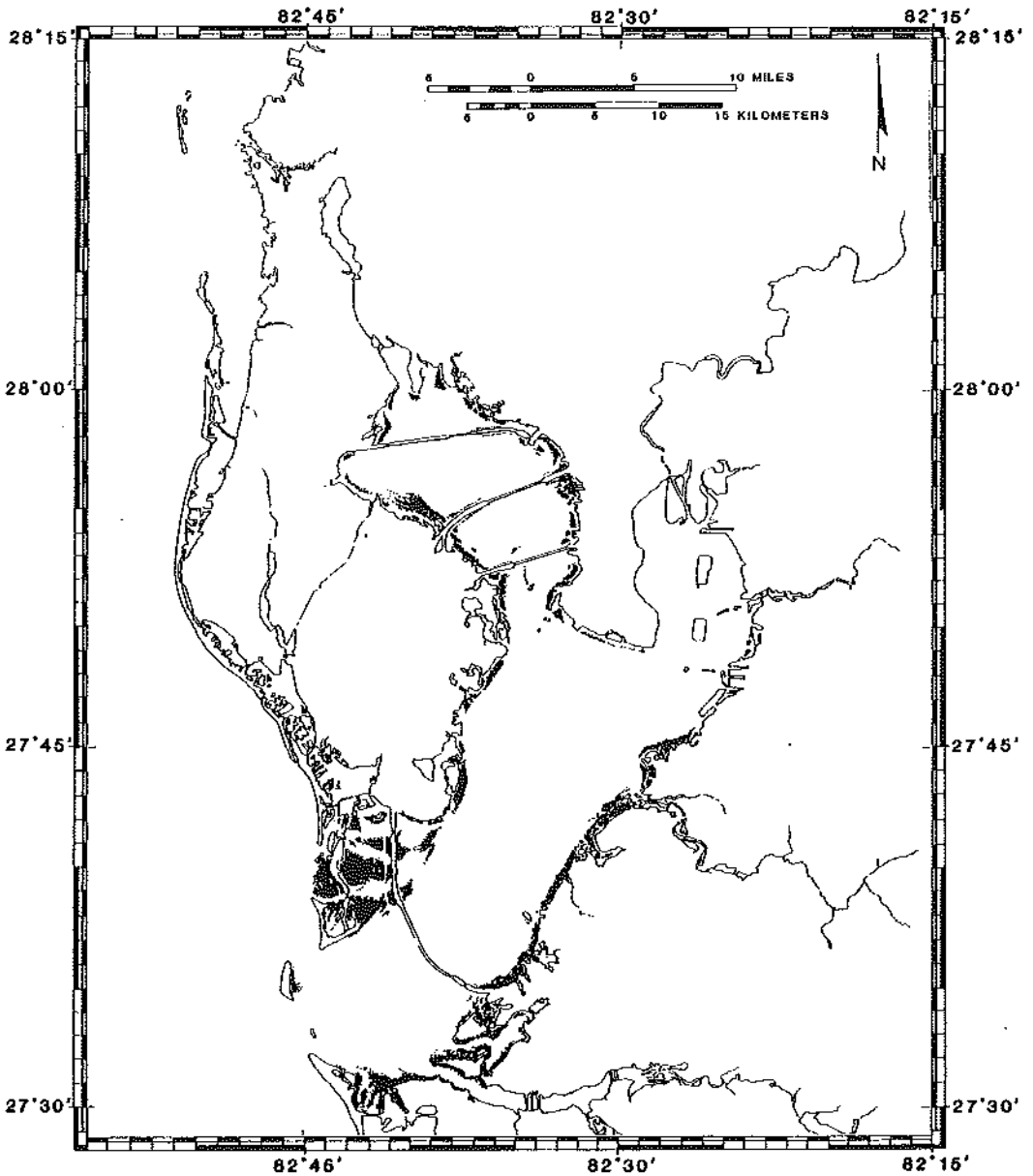

Figure 2. Extent of seagrass meadows in Tampa Bay - 1982.

Table 2. Seagrass species associations, Tampa Bay (Lewis and Phillips 1980). 226 samples.

ASSOCIATION	PERCENT OCCURRENCE	STATIONS
Halodule wrightii Ruppia maritima	8.8	5, 7, 10, 12
Thalassia testudinum Syringodium filiforme	5.3	1, 6, 10
Thalassia testudinum Halodule wrightii	2.2	2
Thalassia testudinum Halodule wrightii Syringodium filiforme	0.5	2

the Soil Conservation Service between 1938 and 1942. These were used in conjunction with maps dating back to 1848 to prepare maps of historical seagrass coverage in Tampa Bay (Fig. 3). It is estimated that seagrass meadows covered 30,970 ha (76,496 acres) prior to man's major impacts upon the bay (c. 1876).

TYPES OF SEAGRASS MEADOWS

Figure 4 illustrates five types of seagrass meadows found in Tampa Bay. These are:

1. Mid-bay shoal perennial - MBS(P)
2. Healthy fringe perennial - HF(P)
3. Stressed fringe perennial - SF(P)
4. Ephemeral - E
5. Colonizing perennial - C(P)

The idealized cross-sections in Figure 4 are derived from actual transects established during 1979-80 (Lewis and Phillips 1980). It is hypothesized that types 2-4 are stages in the eventual disappearance of a seagrass meadow due to man-induced stress, as illustrated by the arrows in Figure 4. A brief description of each seagrass meadow type follows.

Mid-bay Shoal Perennial. These meadows are generally composed of Halodule, Thalassia and Syringodium. Ruppia is rarely observed, which may be attributed to the generally high current regime and/or higher salinities not typically found in meadows closer to shore. These meadows are located on natural shoals existing in the middle portion of the bay. They are present year round (perennial), although variations in cover by the different species occur seasonally.

Healthy Fringe Perennial. These meadows are the most common meadow type in the bay and extend from approximately the mean low water mark into water depths of approximately -2 m MSL. All five species of seagrasses found in the bay occur in this meadow type. Zonation begins with Ruppia in the shallowest water close to shore, and grades with increasing depth through nearly pure patches of Halodule, followed by Thalassia and then Syringodium. Unlike the generalized meadow cross-section from McNulty et al. (1972; Fig. 5), healthy fringe meadows in Tampa Bay normally have an offshore, unvegetated sand bar separating the main portion of the meadow from open bay waters and creating a "basin" behind the bar. This basin was described by Phillips (1960a) as a "central declivity" (Fig. 6). Similar sand bars have been observed offshore of seagrass meadows in Charlotte Harbor and are plainly visible in aerial and satellite photography of that area (Allen Huff, Florida

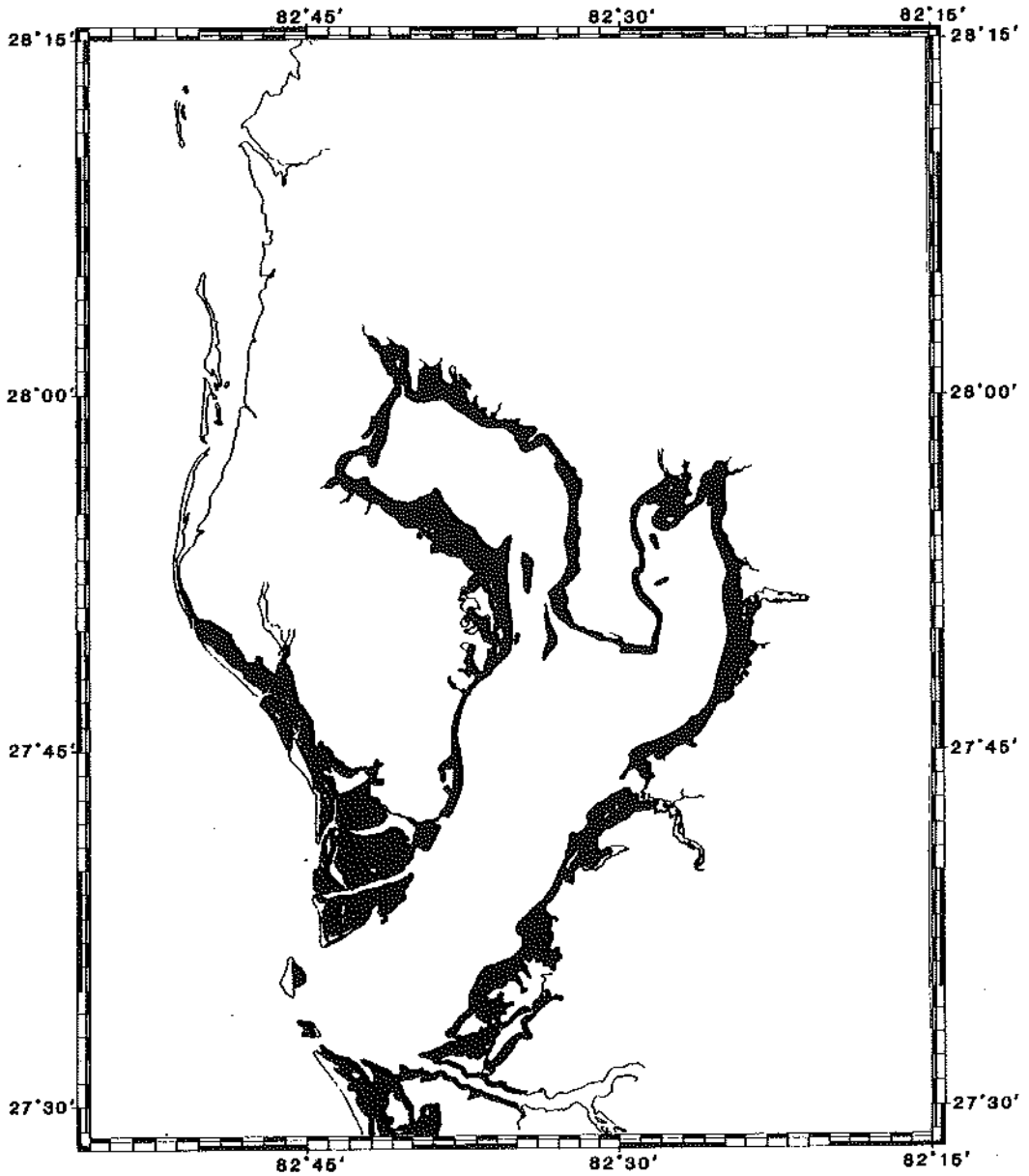

Figure 3. Estimated extent of seagrass meadows in Tampa Bay - 1879.

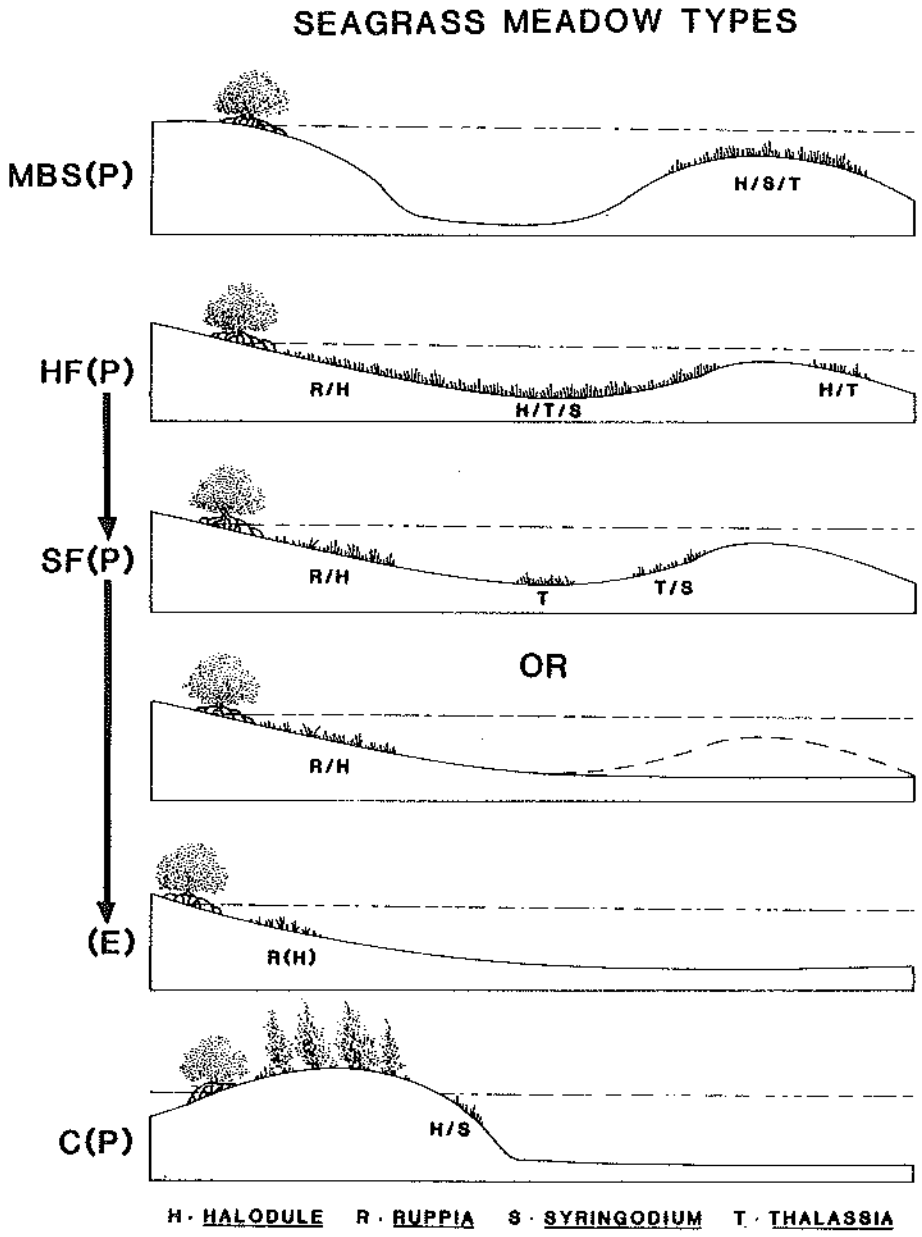

Figure 4. Seagrass meadow types. MBS(P) - mid-bay shoal perennial; HF(P) - healthy fringe perennial; SF(P) - stressed fringe perennial; (E) - ephemeral; C(P) - colonizing perennial.

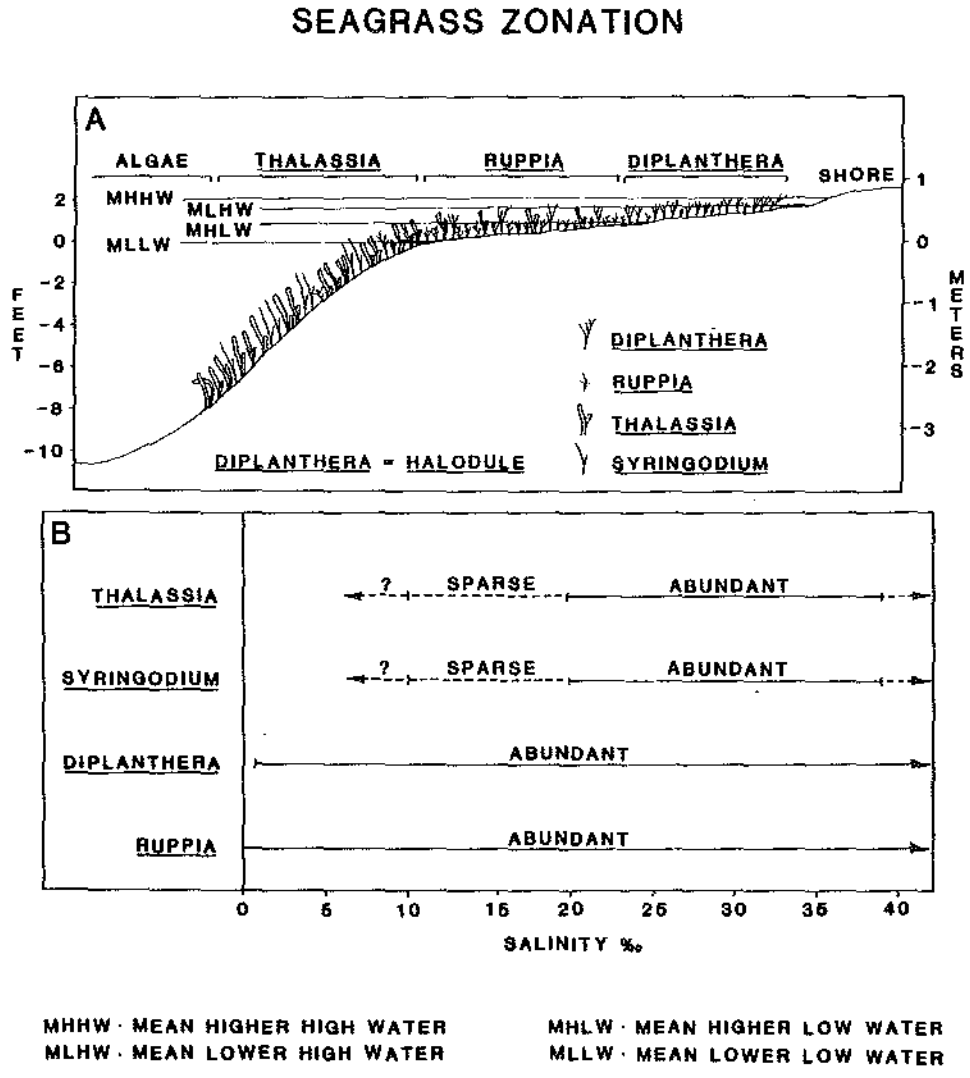

Figure 5. Seagrass zonation (McNulty et al. 1972). A - the zonation of seagrasses in shallow water in Boca Ciega Bay just north of the Bayway to St. Petersburg Beach and in Tampa Bay just south of Bayboro Harbor, St. Petersburg. B - salinity preferences and tolerances of seagrasses (modified from Phillips 1960a and Moore 1963).

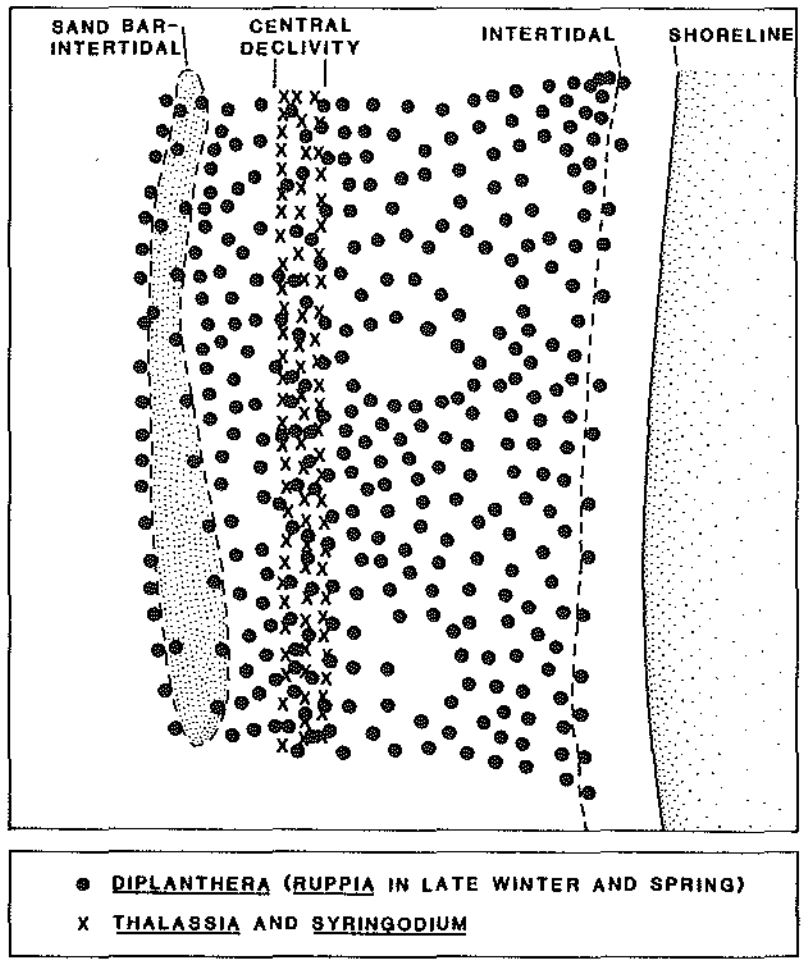

Figure 6. Schematic drawing of Beach Drive station showing intertidal zones and maximum depth declivity with location of grasses (from Phillips 1960b). Diplanthera = Halodule.

Table 3. Chlorophyll a amounts for stations in various parts of Tampa Bay, 1969-1971 (mg/m^3) (from Turner and Hopkins 1974).

SUBDIVISION	FALL	WINTER	SPRING	SUMMER	MEAN
Old Tampa Bay	16.5	3.6	5.4	26.6	13.0
Hillsborough Bay	31.6	56.5	22.0	41.7	40.0
Middle Tampa Bay	21.8	19.3	2.8	21.1	16.3
Lower Tampa Bay	4.8	5.6	11.4	16.1	9.5
Tampa Bay entrance	3.8	3.1	1.6	6.1	3.7
Boca Ciega Bay	12.5	6.7	7.4	16.4	10.8
Terra Ceia Bay	19.7	2.5	13.7	16.7	13.2

Department of Natural Resources, personal communication). A typical cross-section through a healthy fringe perennial seagrass meadow is diagrammed in Figure 7.

Stressed Fringe Perennial. These meadows are similar to healthy fringe perennial meadows except that total cover is reduced within the basin behind the offshore bar. Destabilization of the offshore sand bar apparently leads to its inshore migration and eventual disappearance (Fig. 4). This type of meadows generally occurs in areas closer to Hillsborough Bay with its typical tenfold increase in average chlorophyll a values (Table 3) and over areas closer to the mouth of Tampa Bay. Although there are no experimental data documenting competition between phytoplankton and seagrasses in Tampa Bay, such competition has been theorized to occur in the shallows of other estuaries where nutrient enrichment has been followed by increases in microalgae (phytoplankton) and macroalgae and decreases in seagrass meadows (Cambridge 1975, 1979; Davis and Brinson 1980; Harlin and Thorne-Miller 1981).

Ephemeral. These meadows are composed almost entirely of Ruppia with occasional sprigs of Halodule. They are not present year round and their locations often vary from year to year. Phillips (1962) noted the unusual appearance of Ruppia patches in Hillsborough Bay along Bayshore Boulevard and at the mouth of Delaney Creek in the winter of 1961. No other seagrass species were seen in these areas. Mangrove Systems, Inc. (1978) also noted the cyclic appearance and disappearance of a monospecific Ruppia meadow near the Big Bend power plant in Hillsborough Bay during 1976-78. These meadows probably represent the final stage of seagrass meadow degradation in Tampa Bay and would be followed by the complete absence of meadows as presently seen in most of Hillsborough Bay.

Colonizing Perennial. This meadow type is commonly found in a narrow band in the euphotic zone of man-made fills such as Courtney Campbell Causeway, Howard Frankland Bridge Causeway, and the Picnic Island fill. It is believed to represent a meadow type dominated by those species that can produce abundant propagules that disperse and colonize appropriate shallow substrates. As noted below, only Ruppia shows large scale sexual reproduction and seed production in Tampa Bay. Seed production of the other four species is rare to non-existent and therefore, these seagrasses colonize by dispersal of shoots/rhizomes produced asexually through fragmentation. Due to the exposed nature of the man-made fills and their generally coarser sediments, Ruppia is not as common as in the inshore portions of the fringe meadows. Both Halodule and Syringodium produce large amounts of detached rhizomes, particularly during storms, and it is theorized that these float into unvegetated areas, attach through new root formation, and establish new meadows. Thalassia produces relatively

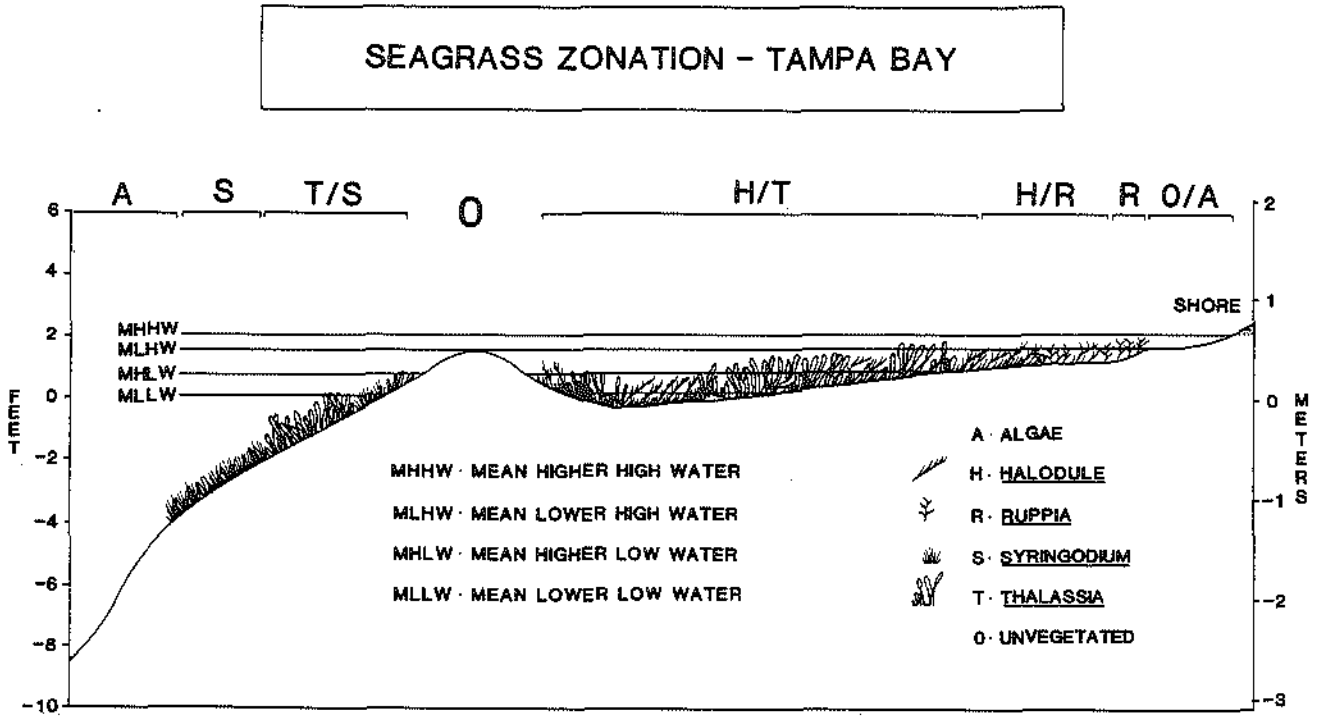

Figure 7. Zonation in a healthy fringe perennial seagrass meadow, Tampa Bay.

fewer detached shoot/rhizomes and, due to their increased buoyancy, these are less likely to sink into an area appropriate for meadow establishment. Even if sinking and attachment do occur, slower root and rhizome growth rates would make establishment of a new meadow by asexual means less likely. This may explain why Halodule and Syringodium are the dominant species in this meadow type.

PHYSIOLOGICAL ECOLOGY

Tidal Zonation. Physiological and morphological differences between seagrass species result in characteristic zonation patterns relative to tidal exposure (Fig. 8). Halodule wrightii is the most abundant species between neap high and neap low tide lines (Phillips 1960a, 1962). This seems to be related to the ability of Halodule to tolerate higher water temperatures and longer air exposures than other species in the bay (Humm 1956). Halodule also can be the dominant species subtidally in lower salinity areas where Thalassia and Syringodium are not found, such as the more turbid parts of upper Old Tampa Bay. Thus zonation of Halodule is not restricted entirely by physical factors; rather it may be out-competed by Thalassia and Syringodium in less turbid, high salinity areas. Ruppia maritima is commonly mixed with Halodule in intertidal areas where the salinity is low (Phillips 1960a, 1962; Earle 1972). Halodule is usually most abundant between the neap low and spring low tide lines in higher salinities (Phillips 1960a).

All four of these species occur subtidally in Tampa Bay. Syringodium filiforme becomes dominant at the spring low tide line, and frequently grows interspersed with Thalassia in deeper water (Humm 1956; Phillips 1960a, 1962; Woodburn 1961b). Although Thalassia is the dominant subtidal species in the Gulf of Mexico (Humm 1956; Earle 1972), Phillips (1962) noted that it occurs in relatively sparse amounts in Tampa Bay. This is probably because salinities in the bay are lower than optimum for this species. However, Thalassia is the dominant species in Boca Ciega Bay (Hutton et al. 1956; Pomeroy 1960; Taylor and Saloman 1968) and in the seagrass beds surrounding Mullet Key. In both of these areas salinity typically exceeds 30 ppt. Halophila engelmannii occurs subtidally mixed with Thalassia and Syringodium.

Phillips (1960b) found that Halodule exhibited three growth forms in Tampa Bay which were related to the tidal zone where they occurred. In areas exposed at both neap and spring low tides plants were dwarfed. Subtidal areas characteristically had more robust plants. Leaf length and width, rhizome thickness, and internode length were all affected by the degree of tidal exposure. Leaf apex features and internal cellular anatomy, features which had been used to distinguish two species of Halodule (H. wrightii and H. beaudetii), were found to vary according to the tidal zone in which the plants were found.

Seagrass growth in the bay has been reported to be limited to bottom areas less than 2 meters (6 feet) deep (Phillips 1962). High turbidity, and consequently low light penetration, seems to be responsible for the relatively shallow depth restriction, whereas desiccation and wave action limit the shoreward edge of seagrass beds.

Salinity. Tidal zonation of Ruppia in Tampa Bay may actually be a secondary effect due to this species' preference for brackish water (Phillips 1962). Of all seagrasses, Ruppia tolerates the broadest range of salinity, occurring in freshwater and in areas with salinities in excess of 35 ppt (although it does seem that somewhat reduced salinity is required for it to set seed). Thorne (1954) and Humm (1973) considered Ruppia primarily a freshwater species that can invade brackish waters and the latter author did not consider it to be a true seagrass. This apparent preference for lower salinites seems to be responsible for its dominance north of the Courtney Campbell Causeway in Old Tampa Bay (Phillips 1962).

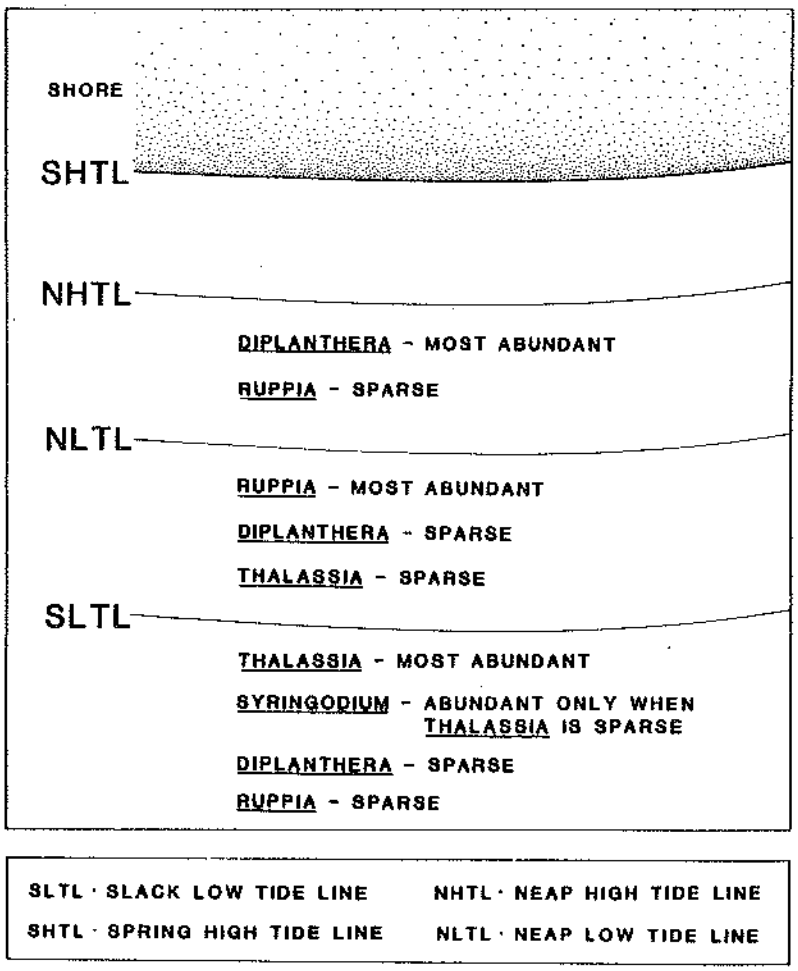

Figure 8. Schematic drawing of seagrass zonation in shallow water. Valid only in areas with salinity over 25.0 ppt. From Phillips 1960a. Diplanthera = Halodule.

Thalassia, by contrast, is relatively stenohaline (Moore 1963) and seems to be restricted to areas with salinity over 25 ppt (Phillips 1960a). Salinity also has been observed to modify the morphology and growth of this species. Phillips (1960a) reported shorter, narrower leaves at low salinities and wider, longer leaves at salinities near those of normal sea water. McMillan (1978) reported similar trends in leaf width of Thalassia cultured at 20, 25 and 30 ppt.

Halodule and Syringodium exhibit maximum growth in moderately brackish water (Phillips 1960a, 1962). Halodule is found throughout Tampa Bay while Syringodium is rarely found where salinities are below 20 ppt, reflecting the broader salinity tolerance of the former (Taylor 1973). Halophila engelmannii has been reported to require relatively high salinities (Taylor 1973), which may partially account for its low abundance in the bay.

Temperature. The distribution of marine plants is largely controlled by temperature (Earle 1972). Optimal temperatures for all 5 seagrass species in Tampa Bay range between 20-30°C (Phillips 1960a; Woodburn 1961b). Temperatures above or below this range can result in leaf damage or dieback (Phillips 1960a; McMillan 1979).

The rate of leaf growth in Thalassia seems to be controlled by water temperature, while ultimate leaf length is related to water depth (Phillips 1960a; Taylor et al. 1972; Durako and Moffler 1982). When water temperatures approach summer maxima in Tampa Bay, Thalassia leaves become soft and flaccid, then break off due to protoplasmic breakdown and accelerated bacterial activity (Phillips 1960b; Durako and Moffler unpub.) Leaf kills also occur during winter when short shoots become desiccated during the extremely low tides associated with the passage of cold fronts. Recovery is slow because the plants are relatively dormant at this time. Unfortunately, leaf growth measurements relative to water temperature are not available for the other species.

McMillan (1978) reported that narrow-leafed variants of Thalassia, Halodule and Syringodium were characteristic of shallow bays with fluctuating temperatures, while broad-leafed variants occurred in water of relatively constant temperature. Chilling tolerances of these three species were also shown to correlate with their geographic distribution; Tampa Bay populations exhibit lower chill tolerances than northern Gulf plants, but higher tolerances than Biscayne Bay or Florida Keys populations (McMillan 1978).

Water temperature is important in modifying floral expression in Thalassia (Phillips 1960a; Moffler et al. 1981; Phillips et al. 1981). Reproductive buds are present as early as October in Tampa Bay populations (Moffler and Durako unpub.) but visible buds are not evident until water temperatures start to increase in spring (May - June).

Vegetative growth, flowering and fruiting of Ruppia coincide with the rise of water temperature from winter to spring and end when high summer water temperatures begin (Phillips 1960a). Fruits seem to remain dormant until winter and germinate when water temperatures again begin to rise.

Substrate. Seagrass-substrate relationships represent a complex cyclical phenomenon. Substrate characteristics are important factors in determining which species of seagrass will be present (Phillips 1960a; Patriquin 1972; Van Breedveld 1975). The presence of a seagrass bed subsequently influences sediment dynamics (Scoffin 1970; Orth 1977; Fonseca 1981), granulometry (Grady 1981) and chemistry (Patriquin 1972; Kenworthy 1981). Sediment, detritus trapping by leaves, and the stabilization of this material by the dense rhizome-root mats are paramount in considering seagrass-substrate relationships (Phillips 1960a; Humm 1975). The mechanisms of sedimentation are related to current flow dynamics in seagrass beds and result in a characteristic bedform raised above the original sediment level (Scoffin 1970; Fonseca 1981).

Thorne (1954) reported that seagrasses in the Gulf of Mexico are limited to soft marl, mud or sand substrates. Dense Thalassia beds in Tampa Bay occur on muddy sand substrates with silt and clay fractions dominating the mud (Phillips 1960a). The substrate also contains calcium carbonate in varying amounts; this may be important in determining phosphate and sulfate availability (Patriquin 1972). The depth of rhizomes and roots in the sediments seems to depend on the depth of the redox potential discontinuity (RPD) layer, as Thalassia requires reducing conditions for normal development. This requirement is related to the nutrient requirements of Thalassia (Patriquin 1972). Anaerobic nitrogen fixation in the sediments seems to be the source of nitrogen for this species' growth. This activity has been shown to be much greater in Thalassia rhizosphere sediments than in non-rhizosphere sediments in Tampa Bay (Babiarz 1976). Fixed nitrogen is taken up in a reduced form as ammonium (Patriquin 1972) while sulfur seems to be taken up as the reduced sulfide (Fry and Parker 1982).

Halodule occurs on the same substrate types as Thalassia, as well as on extremely coarse muddy sands (Phillips 1960a; Grady 1981). However, Halodule is more prevalent on oxidized substrates. Substrate type does not seem to directly influence the distribution of Syringodium (Phillips 1960a). The depth of the RPD layer also seems inconsequential as Syringodium roots occur in both oxidized and reduced substrates (Patriquin and Knowles 1972). This ability to grow in both types of substrates reflects the intermediate successional nature of Syringodium, which is thought to follow Halodule and precede Thalassia in the temporal development of a seagrass bed.

Ruppia is found on predominately mud and silt substrates containing finer textured sand than substrates associated with the other three species (Phillips 1960a). Halophila has been observed to grow on substrates ranging from soft muddy sand (Phillips 1960a) to limestone bottoms and even the prop roots of mangroves (Earle 1972).

The predominance of fine sediments in seagrass beds indicates that once this material reaches the rhizome-root mat it is usually not easily resuspended. Transects across seagrass beds have shown that sediment sorting and mean particle size decrease and percent organic matter increases as one proceeds from bare sand to the interior of the bed (Fig. 8; Orth 1977). Water depth also decreases from fringe to mid-bed regions (Zieman 1972; Durako and Moffler 1982). Intertidal seagrass sediments have almost twice the organic and carbonate carbon content of unvegetated sand flats (Grady 1981).

Growth. It is somewhat paradoxical that rhizome branching and growth are recognized as being largely responsible for the building of seagrass meadows (Tomlinson 1974), yet most of the information on seagrass growth deals with leaf blade growth. This is due to the ease with which leaf growth can be monitored and the importance of leaves as a substrate and food for many organisms. Until recently it was not possible to directly measure growth rates for below-ground structures in a nondestructive manner. In this regard, Fuss and Kelly (1969) measured Thalassia root growth by systematically sacrificing transplants over a 12-month period and comparing root lengths to native plant samples in Boca Ciega Bay. Durako and Moffler (1981) developed a laboratory culture technique in which both leaf blade and root growth of individual Thalassia seedlings could be directly measured. Their results revealed morphogeographic variations in growth patterns for seedlings from Tampa Bay, Biscayne Bay, and the Florida Keys. Tampa Bay seedlings exhibited the lowest leaf blade and root growth rates (Tables 4 and 5), and generally had the narrowest leaf blades of the three populations under a variety of conditions. McMillan (1978) also found the same pattern for leaf blade widths and suggested that the ecoplastic limits

Table 4. Root and leaf blade growth of Thalassia testudinum seedlings in agar/seawater cultures after three months. I.O. = Instant Ocean; N.A. = nutrient agar; NH-15 = nutrient enriched seawater; M.A. = marine agar. Values represent the mean of four replicates.

	Total Root Length (cm)			Leaf Area (cm^2)		
Treatment	Tampa Bay	Biscayne Bay	Florida Keys	Tampa Bay	Biscayne Bay	Florida Keys
60 ml tubes						
NH-15/N.A.	0.95	5.65	4.03	4.32	4.03	6.42
I.O./N.A.	2.48	7.00	6.35	4.48	4.05	6.27
NH-15/M.A.	2.52	6.40	4.75	4.29	4.13	4.58
I.O./M.A.	2.75	5.52	6.00	3.63	5.20	7.00
Mean	2.18	6.14	5.37	4.18	4.35	6.04
Root #/ Seedling	2.50	3.81	2.47			
Length/root	0.87	1.61	2.21			
80 ml tubes						
I.O./N.A.	3.27	12.10	14.98	3.18	4.21	4.50

Table 5. Leaf growth rates of Thalassia testudinum seedlings in laboratory cultures. Numbers in parentheses indicate a growth index where: growth index = (mean leaf area/seedling)/(mean leaf #/seedling).

	Growth Interval (months)	Shoot Growth Rates (cm^2/mo)		
Treatment		Tampa Bay	Biscayne Bay	Florida Keys
Tube Cultures				
60 ml tubes	3	1.38	1.47	2.07
80 ml tubes	3	1.08	1.40	1.50
Pot Cultures				
Instant Ocean	5	0.72	1.04	1.78
von Stosch's	5	1.76	2.53	2.94
Peat Pellets	3	0.93 (1.70)	1.78 (2.52)	1.72 (2.80)

of populations are genetically controlled.

Several authors have measured leaf lengths of Thalassia to monitor its growth in Tampa Bay (Phillips 1960a; Taylor et al. 1973; Durako and Moffler unpub.) These measurements have revealed a bimodal seasonal growth pattern (Fig. 9). Leaf lengths increase from winter minimums to a peak in early summer. There is a summer dieback related to high water temperatures, decreasing salinity, and flowering. This is followed by an increase to a typically lower peak in early fall. Leaf lengths increase at a rate of 5 cm/month during the period of maximum growth and can reach lengths exceeding 30 cm. Taylor et al. (1973) showed that Thalassia can withstand periodic leaf cutting and harvesting without apparent damage. The authors qualified their findings, stating that they did not study the long term effects of harvesting, and suggested that this might be detrimental to both the plants and the associated communities.

Leaf growth of Thalassia near the Anclote River is lower than that in Tampa Bay, with an average growth rate of 1.3 cm/leaf/month and a maximum rate of 2.5 cm/leaf/month (Ford et al. 1974). Syringodium had higher leaf growth rates, averaging 6.7 cm/leaf/month, and a maximum rate of 17.4 cm/leaf/month during the fall. Halodule leaf growth was the highest and ranged from 12.9 to 19.5 cm/leaf/month.

Biomass and Productivity. Humm (1964) suggested that Thalassia is probably the most important plant species in the shallow marine waters of the Gulf of Mexico. In terms of biomass, Burkholder et al. (1959) estimated the standing crop of Thalassia in Puerto Rico to be 2,809 g dry weight/m^2 (g dwt/m^2), of which 23% was leaf biomass. Phillips (1960a) determined standing crop values of Thalassia blades in Boca Ciega Bay (Table 6), which ranged from 98 to 325 g dwt/m^2. However, Bauersfeld et al. (1969) reported much higher leaf values (636 g dwt/m^2) for this area. These values would more than double if roots, rhizomes and below-ground portions of shoots were included (Pomeroy 1960).

Biomass values reported for leaves of Thalassia from Tarpon Springs are higher (601-819 g dwt/m^2) than most previous studies because samples were taken in dense grass beds rather than at random (Table 6; Dawes et al. 1979). By contrast, values in Tampa Bay are much lower, ranging from 0.41-52.7 g dwt/m^2 (Heffernan and Gibson, pers. comm.) to 25-180 g dwt/m^2 (Lewis and Phillips 1980), reflecting suboptimal conditions for this species within the bay. The latter study also reported root biomass values of 600-900 g dwt/m^2 (Table 6).

Below-ground biomass exceeds shoot biomass in Halodule and Syringodium within the Bay as well (Table 6). Lewis and Phillips (1980) reported root and rhizome biomass ranges from 60-140 g dwt/m^2 for Halodule and from 160-400 g dwt/m^2 for Syringodium. The comparatively lower shoot biomass values were 38-50 g dwt/m^2 and 50-170 g dwt/m^2 respectively. These values are much higher than those reported by Heffernan and Gibson (pers. comm.), 4-27 g dwt/m^2 and 5-11 g dwt/m^2 for Halodule and Syringodium respectively. Ruppia biomass is almost equally divided between above- and below-ground structures, being approximately 48 g dwt/m^2 for each component during the spring (Lewis and Phillips 1980). Shoot biomass then decreases to almost zero in the winter while root biomass decreases to a low level of 18-20 g dwt/m^2 in the fall and levels off. The higher biomass values generally reported for Thalassia compared to the other species are a result of the larger size of all three major plant parts (Dawes and Lawrence 1980).

The productivity of seagrass systems is regarded as high for marine communities (Earle 1972). Pomeroy (1960) reported that at depths of less than 2 meters, which constituted 75% of Boca Ciega Bay, Thalassia and Syringodium leaves were as important as phytoplankton and benthic microflora in terms of primary production, fixing 500 g C/m^2/yr. Indeed, values for annual

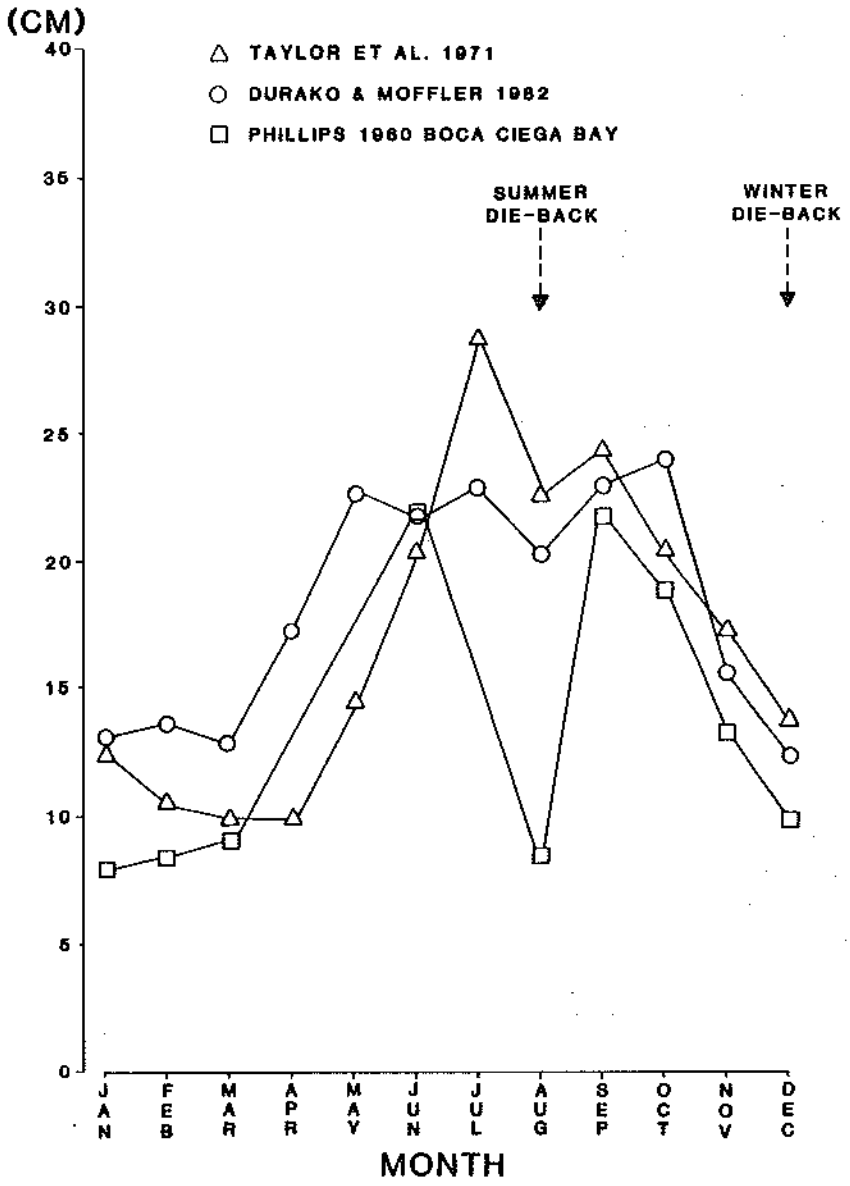

Figure 9. Monthly leaf length of Thalassia testudinum in Tampa Bay.

Table 6. Biomass values for seagrasses in the Tampa Bay area.

SPECIES	Biomass (g dwt/m^2) ABOVE-GROUND	BELOW-GROUND	REFERENCE
Thalassia testudinum			
Boca Ciega Bay	32.4	48.6	Pomeroy 1960
Bird Key	325	-	Phillips 1960a
Cat's Point	98	-	Phillips 1960a
Boca Ciega Bay	636	-	Bauersfeld 1969
	320-1,198	-	Taylor and Saloman 1968
Tarpon Springs	601-819	-	Dawes et al. 1979.
Tampa Bay	0.41-52.7	-	Heffernan and Gibson 1982
Tampa Bay	25-180	600-900	Lewis and Phillips 1980
Syringodium filiforme			
Tampa Bay	5-11	-	Heffernan and Gibson 1982
Tampa Bay	50-170	160-400	Lewis and Phillips 1980
Halodule wrightii			
Tampa Bay	4-27	-	Heffernan and Gibson 1982
Tampa Bay	38-50	60-140	Lewis and Phillips 1980
Ruppia maritima			
Tampa Bay	1.48	18-48	Lewis and Phillips 1980

production of Thalassia range from 200-4,650 g C/m^2 (Odum 1957; Phillips 1974). The higher values exceed the productivity of all agricultural crops (Odum 1959) on a m^2 basis and are also greater than phytoplankton production in upwelling areas off Peru, which are considered some of the most productive in the world (Ryther 1969). Recent work in Tampa Bay using ^{14}C techniques has estimated production rates of Thalassia, Syringodium and Halodule during the fall to be an order of magnitude higher than previously reported: 95, 72.6 and 81.2 mg C/g dwt/h respectively (Heffernan and Gibson, pers. comm.). Areal production rates were calculated to be 0.05, 0.12 and 0.05 g C/m^2/day for Thalassia, Syringodium and Halodule using the radiocarbon techniques. Production values based on leaf growth range from 2-15 mg C/m^2/h for Thalassia, from 2-37 mg C/m^2/h for Syringodium, and from 0.9-1.4 mg C/m^2/h for Halodule near the Anclote River (Ford et al. 1974; Ford and Humm 1975).

The variation in productivity levels determined using oxygen, ^{14}C and leaf growth techniques demonstrates the difficulty involved in accurately measuring this parameter in seagrasses. Storage and recycling of O_2 and CO_2 in the internal lacunar spaces of these macrophytes can cause considerable errors when measuring production rates via O_2 and ^{14}C techniques (Hartman and Brown 1967). Stapling techniques for measuring leaf growth can be traumatic to the leaf and may affect basal growth (Ford and Humm 1975). Therefore, the values obtained should be viewed as estimates of relative rates rather than as absolute values. Also, most seagrass productivity rates are expressed as per m^2 without consideration of total area and production to a system.

Chemical Composition. Because of their high productivity and organic matter production, the chemical composition of the seagrasses has been analyzed by numerous investigators (Burkholder et al. 1959; Bauersfeld et al. 1969; Walsh and Grow 1972; Dawes et al. 1979; Dawes and Lawrence 1979, 1980; Durako and Moffler unpub.) These studies have revealed the presence of annual cycles in the levels of proximate constituents. These seasonal variations in the levels and the changes in allocation of the constituents within the plants are important energetic considerations because many animal communities depend either directly on the plants or on detritus derived from them (Fenchel 1970; Buesa 1974; Greenway 1974).

The chemical composition of Thalassia has been studied in more detail than the other locally occurring species (Tables 7 and 8). Walsh and Grow (1972), and Dawes and Lawrence (1980) reported that protein levels generally are highest during the spring and late summer, while carbohydrate, ash and dry weight levels peak in the fall. Durako and Moffler (unpub.) found slightly different seasonal patterns; protein and carbohydrate levels were low in spring and highest during fall and winter. Ash levels were lowest during the fall and late winter, and highest in mid-winter and summer. Dry weight levels of shoots and rhizomes decreased during the spring, a period of high growth, and increased to high levels in late summer and early fall. Dry weight of roots decreased from a peak in the spring to fall, then increased during the winter. The importance of spatial influences on seasonal patterns of chemical constituents was also demonstrated in this study. Distinctions between fringe and mid-bed samples were significant and of sufficient magnitude to alter apparent seasonal cycles. These spatial differences may represent successional gradients in which colonization occurs on the fringe and maturity is approached in the interior of the bed.

Protein levels in Thalassia are highest in leaves, shoots and roots, reflecting biosynthetic activities. Carbohydrate levels are greatest in rhizomes, which function as storage organs (Tables 7 and 8). In this regard, leaf cropping results in decreased carbohydrate levels as the reserves are utilized in blade regeneration (Dawes et

Table 7. A comparison of proximate constituent values of Thalassia testudinum in the Tampa Bay area.

Dry weight (% fresh wt)	Ash (% dwt)	Protein (% dwt)	Carbohydrate (% dwt)	Lipid (% dwt)	Reference
Leaves					
-	24.8	13.0	35.6	0.5	Burkholder et al. 1959
8-19	46-50	9-12	38.0	0.7	Bauersfeld et al. 1969
15-20	30-40	3-12	3-12	-	Dawes et al. 1979
15-22	33-43	5-15	5-10	-	Dawes and Lawrence 1979
15-20	29-44	8-22	6-9	0.9-4	Dawes and Lawrence 1980
Short Shoots					
12-12.9	47-56	3-10	8-12	-	Dawes and Lawrence 1979
9-12	24-42	2-5	9-16	-	Durako and Moffler 1982
Rhizomes					
6	50	9.6	-	-	Bauersfeld et al. 1969
14-21	21-37	5-12	21-51	-	Dawes and Lawrence 1979
14-18	24-36	7-16	12-36	0.2-1.6	Dawes and Lawrence 1980
15-17	19-27	1-3	19-32	-	Durako and Moffler 1982
Roots					
11-15	26-36	2-5	9-16	-	Durako and Moffler 1982

Table 8. Chemical composition of Syringodium filiforme, Halodule wrightii, and Ruppia maritima in Florida.

Dry weight (% fresh wt)	Ash (% dwt)	Protein (% dwt)	Carbohydrate (% dwt)	Lipid (% dwt)	Reference
S. filiforme					
leaves:					
17-21	28-33	8-13	16-22	1.7-6.2	Dawes and Lawrence 1980
short shoots:					
13-18	27-41	10-14	13-27	0.9-3.6	
rhizomes:					
14-26	16-19	5-12	36-50	0.1-4.7	
H. wrightii					
leaves:					
16-27	25-32	14-19	13-19	1.0-3.2	Dawes and Lawrence 1980
short shoots:					
13-19	25-36	5-9	16-31	0.8-3.5	
rhizomes:					
20-30	14-22	7-9	40-54	0.1-1.6	
R. maritima					
leaves:					
-	16-24	11-26	20-28	-	Walsh and Crow 1972
rhizomes:					
19-25	19-25	11-21	40-57	-	

al. 1979; Dawes and Lawrence 1979). Protein levels are higher and ash levels lower in the regenerated blades due to the presence of new growth and the absence of epiphytes (Dawes and Lawrence 1979).

Caloric (i.e. energy) values are similar for all four species, averaging approximately 3.5 kcal/g dwt for leaves and 3.7 kcal/g dwt for rhizomes (Walsh and Grow 1972; Dawes and Lawrence 1980). These values are comparable to those of other seagrasses (McRoy 1970; Birch 1975; Harrison and Mann 1975). No seasonal patterns have been reported for energy levels, indicating that although proximate composition varies seasonally, the energy contents of the plants remain unchanged.

REPRODUCTIVE ECOLOGY

Seagrasses exhibit two modes of propagation, vegetative and sexual. Thalassia testudinum, Syringodium filiforme, Halodule wrightii and Halophila spp. are hydrophilous, producing flowers under the water surface with submarine pollination. Ruppia maritima produces flowers which anthese at the water surface and has hydroanemophilous pollination.

The majority of the past work on Florida seagrass reproductive biology has principally concerned descriptive floral morphology and anatomy (Phillips 1960a; Orput and Boral 1964; Tomlinson 1969; Tomlinson and Posluszny 1978), reproductive physiology (Marmelstein et al. 1968; McMillan 1980; Phillips et al. 1981), and seed occurrence and seed reserves (Lewis and Phillips 1981; McMillan 1981). Except for brief commentaries in Phillips' 1960 publication on seagrass ecology and distribution, research on seagrass reproductive ecology has only recently been published for Florida populations (Grey and Moffler 1978; Moffler et al. 1981; Phillips et al. 1981).

Studies on the reproductive biology of Tampa Bay seagrasses have primarily been confined to Thalassia testudinum. Phillips (1960a) did not find reproductive Halodule, Syringodium or Halophila in the Tampa Bay system. We (Moffler and Durako) have collected several male specimens of Halodule in June at Sister Key off Bunces' Pass. However, Phillips et al. (1974) and McMillan (1976) found abundant reproductive Halodule in Texas during the summer. Intensive collection efforts are needed in order to determine the reproductive dynamics of Halodule in Tampa Bay.

With regard to the other species, McMillan (1981) suggested that Syringodium filiforme floral initiation occurs during late fall or early spring in Gulf of Mexico and Caribbean populations, with fruits occurring from January through June. Although reproductive material was rare, we (Moffler, Durako and Lewis) have collected female specimens of Syringodium during May at Lassing Park and Egmont Key. McMillan (1981) speculated that the rare flowering of Gulf and Caribbean Syringodium may be related in part to nutrient conditions. He observed highest fecundity in populations in coarse sediments at St. Croix, U.S. Virgin Islands, and Texas, and lowest flowering in areas with high silt accumulations.

Although reproductive Halophila has not been found in the isolated populations of Tampa Bay, McMillan (1976) has documented extensive flowering in Redfish Bay, Texas. He indicated that a coincidence of day length, salinity and temperature were critical for reproduction.

Phillips (1960a) reported the occurrence of abundant flowering Ruppia in Tampa Bay. Flowering and fruiting typically occur in May and disappear in June in these populations. Although Phillips did not observe Ruppia seedling germination and development, he speculated that because flowers and fruits are so abundant, colonization of new areas and expansion of existing beds are quite likely. We (Moffler and Durako) have observed apparent expansion of the Ruppia population at Lassing Park, but do not have quantitative data for documentation. The growth habit of Ruppia with its

profusely branched rhizomes, and its ability to rise off the bottom toward the surface (reaching better light conditions and allowing sexual reproduction), are conducive to survival in Tampa Bay. Since Ruppia is the major component of an ephemeral meadow, areal expansion of this species in Tampa Bay may occur if seagrass meadow degradation continues.

The majority of the literature concerning seagrass reproductive biology in Tampa Bay concerns the dioecious Thalassia testudinum. Phillips (1960a) was the first to publish such information. He found flowering Thalassia on several occasions during his survey of Tampa Bay seagrasses and reported that ten percent of the plants collected in Boca Ciega Bay on May 22, 1958 were flowering. In a large grass flat off Lassing Park, he observed only a very restricted patch of flowering plants. He further pointed out that when Thalassia was in flower, only one sex was observed and no mixing of sexes occurred, which might explain the lack of fruits and seeds in this population. Phillips (1960a) was also the first to report the occurrence of Thalassia seedlings at our latitude at Anclote Key.

In 1976, Grey and Moffler (1978) conducted the first quantitative study of flowering Thalassia populations in Tampa Bay and surrounding waters. Nine sites were surveyed in the Tampa Bay area (Fig. 10); six of these were in the bay proper. Flowering occurred at all sites with females predominating over males at a ratio of 3:1. In addition, they found flowering density to vary independently of short shoot density. Patchiness in the spatial distribution of reproductive short shoots was also noted.

In January 1979, Durako collected Thalassia testudinum short shoots with immature fruits at Lassing Park (Moffler et al. 1981). The presence of fruits at this time of year represented a possible phenological inversion for this species, since fruits of this size are normally found in June. In addition to the early fruits, Moffler et al. (1981) also reported the presence of early immature reproductive buds in January. This was the first report of flower buds of Thalassia occurring in mid-winter. These early buds continued to develop and anthesis occurred during May and June, the typical time for the species.

Phillips et al. (1981) conducted a phenological investigation of Thalassia from selected sites in the western tropical Atlantic, including Tampa Bay, from February 1976 to April 1979. Based on field and laboratory studies, they indicated nearly synchronous flowering of Thalassia at different latitudes which was related to an indigenous temperature regime and natural photoperiod. They suggested that flowering was primarily related to temperature progressions following winter minima. These temperature responses may be genotypically different, thereby accounting for a nearly synchronous anthesis at different latitudes.

Work is continuing on Thalassia testudinum reproductive ecology in Tampa Bay (FDNR, Marine Research Laboratory, St. Petersburg). Investigations to date have indicated the following:

- Unpublished data collected by Moffler and Durako indicates that floral initiation in Tampa Bay populations of Thalassia may occur in late summer or early fall. Inflorescence growth is slow over winter and increases logarithmically during March and April with anthesis occurring during May and June. However, throughout this time period early developmental stages of inflorescences occur which may indicate genetic diversity for floral induction, and that T. testudinum may be a day neutral plant.

- The distribution of sexually reproductive Thalassia shoots within populations is typically patchy or clustered. The Lassing Park population, however, has one of the highest percentages of reproductive short shoot density reported for this species (average 23.05%, range 0-92.31%). One of the Lassing Park

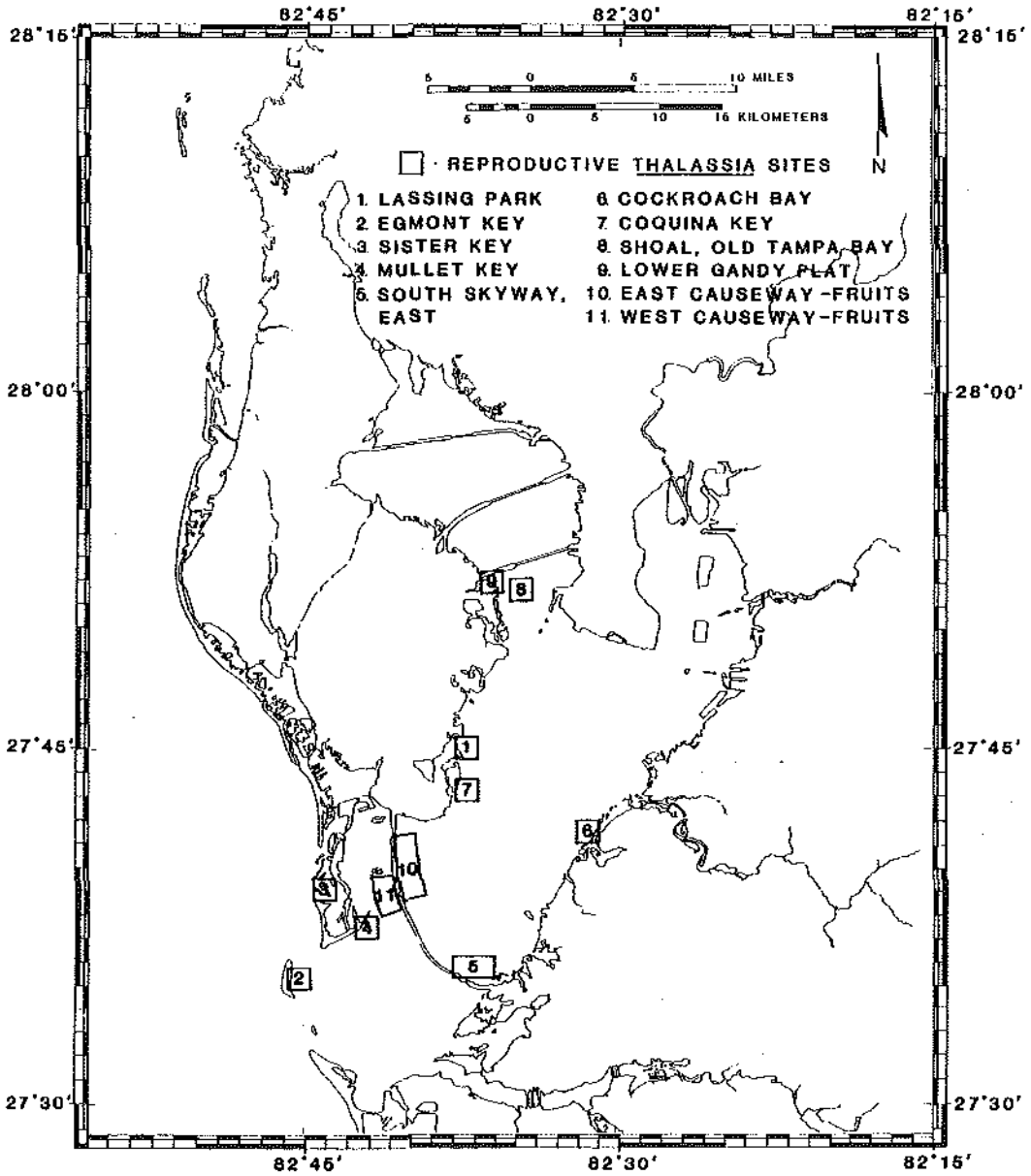

Figure 10. Reproductive Thalassia sites in Tampa Bay.

Thalassia meadows studied (circular bed) was comprised of all female shoots, while surrounding Thalassia beds contained both males and females. Yet, a puzzling phenomenon at the Lassing Park site is the lack of fruit and seed production. When looking at percentages of male and female short shoots in anthesis over time we find females in anthesis first, followed by male anthesis. Percentage of females and males in anthesis peaks at the same time and females are in anthesis past the time of male anthesis; therefore, there should be ample opportunity for pollination and fertilization to occur. The seagrass meadows at Lassing Park are shallow and during low tides water temperature becomes high (35°C). These conditions may inactivate the pollination process or possibly lead to fruit abortion due to pathogens; a high percentage of decaying inflorescences has been observed. It is unclear, however, whether decay is a cause or effect phenomenon. On the other hand, Egmont Key populations complete their reproductive cycle and produce viable seed. This population is at a site with good flushing and more stable temperatures and salinity, with perhaps less opportunity for disease.

Thalassia testudinum seed production in Tampa Bay is apparently confined to areas south and west of Pinellas Point. Fruits have been collected in the beach wrack along the Skyway causeway, Mullet Key and Egmont Key. Large numbers of fruits have never been found during the last 5 years of collecting in these areas; typically less than 100 fruit (200-300 seed) are collected in any one year. Seed production in Tampa Bay is apparently quite low compared to that in Biscayne Bay and the Keys (Lewis and Phillips 1981). It appears that quantities are insufficient for restoration efforts.

Further research is needed on seagrass reproductive biology and ecology in Tampa Bay. Information on the role of sexual reproduction in seagrass population maintenance and distribution is critical. These studies should include reproductive phenology and the role of seed reserves. In addition to furthering our knowledge of the reproductive dynamics of Thalassia, information on the reproductive biology and ecology of the other seagrass species is enthusiastically encouraged.

MANAGEMENT PROBLEMS

Documentation of Functional Role. The functional role of seagrass meadows in the Tampa Bay ecosystem is essentially unknown. From 12 box cores taken at four stations (three with seagrass) in Boca Ciega Bay in August 1964 (Taylor and Saloman 1968), infaunal biomass (excluding large molluscs and crustaceans) was estimated to be 137 g/m^2 (dry weight) for well-vegetated bottoms in comparison to 12 g/m^2 for the three replicates taken in an unvegetated area. Sieve size for these samples was 0.701 mm. Santos and Simon (1974) sampled quarterly for one year in a seagrass meadow and adjacent sand areas and found the greatest density of polychaetes (mean = 33,485/m^2) at the Thalassia stations, second highest at the inshore sand stations (mean = 17,220/m^2) and third highest at the Halodule stations (mean = 13,313 g/m^2). The two sets of offshore sand zone stations had much lower densities (means of 4,934 g/m^2 and 3,231 g/m^2). It is quite probable that the high densities at the inshore sand station were due to the seagrass and algal wrack decomposing along the shore and providing a rich detrital food source not available at the two offshore sand stations.

Routine fish sampling in Tampa Bay (Springer and Woodburn 1960; Springer 1961) has resulted in the identification of 271 species. Springer and Woodburn (1960, p. 97) noted that:

> The characteristic ecological features of the shallow bay habitats we studied are the presence of heavy bottom vegetation (seagrass and algae) and moderately high and stable salinities ... The fish fauna decreases also in

numbers and species with the change from summer to winter. The decrease is probably associated as closely with the decrease in flora as temperature, for even in summer the areas over the sandy bottoms contain few fish. The majority of the fish present are either young or small; the adults of most species eluded capture with the equipment used.

Individual species accounts in the same reference indicate the importance of seagrass habitat to certain species. Regarding the sheepshead, Archosargus probatocephalus (Walbaum), "we found them (young to about 50 mm) primarily in Diplanthera (Halodule) beds" (p. 64); the speckled trout, Cynoscion nebulosus (Cuvier), "spends most of its life over the grass flats ... juvenile stomach contents were comprised mainly of crustaceans: mysids, copepods, and especially caridean shrimp" (p. 52); and the pinfish (Lagodon rhomboides L.), "one of the most ubiquitous and plentiful species in the Tampa Bay area ..." (p. 65), they noted was very abundant in seagrass meadows. This species is noted as an important item in the diet of larger predatory fishes such as snook.

Unfortunately, beyond these few studies there have been essentially no quantitative faunal collections in seagrass meadows in Tampa Bay. Work in other parts of Florida (Carr and Adams 1973; Stoner 1979; Zimmerman et al. 1979; Gore et al. 1981; Greening and Livinston 1982; Zieman 1982) has shown the value of seagrass meadows and their associated invertebrate and fish communities; such data is vital to more fully understand the functional role of seagrasses in Tampa Bay.

Current Status. As indicated previously, large declines in seagrasses have occurred in Tampa Bay. Vital questions presently unanswered are the reasons for these losses (beyond actual burial or excavation), and whether they are continuing.

Concerning the first question, a number of hypotheses have been generated. These include biocide accumulations, stingray or manatee feeding damage, erosion due to increased boat wakes, and reduction in downwelling light reaching seagrass leaves due to phytoplankton, algal blooms, and turbidity. Figure 11 shows the relative chlorophyll a concentrations for the major subunits of Tampa Bay measured monthly between 1972 and 1981. It is apparent that there is an order of magnitude difference between those areas at the mouth of Tampa Bay (2-3 mg/l) and Hillsborough Bay (20-30 mg/l). Hillsborough Bay has historically received large amounts of treated and untreated sewage and urban runoff, and presently supports no perennial seagrass meadows. Only scattered ephemeral beds of Ruppia are found there. The lower portions of Tampa Bay, with lower average chlorophyll a levels, presently do support relatively healthy seagrass meadows. In addition, massive blooms of marine macroalgae were documented in the mid-1960s (FWPCA 1969) in Hillsborough Bay and continue to reappear (Lewis et al., in press). These were attributed to high nutrient (nitrogen, phosphorus) levels due to minimal sewage treatment in the 1950s and 1960s, but more advanced sewage treatment begun in 1978 has not apparently reduced the incidence of algal blooms. Competition among several groups of primary producers (microalgae, macroalgae, and seagrasses) has been documented to result in declines in seagrasses in favor of microalgae in the form of phytoplankton or epiphytic algae on seagrass blades (Sand-Jensen 1977; Cambridge 1979).

However, most of the work on eutrophication and the resulting changes in aquatic plant communities has been done on freshwater systems (Davis and Brinson 1980; Spence 1982) and thus much remains to be learned about these problems in marine ecosystems. Guist and Humm (1976, p. 270) reported that the macroalgae Ulva lactuca L., from Tampa Bay, grew progressively faster in increasing concentrations of sewage effluent and noted that as the water temperature rises, "Ulva growth slows

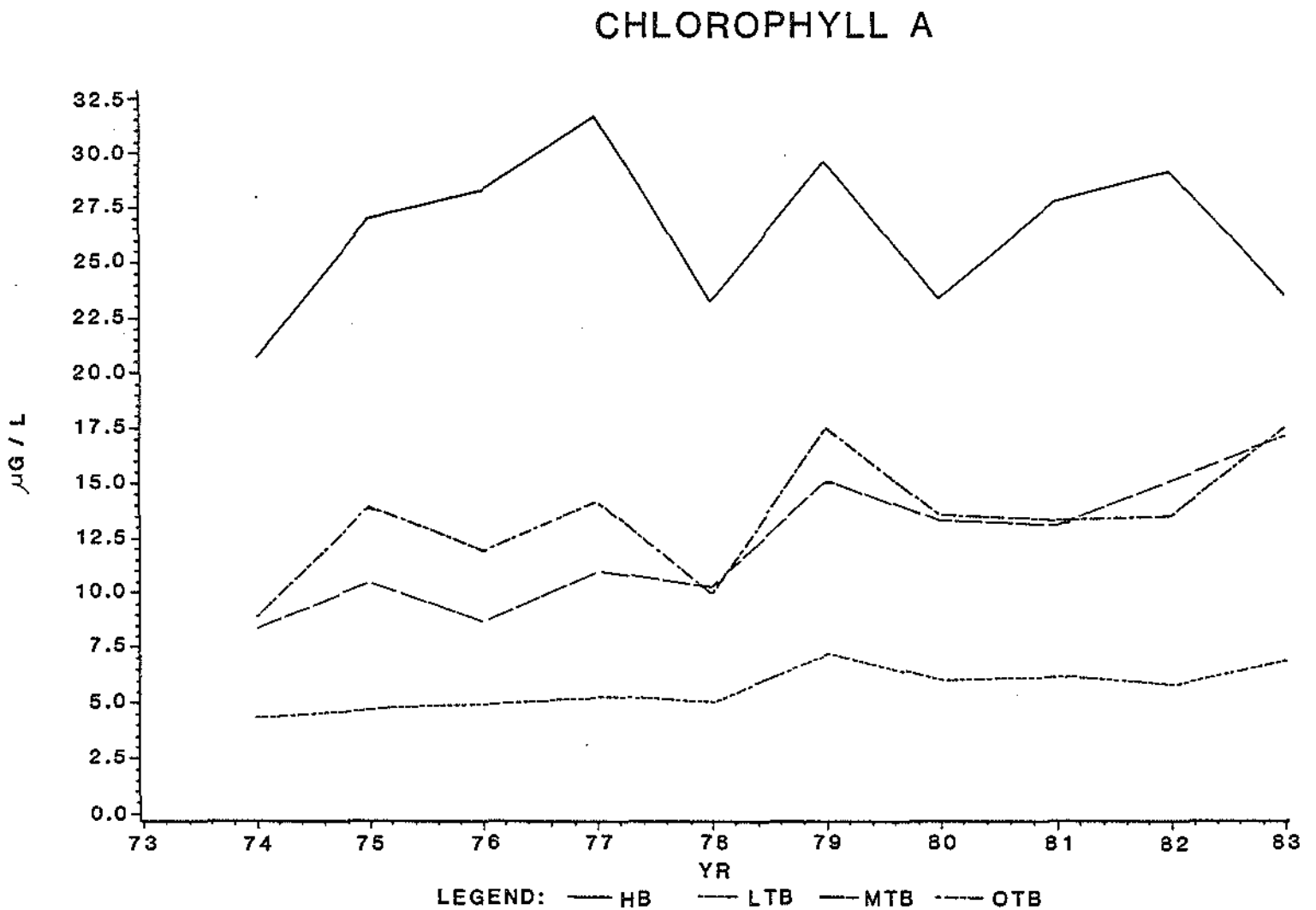

Figure 11. Chlorophyll a concentrations in major portions of Tampa Bay. HB - Hillsborough Bay; LTB - Lower Tampa Bay; MTB - MiddleTampa Bay; OTB - Old Tampa Bay.

and loose masses ... are widely distributed by tidal currents ... these masses remain over seagrass beds long enough to kill seagrass beneath them ... sheets of Ulva up to 10 ft in diameter will develop in early spring."

In light of the lack of research on other factors, progressive eutrophication and reduction in downwelling light reaching seagrass meadows due to absorption by more abundant micro- and macroalgae appears to be the most viable hypothesis concerning declines in seagrasses in Tampa Bay. Research on the other hypotheses should be conducted, but only after the questions of the role of nutrients and algae in Tampa Bay and the contribution of algal by-products and resuspended sediments to "turbidity" are answered.

Concerning the second question, regular monitoring (at least every two years) of the areal extent of seagrass meadows in Tampa Bay should be conducted to determine if their decline is continuing. Thompson (1981) noted the continuing disappearance of meadows of Syringodium in upper middle Tampa Bay in 1979-80. This is not an encouraging sign, particularly since a monitoring program conducted by the U.S. Army Corps of Engineers (Jacksonville District) designed to detect such losses failed to document their disappearance.

Potential for Restoration. Techniques for the replanting of seagrass meadows damaged or eliminated by man's activities have been investigated for 35 years (Phillips 1982). Twelve species of seagrass around the world have been tested for their suitability in restoration projects. Some success has been achieved using the three dominant species in Tampa Bay: T. testudinum, H. wrightii, S. filiforme (Phillips and Lewis, in press). Small scale experimental work on seagrass transplantation has been conducted by a number of researchers in Tampa Bay since 1968 but no large scale attempts to restore significant areas of seagrass in Tampa Bay have been attempted. The reasons for this are twofold. First, no program or agency has any responsibility for "restoring" lost habitat in Tampa Bay and thus no funds are available presently for such work. Secondly, because of the previously discussed problems of water quality degradation, it is not possible to presently identify, with any confidence, areas of barren bay bottom that might now support seagrass meadows. Obviously, if downwelling light has been reduced to the point that seagrasses disappeared and light levels remain low, then it would be a waste of time to try and replant seagrasses in those areas.

On the other hand, due to the low level of successful sexual reproduction of seagrasses in Tampa Bay, few seeds are produced to recolonize barren bay bottoms if downwelling light levels have improved. For this reason, it is recommended that restoration plantings using the latest technological advances in this field be employed to install test plantings along a gradient from relatively clean water at the mouth of the bay to more polluted areas in or near Hillsborough Bay. Such a gradient of installations, properly monitored, could relatively quickly indicate the potential for restoring seagrass meadows in Tampa Bay through active planting efforts.

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SEAGRASS PRODUCTIVITY IN TAMPA BAY: A COMPARISON WITH OTHER SUBTROPICAL COMMUNITIES

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ABSTRACT

Comparisons of primary production rates for Thalassia testudinum, Syringodium filiforme and Halodule wrightii were made for Tampa Bay and Indian River, Florida, and the west end of Grand Bahama Island, Bahamas, in October 1981 and February 1982. Comparisons were also made for the corresponding seagrass epiphytes, benthic microalgae and phytoplankton. Tampa Bay seagrasses showed the highest productivity rates on both a gravimetric and areal basis. Productivity estimates for all three species were an order of magnitude higher than ever reported in the literature. The values in October ranged from 72.6 mg C/g dry wt/hr for S. filiforme, 81.2 for H. wrightii, and 95.0 for T. testudinum. Thalassia dominance was also shown with a productivity rate of 5.2 g $C/m^2/hr$ which was two times higher than Bahamas grass beds (2.3) and 40 times higher than Thalassia beds in the Indian River (0.1). In February, productivity rates for the three seagrasses in Tampa Bay were 6.64 mg C/g dry wt/hr (Thalassia), 9.6 (Syringodium) and 2.98 (Halodule). While Syringodium had the highest gravimetric productivity, the large biomass of Halodule (26.9 g/m^2 vs. 5.4 for Syringodium) made this species the dominant seagrass on an areal basis (0.1 g $C/m^2/hr$ vs. 0.054 for Syringodium). Thalassia biomass was low in February (0.41 g/m^2) and the blades were heavily covered with bryozoans. Productivity rates for Thalassia were 6.6 mg C/g dry wt/hr and 0.004 g $C/m^2/hr$. In general, Tampa Bay seagrasses had more epiphytic biomass than seagrasses in the Indian River and Bahamas. In February, 76% of the weight of a seagrass blade was epiphytic in Tampa Bay compared to 29% and 26% in the Indian River and Bahamas, respectively. Productivity of benthic microalgae and phytoplankton were highest in Tampa Bay and lowest in Bahamian waters.

EMERGENT VEGETATION

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INTRODUCTION

Plants growing in tidal wetlands are the most conspicuous element of the coastal landscape associated with Tampa Bay. The mangroves are short to tall, densely foliated trees growing as solitary individuals, narrow bands, wide forests, or islands around the Bay. Salt marshes are the low, broad grassy meadows growing on protected shorelines and backwaters of tributaries to the Bay. Marshes and mangroves also occur together in a complex mosaic of forms, depending on local conditions.

Dominant mangroves are the red, Rhizophora mangle; black, Avicennia germinans; and white, Laguncularia racemosa forms. Smooth cordgrass, Spartina alterniflora, and black needlerush, Juncus roemerianus, are the principal tidal marsh species around the Bay (Fig. 1). The buttonwood, Conocarpus erectus, and leather fern, Acrostichum danaeofolium, are occasionally found in mangrove or marsh communities, respectively. These species are well studied throughout their ranges. Valuable summaries of information on mangroves can be found in Lugo and Snedaker 1974; Walsh 1974 and Odum et al. 1982. Comparable reviews for salt marsh literature have been prepared by Chapman (1974) and Reimold (1977).

Mangrove and salt marsh communities occur throughout the lower west coast of the Florida peninsula. The largest mangrove forests and continuous salt marshes are located south of Charlotte Harbor to Florida Bay. North of Tampa Bay mangrove abundance declines and salt marsh is the dominant emergent tidal wetland. Red and white mangroves may be found as far north as Cedar Key if the winters of antecedent years have been mild. Black mangroves grow beyond Cedar Key, across the northern Gulf coast, as scattered shrubs but are not organized as forests north of Pasco County. We consider the inner shorelines of Tampa Bay to represent the northernmost assemblages of red or white mangroves as forest on the Florida west coast. Tampa Bay does not represent a significant geographical point in the dispersion of either salt marsh species.

DISPERSION IN THE BAY

The general modern dispersion of emergent vegetation in Tampa Bay is shown in Figure 2. Major stands occur in Upper Old Tampa Bay (marsh dominated); the east shore of the Pinellas peninsula; in and near the mouth of the Little Manatee River, including Cockroach Bay; and the Terra Ceia area (all mangrove dominated). Well developed tidal marshes are also found upstream in the Alafia, Little Manatee, Manatee and Braden Rivers, where mangroves are few and evanescent.

McNulty et al. (1972) reported 1,728 acres of saltwater marsh and 17,514 acres of mangroves in the Bay as a whole. Using more sophisticated techniques but different boundaries, the National Wetland Inventory (NWI) has mapped 23,065 acres of mangroves and 3,127 acres of marsh in the Bay area. For perspective, the NWI estimate of 10,095 acres of mangrove in the

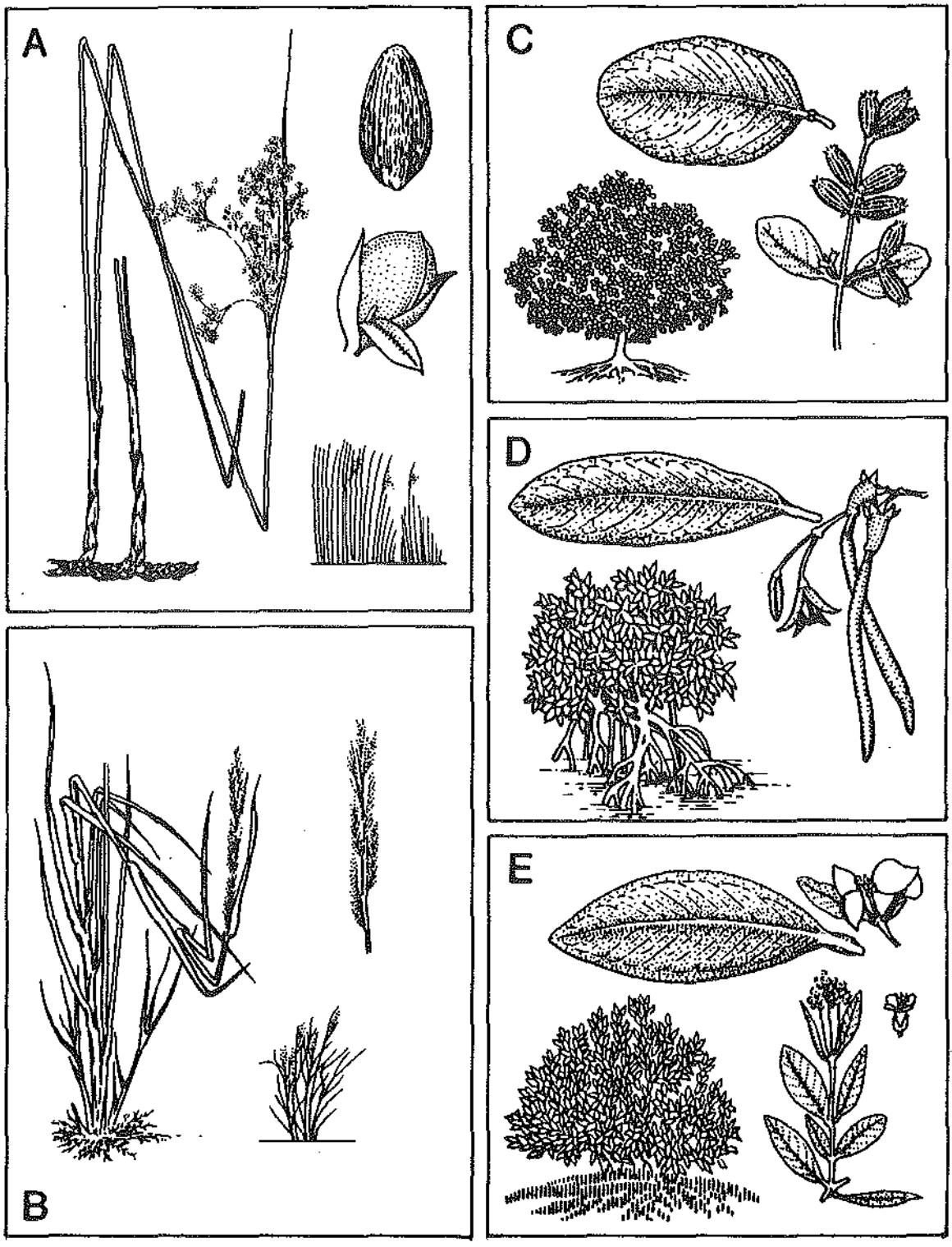

Figure 1. Dominant mangrove and salt marsh species in Tampa Bay. A, Juncus roemerianus (black needlerush); B, Laguncularia racemosa (white mangrove); C, Spartina alterniflora (smooth cordgrass); D, Rhizophora mangle (red mangrove); E, Avicennia germinans (black mangrove). Adapted from Eleuterius (1980) and Odum et al. (1982).

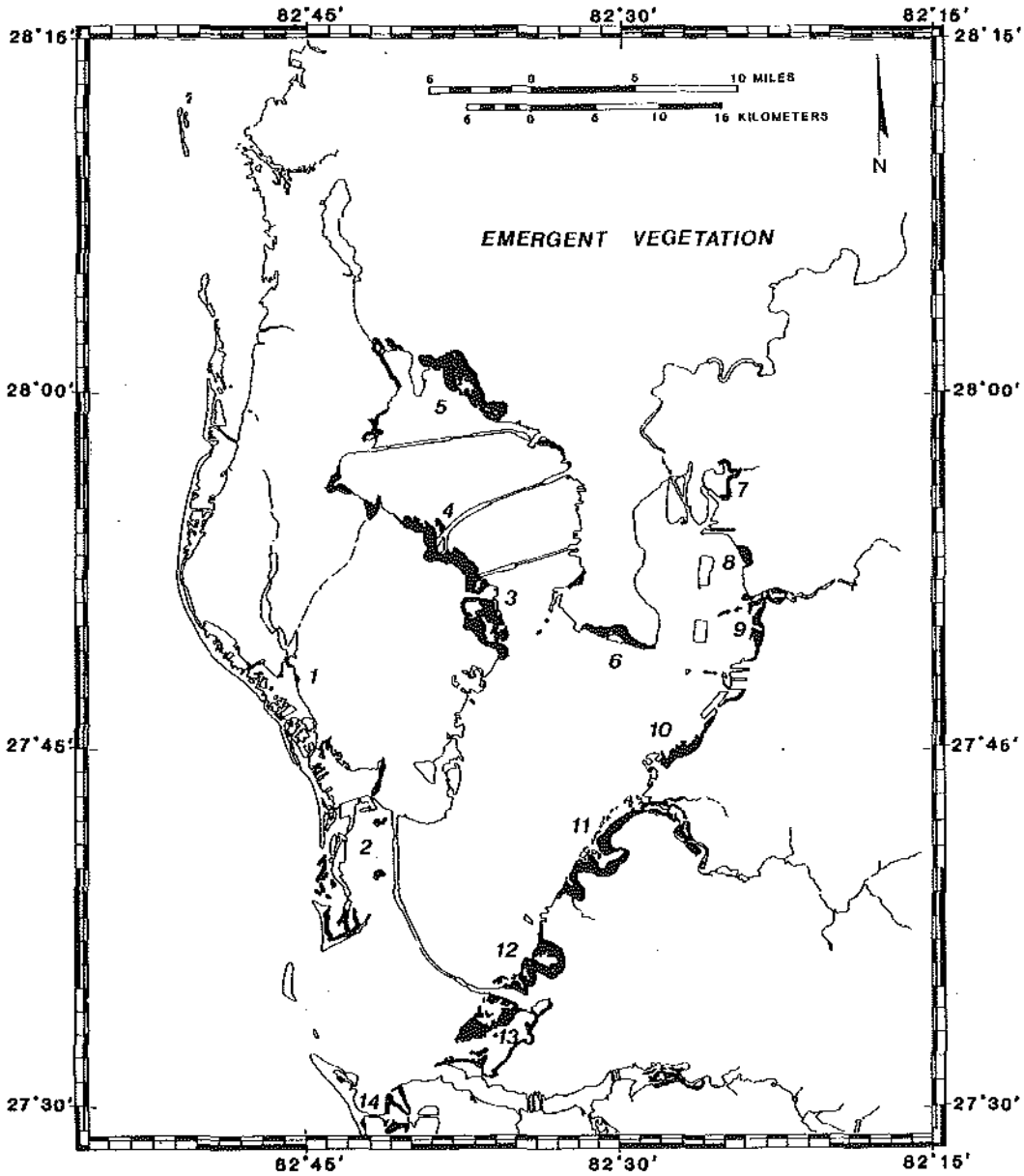

Figure 2. The generalized dispersion of mangrove forests and tidal marshes in Tampa Bay. Names of numbered areas are listed in text.

Hillsborough County portion of Tampa Bay compares well with the Sipe and Swaney (1979) estimate of 10,063 acres for the same area. Tidal vegetation was historically more abundant and widely dispersed than today, although at no time in recent geologic history were all Bay shorelines vegetated by marsh or mangrove. For example, headlands on estuarine shorelines (e.g. Piney Point) and the eastern shores of Pinellas and Interbay Peninsulas were instead vegetated by cedar forests or pine flatwoods ending abruptly at the water's edge. The exact dispersion of historical forests and marshes is not known. Sipe and Swaney (1979) depicted 5,358 acres of salt marsh and 10,063 acres of mangrove for Hillsborough County in 1820. Lewis (1976) measured 13,906 acres of marsh and mangrove excluding the upper area of the Manatee River. Historical coverage was estimated to be approximately 25,000 acres. Shoreline modification has resulted in fragmentation of remaining bayshore mangrove and marsh into discrete patches which for convenience we will name as: 1) Upper Boca Ciega, 2) Lower Boca Ciega, 3) Weedon Island Complex, 4) Gateway, 5) Upper Old Tampa Bay, 6) Interbay, 7) McKay Bay, 8) Archie Creek, 9) Alafia to Kitchen Complex, 10) Wolf Creek, 11) Little Manatee and Cockroach Bay, 12) Bishop Harbor, 13) Terra Ceia and 14) Perico units. Other bayshore stands are referred to as fragments. The structurally intact marshes of the Alafia, Little Manatee, Manatee and Braden Rivers, and their tributaries, are also designated as discrete units.

FOREST TYPES

Lugo and Snedaker (1974) have classified mangrove assemblages into six forest "types" based on the influence of environmental factors, appearance of the vegetation, and community energetics (Fig. 3). Not all mangrove stands in Tampa Bay are easily categorized by this system but in general most forests resemble the "fringe" forest type of Lugo and Snedaker (1974) wherein the plant assemblages:

- grow on mainland shorelines of gradual slope;
- are exposed to tides but are not daily overwashed;
- have sluggish internal water flow on high tides, and minor to no scouring; and,
- export particulate as well as labile organic matter.

The "overwash" mangrove forest type is well developed along the north shore of Upper Old Tampa Bay and the east shore of Lower Tampa Bay, especially in Cockroach Bay. The salinity and velocity of water in overwash forests is higher than in fringe forests, and islands are completely inundated by daily tides. Overwash islands are often uniform stands of red mangrove, although some black mangroves may be present. As explained below, fringe forests may contain mixtures of all local mangrove species or be monospecific.

Mangroves grow on mainland banks in the mouths of rivers but we regard these as extensions of the fringe form rather than the "riverine" forest type of Lugo and Snedaker (1974). Where upriver but tidal habitat is available for the development of the riverine forest one instead finds Juncus marshes.

One new forest type may be appropriate for mangrove assemblages in Tampa Bay, the "shrub" form created by repetitive freezes, water stress, and other factors (Fig. 3). As another forest type it is distinguished equally by energetics and physiognomy. Depending on regional climate trends and micrometeorology, the shrub forests may be ephemeral or permanent features of the Bay shorelines. Provost (1967) described this type as "scrub-marsh" and noted its occurrence around Tampa.

The shrub forest grows primarily on mainland shorelines, like fringing forests. It is comprised of a mixture of red and black mangrove, the reds being shorter and denser in aspect. The forests are low, often averaging 2-3 meters. Lugo and Zucca (1977) related temperature stress to decreased leaf size and number, and increased tree density.

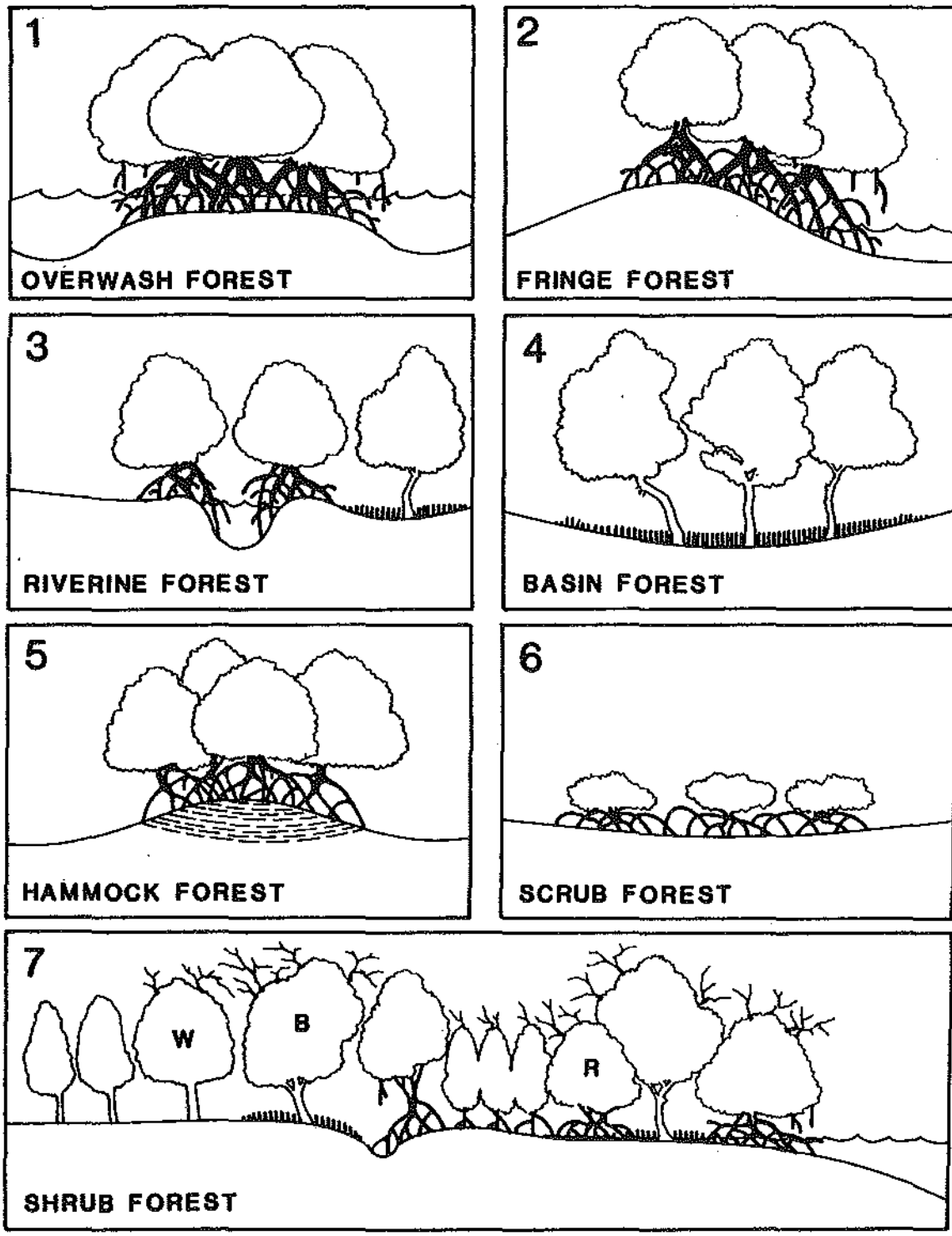

Figure 3. Mangrove forest types described by Lugo and Snedaker (1974). Forests in Tampa Bay are primarily overwash or fringe types, or a "shrub" type described in text under Forest Types.

These features are typical of shrub forests in the Bay. Dead limbs of both red and black mangroves, killed by previous frosts, are frequently evident above the live canopy. The shrub forest may support epiphytes or fungal galls, or both. Inundation is variable but commonly disrupted by drainage ditches dug for mosquito control. Examples of shrub forests are on the eastern shore of Tampa Bay north of Wolf Creek, including the stands in McKay Bay, and the Bower tract in Upper Old Tampa Bay.

MARSH TYPES

Regrettably little is known of the organization or functioning of tidal marshes in Tampa Bay. To our knowledge, only two Spartina marshes of consequence occur on the open bayshore, one near Double Branch Creek (Upper Old Tampa Bay) and the other at Archie Creek (Hillsborough Bay). Spartina grows less abundantly with Juncus, the dominant species in upriver marshes, but no quantitative data are available. Spartina standing crop in summer at Archie Creek was determined for 12 0.25 m^2 quadrats and averaged 1,222 g (dry wt)/m^2, about the same as the long-term mean for Spartina near Crystal River (Montague, unpublished data). No standing crop data for Juncus are available for Bay marshes.

COMMUNITY GROWTH

The expansion or reduction of mangrove forest area for natural reasons has not been studied extensively. A central question in this regard is the role of salt barrens (also called salterns) relative to upland forest expansion. Sipe and Swaney (1979) tabulated a remarkable doubling of saltern area in Hillsborough County from 1820-1948, from 654 acres to 1,197 acres, with most increases from Big Bend south to Piney Point. Loss of coastal strand at Piney Point has been popularly attributed to storms and this may be the cause of saltern growth, either by upland or wetland damage. Freeze damage may be involved in saltern growth and rising sea level effects must not be discounted.

Estevez (1978) examined changes in area along the seaward edge of overwash islands and fringe forests in Cockroach Bay, over the period 1938-1976, and found that canopy cover shown in aerial photographs varied little overall, but that more growth than loss was evident. Prior to 1957, canopy coverage increased at the mouth of Cockroach Creek and there was some island growth or fusion in the middle Bay. From 1958 to 1976 new mangrove growth was observed in Little Cockroach Bay.

STRUCTURE

Major areas vegetated by mangroves in Tampa Bay vary by species composition, size and condition (Table 1). Compare the size of small white mangroves at Double Branch Creek to those growing between Piney Point and the Manatee River. It can be seen in Table 1 that black and white mangroves are conspicuous elements of many mangrove forests in the Bay. The presence of Juncus in or near these forests is also noteworthy. The size of each mangrove species has been tabulated as a function of forest type by Williamson and Mosura (1979) in Table 2. The tributary or shrub forest type is used in place of riverine forests as the mangroves on tidal creeks and rivers with low base flows do not truly reflect the riverine forest structure described by Lugo and Snedaker (1974). It can be seen from Table 2 that all three species occur in both fringe and shrub forest types, but that white mangroves are not common on overwash islands. Otherwise, there are no structural differences which can be attributed solely to forest type. (This statement does not apply to sediment characteristics or community energetics, however.)

ZONATION

The zonation of a large forest at one place in Tampa Bay has been worked out by Detweiler et al. (1975) (Table 3). In this study a transect of 1,440 m was mapped across 38 wetland species growing from the subtidal to high

Table 1. Summary of mangrove forest characteristics in selected study areas of Tampa Bay. Types of mangrove: R, Rhizophora mangle (red mangrove); B, Avicennia germinans (black mangrove); W, Laguncularia racemosa (white mangrove). Marsh types: J, Juncus roemerianus; S, Spartina alterniflora. DBH, diameter at breast height. Adapted from Williamson and Mosura (1979).

Area	Fringe Mangrove Types	Freeze Damage	Avg. Drainage	Avg. Canopy Ht., m	DBH, cm	Zonation	Marsh Type
Boca Ciega Bay	R, A	moderate	major	-	-	-	J, S
Weedon Island/ Gateway	R	severe in patches	extensive	-	-	yes	absent
Cooper Point	R	mild to moderate	moderate	2.9 (R)	2.43 (R)	no	absent
Double Branch/ Bower	L	severe	minor	0.7 (L)	0.49 (L)	no	J, S
Interbay	R	mild	moderate	-	-	casual	absent
Alafia River North	L	severe	moderate	1.4 (L)	0.82 (L)	no	absent
Alafia - Little Manatee River	L, A	moderate	extensive	1.5 (L) 3.7 (A)	1.52 (L) 3.92 (A)	yes	J
Cockroach Bay	L, A	minor	moderate	4.4 (A)	5.17 (A)	yes	J, S
Piney Point - Manatee River	L, A	minor	minor to moderate	4.0 (L) 4.3 (A)	4.23 (L) 6.34 (A)	yes	-
Anna Maria Sound	L, A	minor	minor	-	-	no	absent

Table 2. Mangrove tree size by species and forest type in Tampa Bay, from Williamson and Mosura (1979).

Forest Type	Cumulative Mean D.B.H. (cm) Rhizophora	Avicennia	Laguncularia
Fringe	2.69 ± 2.26 (139)	4.59 ± 3.16 (186)	2.31 ± 2.64 (203)
Overwash	3.37 ± 2.04 (90)	5.27 ± 1.37 (7)	
Tributary	2.91 ± 2.01 (50)	1.85 ± 0.99 (17)	2.57 ± 0.38 (10)

Table 3. Elevation ranges and mean elevations of 10 plant species found in the control area (CA) of an undisturbed mangrove community near Wolf Creek. (Elevation in feet). From Detweiler et al. (1975).

Species	No. of Quadrats	Range	Mean Elevation
Rhizophora mangle	35	+1.6 - +0.2	+1.0
Avicennia germinans	49	+2.5 - +0.4	+1.5
Laguncularia racemosa	47	+2.5 - +0.7	+1.5
Spartina alterniflora	4	+1.7 - +1.6	+1.7
Salicornia virginica	10	+1.9 - +1.6	+1.7
Sesuvium portulacastrum	2	+1.7	+1.7
Limonium carolinianum	6	+1.7 - +1.6	+1.7
Batis maritima	14	+2.2 - +1.6	+1.8
Borrichia frutescens	2	+1.9	+1.9
Philoxerus verminicularis	5	+2.2 - +1.6	+1.9

intertidal habitat. In terms of their mean vertical distribution, red mangroves occurred in deepest water followed by black and white mangroves, then Spartina. It is interesting to note that although black and white mangroves both grew to an upper elevation of 2.5 feet, the lower limit of black mangroves was 0.3 feet below white mangroves. The narrow range of elevations occupied by Spartina alterniflora, Sesuvium portulaçastrum, Limonium carolinianum and Borrichia frutescens are also noteworthy in this context.

Data from Detweiler et al. (1975) are shown in Figure 4 for the control area transect in the mangroves south of Wolf Creek. Elevations relative to mean high water are also indicated. Rhizophora occurs seaward of other mangroves but little difference in the dispersion of Avicennia and Laguncularia was found. By means of other calculations it was found that although red and black mangroves occurred with low densities, their absolute and relative frequencies were sufficiently high (Table 4) to give all three mangrove species high importance value.

Except for areas severely affected by freezes or human disturbance, the well-mixed quality of mangrove species appears to be a prevalent attribute of forests in Tampa Bay. A typical fringe forest of mangroves in Tampa Bay can be described on the basis of data composited from Williamson and Mosura (1979; Table 5). Although the presence of Rhizophora in the front zone of the fringe forest is common, it is equally clear that white mangroves occur throughout the fringe and that even high forest areas may have as much as 49.5% red and black mangroves. The considerable intermixing of these species is caused in part by the low relief of shorelines in Tampa Bay and also by a recent rise in sea level, as shown by Figure 5. Rising sea level promotes the inland expansion of mangrove forests (as in salina expansion in Hillsborough County ca. 1820-1948) and promotes erosion of the seaward edge of fringe forests; moreover, rising sea level causes the dissection of overwash islands and the intermixing of black and red mangrove species along the forest edge (Scholl 1964).

The effects of rising sea level on forests growing on shores of low slope are aggravated by the effects of storms as at Beacon Key, Double Branch Creek, and other places around Tampa Bay where large black mangroves grow on the seaward fringe of the forest among small to medium sized red mangroves.

Freezes may also impart or confuse patterns of apparent zonation in a mixed mangrove stand by killing or stunting trees over small ranges of micrometeorological conditions. In other words, temperature differences through the forest, from bay to uplands or from canopy to forest floor, can cause stunting or death in trees during freezes, depending on wind, tide, or exposure. Odum et al. (1982) review the large literature surrounding zonation in Florida mangroves. Much historical interpretation of vegetative patterns has been discounted, and of the current views fewer still apply in Tampa Bay for the reasons described above. The idea by Rabinowitz (1978) - that patterns of zonation are the result of propagule sorting by tides - deserves examination in undisturbed forests of the Bay area.

Salt marsh zonation is an unstudied topic in Tampa Bay. The best formed salt marsh occurs on the upriver islands and nearby shorelines of the Alafia, Little Manatee and Braden Rivers, and in undisturbed creeks. The mouths of Double Branch Creek (Hillsborough County) and Gamble Creek (Manatee County) have interesting marshes where the transition from Juncus to freshwater forms (Typha, Cladium) could be studied. On a smaller scale, marsh islands of the Little Manatee River are commonly fringed by shrubby red or black mangroves, with a narrow Spartina band between the mangroves and Juncus. Juncus occurs as monospecific stands within the interior of the marsh islands but may be interspersed with salt-tolerant herbaceous or succulent growth on high spots or levees. In well

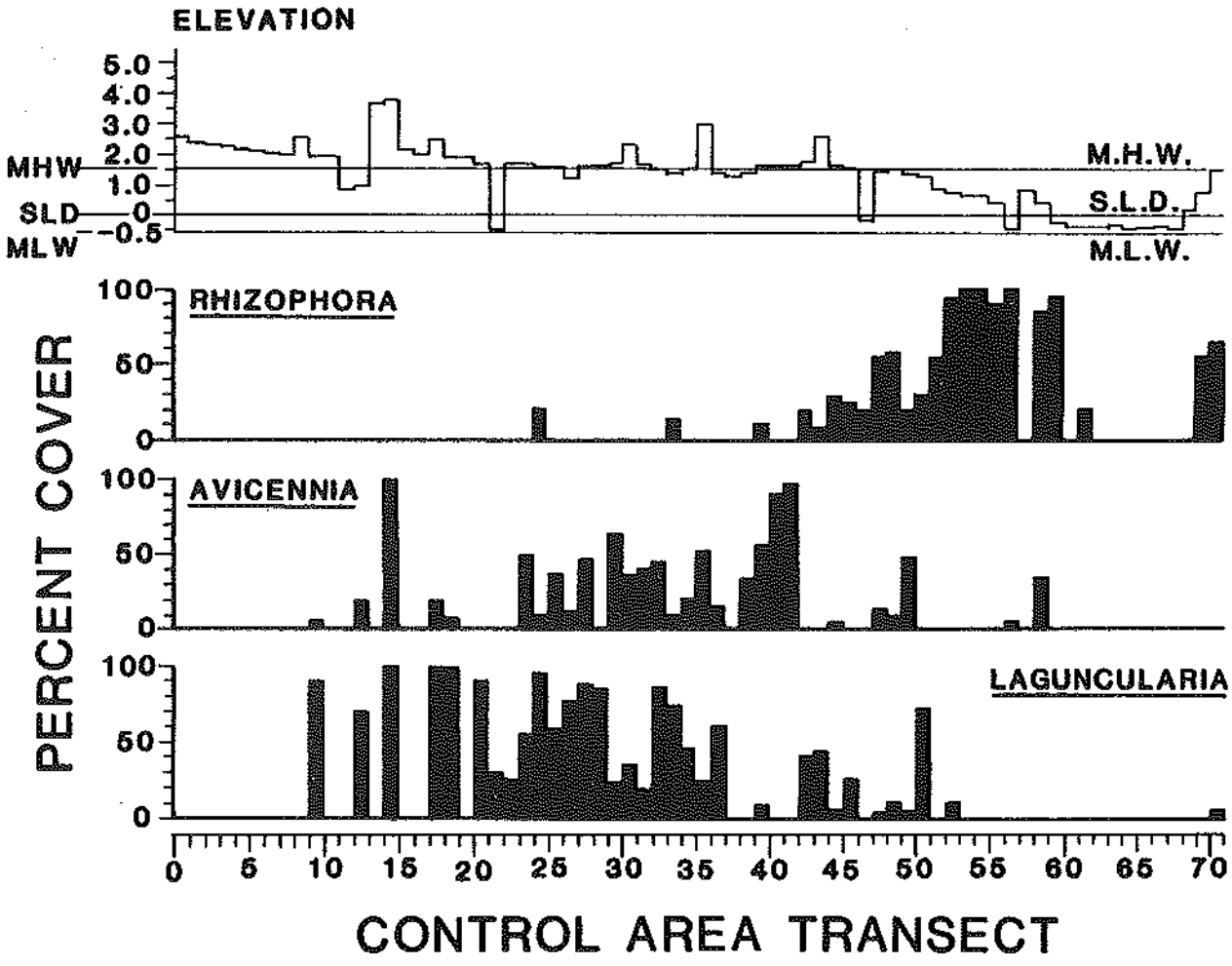

Figure 4. Dispersion of red, black and white mangroves on an undisturbed shoreline near Wolf Creek, illustrated on 20 m intervals. Elevations are shown in feet. From Detweiler et al. (1975).

Table 4. Importance values and spatial distribution of 3 mangrove species in 76 quadrats, each 4 m^2 area, in an undisturbed forest at Wolf Creek. Adapted from Detweiler et al. (1975).

	Laguncularia racemosa	Avicennia germinans	Rhizophora mangle	Total
No. Quadrats of Occurrence (Q)	49	48	30	132
No. of Plants (N)	1,209	282	238	1,729
Frequency (F)	63%	62%	45%	
Density (D)	15.9	3.7	3.1	
Relative Frequency (RF)	37%	36%	27%	
Relative Density (RD)	70%	16%	14%	
Average Cover (%)	33%	21%	27%	
Importance Value (IV)	96	83	72	

Table 5. Organization of a composite fringe mangrove forest in Tampa Bay, from Williamson and Mosura (1979).

Zone	Rhizophora	Avicennia	Laguncularia
front	56.7%	4.1%	39.2%
middle	22.0%	35.6%	42.4%
back	11.5%	38.0%	50.3%

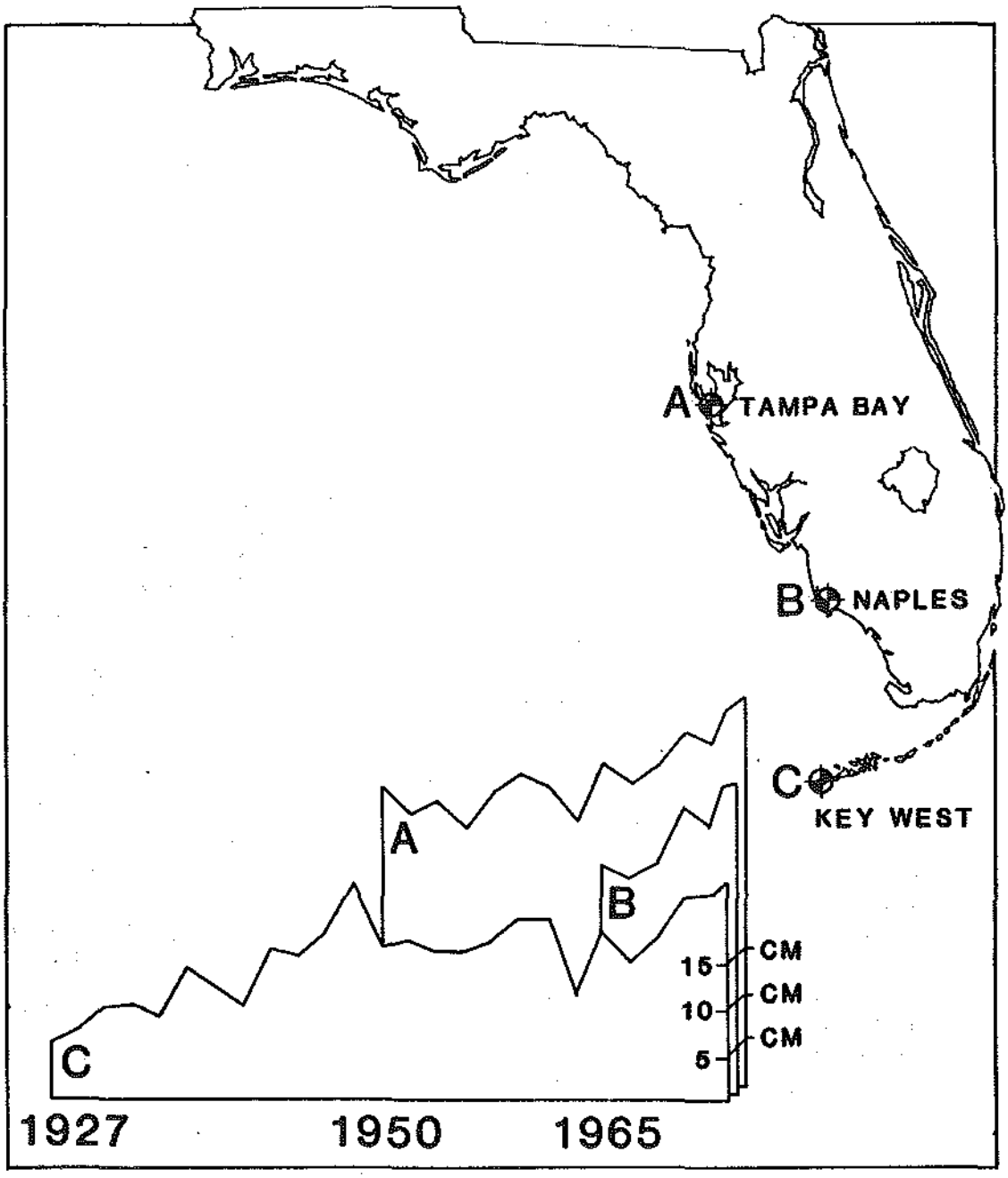

Figure 5. Sea level for periods of record at St. Petersburg, Naples and Key West gaging stations. Adapted from Estevez (1978).

developed marshes both tall and dwarf forms of Spartina alterniflora (as in Valiela et al. 1978) and low and high marsh assemblages (Adams 1963) are in evidence. Based on experience but no particular data for Tampa Bay we do agree with Provost (1976) that the upland side of fringing marshes corresponds with the mean annual high water datum.

ABIOTIC STRESS

Low Temperatures. Because of their presence near the northern latitudinal limit for mangroves in southwest Florida, mangroves in Tampa Bay are subject to low temperature stress. Cold can affect trees without producing visible canopy effects; by damaging foliage at the tops of the canopy; or by killing entire trees. A pattern of vulnerability to low temperature stress has been proposed by Williamson and Mosura (1979) on the basis of forest attributes and measurements of low temperatures within different forests (Fig. 6). The deviation from minimum temperatures recorded at Tampa International Airport during 1978 was computed for several forests around Tampa Bay. It can be seen that measurements made on the east side of Pinellas Peninsula and in Lower Tampa Bay produced relatively insulated conditions, whereas Upper Old Tampa Bay temperatures were below those recorded at the airport. The total range in minimum temperatures recorded by Williamson and Mosura (1979) by this method was nearly 4°C. The authors opine that freeze damages on the eastern shore of Hillsborough Bay and Middle Tampa Bay are aggravated by exposure to northwest winds, and that landform, tributaries and perhaps oyster formations provide microscale protection against cold. Freezes have caused the nearly complete loss of mangroves in Upper Old Tampa Bay, while mangroves in the Gateway area of Pinellas County demonstrated vigorous growth following the same freezes. At Bullfrog Creek the greatest damage to mangroves was found farthest inland, and the least damage was found near Tampa Bay.

Repetitive freezes intensify the effects on the canopy. One episode of low temperatures will partially destroy a canopy and a subsequent freeze will kill the tree entirely, a phenomenon easily observed from Highway 41 between Gibsonton and Big Bend, or near Frog Creek in Manatee County. Williamson and Mosura (1979) have demonstrated differential vulnerability of each mangrove species as a function of size. Table 6 compiles survivorship data based on observations before and after the freeze of 1978 for seedlings, saplings and trees. Young white mangroves were the most vulnerable, followed by seedling and sapling red mangroves. Black mangroves exhibited the hardiest resistance to low temperature stress, a fact reflected by their presence on the Texas and Louisiana coasts (McMillan 1971).

Forest reproduction and recruitment are also affected by cold stress acting on the survivorship of propagules. Figure 7 illustrates data collected by Mosura and Estevez (1977) on red mangrove fruit contributions to monthly litter at Cockroach Bay for the period August 1976 to June 1977. Most

Table 6. Freeze damage as percent survival, by species and age-class, for mangroves in Tampa Bay, from Williamson and Mosura (1979).

	Freeze Damage by Age Class, % Survival		
	Seedling	Sapling	Tree
Rhizophora	62	86	100
Avicennia	100	100	100
Laguncularia	56	80	98

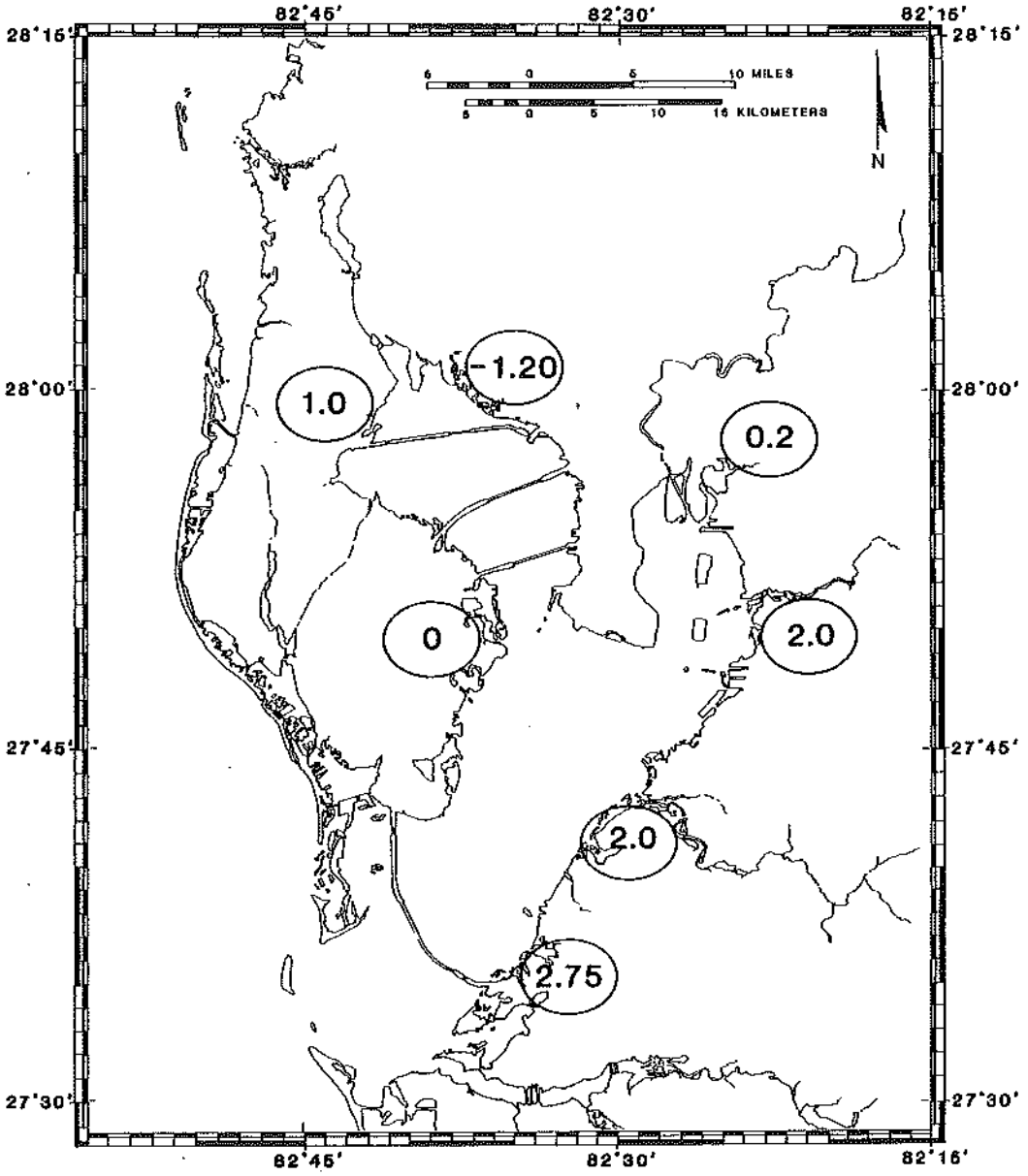

Figure 6. Local temperature deviations (°C) from the reference data at Tampa International Airport in study areas occupied by Williamson and Mosura (1979) for the period December 1977 - May 1978.

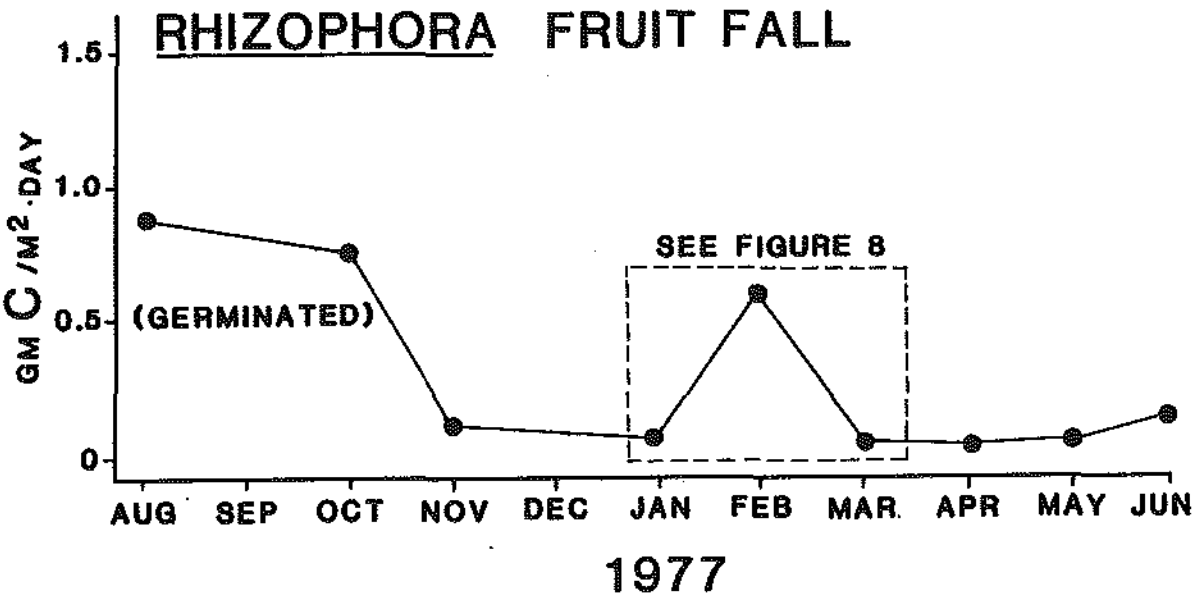

Figure 7. Monthly variation in mean dry weight of Rhizophora fruit-fall from August 1976 - June 1977 at Cockroach Bay. Fruit falling until November 1976 were germinated whereas winter (post-freeze) fruit were ungerminated. The time-course of litter fall after the freeze is shown in Figure 8. Adapted from Mosura and Estevez (1977).

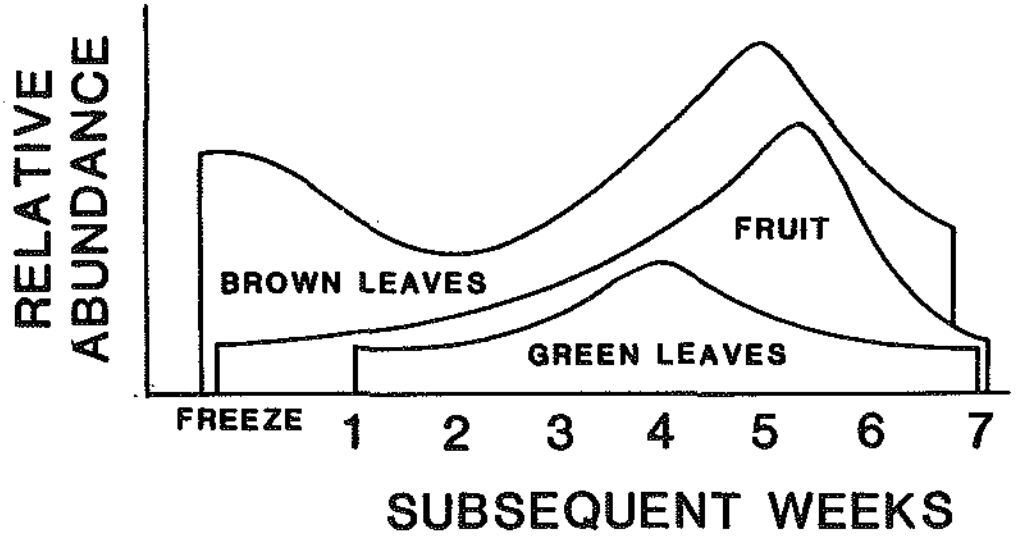

Figure 8. Generalized sequence of tissue loss under red mangrove canopy in Cockroach Bay following a freeze. Total litter production during these periods can far exceed summer rates or those reported for forests at lower latitudes. Adapted from Mosura and Estevez (1977).

spent fruit (germinated) fell from trees during August, September and October, but a second episode of ungerminated fruit loss was recorded in February. Mosura and Estevez determined that these prematurely aborted fruit represented a significant loss of the following year's reproductive effort. They also concluded that the fruit fell from the canopy of otherwise undamaged forests in large numbers following the freeze of 1977 as an acute response to cold stress. Based on an analysis of litter fall during weeks following the freeze of 1977, Mosura and Estevez (1977) determined that litter fell from the canopy in phases (Fig. 8): immediately following the freeze there was an episode of senescent leaf loss, followed in two to three weeks by the loss of green leaves from the canopy, followed by the loss of more brown leaves and fruit. Most of the green leaves and fruit had fallen from the trees within two months following the freeze. The brown and green leaves and fruit represented a significant production of litter, as discussed below.

In summary, the effects of low temperatures on mangroves in Tampa Bay include mortality, altered growth forms, canopy loss, litter fall changes, reproductive loss, recruitment impact and possibly replacement by marsh. More will be said below of the implications of cold stress for succession.

BIOTIC STRESS

The mangroves of Tampa Bay are relatively well studied in terms of biological stresses. Agents of biotic stress include wood-boring isopods and beetles, herbivorous crabs, gall-forming fungi and fungal leaf pathogens. Each has been studied in Tampa Bay to some degree and for that reason biotic stresses acting on mangroves in Tampa Bay are generally better studied than for other areas of the world.

Isopods. Estevez and Simon (1974) and Estevez (1978) have described the dispersion and abundance of isopods in mangrove forests of Tampa Bay. One species, Sphaeroma terebrans Bate, burrows into prop roots of the red mangrove. Sphaeroma was first collected in Tampa Bay in 1922, but was rediscovered by Rehm (1974). The wood borer occurs in mangrove and other wood throughout the Tampa Bay area. Red mangrove prop roots are the favorite habitat of wood-boring Sphaeroma, which create their burrows strictly in the intertidal zone. The burrow is a hydrodynamic structure within which particulates can be filtered from the water column for ingestion as food. The burrow also serves as habitat for the organism. Studies by Estevez (1978) of borers in red mangrove roots showed highest borer densities and lowest burrow evacuation rates in the summer and fall. Most borers lived between mean high water and mean tide level, a zone in Cockroach Bay where many red mangrove roots are severed. The borers, which occur along red mangrove shorelines in all forests of Tampa Bay, dispersed throughout the year, but did so most during late summer and early fall in Cockroach Bay. Their overall abundance appears to be determined primarily by the frequency of tidal submergence, food supply, and habitat availability.

Sphaeroma damage to mangroves in Tampa Bay has been widespread but not of extreme intensity. Estevez (1978) examined 130 dead red mangroves in Cockroach Bay and found a mean root number of 44 per tree, of which 56.7% were anchored. Moreover, 41% were adventitious but 60% were occupied by Sphaeroma terebrans, indicating a high level of borer activity and root response. No data are available to support the view that borers undermine trees to the point of toppling, although borers undoubtedly accelerate tree loss on shorelines eroding for other reasons. On the other hand, root architecture can be interpreted to support the view that borer damage is beneficial to trees by stimulating root growth (Simberloff et al. 1978). Studies of long-term borer occupation and root growth will be needed to test the borers' actual impact on mangroves.

Isopod borers may also inhabit red mangrove propagules to noteworthy levels (Table 7). Estevez (1978) collected and examined 100 floating propagules for 11 months and found 0-8% of the total (average 4.7% ± 3.4%) damaged by isopods. The role of isopod borers in reducing propagule survival and hence recruitment has not been evaluated, but studies by Mosura (1978) on beetle damage are instructive.

Beetles. The scolytid beetle Poecilips rhizophorae is a common herbivore of red mangrove seedlings. The bark beetle burrows small holes into seedlings still on the parent tree (Estevez 1974) and feeds on damaged tissue. Mosura (1978) surveyed numerous sites in Cockroach Bay, checking 5,350 propagules for Poecilips. The overall incidence of beetles was 4.6% (range 0-25.5%), shown by analysis to be distributed in a clumped dispersion pattern. Propagules were also collected with litter nets as they fell. Table 8 illustrates the severity of damage caused by the beetle, damage caused by the mangrove tree crab Aratus pisonii, and the sum of serious damage for propagules during the period August - November 1977. Between 37.3-58.9% of all propagules collected during this time were seriously damaged due to biotic stresses exerted in the canopy, of which an average of 20% was due to Poecilips.

By means of follow-up experiments based on actual and contrived damages to propagules, controlled plantings, and laboratory studies, Mosura (1978) was able to estimate the overall survivorship of seedlings damaged by insects and other canopy herbivores. In Table 9 the decrement in survivorship among 100 original seedlings is shown for damaged and undamaged types. Field surveys demonstrated that roughly half of all propagules in the canopy were damaged (48.9%). After the numbers of these damaged and undamaged propagules were corrected for establishment and survival rates, Mosura determined that about 12 (11.8%) and 1 (0.9%) seedlings from the original undamaged and damaged stock, respectively, would survive beyond six months.

Other Agents. The climbing tree crab Aratus pisonii is an herbivore of red mangrove leaves (Beever et al. 1979) and commonly damages propagules. Mosura (1978) recorded an average 26.7% of Aratus damage to propagules as they fell from the canopy (Table 8) and Estevez (1978) observed mean incidence of crab damage to floating propagules of 11.5% (Table 7). Beever et al. (1979) correlated grazing damage to crab density in red mangrove forests in Charlotte Harbor.

Table 7. Monthly variation in types of damage to 100 floating propagules collected in Cockroach Bay during April 1976 - February 1977. S. t., Sphaeroma terebrans; P. r., Poecilips rhizophorae; A. p., Aratus pisonii. (Estevez 1978).

Period		S. t.	P. r.	A. p.	Other	Cumulative Percent
1976	April					65.2
	May					39.6
	June	8.0	8.0	17.6	0	33.6
	July	0	14.1	7.2	15.3	36.6
	August	2.1	18.5	6.0	8.0	34.5
	September	2.0	9.6	19.2	7.1	37.0
	October	8.2	2.2	5.2	2.5	20.9
	November	5.1	9.2	6.1	15.4	35.5
	December	8.0	24.0	10.0	20.0	62.0
1977	January	1.0	6.0	22.0	3.0	32.0
	February	1.0	1.0	10.0	4.0	16.0

Table 8. Type of damage to seedlings. Damage is expressed as percent total monthly collection. "N" refers to total seedlings in each collection. From Mosura (1978).

Month	Poecilips	Aratus	Other	Total Serious Damage	N
August	8.7	23.3	5.3	37.3	150
September	16.6	28.9	1.9	47.7	904
October	32.3	25.0	1.6	58.9	375
November	23.5	29.4	0	52.9	17

Table 9. A model of seedling production, herbivory damage, recruitment, and survivorship in red mangrove seedlings based on field and laboratory studies. An initial population of 100 seedlings is assumed. From Mosura (1978).

		Undamaged	Damaged
A.	Number of seedlings at time of dispersal	51.1	48.9
B.	Percent established	36.0	9.0
C.	Number of seedlings established (product of A and B)	18.4	4.4
D.	Percent of post-establishment survival	64	22
E.	Number of seedlings surviving after 6 months (product of C and D)	11.8	0.9

Fungi exert biotic stresses in mangrove forests of Tampa Bay. One form, Cylindrocarpon didymum, forms galls on the trunk and branches of red mangrove, and occasionally is found on black mangrove. These galls cause limb loss by the constriction of vascular tissue and may kill entire trees where infestation is severe. Olexa (1976) cites the northernmost distribution of the fungal gall to be approximately the Little Manatee River. Olexa (1974) also lists three fungal pathogens of leaves which may be important in affecting forest litter production.

Other types of biotic stress occur in Bay mangroves and are mentioned in passing. A browse line occurs in red mangroves near Double Branch Creek, caused by cattle grazing during low tide. Red mangrove saplings have been eliminated by grazing but small black mangroves seem unaffected.

PRODUCTION

Data on primary production for mangroves or salt marshes in Tampa Bay are sorely needed. No total standing crop data exist for area mangroves and only one unpublished study by Montague is available for Spartina (see Marsh Types). Gas exchange estimates are lacking for mangrove and marsh, but some mangrove production data based upon litter-fall rates are of interest.

Litter is the organic debris falling from the canopy. Odum et al. (1982) present a salient review of the technique for measuring litter production and available findings. The rate of litter production is an easily determined, well-calibrated indicator of net (gross minus respiration) productivity. Litter production rates reflect the ecological condition of mangroves and their response to natural stresses such as extreme salinity or nutrient deficiency. Moreover, litter decomposes into detritus, a major foodstuff for estuarine animals (Heald 1969; Odum 1970). Further decomposition results in dissolved organic matter of nutritive value to estuarine biota.

Some data are available on the litter production of Tampa Bay mangrove forests. Estevez and Woodin (unpublished) have evaluated the microscale variation in litter fall rates for a forest of uniform canopy in Cockroach Bay. By deploying 100 nets, each of 0.125 m^2 surface area, in a tight array beneath mixed red and black mangroves, they were able to evaluate local variations in litter fall rates. Litter production varied from negligible (0.1) to nearly 10 g/m^2 per day for each net (Fig. 9). Estevez and Woodin recommended the use of nets with a minimal surface area of 0.25 m^2 deployed randomly in the forest, in sets of at least ten, for the purpose of accurately sampling litter fall rates in Tampa Bay mangrove forests.

Not surprisingly, litter production varies seasonally in Tampa Bay. Mosura and Estevez (1978) tracked litter fall for a year on a monthly basis in Cockroach Bay. Total average litter fall in Cockroach Bay varied from a high in August 1976 of 10.0 g/m^2 per day to a low in December 1976 of 0.2 g/m^2 per day, but rates were higher in late summer and fall, and in winter following the freeze of 1977 (Fig. 10). The contribution of seedlings to total litter is also illustrated. Seedling contribution was very significant in autumn. However, litter fall rates corrected for seedling contributions were still notably high.

Existing litter production data for Tampa Bay have been summarized in Table 10. The study conducted in Simmons Park was reported by Lewis (1980). The species composition of the canopy, the number of nets, and harvest time employed in the study all varied, as did the range of litter fall rates. The first study is probably the most precise, and yielded a rate of 1.8 g/m^2/day; the second study is probably the most accurate, and obtained a mean rate of 4.0 g/m^2/day. Overall, a mean rate of 3.1 g/m^2/day, or 11.3 metric tons (dry weight)/hectare/year is available for Tampa Bay.

Heald (1969) reported a cumulative mean of 2.41 g /m^2/day for the North

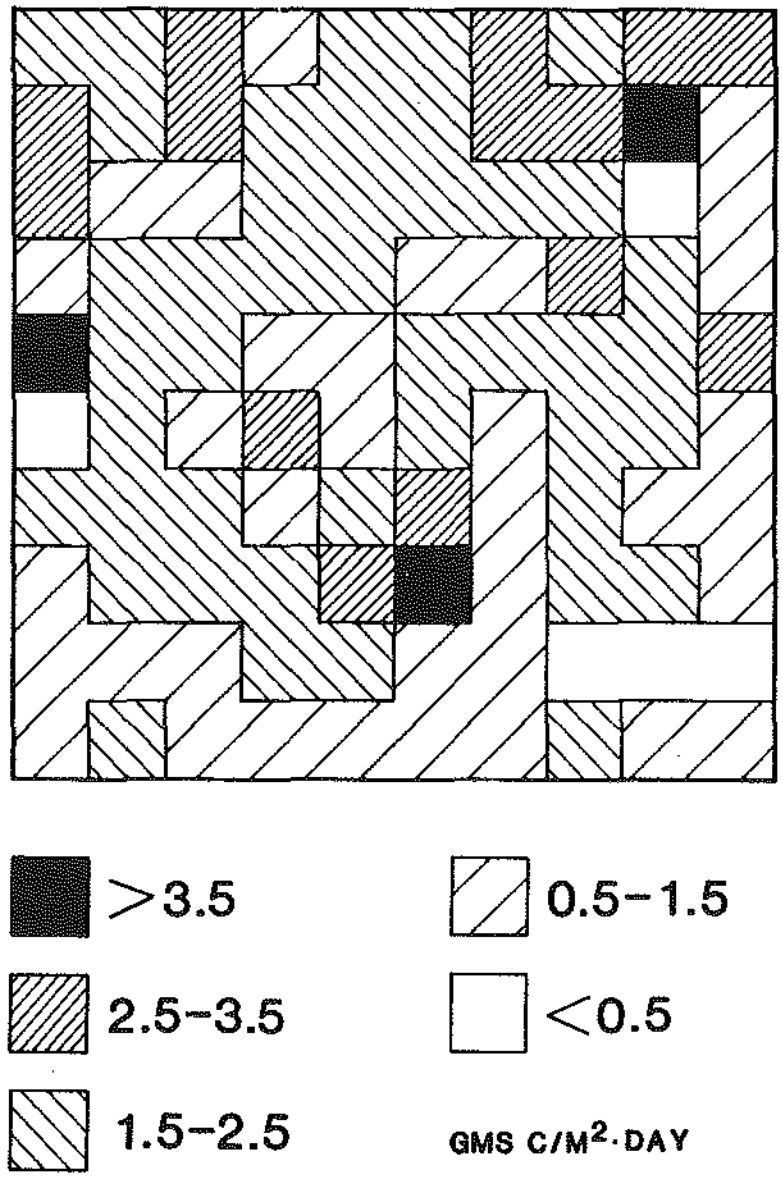

Figure 9. Small scale variation in litter production by red and black mangroves at Cockroach Bay. Each net was 0.125 m^2 and collected litter for 10 days. Data are summarized in Table 10. From Estevez and Woodin (unpublished).

Table 10. Summary of available litter production data for Tampa Bay mangroves. R, red mangrove (Rhizophora mangle); W, white mangrove (Laguncularia racemosa); B, black mangrove (Avicennia germinans). 1981 Cockroach Bay data from Estevez and Woodin (unpublished); 1976-1977 Cockroach Bay data from Mosura and Estevez (1977); Simmons Park data from Lewis (1980).

	COCKROACH BAY	COCKROACH BAY	SIMMONS PARK
Species	R, W, B	R	R, W, B
Period	Jan 81	Aug 76 - Apr 77	May - Jul 80
Replicates	100	12	4
Harvest Time	10 days	7 days	21 days
Litter Production, $g/m^2/day$:			
minimum	0.1	0.1	2.5
mean	1.8	4.0	3.6
maximum	11.5	10.0	4.4
		3.1 $g/m^2/day$	

3.1 $g/m^2/day$ = 11.3 metric tons (dry wt.)/hectare/year.

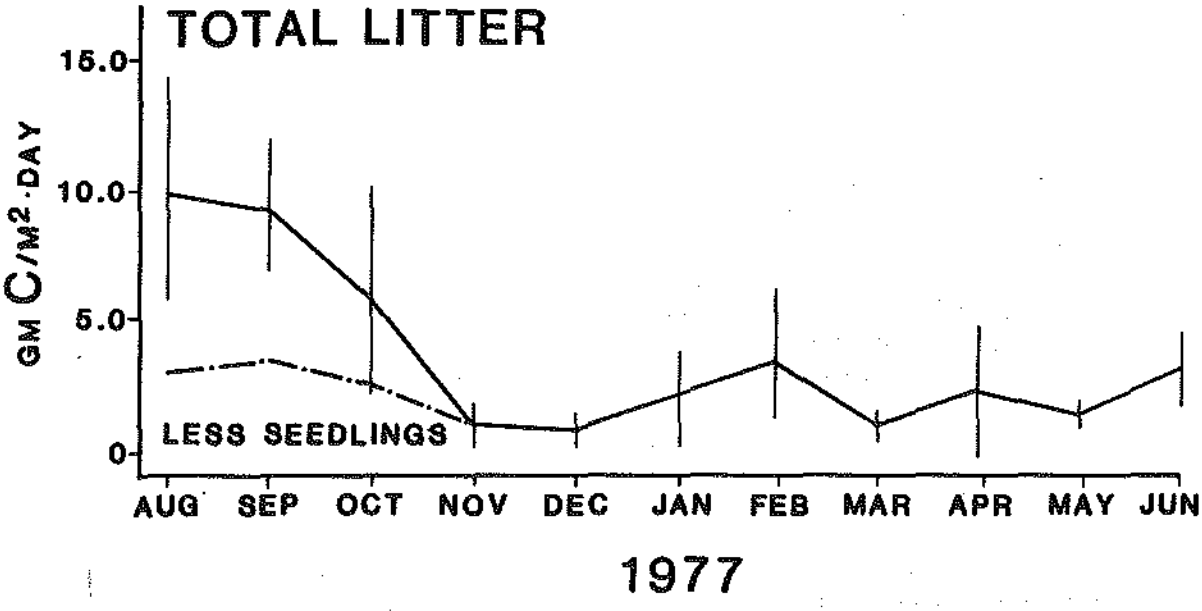

Figure 10. Monthly variation in mean dry weight of Rhizophora litter fall from August 1976 - June 1977 at Cockroach Bay. Propagule contribution was significant from August to October, inclusive. See Figures 7 and 8 for details of fruit and leaf contribution, respectively. From Mosura and Estevez (1977).

River estuary in south Florida and Odum et al. (1982) cite 2.0-3.0 gC/m^2/day as the typical productivity of red mangroves in "south" Florida. Factors responsible for the relatively high rates of litter fall in Tampa Bay include the relatively small size of the trees, cold stress, the contribution of reproductive tissue to litter, and water stress. From an energetic standpoint, mangroves of Tampa Bay are small because less energy is invested in wood and more is invested in maintenance tissues (leaves) and reproductive tissues (propagules) in the face of environmental stress, principally cold.

REPRODUCTION AND RECRUITMENT

The loss of reproductive tissue by red mangroves in response to acute cold stress has been discussed. A related question concerns the reproductive effort of shrub forests which are regularly pruned to uniform size by freezes. Estevez and Evans (1978) studied pruned mangrove hedges along residential shorelines because of the analogy between pruning and freezing. Hedges of increasing canopy to total height ratios were examined to evaluate the relationship, if any, between rigidly imposed canopy size and reproductive output. Estevez and Evans found that groups of trees displayed a characteristic fruiting incidence among trees, relative to average numbers of fruit per tree; where few trees per hedge bore fruit, those trees bore few fruit. Since the developmental stage of fruit found in all hedges was the same, the effect of asynchronous flowering was discounted. Also, the incidence of fruiting increased with increasing relative canopy size. Finally, canopy loss in unpruned trees damaged by freezes was inversely related to both the incidence of fruiting and average number of fruit per tree. The study concluded that cold stress has long-term reproductive consequences in red mangrove forest, effected by controlling canopy size, and that this secondary reduction in reproductive effort may be a significant mechanism in limiting red mangroves at their latitudinal limits.

Mention has been made of propagule damage in the canopy and water column. Data are lacking but needed on the fate of propagules in the Bay, and on colonization rates needed to offset mortality in situ. Estevez (1978) mapped the occurrence of 845 established red mangrove seedlings in 10 overwash island in Cockroach Bay and found most (53%) young trees within the island interior, with 28% and 19% along the island fringe or on exposed areas, respectively. This pattern suggests forest regeneration from within, perhaps as a result of erosion or boring at the island periphery, but more long-term survivorship data are needed. Pulver (1976) examined the size frequency distribution of all 3 mangrove species in Tampa Bay and demonstrated thinning due to light competition (Fig. 11).

RECRUITMENT AND PRIMARY SUCCESSION

Mangrove propagules or seeds can be found in Tampa Bay on virtually every shoreline affected by tides. Their dispersal is presumably planktonic although mangroves in basins, areas diked by ditch spoil, or the upper ends of tidal creeks probably are related more closely to their neighbors than trees on overwash islands or exposed fringes.

Given the paucity of information on marsh ecology in Tampa Bay, we find it ironic that the only account of primary succession in emergent Bay wetlands gives a key role to salt marsh, even in the formation of mangrove forests. Lewis and Dunstan (1975) described Spartina as the first natural recruit on new intertidal substrata. Marsh patches they examined were circular due to earlier sedimentary events. The center of the patch was occupied by young mangroves apparently "trapped" by the marsh. As mangroves grew they displaced nearby Spartina forming a donut of marsh. Lewis and Dunstan (1975) opined that such marsh donuts would eventually be excluded through competition by mangroves.

Lugo (1980) has attempted to answer several central questions concerning succession in mangrove ecosystems. Space does not permit a review of his analysis, but we suggest that mangrove succession near their latitudinal limits (such as Tampa Bay) may be exceptional and certainly deserves study, particularly where mangrove and marsh coexist. The relationship between mangroves and salt marshes is not precisely defined. In Upper Old Tampa Bay and in rivers flowing to the Bay, or north of the Anclote River along Florida's west coast, the mangrove community is replaced by a Juncus dominated salt marsh community. According to observations by Lugo and Zucca (1977), when mangroves and Juncus occur together, mangroves occur seaward of Juncus. The explanation is that mangroves are limited by physical factors (primarily frost) while Juncus is limited by competition for light with mangroves. In addition, the salinity of the water or soil may compound effects of cold stress to favor Juncus over mangroves in areas impacted by sublethal cold spells.

SECONDARY SUCCESSION

Secondary succession occurs in mangroves or salt marsh as a consequence of natural or cultural disturbance. Man-induced changes include island creation, oil spills and land-clearing. The effects of spoil and oiling are discussed by other papers in this volume. Here we consider succession following such natural events as hurricanes, freezes, lightning, and biotic damage.

There are no direct data on wetland changes caused by hurricanes, which elsewhere cause deforestation and redistribution of substrata (Craighead and Gilbert 1962). We view land-clearing as roughly analagous to a hurricane in these effects, and find studies by Detweiler et al. (1975) at Wolf Creek to be instructive. Developers bulldozed a large area of forested wetlands and altered the topography of the shoreline. Detweiler et al. (1975) found red mangrove destruction to be more extensive than in the black mangrove

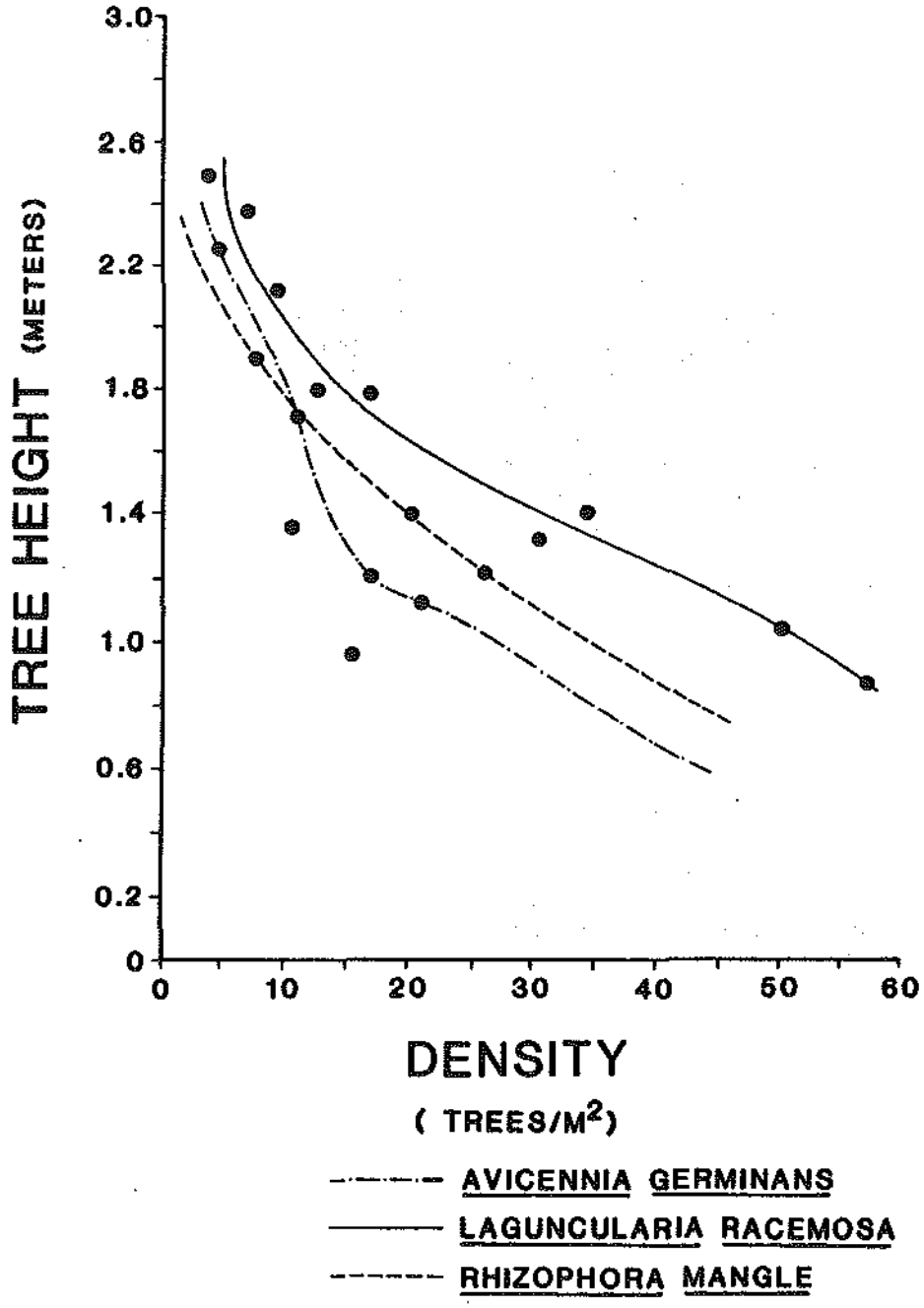

Figure 11. Size frequency distribution of sapling mangroves in Tampa Bay, from Pulver (1976).

zone where trunks had begun to sprout new shoots. Herbaceous and succulent ground cover increased in the higher intertidal zone. Overall, the forest appeared to be returning to a pre-disturbance state in which red mangroves would develop from recruits rather than survivors. Our observations on Perico Island (Manatee County), which was also bulldozed and abandoned, support the interpretation of regrowth at Wolf Creek.

Secondary succession following freezes depends upon their severity and frequency. We suggest that uniform, fringing stands of red mangrove killed by a freeze are not replaced by black mangroves but can remain unvegetated or develop as marsh. Severe freeze damage to Spartina marsh may lead to Juncus marsh. Less intense or frequent freeze damage may destroy patches of mangrove, as do lightning strikes, disease, or intense herbivory. In these cases secondary growth is localized and appears to follow patterns described by Ball (1980) for light-gaps.

HUMAN IMPACTS

Drainage ditches for mosquito control are found throughout many wetlands of Tampa Bay, and are the principal alteration to mangroves and marshes in Tampa Bay short of their destruction by dredging and filling. McNulty et al. (1972) estimate that roughly 60% of all wetlands in Tampa Bay and Sarasota Bay have been drained to some extent (Table 11). No studies have been reported demonstrating that the ditching of mangroves reduces source populations of mosquitos, but on the other hand, no studies have been published to authenticate the claims of ecological damage due to ditching in mangrove forests. One consequence of probable but unstudied significance in wetlands of Tampa Bay is the creation of habitat suitable for noxious or exotic vegetation such as Australian pine (Casuarina equisetifolia) and Brazilian pepper (Schinus terebinthifolia). (Studies of mosquito production in ditched vs. unditched areas of Beacon Key mangroves and an assessment of ecological impacts associated there are presently underway by Mr. Chris Miller, University of Florida).

Habitat loss has been extensive in emergent Bay wetlands. In Hillsborough County alone Sipe and Swaney (1979) determined that 2,888 acres of saltwater marsh and 1,417 acres of mangrove have disappeared during the period 1820-1978. Losses in marsh and mangrove since 1948 amounted to 39% and 33%, respectively. Lewis et al. (1979) calculated that 44% of the original tidal vegetation Bay-wide has been lost to development and other causes during the last century. The Florida Department of Natural Resources has undertaken an

Table 11. Area and condition of wetlands in Tampa Bay, from McNulty et al. (1972).

Location	Wetland Area, acres		Drained Wetlands	
	Marsh	Mangrove	Acres	Percent total
Sarasota Bay	235	3,616	1,732	44.9
Tampa Bay	843	8,949	3,780	38.6
Hillsborough Bay	203	1,077	1,442	100
Old Tampa Bay	533	5,042	3,302	59.4
Boca Ciega Bay	149	2,464	1,058	40.4
Total	1,963	21,130	11,314	59.1
Percent west coast	0.3	5.3		

extensive satellite mapping and computer analysis study of wetland trends in Tampa Bay, and results are anticipated by 1986 (A. Huff, personal communication).

Another human impact to mangroves of Tampa Bay is that caused by the beaching of oil spilled from maritime commerce. Figure 12 from Getter et al. (1981) illustrates the location of oil spill landings in mangroves resulting from the Howard Star accident of 1978. Forty thousand gallons of Bunker C and lubricating oils escaped Upper Hillsborough Bay and came ashore in the Kitchen and Apollo Beach, Wolf Creek, and Simmons Park areas. Getter et al. (1981) considered mortality, defoliation, epiphyte desiccation, tree crab density decreases and infaunal impacts to be relatively minor, but found that major changes in leaf size and shape, seedling mortality, root mortality and epiphyte density occurred. The impacts of oiling in mangroves may be more severe than observed from the 1978 spill. Lewis (1980) reviewed the generalized consequences of severe oil spills in mangrove forests and opined that complete recovery may take 10-50 years. Long term impacts of oiling are presently unknown, and unfortunately, the locations of wetlands oiled by the Delion Apollo spill in Old Tampa Bay are not precisely mapped.

MANAGEMENT OF WETLANDS

The values of wetlands are manifest in the services they perform. Wharton et al. (1977) and Odum et al. (1982) summarize these services for mangroves (Table 12), which in most cases also apply to saltwater marshes. If 44% of the tidal wetlands in Tampa Bay have been destroyed, has society been deprived of an equal or greater level of free "services"? Can restoration or habitat creation offset these losses to any significant degree? What will be the long-term cost of historical and continuing wetland loss?

Odum et al. (1982) conclude that preservation is the best management strategy for mangroves. We concur but add with equal vigor that holistic management of the Tampa Bay estuarine ecosystem will require a substantial research effort focusing on tidal wetlands. Bay wetlands are sufficiently different than better studied wetlands (to the south) or marshes (to the north) that such research efforts are justified. Some important questions facing ecologists interested in the wetlands of the Bay area are listed:

- What was the historical extent of tidal wetland in the Bay as compared to other communities?
- What is the modern dispersion, structure and function of salt marshes, particularly in rivers and tidal creeks?
- What are the ecological consequences of freezes in terms of zonation, production, recruitment, or habitat value of wetlands?
- How do man-induced environmental changes affect natural, biotic stresses in mangroves?
- What is the actual production by tidal wetlands of nuisance insects, and what are the ecological impacts to wetland communities of physical and chemical control techniques?
- What are the roles of marshes or mangrove forests in the Bay as habitat for sport or commercial fishes: do other habitat qualities outweigh the significance of providing food for secondary production?
- What goals based upon ecological evidence are desirable or practical to guide wetland restoration in the Bay?

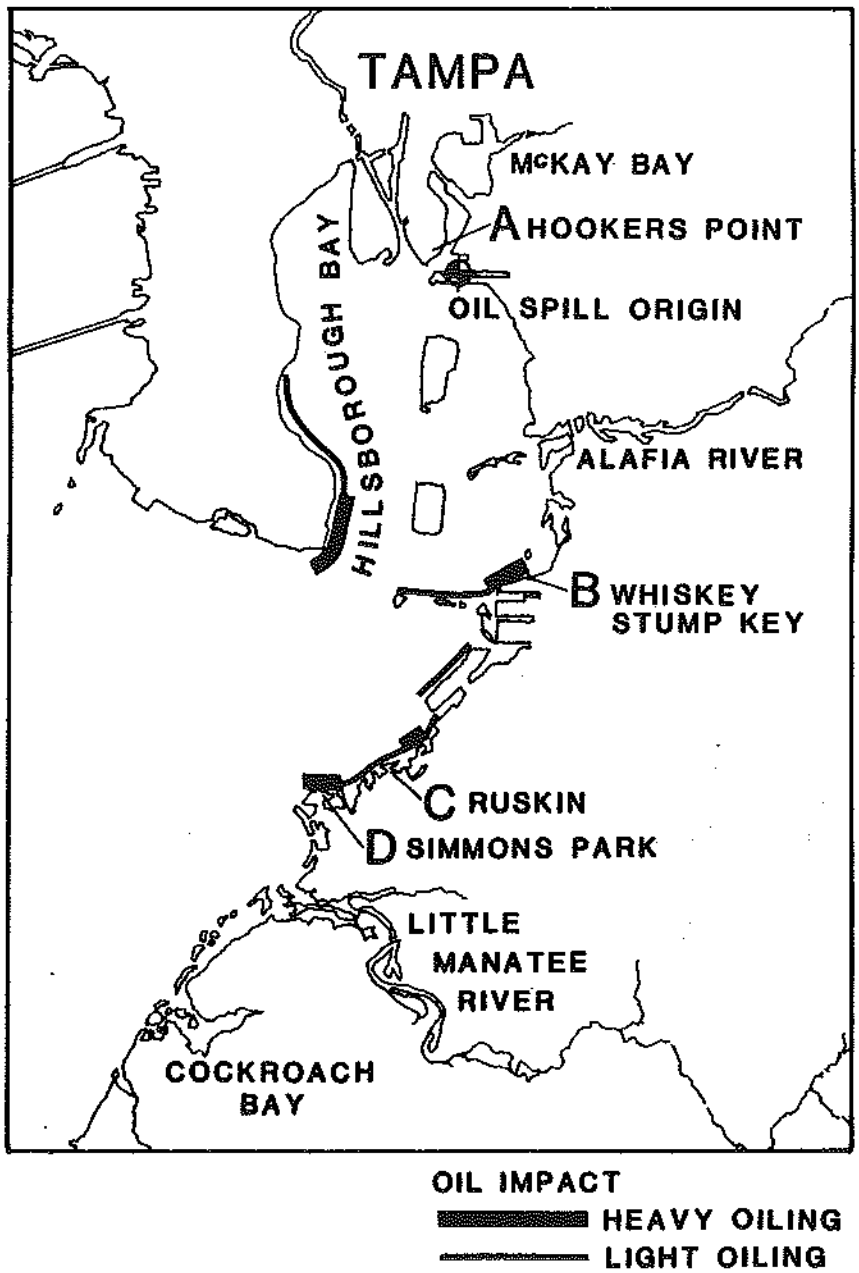

Figure 12. Location of oiled shorelines resulting from the Howard Star accident of October 1978, from Lewis (1983).

Table 12. Services performed by tidal wetlands in Tampa Bay. (Adapted from Wharton et al. 1977 and Odum et al. 1982).

1. Production of organic matter for consumption by detritovores (filter feeders and bottom feeders) which are in turn fed upon by other animals, including valuable fish species;

2. Refuge, habitat and/or nursery area for sport and commercial fishes and invertebrates, whether or not foodstuffs (item 1) are also important;

3. Refuge, habitat and feeding area for several rare, threatened or endangered species;

4. Production of fuel (wood) and food (honey) for humans;

5. Acceleration of shoreline accretion by stabilizing sediments and retarding erosion;

6. Buffering valuable coastal residential, commercial and/or agricultural areas from storm damage by retarding surges;

7. Buffering suburban and rural areas from urban congestion by providing visual, acoustic, and air pollution buffer;

8. Retaining flood waters, both tidal and fresh, and assimilating nutrients from runoff. Toxic materials can be "scrubbed" from runoff by wetlands.

9. Mangrove and salt marsh are popular landscaping elements because they are salt and flooding tolerant and grow where conventional landscaping plants cannot.

10. Scientific and educational value.

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PRIMARY PRODUCTION IN TAMPA BAY, FLORIDA: A REVIEW

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INTRODUCTION

The Tampa Bay system is a nitrogen and phosphorus enriched shallow estuary supporting, seasonally, extremely high phytoplankton biomass and productivity. Seagrass beds in less than 2 m depth, attached and drift macroalgae, and benthic microflora also add to the total primary production of the bay system. Additionally, the system is fringed by limited mangrove stands and marsh areas, which contribute detrital litter and consequently particulate and dissolved substrates.

Primary production data for Tampa Bay is very limited. The phytoplankton component has received the greatest study effort; however, even knowledge of this group is limited and biased by the lack of area-wide and long-term studies, and the use of questionable methodologies. This review will summarize historical primary production data; discuss methodologies and their shortcomings; outline future research needs for understanding the carbon cycle of the Tampa Bay system; and discuss the carbon cycle in relation to trophic dynamics.

HISTORICAL DATA

The first measurement of primary production in the Tampa Bay system was by Pomeroy (1960) in May and September of 1958. He compared the relative production of seagrasses, benthic microflora, and phytoplankton in Boca Ciega Bay (Fig. 1). The only other study of that type, with more than one production component, was not performed until 1981 when Gibson (Harbor Branch Foundation, pers. comm.) initiated a multi-component productivity study of the shallow waters of Lassing Park, in the Middle Tampa Bay region (Fig. 1). In addition to the components measured by Pomeroy, Gibson distinguished between productivity of the seagrasses themselves and their epiphytes. These two studies will be discussed in detail later in this review.

Other studies on primary production of the Tampa Bay system have mostly involved phytoplankton measurements. Only two phytoplankton production studies, to this date, have been of sufficient duration to estimate seasonal cycles in production. These two studies are those by the U.S. Fish and Wildlife Service (FWS) from 1962 through 1973 (Saloman et al. 1964; Dragovich and Johnson 1966; Finucane and Dragovich 1966; May 1966; Kelly and Johnson 1967; McNulty 1968, 1969; Saloman and Taylor 1968, 1971a, b, 1972; Taylor and Saloman 1968; McNulty et al. 1970; Taylor 1970; Saloman 1973, 1974; Collins and Finucane 1974; Saloman and Collins 1974) and the study by the City of Tampa (COT) from 1978 to present (Johansson

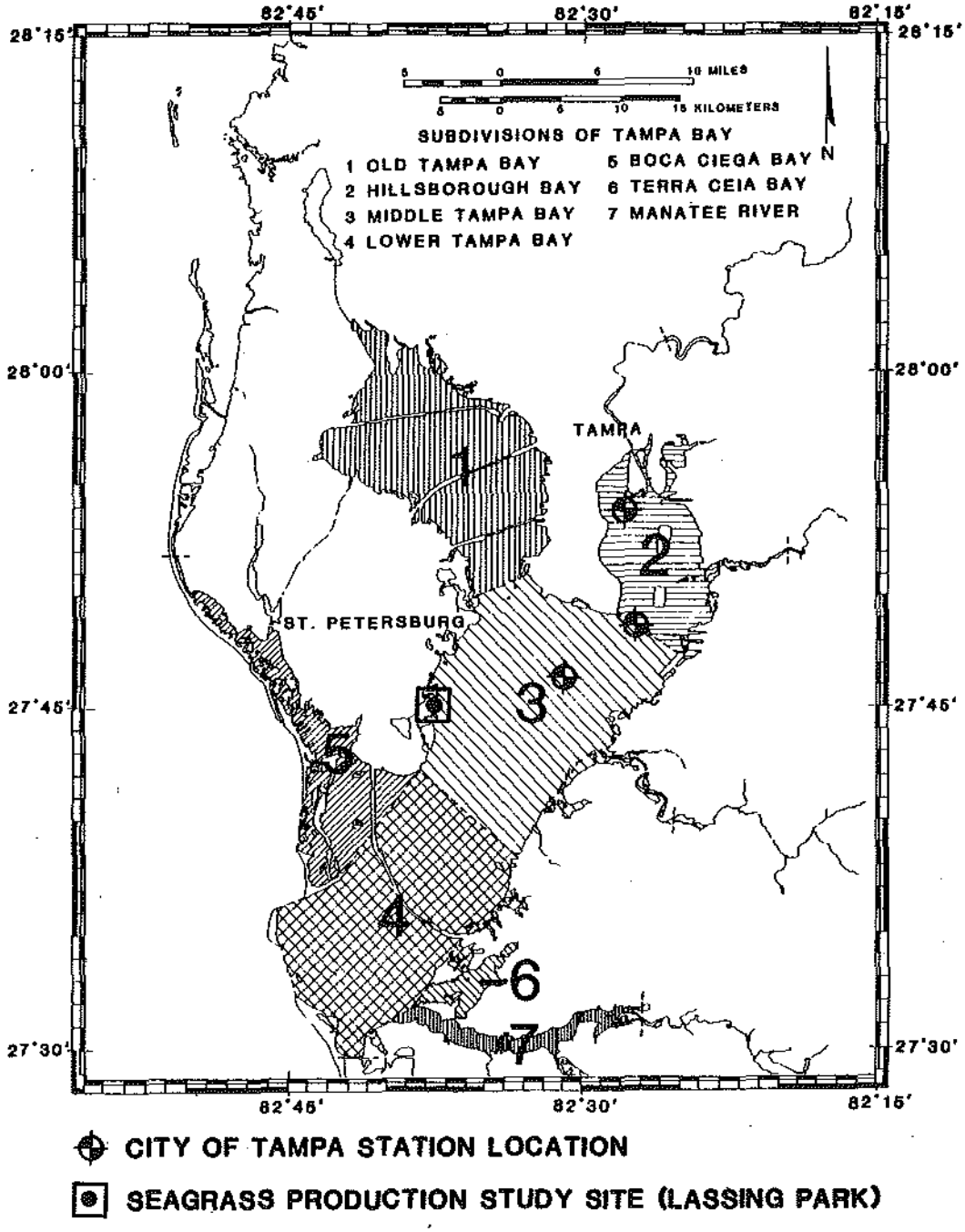

Figure 1. Sites of productivity studies.

and Carpenter, in prep.). However, only the FWS study had stations in all major parts of the bay; the COT study has stations in Hillsborough Bay and Middle Tampa Bay only. Therefore, no phytoplankton production information on the bay system as a whole has been generated since 1973. Further, most of the production data from FWS was estimated from the chlorophyll and light method of Ryther and Yentsch (1957), which does not involve any direct measurements of photosynthetic rates. The lack of comparative production information based on rate measurements between different parts of the bay is a serious shortcoming in the total data base.

The FWS study, in addition to the chlorophyll and light method, also measured phytoplankton production from the dissolved oxygen technique using the light and dark bottle method (Gaarder and Gran 1927) during 1964-1968. The FWS group compared the two methods. The COT study group estimates phytoplankton production from the ^{14}C method (Steeman-Nielsen 1952).

The FWS annually summarized production information by reporting an average monthly rate for each of the four major sections of the bay (Old Tampa Bay, Hillsborough Bay, Middle Tampa Bay, and Lower Tampa Bay). To reduce the data further for this review, only seasonal averages are presented for both FWS and COT data. Monthly values from June, July, August and September are grouped into a wet season category, and the remaining months represent the dry season. Forty years of rainfall data from the Tampa area were used to separate months according to season.

Figure 2 shows the FWS seasonal production data estimated from the chlorophyll and light method. Similarly, Figure 3a shows FWS light and dark bottle estimates of production and Figure 3b shows ^{14}C production measurements of COT. The chlorophyll and light data indicate a weak seasonal pattern with highest production rates during the wet season. There are no obvious long term trends present for Lower Tampa Bay; however, for other parts of the bay, rates increased in 1969 and remained relatively high until the termination of the study (Fig. 2). No explanation for the sudden and long-lasting increase in phytoplankton production, which started in 1969, was offered by the original authors.

Gross production, measured by the oxygen method concurrent with the chlorophyll and light method, was about 2.5 times greater than production estimated from chlorophyll and light data. Further, the oxygen method shows a much clearer seasonal pattern in all areas except the lower bay (Fig. 3a).

Phytoplankton production measured by the ^{14}C method clearly shows a very distinct seasonal pattern with the highest values, as expected, in the wet season which is coincident with the highest water temperatures. These recent measurements by COT appear higher than rates measured by FWS. Whether these differences are due to different methods used, and/or actual differences in production, cannot be determined.

Discussion of the Chlorophyll and Light Method of Estimating Phytoplankton Production

Lack of a strong seasonal pattern in FWS chlorophyll and light estimates was probably due to the extraction technique and specifically, not grinding the filters and phytoplankton residues. Grinding was recommended by SCOR-UNESCO (1966) and has subsequently been adopted by most researchers.

Figure 4 shows the long term record of chlorophyll *a* concentration for Tampa Bay. Data from the period 1974-1981 have been collected by the Hillsborough County Environmental Protection Commission (HCEPC) and have been added to the records of FWS. The HCEPC chlorophyll data is available from the STORET data storage system. There is little known variation between FWS and HCEPC data sets, since both do not incorporate grinding of filters. The COT has measured chlorophyll *a* concentrations from filter-ground samples, in Hillsborough Bay and Middle

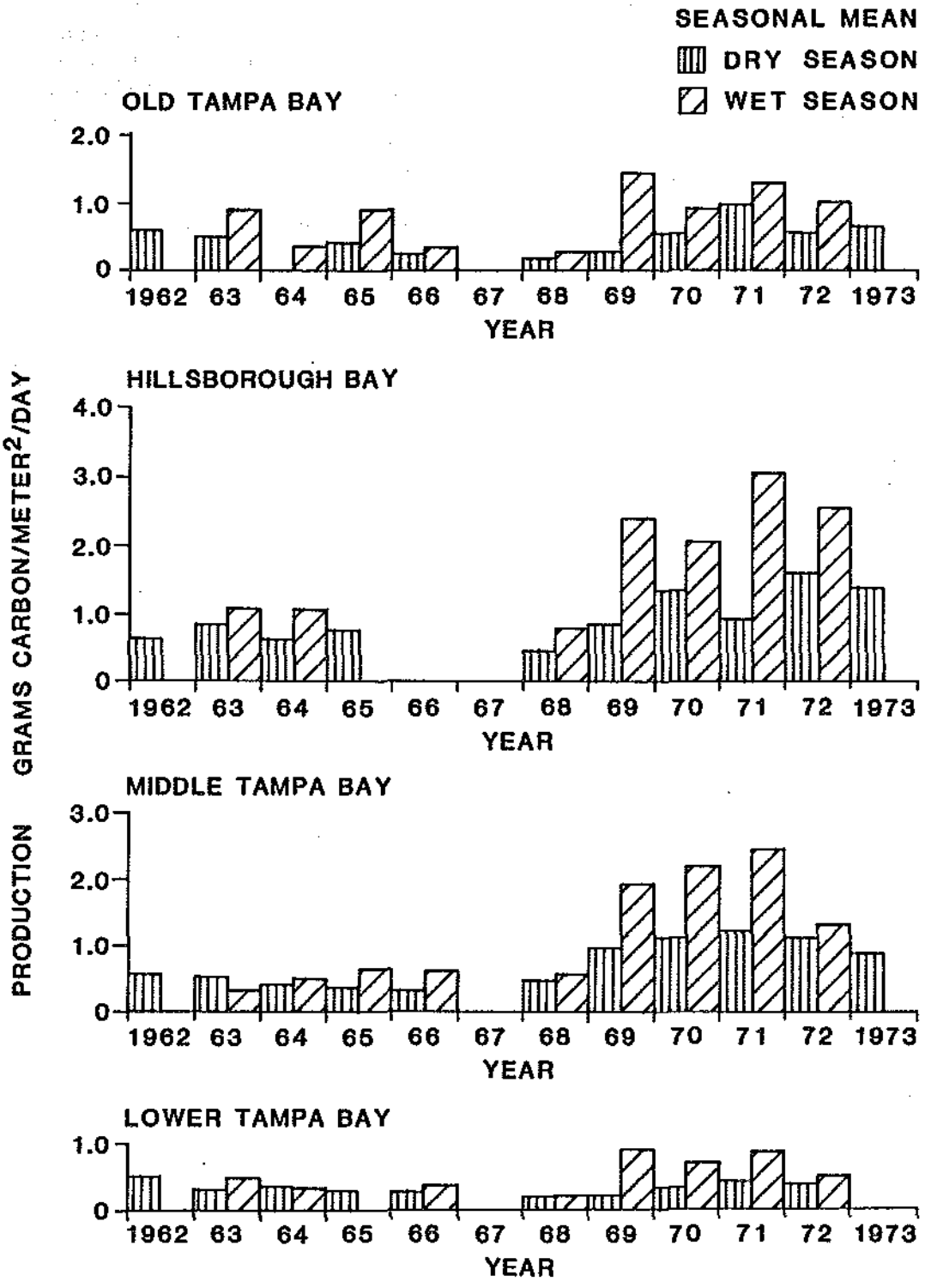

Figure 2. FWS data, chlorophyll + light.

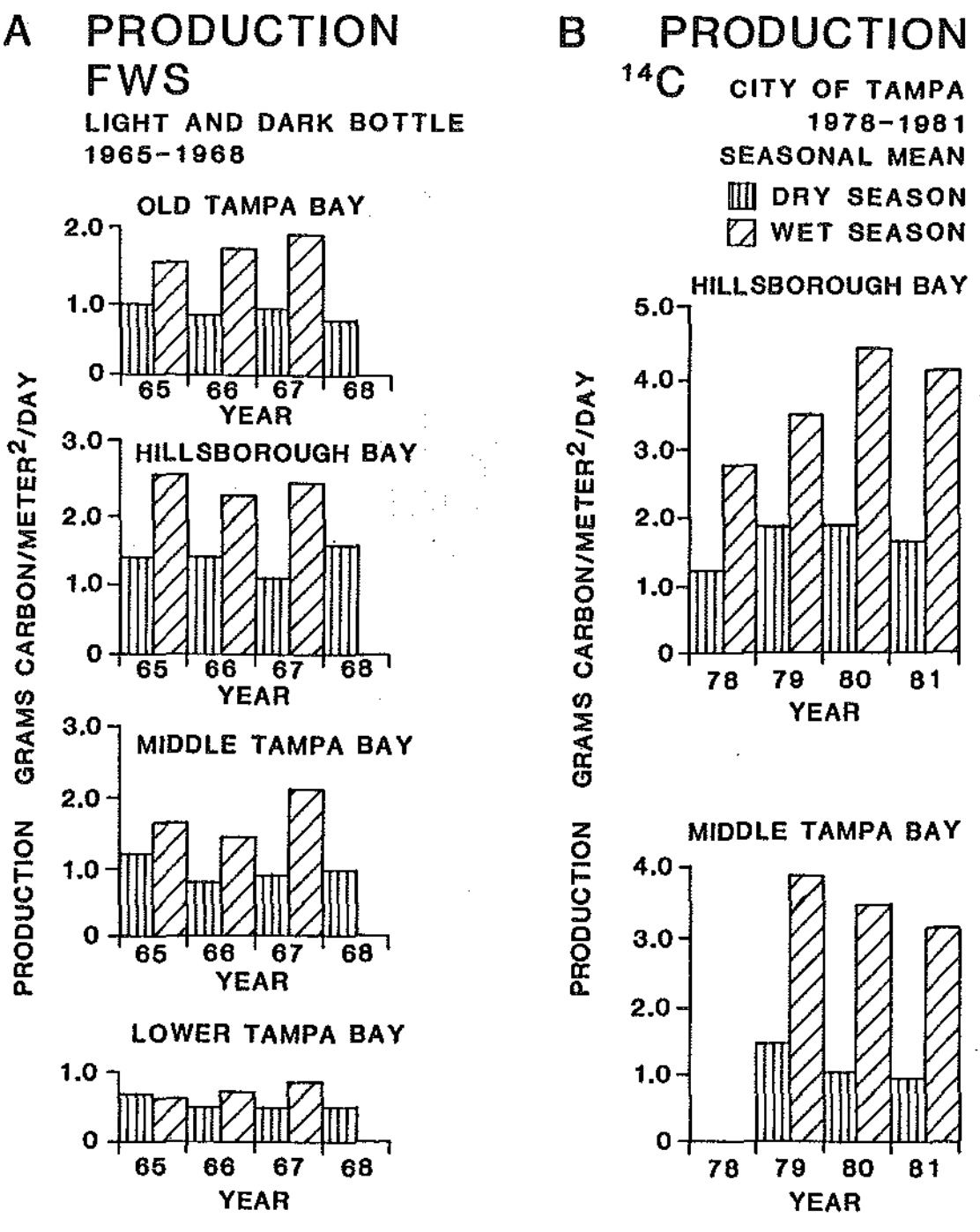

Figure 3. A - FWS data, light & dark bottle; B - COT data, ^{14}C.

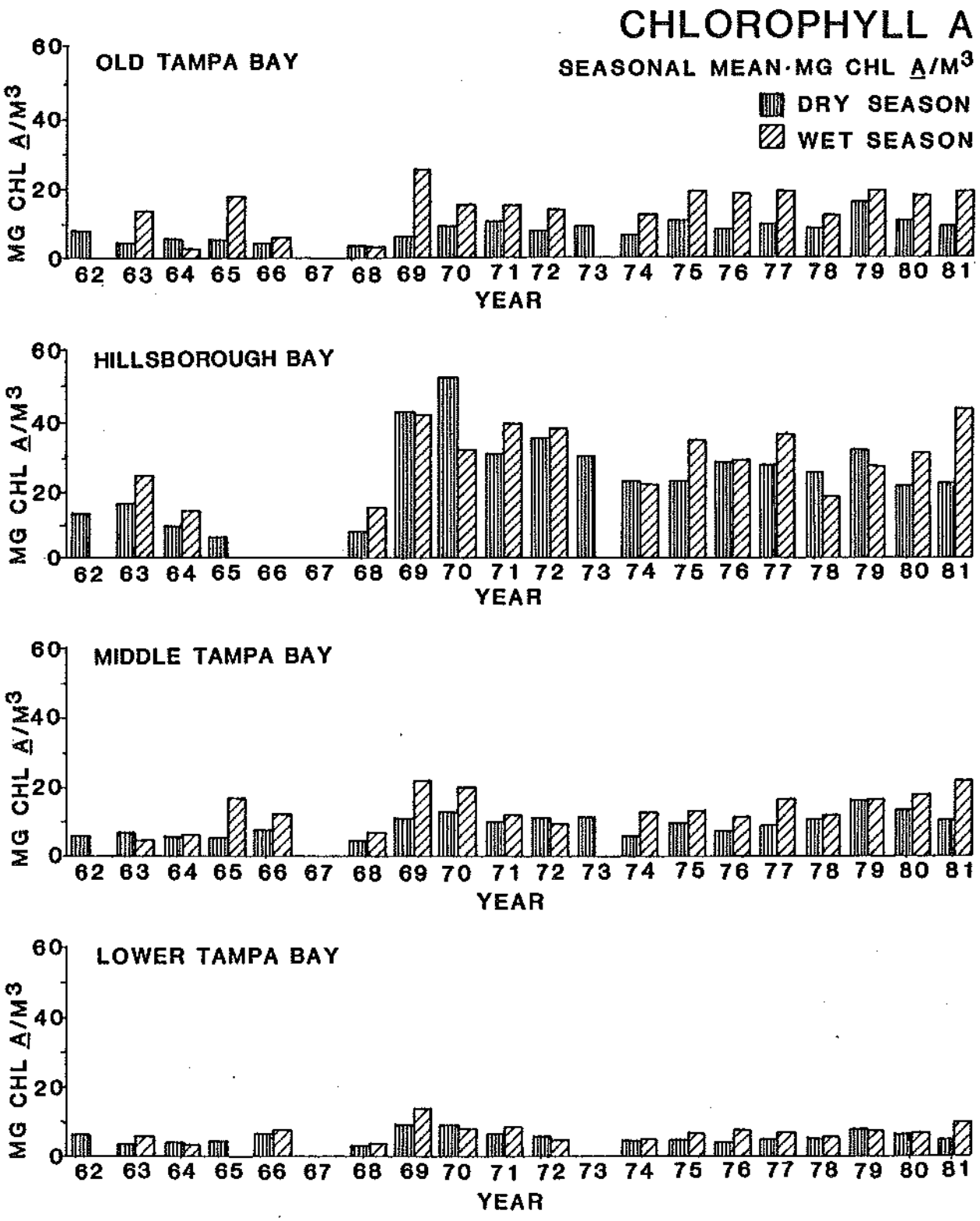

Figure 4. Chlorophyll a, FWS and HCEPC data.

Tampa Bay, since 1978 and 1979, repsectively. These data are presented in Figure 5. Marked seasonal patterns and generally higher concentrations found in the COT data are in clear contrast to the data collected by FWS and HCEPC in Hillsborough Bay and Middle Tampa Bay.

Not grinding chlorophyll samples has been shown to underestimate chlorophyll a concentrations (Fig. 6). Particularly large errors occur during periods when blue-green algae are abundant (Yentsch and Menzel 1963). The blue-green Schizothrix calcicola has been the dominant phytoplankton, both in terms of abundance and biomass, in Hillsborough Bay from late summer to early winter every year of the COT sampling program (1978-1982). Other records (HCEPC pers. comms. and Tampa Electric Co. 1973) indicate that blue-greens (probably S. calcicola) were present in Hillsborough Bay prior to the COT study. Dense concentrations of blue-greens have also been found in Old Tampa Bay and Middle Tampa Bay by the COT. Long-term and area-wide phytoplankton records, generated by FWS from the chlorophyll and light method, may therefore be of limited value for the following reasons: 1) phytoplankton production was calculated from a method which does not involve any direct measurement of photosynthetic rates, and 2) production rates for the eutrophic upper reaches of Tampa Bay may have been greatly underestimated during periods of high blue-green algae abundance due to the lack of sample grinding. The large difference between ground and unground chlorophyll a concentrations in Hillsborough Bay and Middle Tampa Bay is clearly demonstrated in Figures 4 and 5.

Discussion of the ^{14}C Technique

Of the different techniques currently used for plankton primary productivity estimates, ^{14}C is the most widely pursued in oceanic and inshore waters because it can be an effective physiological tracer. However, over the last ten years potential and actual problems with the application of the method have received critical discussion, e.g. bottle confinement, incubation time, heterotrophic uptake, photoinhibition, dark respiration and photorespiration in relation to balanced growth over time, phased assimilation, sample preservation, filter retention and ^{14}C-DOC, autotrophic size components retained and measured, and other facets associated with theory and practice (cf. Steidinger 1973; Eppley et al. 1977; Savidge 1978; Gieskes et al. 1979; Lean and Burnison 1979; Peterson 1980; Platt 1981; Redalje and Laws 1981; Li et al. 1983). Oceanic sampling practices and data assumptions appear to present the most problems by giving underestimates, because of the previously assumed low generation times and size composition of phytoplankton in oligotrophic waters. The ^{14}C method would appear to be more accurate for nutrient-rich inshore waters, yet many of the above problems can still apply. Additionally, bottle incubation and O_2 evolution measure gross production by incorporating respiratory activities (assuming equal respiration rates in light and dark) while ^{14}C incubations can measure gross or net productivity depending on the length of incubation, and grazers and bacteria present.

Annual Phytoplankton Production Estimates

Estimated annual phytoplankton production rates of the four major areas of Tampa Bay are presented in Table 1. Also shown in this table are comparisons of the three different methods of estimating phytoplankton production. The increase in chlorophyll and light estimated production after 1968, discussed above, is very evident when the period 1963-1968 is compared to the period of 1969-1972. Annual rates from the latter period are approximately twice the rates from the preceding period for all parts of the Bay. Methodological differences between the chlorophyll and light method and the oxygen method are reflected in the large discrepancies of estimated production

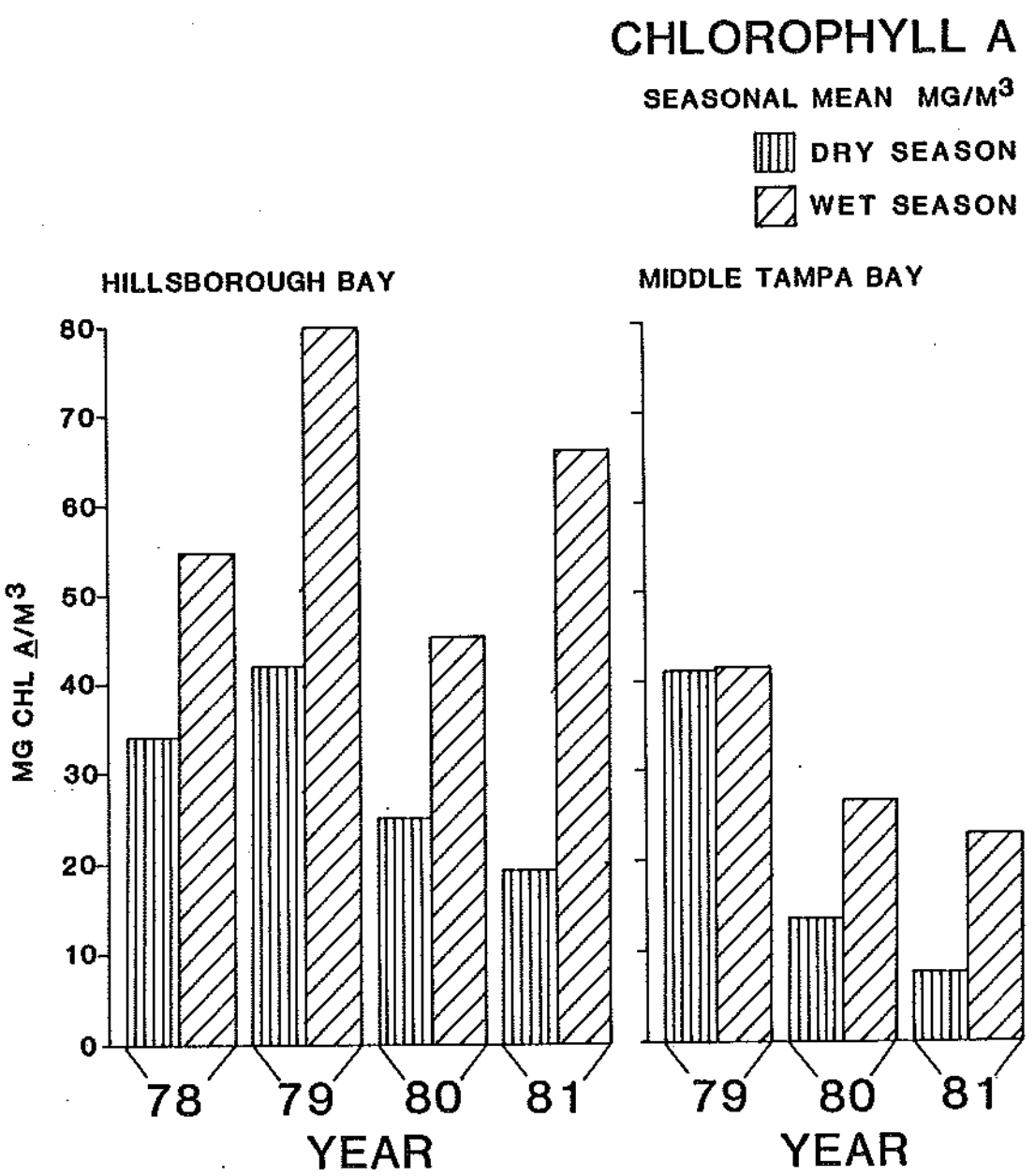

Figure 5. Chlorophyll a, filter-ground samples, COT data.

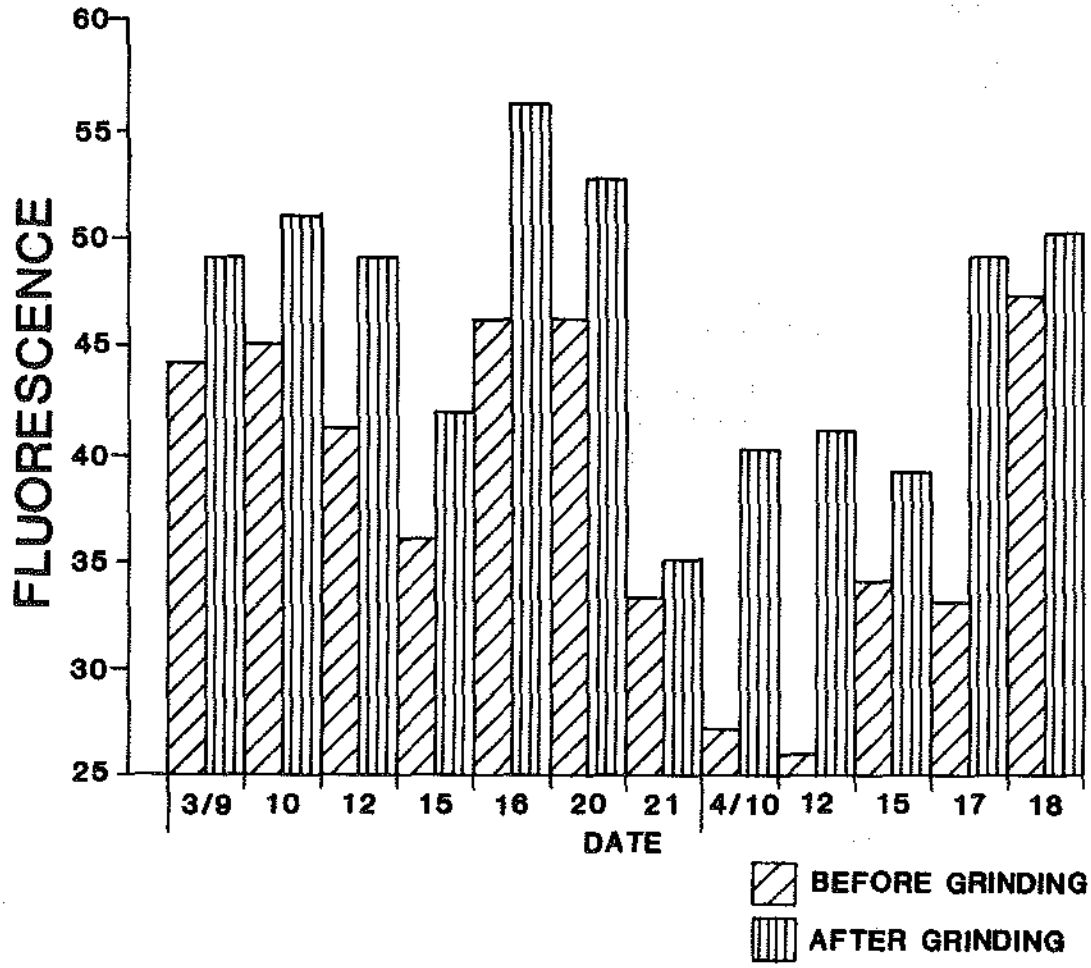

Figure 6. Comparison of fluorescence in 85% acetone extracts of natural phytoplankton in Woods Hole waters before and after grinding. (From Yentsch and Menzel 1963).

Table 1. Estimated annual phytoplankton production rates in the Tampa Bay system (g $C/m^2/yr$)

	Old Tampa Bay	Hillsborough Bay	Middle Tampa Bay	Lower Tampa Bay
1963-1968, chlorophyll + light	170	270	170	120
1965-1967, O_2	430	610	440	220
1969-1972, chlorophyll + light	290	580	490	180
1978-1983, ^{14}C	...	620	620	...

rates during the earliest periods of measurements.

Annual rates calculated from the ^{14}C method are only available for Hillsborough Bay and Middle Tampa Bay. These regions had similar rates during the period 1978-1983; however, the distribution of production in the water column was different. In Hillsborough Bay, a proportionally large amount of carbon was fixed near the surface, while production was more evenly distributed over the water column in the Middle Tampa Bay reigon.

Comparisons between annual rates calculated from the O_2 method and the ^{14}C method (Hillsborough Bay and Middle Tampa Bay) show that ^{14}C-measured production for the period 1978-1983 was similar to O_2-measured production for the period 1965-1967 in Hillsborough Bay. During the same period, ^{14}C-measured production in Middle Tampa Bay was approximately 1.4 times greater than production measured from the O_2 method. It is not known if these differences in production are true or artifacts caused by the use of different methods. It is reasonable to assume, however, that phytoplankton production in Tampa Bay has increased as a response to eutrophication of the bay system and reduced flushing. The suggested almost constant production in Hillsborough Bay since 1965-1967 may indicate that this portion of Tampa Bay has reached a level of maximum phytoplankton production.

Comparison of Primary Producing Components

Above, we discussed some of the shortcomings of the phytoplankton production information available for the Tampa Bay system. Phytoplankton data, however, appear plentiful when compared to information available on other primary producing components (i.e. seagrasses, macro- and microalgae, mangroves and salt marshes). To this date, there have not been long-term and area-wide production studies of any of these components.

Two studies (Pomeroy 1960 and Gibson, pers. comm.) have measured the production of several benthic components and both studies compared benthic production to planktonic production. Pomeroy compared the relative importance in production of the seagrass Thalassia, the benthic microflora, and the phytoplankton in Boca Ciega Bay (Fig. 7). He concluded that the relative importance of the three components was a function of water depth. In water less than 2 m, which was 75% of Boca Ciega Bay in 1958, the three groups were of approximately equal importance. Benthic plants became unimportant in deeper waters where all production was assumed to be planktonic.

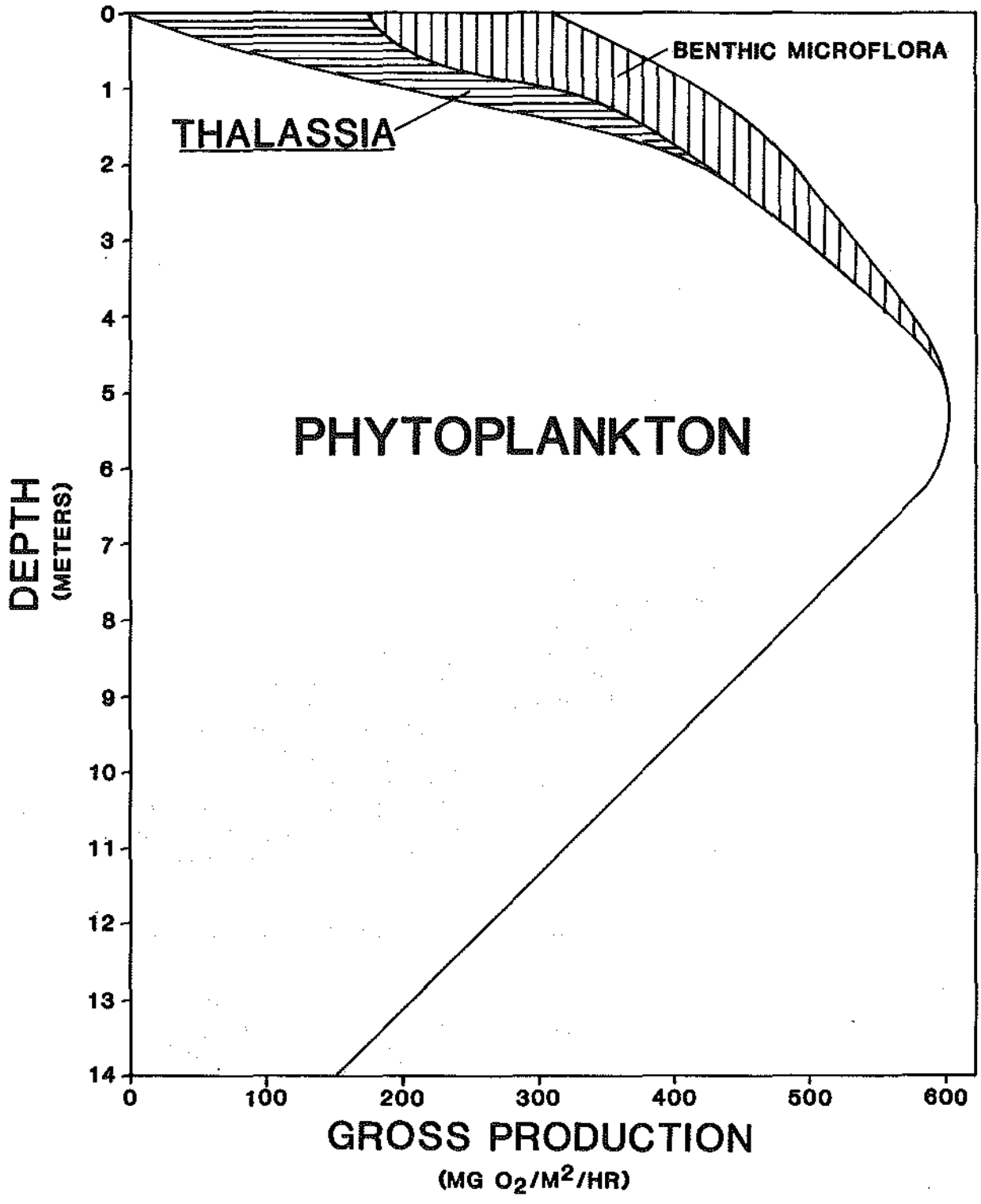

Figure 7. Variation with depth of the relative primary production of the plant populations in Boca Ciega Bay. Most of the bay is less than 2 m deep. (From Pomeroy 1960).

In 1981, Gibson initiated a quarterly investigation of seagrass and epiphyte production. He also measured production of benthic microflora and phytoplankton near the seagrasses. Preliminary results of this study indicate that seagrass beds are highly productive on a per m^2 basis. However, due to the limited coverage of seagrasses in Tampa Bay (Lewis et al., this volume), he suggests that the phytoplankton community is much more important in terms of carbon production than the seagrasses with epiphytes and the benthic microflora. His report will be published in full elsewhere.

Table 2 was constructed in order to discuss the relative importance of production by selected primary producer groups and also to calculate a crude estimate of total annual primary production for the system. Mangrove and salt marsh production are not listed in this table. Although these components have high primary production, little is known of their importance to the bay system. These producers supply organic matter to the bay proper, but could possibly be consumers or net importers of organic carbon from the bay (Haines 1979).

The data in Table 2 are presented as possible primary production by selected components and are not intended to give a complete carbon budget. It should also be emphasized that areal coverage of macroalgae and benthic microalgae are crude estimates. The City of Tampa and Mangrove Systems, Inc. have been conducting studies of biomass, and species and chemical composition of macroalgae in Tampa Bay, with emphasis on Hillsborough Bay. Large drifts of Gracilaria, Ulva and Chaetomorpha are common in the shallows of Hillsborough Bay. These studies will yield a biomass estimate of the macroalgae; however, little is known of their productivity. Hoffman and Dawes (1980) measured the productivity of Gracilaria during the summer at the Weeki Wachee River. The authors caution about extrapolating their single season rates to an annual rate, but for the purpose of Table 2 this has been attempted and the annual rate resulting was approximately 70 g C m^{-2}. This rate is generally lower than rates reported from other areas, but Hoffman and Dawes suggest their value is more realistic since they accounted for diel fluctuations in production. Macroalgae production in Tampa Bay may possibly be greater than at Weeki Wachee due to higher nutrient concentrations present.

The seagrass plus epiphyte production rate in Table 2 is an annual average of the Lassing Park seagrass bed (Gibson, pers. comm.). This rate is low in comparison with rates from Biscayne Bay (Jones 1968), but is similar to rates measured during the summer by Bittaker

Table 2. Estimated annual production of selected primary producers based on areal coverage in the Tampa Bay system.

	Production g C/m^2/yr	Area 10^6 m^2	Total Production g C/yr x 10^9	Percent Total
Seagrasses & epiphytes	130	57.5	7.5	2.3
Macroalgae	70	100	7.0	2.1
Benthic microalgae	80	200	16.0	4.9
Phytoplankton deep area	340	864	293.8	89.3
shallow area	50	96	48	1.5

and Iverson (1976) in northeastern Gulf of Mexico Thalassia beds. The latter study, however, did not account for epiphyte production.

Benthic microalgae production rates measured by Gibson are close to rates reported in the literature, which usually range between 100-200 g C m^{-2} yr^{-1}.

Phytoplankton productivity in Tampa Bay, according to the data presented in Table 2, accounts for 91% of the production by the selected primary producers. Similarly, Gibson (pers. comm.) found that the phytoplankton in the Indian River estuary contributed 93% of the annual production. McNulty (1969) first calculated the total production of phytoplankton, seagrasses and benthic microalgae in Tampa Bay on an area coverage basis. He concluded that the combined annual production by benthic algae and grasses was 2-3 times greater than the annual production by the phytoplankton. His calculations are in stark contrast to ours.

Annual Recurring Blue-Green Algae Bloom in Hillsborough Bay

Records of annual blue-green blooms (Schizothrix calcicola) in Hillsborough Bay date back to 1975 (see above). There are also reports of dense blue-green blooms in Tampa Bay from the 1960s (Saunders et al. 1967). The COT study has found S. calcicola to dominate the ultra and net (greater than 2 um) phytoplankton community from August through November every year of the study (1978-1982). Schizothrix calcicola displaces Skeletonema costatum and other small diatoms from dominance at the peak of summer temperatures (30°C and above). It reaches maximum concentrations of approximately 80,000 filaments per ml later in the summer and early fall. By the end of the year, S. costatum and other small diatoms again dominate the phytoplankton and S. calcicola becomes less abundant. The blue-green is virtually absent from the phytoplankton community between late winter and early summer.

The annual curve of phytoplankton in Hillsborough Bay (Figs. 8a and 8b) generally follows the temperature curve, which is a common phenomenon for shallow estuaries (Eppley 1972). However, maximum production does not occur when S. calcicola and chlorophyll a are at maximum concentrations (Figs. 8c and 8d). The blue-green is therefore a relatively inefficient producer of organic carbon. The primary productivity to chlorophyll a ratio (assimilation number) further illustrates the inefficency of S. calcicola (Fig. 8e). The phytoplankton community of Hillsborough Bay is least efficient when the blue-green is at maximum abundance. The greatest efficiency occurs in early summer when the bay has a "typical" estuarine community of small photosynthetic flagellates, S. costatum, and other small diatoms. Similar succession of phytoplankton groups, including filamentous blue-green algae, and associated seasonality in efficiency of carbon assimilation have been reported by others (e.g. Revelante and Gilmartin 1981).

Little is known about the food value of Schizothrix calcicola, although blue-greens generally are considered undesirable as food (Forsskahl et al. 1982). Therefore, if blue-greens compete with and replace better food species such as small diatoms, less particulate organic carbon will be available to secondary production. More fixed carbon will be lost to export, the sediments, and bacterial remineralization processes, and as a result the ecological efficiency of the system will be lowered.

CARBON FLOW AND TROPHIC DYNAMICS

A realistic limitation with any primary productivity measurement is its usage in trophic and energy flow schemes. Questions such as how is the resultant POC used, or lost and recycled, and what trophic level benefits, and at what cost to ecological efficiency, are not addressed. Carbon flow is indeed not

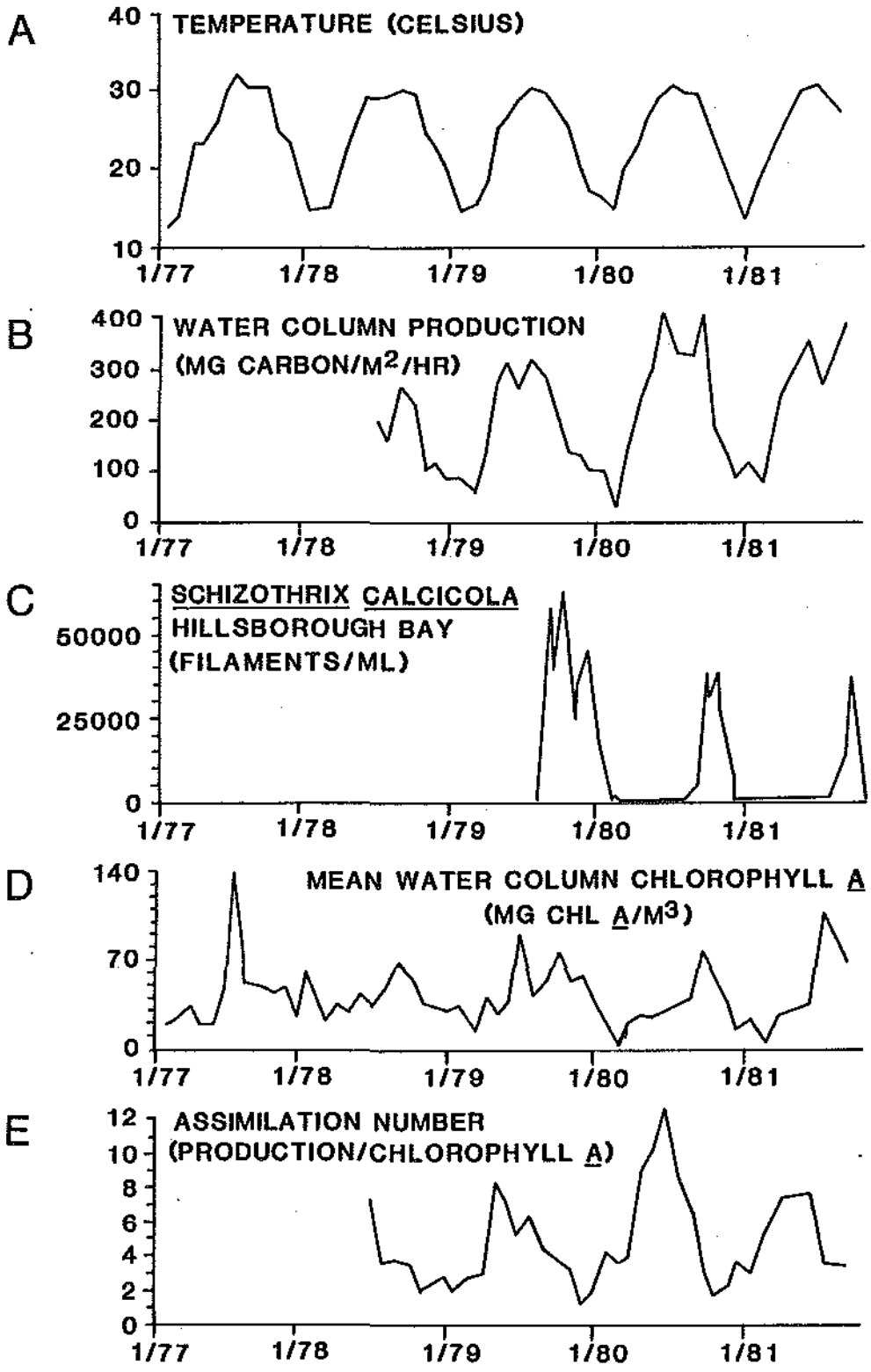

Figure 8. Hillsborough Bay water temperature (A), production (B), Schizothrix calcicola filaments (C), chlorophyll a (D) and assimilation number (E), 1977-1981.

unidirectional as Peterson (1980) stressed. He also made statements that 10 years ago would have been considered radical:

> I think the most significant advance of the last few years in interpreting the meaning of ^{14}C-CO_2 uptake has been the realization that our conceptual model of carbon flow has been too simple. The idea that simply calculating the fraction of the inorganic carbon pool converted to POC and DOC in a 4 hr incubation is a sufficient measure of primary production is no longer valid ... It seems unacceptable to guess at the proper interpretation of ^{14}C data ... We need to know how much of the carbon fixed in photosynthesis is available to grazers and other heterotrophs in aquatic systems ... The ^{14}C method will surely help in reaching this goal, but it may not be sufficient unless coupled with other tools now available to aquatic ecologists. (Peterson 1980, p. 376-377).

Although Peterson's comments were directed primarily to open pelagic realms, they also apply to estuarine areas where planktonic values are complicated by nonphytoplankton detrital inputs, benthic macro- and microphytes, and monospecific blooms that are not grazed but often cause decomposition and anoxia when developing in a restricted water mass.

System Production

The Tampa Bay system has high phytoplankton standing stock and primary productivity. The system is fringed by limited mangrove stands and marsh areas, and has submerged seagrasses and micro- and macroalgae which constitute other primary producers. Major inorganic nutrients would not appear to be limiting primary productivity, particularly in upper and middle reaches, and the system probably has a high nitrogen turnover rate. Consequently, the Tampa Bay system is considered enriched and "productive".

The most limiting factors to total primary production for the system, therefore, would be water clarity and temperature, particularly in the upper reaches such as Hillsborough and Old Tampa Bays. Water clarity, or rather turbidity, has restricted benthic macrophytes to shoreline areas of less than 2 m depth in those areas that still support submerged vegetation. These shallow depths represent about 10% of the bay system. Although primary productivity of seagrasses and their epiphytes in many subtropical and tropical areas can be high (Jones 1968), and micro- and macroalgae also can be significant primary producers, their limited surface area coverage reduces the total contribution when compared to phytoplankton productivity based on integrated m^2 calculations for total area (see Table 2). If primary productivity was used as an hourly or yearly per m^2 value alone, then seagrasses and their epiphytes would have the highest values, followed by benthic macroalgae and planktonic microalgae in shallow estuaries and specifically the Tampa Bay system. When the total bay area is used, assuming that the benthic components are limited to less than 2 m, then planktonic microalgae dominate as primary producers and always have because of the bathymetry and size (960 km^2) of the bay system. It is not that the system is changing from one dominated by seagrasses to one dominated by phytoplankton; rather, where seagrasses have been removed or destroyed (81% of the grassbeds have been lost since 1876; Lewis et al., this volume), phytoplankton now dominate the system's shallow perimeter as well as deeper water.

Even though benthic primary producers, such as seagrasses and macroalgae, assimilate inorganic carbon and photosynthesize, their immediate particulate organic carbon (POC) contribution is unquantified. Seagrass leaves in the Tampa Bay area are rarely grazed directly, although seagrass epiphytes are; however, leaves detach

and become drift twice yearly and this POC contributes to detrital and remineralization cycles. Also, massive amounts of drift Gracilaria and Ulva can dominate aquatic biomass and primary productivity, yet their contribution also is principally to particulate detrital and dissolved nutrient cycles. In addition to these detrital inputs, mangrove leaf and twig litter from fringing trees and saltmarsh plant detritus contribute POC and DOC that support some estuarine food webs or portions thereof. Grazers, such as amphipods, further break down the vegetation into smaller particles (Fenchel 1970) and these animals contribute DOC, nutrients, and fecal matter to the system which is then recycled, thus building in a time lag to total production, injecting a lower trophic level, and decreasing ecological efficiencies. Microcolonizers of detrital particles utilize these substrates and release DOC and nutrients in addition to increasing the nutritional value (e.g. protein) of the total detrital biomass. Again, carbon flow is not unidirectional. As Pomeroy stated, "In the real world there are other energy pathways involving such entities as microorganisms, detritus, and dissolved organic materials (DOM)" (Pomeroy 1979, p. 165). Consequently, there are direct and indirect trophic pathways. For many of Florida's recreational and commercial fishes, e.g. tarpon, redfish, spotted seatrout, snook, black mullet, black drum, gag grouper and others, food items vary with a fish's age and habitat. Fenchel (1972) suggested that detrital-based trophic systems acted as energy reservoirs or reserves, making seasonally fixed carbon or sporadic allochthonous carbon inputs available for longer time periods to herbivores and carnivores.

Recommendations for Future Primary Production and Trophic Studies

Sackett (in press), in a review of stable carbon isotope studies and applications, stated "... the carbon isotope composition of an organism is a weighted average of the isotopic composition of its organic carbon food intake." This was further supported by Fry and Parker (1979) and Haines and Montagne (1979) where carbon pathways, particularly those based on microalgae/phytoplankton and vascular plant sources, were differentiated by analyzing tissue from higher animal trophic levels. However, stable values for a given group, or even a given species, can vary 14°/oo because of natural fluctuations in lipid metabolism and reserves, photosynthetic pathways, temperature, season, geographic location, plant part if vascular, and decomposition (Gormly and Sackett 1977; McMillan et al. 1980; Fry 1981; McMillan and Smith 1982; Sackett, in press). Hughes and Sherr (1983) pointed out that ^{13}C was selectively biomagnified at each trophic level because ^{12}C is respired; therefore, higher trophic levels are ^{13}C enriched with each step increasing 0.5 to 1.5°/oo. Since there are recognized problems with the overlap in and interpretation of $^{13}C/^{12}C$ ratios, other stable isotopes, e.g. $^{15}N/^{14}N$ and $^{35}S/^{34}S$, are being pursued because they are subject to little change with trophic levels (cf. Macko et al. 1982; Fry et al. 1982). Another stable isotope being used to trace food webs is deuterium/hydrogen (cf. Estep and Dabrowski 1980). Using a combination of stable isotopes, researchers can differentiate between phytoplankton, seagrass, macroalgae, and mangrove sources as primary production components in food webs.

Based on the above discussion of isotope ratios and how these techniques can be applied to food webs with both auto- and allochthonous inputs, this approach could be taken to compartmentalize and identify the significance of various detrital sources at succeeding levels of food webs in the Tampa Bay system. Primary productivity measurements for potential major direct pathways, e.g. planktonic and benthic microalgae and epiphytes, could still be pursued, but interpretation of resultant data must be correlated with herbivores or omnivores, secondary production, and system dynamics. Are

the potential direct sources actually used as POC or is DOC more significant in food webs? What is the significance and contribution of planktonic bloom events. What is the yearly production of benthic microalgae and what does it support? What time lag is built into total system production because of detrital and DOC utilization? In other words, we may need to determine the major inputs and their form before a sampling and analytical strategy can be properly designed to evaluate and quantify primary and secondary production in relation to carbon flow, trophic pathways and interactions in such a diverse system. Secondary production, depending on definition, would appear to be multilevel, while much of the primary production is lost as sedimented POC and recycled, thus introducing additional trophic levels. Such an approach requires a "rethinking" of the value and application of primary production measurement as carbon per area per time interval as they relate to systems production and trophic structures.

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VIROLOGICAL STATUS OF TAMPA BAY

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INTRODUCTION

Environmental virology is a relatively new field of endeavor even though it has been recognized for years that human viruses are present in large numbers in sewage effluents and other human biological wastes. The lack of interest in the past is probably related to the fact that viruses cannot multiply as do bacteria. Rather, viruses behave as inert, macromolecular proteins in the environment. It is only when they come in contact with a living cell that they become active, i.e., they adsorb to and enter the cell and are replicated by the cell itself under the influence of the viral nucleic acid core. For the most part, viruses are species specific, particularly those which are most frequently found in the environment. These are viruses which enter the alimentary tract of man, are replicated therein and are excreted into the sewerage system. Thus, the only human viruses present in the Bay would be those which were an integral part of the sewage effluents or septic tank leachates discharged directly or indirectly into the Bay. Because of the dilution factor, relatively low numbers of viruses would be expected, so they must be concentrated either by mechanical or biological methods before they can be demonstrated.

None of the microbiological studies of Tampa Bay has included a virological component. This may have been an oversight in planning, but most probably was due to the complexity and expense of environmental virological studies. Not only must large volumes of water be processed on site but additional concentration must be done in the laboratory to further reduce the volume of the original concentrate because of the excessive cost of assaying the sample in cell culture and/or mice.

Biological concentration, by oysters for instance, is not very efficient because of the sedentary nature of oysters and the lack of viral homogeneity within the Bay waters. Unfortunately, the mechanical techniques available for virus concentration from sea water are also inefficient, varying from 0 to 50 percent efficiency. This inefficiency is related to the inability to filter out the viruses because of their minute size, roughly 25 to 40 nm. Thus, concentration of viruses relies on adsorption of the agents to a filter media, but the virions must compete for adsorption sites with various other organic and inorganic substances present in the test sample. This, naturally, decreases the virus concentration efficiency of the filter media. In addition, virus adsorption is acutely affected by both pH and the presence of ions which further complicates the adsorption procedure.

A second problem encountered in virus monitoring is the large number of virus types which may be present. There are over 100 different types of human viruses, some of which may be isolated in cell culture only, others in mice only, a few which can be replicated in both host systems, and some, like hepatitis, which cannot be demonstrated by growth in any host system. Because of this, the assay system may be only 50 percent efficient. Even if concentration procedures were 100 percent efficient, all of the viruses present could not be demonstrated. For these various reasons, environmental virology has developed relatively slowly and is seldom included in routine microbiological survey work.

THE REVIEW

In 1971, when the Epidemiology Research Center first became involved in environmental virology, techniques were even less efficient than present methods for concentrating viruses from water and no specific techniques had been established for processing crustaceans or fish for virus isolation. Even so, in response to a problem that was reported on the east coast of Florida, various types of fish and crustaceans were tested for virus using techinques developed for processing human specimens. The 73 fish tested were caught at various sites in Tampa Bay and near the sewage outflow pipe at Anclote Key in Pinellas County. Sixteen species were represented among the catch. After a thorough cleansing of the intact fish, sections of gills, muscle, intestines, and a rectal swab and feces, aseptically removed from a section of the intestines, were obtained from each. In all, 326 specimens were assayed in cell culture and 359 companion specimens were assayed in newborn white Swiss mice. No isolates were obtained from any of the specimens. These data failed to confirm the East Coast report that viruses could be isolated from most any fish tested. It was later ascertained that toxicity of the inoculum to the cell culture was responsible for the cell destruction rather than a virus-induced cytopathogenic effect.

Unfortunately, the same negative results were not achieved with the oysters tested. Poliovirus type 1 was isolated from an oyster harvested on November 17, 1971, from a bed at the northwest end of the Gandy Bridge. A total of 76 oysters were tested, 13 harvested at the west and southwest of the Ben T. Davis Beach on Courtney Campbell Causeway, 29 from the Anclote River near the sewage outfall pipe and 34 from the Bay waters at the southwest and northwest ends of the Gandy Bridge. It is interesting that oysters from the sewage outflow area in the Anclote River were negative. Literally millions of virus particles must have been present in the waters because of the poorly treated sewage being discharged. Conversely, the one oyster which did yield virus was taken miles away from a sewage discharge site. However, a trailer court served by a septic system was located within 100 to 200 feet of the harvest site. Leachate from the septic tank was considered to be the source of the contamination.

One explanation for the lack of virus in the oysters from Anclote River may be the high turbidity of the waters there. Controlled laboratory experiments conducted by Hamblet et al. (1969) showed that virus uptake in low turbidity waters over a 24 hour period was approximately three times greater than in high turbidity waters. The authors suggested that the oysters in the high turbidity waters rejected as pseudofeces much of the high turbidity virus-laden silt in the aquarium. Whether or not this would occur under natural conditions is a moot question.

Considering the unsophisticated processing techinques used, there must have been a large number of virions present to have afforded even a single isolate from the oyster. Unfortunately, because of a lack of funding, these studies were not pursued further.

In November 1972, when the City of Tampa was discharging poorly treated effluents in Tampa Bay, 1500 ml of bay water was processed by the aqueous polymer two phase separation technique and half of the concentrate assayed for virus. This yielded five isolates of echovirus type 8. Again, this technique is extremely inefficient and yet, 750 ml of bay water yielded five isolates or 24.2 plaque forming units (PFU) per gallon. This single sample was tested strictly out of curiosity and represents the only virological testing done on Tampa Bay waters to my knowledge. What the virological status of the Bay is at present is not known but it should be presumed to be contaminated with human viruses. Rather extensive studies of Galveston Bay in Texas and two bays in New York are the basis for this statement.

The Texas studies done by Goyal et

al. (1979) covered a ten month period. Samples of oysters and their overlying waters from beds which were either approved or disapproved, i.e. open or closed to shellfish harvesting based on bacteriology standards, were tested for viruses. As shown in Table 1, the difference between the number of viruses isolated from the closed versus the open beds was not reassuring as to the validity of the currently accepted bacteriological standards. Fifty percent of the water samples and 20 percent of the oysters tested from the beds open to harvesting were positive as opposed to 63 percent and 40 percent, respectively, in samples from the closed beds.

Studies done on Long Island by Vaughn et al. (1979) provide confirmation that virus-containing septic tank leachates do reach surface waters and may be responsible for contamination of shellfish. Two bays, Great South Bay and Oyster Bay, were sampled over an eight month period. Great South Bay received water from creeks carrying septic leachates but Oyster Bay received both septic leachates and sewage effluents. The inflow site of the latter was located several miles away from the shellfish growing beds.

Table 2 shows the virus isolations made from waters overlying the shellfish harvesting beds. As was noted in the Texas study, there was no significant difference in the viral content of the water between the open and closed beds.

Oysters harvested from the open beds yielded virus only once during the test period, 0.48 PFU/gal in March 1977. The failure to demonstrate virus in waters overlying the closed beds was surprising in view of the fact that oysters yielded virus on three occasions: 0.48 PFU/gal in July and 0.08 PFU/gal in November 1976, and 0.2 PFU/gal in April 1977.

In Great South Bay where viruses were isolated from the overlying waters fairly frequently, clams harvested also yielded virus whether or not the clams were harvested from closed or open beds. Clams tested from the closed beds yielded 0.16 PFU/gal in July 1976 and 0.1 PFU/gal in June 1977. Likewise, clams harvested from the open beds yielded 0.3 PFU/gal in April and 0.1 PFU/gal in June 1977. Thus, there was no significant difference between the number of positive specimens obtained from the closed as opposed to the open shellfish harvesting sites.

COMMENTARY

As is evident from the data presented, relatively little attention has been accorded the problem of viruses in bay waters, whether in Tampa or elsewhere in the United States. As suggested initially, the cost and difficulties of virus concentration and assay procedures is probably a major deterrent, but the lack of appreciation by the general public and funding agencies of the importance of viruses in the environment may be an equally important deterrent. It would appear that because human viruses are not involved in fish kills, they do not receive the publicity accorded the red tide, for instance. Even though disease in man has been demonstrated to be due to the consumption of raw oysters, such reports are frequently downgraded in an effort to prevent monetary damage to the shellfish industry.

From the data presented it is evident that the current methodology used for approving shellfish harvesting beds are inadequate to protect the consumer. Research should be undertaken to define more reliable criteria for approving shellfish harvesting sites. If sufficient data were accrued on the bacteriological and virological status of oysters and their overlying waters, they may be sufficiently convincing to stimulate the establishment of a viral standard in conjunction with or in place of the present bacteriological standard.

It should be recognized that a single virus particle has the capability of establishing an infection in man but not necessarily producing overt disease. The infected individual excretes thousands of virions and may serve as the source of infection in others. Under such

Table 1. Virus isolation from oysters and overlying waters, Galveston Bay, Texas (revised from Goyal et al. 1979)

Harvesting Status	No. of Sites	WATER SAMPLES Number Positive / Number Tested	Percent Positive	Total Number of Isolates	OYSTER SAMPLES Number Positive / Number Tested	Percent Positive	Total Number of Isolates
Closed	6	19/30	63.3	364	12/30	40	223
Open	4	7/14	50.0	143	2/10	20	29

Table 2. Virus isolation from water overlying oyster beds, Long Island, New York. (revised from Vaughn et al. 1979)

Sampling Site	Harvesting Status	WATER SAMPLES Number Positive / Number Tested	Percent Positive	Range in Number of PFU/gallon
Great South Bay	Open	3/8	37.5	1.2 to 8.0
	Closed	3/8	37.5	1.1 to 4.4
Oyster Bay	Open	1/8	12.5	2.8
	Closed	0/8	0.0	-

conditions, the actual source of the initial infection, i.e. a subclinical case of hepatitis from eating raw oysters perhaps, would never be recognized.

The presence of viruses in bay water poses another problem for bathers. An epidemiological study done by Cabelli (1980) in New York, Massachusetts, Louisiana and Egypt showed a relationship between swimming-associated gastroenteritis and the quality of the bathing water. The causative organisms implicated on the basis of incubation period, symptomatology, severity and duration of disease, and age distribution were the human rotavirus and the parvo-like viruses, which are found in high titers in feces from infected individuals. Thus, their entry into septic tanks and sewage systems is assured.

In this era of economic decline, interest in the protection of the environment appears to be on the decline as well. If this is so and the use of septic tanks and land disposal of poorly treated effluents becomes more widespread to accomodate the ever increasing population in the Bay area, virological contamination of Tampa Bay well be exacerbated. Fortunately, the restraints on sewage discharge into the bay over the past few years have been of real value but only vigilance can maintain these gains.

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EFFECT OF MICROBES ON THE WATER QUALITY OF TAMPA BAY: YESTERDAY, TODAY, AND TOMORROW

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ABSTRACT

Microbial activity underlies all other biological and chemical aspects of the Tampa Bay system, but is almost untouched by basic research. The procaryotic microbes most important in the element cycles of C, H, O, N, S, P, and the stabilization or mobilization of toxic metals in Tampa Bay, have yet to be determined. The microbiological quality of the water and sediments impacts heavily on the function of the bay as an estuarine system, its aesthetic and recreational uses, its value as a source of human foods, and its ability to function as an adequate sink for the conveyance and disposal of natural drainage, waste heat, sewage, urban runoff, the residues of mining and agriculture, and bilge. Almost all the bacteriological data available are assessments of sanitary significance, mostly coliform counts. Sanitary water quality trends are mixed. During the 1970s there were significantly positive improvements in the treatment of some sewage discharged to the bay. As population and urbanization continue to increase in the Tampa Bay drainage basin, maintenance of adequate water quality will depend on uniform application of high sewage treatment standards and, crucially, on control of the discharge of urban runoff.

FUNGI: THEIR OCCURRENCE AND POTENTIAL ROLES IN THE TAMPA BAY ECOSYSTEM

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ABSTRACT

About 500 species of fungi are limited to the marine environment. All major goups of fungi and some lichens have been found in Tampa Bay and its estuarine environs. The fungi occur in and on various substrates such as beach sands, mangroves, seagrasses, wood pilings, and man-made objects, as well as in the guts and on the gills, shells, and exoskeletons of various invertebrates. The potential relationships between fungi and man are discussed.

INTRODUCTION

Fungi are eukaryotic organisms ranging in appearance from single cells to highly branched filaments (Fell 1976). Most fungal cell walls are composed primarily of chitin. One group (Oomycetes) has cell walls made up of cellulose. Because fungi lack chlorophyll, they must derive their nutrients heterotrophically from the environment. The above features combine to separate fungi from bacteria and algae.

Park (1968) suggested that the large surface area:volume ratio in yeast, or the hyphal growth form of fungi, allows an increased contact with the environment and greatly affects fungal biology. He pointed out that not only was the area of contact large but there was no great distance between any point in the protoplasm and the environment, a difference from multicellular organisms which have their protoplasm protected from the environment by both physical and physiological barriers. Park (1968) further suggested that the environment played a more immediate and direct part in fungal physiology than in other organisms. Conversely, the fungi may influence the environment rapidly by their active metabolism.

Fungi are found in a wide variety of aerobic and some anaerobic habitats in terrestrial and aquatic environments (Emerson and Natvig 1981). They can tolerate a wide range of temperature and salinity conditions. Their nutritional conditions may be met by living or dead substrates.

The purpose of this paper is to discuss some aspects of research on fungi in the marine environment generally. Prominent studies will be then related to work done in Tampa Bay, and needs for future research will be outlined.

ON THE NATURE OF FUNGI FROM MARINE ENVIRONMENTS

A very small percent of known fungi occur in marine environs. A generalized summary of marine fungal groups is shown in Figure 1. There are relatively few species of lower fungi characterized as marine or estuarine (Table 1). Although the labyrinthulids and the thraustochytrids (net plasmodium types) may be very important in marine environments, their relationships to true fungi is tenuous at best. For a comprehensive review of the taxonomic dilemmas associated with these groups see Johnson (1976) and Perkins (1976).

By virtue of their sexual reproduction, morphology, and the biochemical composition of the cell walls, the more complex and advanced fungi appear to be monophyletically related. Kohlmeyer and Kohlmeyer (1979) have assembled information on the higher groups of fungi, including keys and illustrations. A summary of these

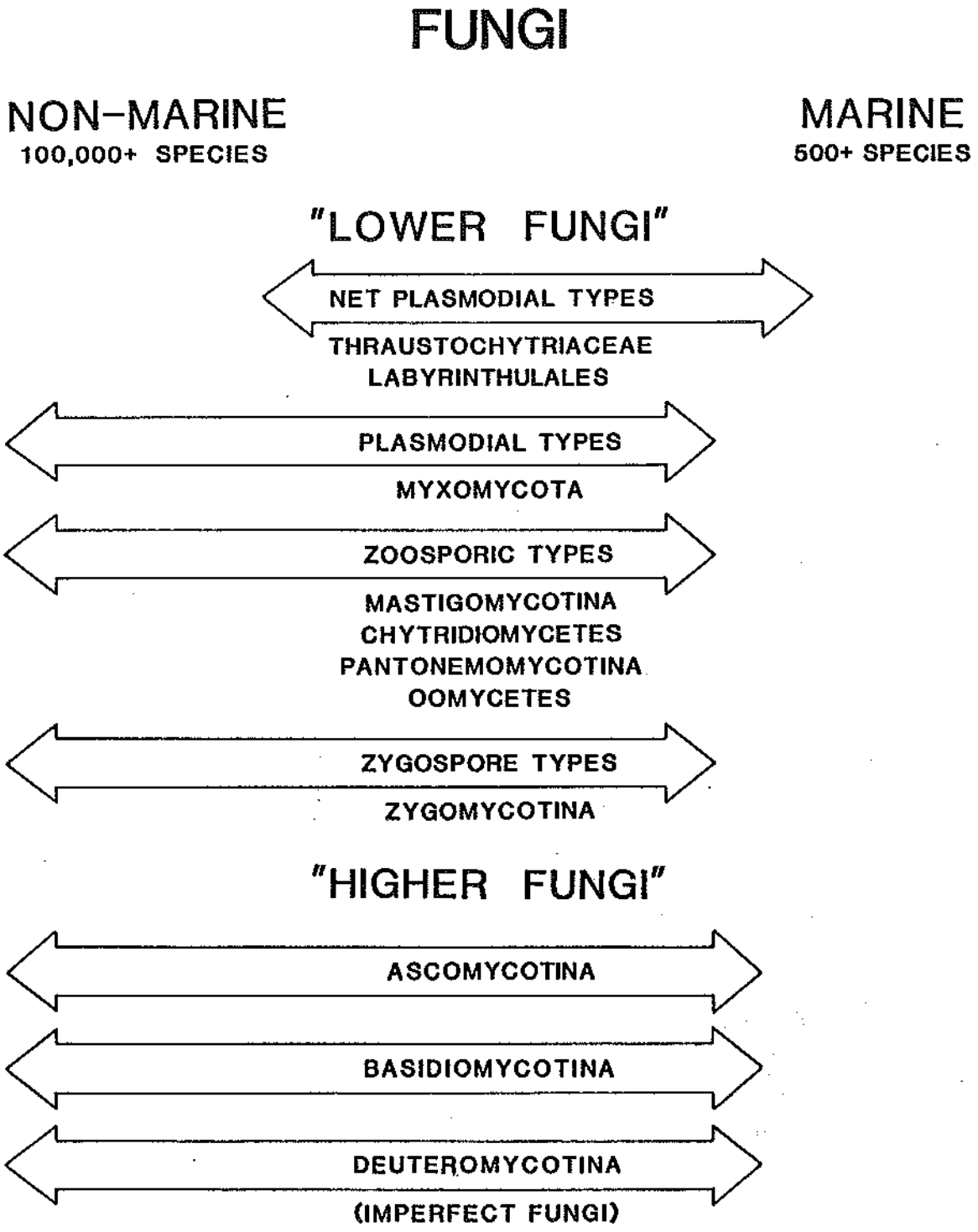

Figure 1. Relative numbers of marine and non-marine species of fungi.

Table 1. Taxonomy of some lower fungi.

CLASS	ORDER	SCIENTIFIC NAME	IMPLICATED ROLE
Chytridomycetes	Chytridiales	*Phlyctochytrium* sp.	decay of algae and vegetative detritus
Oomycetes	Saprolegniales	*Saprolegnia parasitica* Coker	fish pathogen
"	"	*Atkinsiella dubia* (Atkins)	pathogen on *Pinnothes* eggs
"	Peronosporales	*Pythium* spp.	can be pathogenic on plants and animals
"	Lagenidales	*Lagenidium callinectes* Couch	pathogen in eggs and larvae of various crustaceans
??	Labyrinthulales	*Labyrinthula* spp.	decay detritus
	"	*Labyrinthomyxa marina* (Mackin, Owen *et* Collier) Mackin *et* Ray	oyster parasite
	"	(=*Dermocystidium marinus*)	
??	??	*Labyrinthuloides* spp.	decay algae and detritus?
??	??	*Haliphthoros milfordensis* Vishniac	pathogen on oyster drill
??	??	*Ostracoblabe implexa* Bornet *et* Flahault	shell disease in oysters
??	??	*Althornia crouchii* Jones *et* Alderman	??
??	??	*Schizochytrium aggregatum* Goldstein *et* Belsky	vegetative material, detritus
??	??	*Thraustochytrium* spp.	vegetative material, detritus

Table 2. Taxonomy of some higher fungi.

Kingdom - Fungi
  Division - Eumycota
    Subdivision - Ascomycotina
      Class - Hemiascomycetes - some yeasts
              Plectomycetes
              Pyrenomycetes - many marine fungi
              Discomycetes
              Loculascomycetes - some marine fungi
              Laboulbeniomycetes
    Subdivision - Deuteromycotina - imperfect fungi
    Subdivision - Basidiomycotina - 2 species

organisms is shown in Table 2.

Johnson and Sparrow (1961) have summarized the early work on the physiology of marine fungi, while subsequent reviews have focused either on lower (Jones and Harrison 1976) or higher fungi (Hughes 1975; Jones and Byrne 1976). There seem to be several generalizations about the influence of salinity on fungal growth:

1. Many lower fungi, especially the net plasmodial types (Thraustochytriaceae and Labyrinthulales), have fastidious nutritional requirements; some require vitamins and/or sterols.
2. Over half of the Thraustochytriaceae have temperature optima of 30°C.
3. Among some lower fungi, there are obligately marine forms which require increased levels of NaCl while many tolerate low salinity waters or soils.
4. Among most higher fungi, optimum growth occurs in the range of 10°-20°C. None require temperatures above 30°C, but many tolerate such temperatures.
5. Salinity does not have an adverse effect on the growth of many terrestrial fungi.
6. Some marine fungi have been found to grow well on media made with distilled water rather than with seawater.
7. Imperfect fungi show a much broader tolerance to high salinity conditions than ascomycetous fungi.

The response of spore germination and reproduction of some major groups of fungi are diagrammatically represented in Figure 2.

FUNGI AND MARINE ANIMALS

There are sound economic reasons why an understanding of the role of fungi in marine animals is important (Johnson and Sparrow 1961). Although extensively studied, relatively few fungal diseases in animals are completely understood. With this in mind the salient features of some fungal-animal relationships are reviewed and occurrences in Tampa Bay noted.

Oyster Pathogens. Notable among studies of the oyster parasite Labyrinthomyxa marina (Mackin, Owen et Collier) Mackin et Ray (=Dermocystidium marinum) in Florida, including studies in Tampa Bay, are those made by Quick (1971a, b, c; 1972a, b, c; 1973; Quick and Mankin 1971). He found that summer infestations coincided with the temperature and salinity optima of the fungus. However, if infections were well established, the pathogen could be maintained in less than optimal salinities. Quick (1974a, b) also isolated several other labyrinthulids from Tampa Bay and nearby marine waters.

Ostracoblabe implexa Bornet et Flahault is another pathogen of oysters. This organism has been shown recently to be the cause of shell disease in Ostrea edulis L. and Crassostrea angulata Link from North European waters (Alderman 1976). Apparently the fungus obtains nutrients from the organic matrix of the

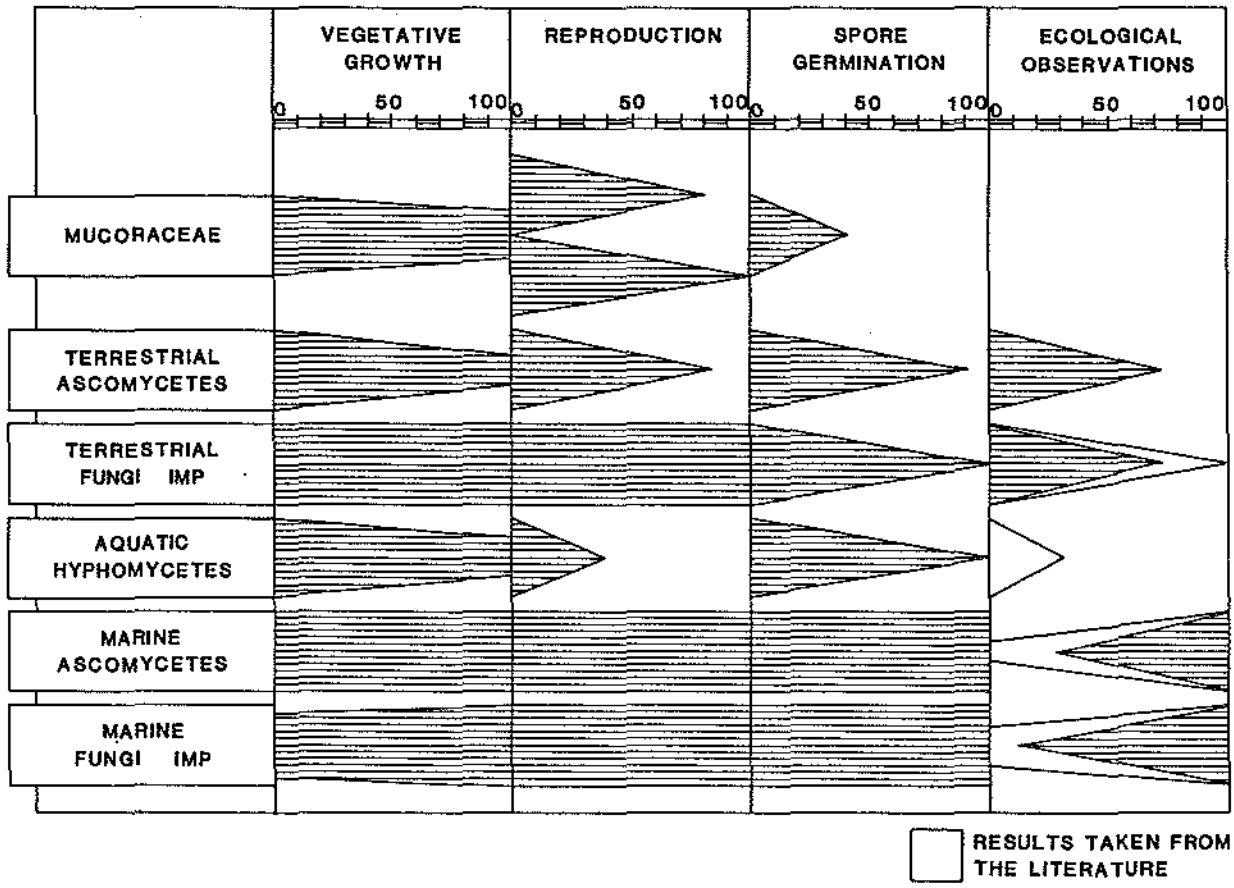

Figure 2. Physiological and ecological responses of various fungal groups to salinity. (From Jones and Byrnes 1976).

shell. Although no harm is done to the living tissues initially, the fungus irritates the living tissues when growing between the shell and the mantle. The oyster responds to the irritation and lays down more shell with a higher protein content. This substrate of horny protein is an ideal nutrient for O. implexa which then grows faster. The situation is self-perpetuating (Alderman 1976).

It is interesting that Ostacoblabe implexa has not spread beyond Northern European waters. Alderman and Jones (1971) verified by field studies that infection of oysters is insignificant unless water temperatures exceed 20°C for two weeks. With large vessel movements occurring throughout the oceans, one wonders why this organism is not found elsewhere.

Endolithic Microbes. Boring or endolithic microorganisms are photosynthetic cyanophytes, eukaryotic green and red algae, and heterotrophic fungi that actively penetrate carbonate substrates (Golubic et al. 1975). They have been known for over 100 years and have been studied from shells and skeletons of living organisms or their fragmented remains. Although microboring activity has a destructive effect on coastal limestones and on carbonate sediments, recent studies strongly suggest that microborings may be suitable as paleoecological indicators (Golubic et al. 1975). These organisms have been observed from jingle and scallop shells, and carbonate sands, as well as fish scales (Wagner-Merner, unpublished data) collected along the shores of Upper and Lower Tampa Bay. The exact role of the fungi in these calcareous and other substrates must await development of isolation and culture techniques. According to Johnson (1976), pending this, the taxonomy of these organisms will continue to be unsettled. Basically, there are serious difficulties in distinguishing algae from fungi in endolithic substrates.

Fungi and Exoskeletons. Burn-like lesions have long been known from the exoskeletons of commercial crustaceans (Alderman 1976). Although chitinoclastic bacteria were first thought to be the causative agents for such lesions, the opportunistic fungal pathogen Fusarium sp. appears to be involved (Lightner 1981). As the lesions expand they become melanized and increasingly visible. Darkening seems to be due to a recognition response by the host to the presence of cell walls of the fungus. Unestam and Soderdeck (1977) suggested that compounds in the wall activated the enzyme phenoloxidase, which then increased melanin production. Claydon et al. (1977a, b) and Lightner (1981) proposed that Fusarium solani (Mart.) Sacc. produced mycotoxins which may have contributed to the virulence of an infection in some shrimp studied. Species of Fusarium are well represented in Tampa Bay and were frequently isolated as contaminants in other fungal studies (Wagner-Merner, unpublished data).

Fungi of Ova and Larval Forms. A number of lower fungi have been recovered from egg cases, ova and larvae of a variety of marine crustacean taxa (Table 3). Alderman (1976) observed that most of the incidences reported do not seem to impact populations of susceptible marine invertebrates. Bland (1977) reported that one of the major shortcomings of successful aquaculture is the inability to control fungal diseases brought about by these few major genera of pathogenic fungi.

It appears from physiological and experimental studies that infection of such invertebrate substrates is enhanced by crowding populations of eggs or larvae (Alderman 1976). Although no formal studies have been done on the occurrence and distribution of these fungi on invertebrates in Tampa Bay, species of Laginidium and Atkinsiella were observed by Sparrow (unpublished) in the early 1970s. Species of Laginidium and Haliphthoros are known to be serious pathogens of a few host species (Lightner 1981). Atkinsiella dubia (Atkins) Vishniac, potentially a serious pathogen of crustacean eggs, is yet to be demonstrated as a disease-causing fungus

Table 3. Some fungi on crustaceans.

FUNGUS	HOST	REFERENCE
Laginidium callinectes	Artemia salina	Bland and Lightner, unpub.
	Callinectes sapidus	Couch 1942
	Cancer magister	Armstrong et al. 1976
	Chthamalus fragilis	Johnson 1953; Johnson and Benner 1960
	Chelonibia patula	Johnson 1953; Johnson and Benner 1960
	Homarus americanus	Nilson et al. 1976; Fisher et al. 1976
	numerous species of penaeid shrimp	Lightner and Fontaine 1973; Lightner 1977
Siropidium sp.	penaeid shrimp larvae	Lightner 1977
Haliphthoros milfordensis	Pinnotheres pisum	Tharp and Bland 1977
	Callinectes sapidus	"
	Artemia salina	"
	Penaeus duorarum	"
Atkinsiella dubia	Hyas chorilia	"
	Oregonea skyra	"
	Pugettia chianectes	"
	Pinnotheres pisum	"

(Lightner 1981).

Saprolegniaceae and Diseases of Fish. Members of the Oomycetes, including Saprolegnia and Achyla, are the most widely distributed and best known of the fish fungal pathogens (Neish and Hughes 1980). It appears that fungi causing fish diseases are facultative parasites and may bring about pathogenesis as primary invaders, or the fungus may invade tissue already damaged by viral, bacterial or mechanical agents (Wilson 1976). Fungi, which are ubiquitous in freshwater environments (Dick 1973), subject fish to a constant challenge (Wilson 1976). It appears that the host occurs with these potential parasites in an equilibrium governed in unknown ways by the environment (Wilson 1976). When this balance is upset, it has been suggested that the resulting stress, reduced physiological capabilities, and lowered resistance give rise to the outbreak of disease (Wilson 1976; Neish and Hughes 1980).

Most of the Saprolegniaceae are considered freshwater fungi, but TeStrake (1959), Padgett (1978) and Wagner-Merner (1980) have demonstrated that these fungi can be found in the estuarine environment in the southeastern United States. Wagner-Merner (1980) reported on the occurrence of these water molds in the brackish waters of Bullfrog Creek (Hillsborough County) at salinites of 4-5 ppt.

Although a number of saprolegnian fish disease studies are reviewed by Neish and Hughes (1980), very little is known of such occurrences in subtropical waters. Recently in southeastern Florida a kill of migrating mullet was reported (Florida Department of Natural Resources, unpublished data). Interestingly, a systemic saprolegnian fungus was identified from the autopsy (Steidinger and Burns, unpublished data).

Fungi Associated with the Digestive Tracts of Some Invertebrates. The Trichomycetes obligately live within the digestive tract of a number of arthropods. They are widely distributed and knowledge of them is based primarily on material obtained from dissected hosts, for they rarely have been cultured (Lichtwardt 1976). One such fungus which was found in Tampa Bay was a species of Entrobryus reported from the hindgut of Uca pugilator Bosc (Wagner-Merner 1979). It was shown by the technique of Lichtwardt (1954) that this fungus occurred in the hindgut of 6.2% of the specimens of this crab. Wagner-Merner and Mattson (unpublished data) have found a similar species in over 90% of the individuals of the mangrove crab, Aratus pisonii (Milne-Edwards) examined. Recently, several species of Thraustochytriaceae were isolated from the guts of Lytechinus variegatus (Lamarck) (Echinodermata) (Wagner-Merner and Lawrence 1980; Wagner-Merner et al. 1980) by pollen baiting techniques. These authors speculated that frequency of isolations may simply signify the occurrence of a mycoflora associated with the vegetative substrate (Perkins 1973) consumed by the sea urchins. The fungi may simply survive passage through the digestive tract. Alternatively, Master and Fell (1977) have emphasized the importance of fungi in conversion of angiosperm material bordering and submerged in subtropical estuaries to more usable forms. Perhaps the echinoids are utilizing these and other fungi, as well as bacteria, as a food source. Wagner-Merner et al. (1980) suggested that there may be a gut microflora (Prim and Lawrence 1975) which includes Thraustochytriaceae.

Marine Mammals. An organism considered to be a fungus was isolated from the bottle-nose dolphin, Tursiops truncatus (Montagu), captured off the coast of Sarasota, Florida (Migaki 1971). The nature of the fungus remains unknown for it has not been grown in culture. The organism Laboa loboi (Fonseca Filho and Area Leao) Ciferri, Asevedo, Campos, and Siquerira Carneiro, was originally found in humans and there causes lobomycosis, a chronic localized subepidermal infection (Rippon 1982). Since first observed in man in 1931, it has been reported sporadically

throughout the American tropics. The isolation from dolphins is indeed puzzling.

Although terrestrial mammals have several fungal diseases, Reynolds (unpublished) recorded the first known in marine mammals, the occurrence of a systemic brain infection by a species of Fusarium in the manatee, Trichechus manatus L. The fungus was isolated from a beached animal and its exact role is not clear.

Fungi and Humans. Intertidal areas in the Tampa Bay area host an array of fungi. Numbers of types of molds were isolated during a study of several beaches with both high and low swimmer density (Bergen and Wagner-Merner 1977). Thirty-six species representing 26 genera were reported (Tables 4 and 5). Beaches used frequently and infrequently by bathers were found to differ in their species composition (Table 6) and average number of colony-forming units (Table 7). These data support other studies (Kishimoto and Baker 1969; Dabrowa et al. 1964) which suggest that the intertidal areas of maritime habitats may constitute a reservoir of propagules of potentially pathogenic fungi.

Fungi typically found in soils and sands sometimes may cause human diseases such as otomycosis, mucormycosis, penicillosis, candidiasis and aspergillosis. In humans these diseases may result from drug therapy, debilitating diseases such as carcinomas, tuberculosis or diabetes, or injuries to the subcutaneous tissue and skin. Chromoblastomycosis and keratomycosis are diseases in which the organisms from soil are probably introduced into the skin through skin abrasions or punctures (Rippon 1982). Potential pathogens isolated from Tampa Bay beaches are listed in Table 8.

Additionally, Thraustochytrium sp., a cosmopolitan marine fungus (Bahnweg and Sparrow 1974) found in Tampa Bay (Table 5), has been reported to contain herpes-type virus particles in its zoospores (Kazama and Schornstein 1972; Perkins 1976). Since thraustochytriaceous zoospores readily attach to organic substrates (Bremer 1976), one sees possible human disease implications; "infected" propagules might be cause for some concern.

The occurrence of fungi in coastal birds and their droppings has been considered by numerous authors concerned with zoopathogenic, phytopathogenic, keratinophilic, and thermophilic species (Ajello et al. 1960; Apinis and Pugh 1967; Hubalek 1974a, b). Fungi typically characterized as saprophytes have been included in recent studies of bird pathogens. It is felt by most that fungi from birds may be potentially pathogenic or capable of producing substances toxic for man. Thus, beaches may be considered as a reservoir of latent pathogenic fungi provided by shore birds.

Some fungi, especially the yeasts, have affinities with warm-blooded animals and may cause disease in humans (Fell 1976). As such they may readily occur in sewage and other runoff waters. Although no studies have been published on the yeasts of the Tampa Bay area, in Biscayne Bay, Florida, Fell et al. (1960) found Candida tropicalis (Castellani) Berkhout and C. parasilosis (Ashford) Langeron and Talice, and more recently C. albicans (Robin) Berkhout (Fell 1976). The latter was found in areas with heavy densities of swimmers and bathers.

It appears that the inability of Candida albicans to exist without a host indicates that there are no truly autochthonous yeast populations in natural waters (Buck 1977). Ahearn (1983) suggested that the isolation of C. albicans from water was associated with recreational bathing or recent contamination with raw sewage.

Until recently there was no recognized "standard" procedure for the isolation of Candida albicans. Now there has been reported a more reliably accurate method for enumerating this fungus from natural waters and beach soils (Buck and Bubucis 1978; Cook 1981). The results of these studies suggest that although C. albicans can be isolated from beaches and adjoining

Table 4. Fungi isolated from populated and unpopulated beach sites in the Tampa Bay area. From Bergen and Wagner-Merner 1977.

	Tampa Site A	Tampa Site B	Clearwater Site A	Clearwater Site B
Alternaria sp.	X	X	X	X
Aspergillus fumigatus (Fr.) Thom & Church		X		
Aspergillus niger van Tiegh.	X			
Aspergillus sp.	X	X	X	X
Bipolaris sp.	X			
Candida sp.	X		X	
Cephalosporium sp.	X	X	X	X
Cladosporium sp.	X	X	X	X
Cunninghamella sp.	X			
Curvularia lunata (Wakker) Boedijn	X			
Diplosporium sp.			X	
Fusarium solani (Mart.) Sacc.	X	X		
Fusarium sp.	X	X	X	X
Geotrichum candidum Link ex. Pers.	X			
Gliocladium sp.		X		
Gliomastix sp.			X	
Helminthosporium sp.		X	X	X
Hyalodendron sp.	X		X	
Monilia sp.	X			
Monocillium sp.			X	
Monosporium apiospermum Sacc.		X		X
Mucor racemosus Fr.		X		
Mucor sp.	X	X	X	X
Paecilomyces sp.	X			
Penicillium sp.	X	X	X	X
Phialophora sp.		X		
Rhizopus stolonifer (Ehrenb. ex Fr.) Lind.			X	
Rhodotorula sp.	X	X	X	X
Sporobolomyces sp.				X
Verticillium sp.		X		

Table 5. Frequency of occurrence at each collecting time for each species of Thraustochytriaceae from all sites. From Bergen and Wagner-Merner 1977.

	April 10	May 1	May 22	June 16
Schizochytrium aggregatum Schneider	100%	100%	75%	50%
Thraustochytrium sp.	25%	75%	100%	75%
Thraustochytrium aggregatum Ulken.	100%	50%	50%	50%
Thraustochytrium aureum Goldstein	0%	25%	0%	0%
Thraustochytrium roseum Goldstein	100%	75%	50%	25%
Thraustochytrium striatum Schneider	50%	25%	25%	75%

Table 6. Indices of similarity of beach sites at Tampa and Clearwater, Florida. From Bergen and Wagner-Merner 1977.

Paired beach sites	Number of shared species	Index of similarity
Tampa Site A - Tampa Site B	9	53
Clearwater Site A - Clearwater Site B	9	69
Tampa Site A - Clearwater Site A	10	61
Tampa Site A - Clearwater Site B	8	55
Tampa Site B - Clearwater Site A	8	52
Tampa Site B - Clearwater Site B	10	74
Tampa (total Sites A, B) - Clearwater (total Sites A, B)	12	57

Table 7. Average number of colony-forming units from 10^{-2} dilution of sand suspension grown on corn meal agar. From Bergen and Wagner-Merner 1977.

Collecting Period	Tampa Site A	Tampa Site B	Clearwater Site A	Clearwater Site B
March 19	34.8	28.0	9.4	2.2
April 10	49.5	39.2	54.0	15.8
May 1	60.8	37.6	34.2	15.0
May 22	129.0	28.8	199.4	17.2
June 16	35.8	66.4	41.6	9.6
Total average	62.0	39.6	67.3	12.0

Table 8. Possible pathogenic fungi isolated from the Tampa Bay area beaches. From Bergen and Wagner-Merner 1977.

		COMMONLY ISOLATED FROM		SPECIFIC FORMS OF FUNGI		
	Diseases from pathogens in taxa	Bird plumage	Bird droppings	Keratino-lytic	Cellulo-lytic	Thermo-tolerant
Alternaria sp.	asthma	X	X	X	X	
Aspergillus fumigatus	aspergillosis				X	X
Aspergillus niger	otomycosis, keratomycosis			X		X
Aspergillus sp.	aspergillosis	X	X			
Candida sp.	candidiasis		X			
Cephalosporium sp.	keratomycosis, maduromycosis					
Cladosporium sp.	keratomycosis	X	X			
Curvularia lunata	keratomycosis					
Fusarium sp.	keratomycosis				X	
Geotrichum candidum	geotrichosis					X
Gliocladium sp.		X			X	
Gliomastix sp.		X				
Monilia sp.		X				
Monosporium sp.	maduromycosis, keratomycosis					
Mucor racemosus	mucormycosis					
Mucor sp.	mucormycosis	X				
Paecilomyces sp.	penicillosis					
Penicillium sp.	penicillosis, keratomycosis	X	X			
Phialophora sp.	chromoblastomycosis					
Rhizopus sp.		X	X			
Rhizopus stolonifer	mucormycosis					
Rhodotorula glutinis Fresen.	endocarditis					
Verticillium sp.					X	

waters, the organism may not survive in the presence of other microorganisms.

BIODETERIORATION

Wood. There has been increasing interest in the role fungi play in the deterioration of wood submerged in the sea (Hughes 1975). Although a number of other organisms such as bacteria, fungi, and animal borers, and abiotic factors such as abrasion, may be involved, the role of fungi in the degradation of wood is of special interest to the marine mycologist. Jones and Irvine (1971) reported estimated costs in the United States of approximately $50 million per year for replacing wharf timbers lost to biodeterioration.

Hughes (1975) reviewed extensively the taxonomy, physiology and ecology of the wood-inhabiting or lignicolous marine fungi which are Ascomycotina or Deuteromycotina. He highlights a study by Meyer and Reynolds (1963) which found that fungal infestation of manila cordage occurred within five days of submergence in Biscayne Bay, Florida. Noteworthy was the reduction of tensile strength in two weeks. Lulworthia floridana (sensu Meyers 1957) was one of the first fungi isolated. This fungus is frequently encountered in Tampa Bay (Wagner-Merner, unpublished data). Leightly (1980) reviewed wood decay by some marine Deuteromycotina (Fungi Imperfecti), Ascomycotina, and one Basidiomycotina. Most of the fungi he found formed soft rot cavities in the wood cell walls. Nia vibrissa Moore and Meyers exhibited white rot timber decay. Based on his morphological observations, Leightly (1980) showed that marine fungi reveal the same mode of growth as their terrestrial counterparts. In wood where moisture content is high and poor aeration prevails, the soft rot fungi predominate. These, however, are conditions inhibitory to Basidiomycotina (Duncan 1961). These observations strongly suggest the explanation for the lack of this taxon in the marine environs. White rot, which is exhibited by Basidiomycotina, decays wood with oxygen-demanding enzymes (Eriksson 1978). In contrast, the soft rot fungi decay cellulose by a non-oxygen demanding hydrolytic reaction (Levi and Preston 1965).

Ritchie (1968), in a study in which the rates of decay of eight tropical timber woods were studied in Panama (salinities 11.9-32.3 ppt), found the amount of fungal infestation varied from almost none to heavy in less than six weeks. He proposed that salinity was a weak factor in determining both the rate and amount of fungal growth. All but one of the fungi reported by Ritchie in this test were terrestrial Deuteromycotina. Hughes (1975) felt that this clearly showed that biodeterioration in relatively high salinity environments can be caused by terrestrial fungi. He further suggested that these fungi should not be overlooked in studies of wood degradation in the marine environment.

Hydrocarbons: Oil, Polyurethane and DDT. In reviewing the distribution of hydrocarbons and chlorinated hydrocarbons in Tampa Bay, Van Vleet (this volume) indicated that data on both classes of compounds was limited. Even though background levels are much lower than levels reported for several other coastal communities in the United States, there are still situations such as acute oil spills or chronic agricultural runoff which must contribute to this residual pool.

While no studies of fungi and their activities have been done pertinent to hydrocarbon deposition in Tampa Bay, there are a few studies which provide interesting insights into the activities of fungi associated with oil, DDT, and polyurethane. In a recent review of fungal degradation of oil in the marine environs, Ahearn and Meyers (1976) pointed out that hydrocarbons of plant origin or oil from natural seeps are normally available in oceans as sources of metabolizable compounds for microorganisms. In addition to these natural sources, marine algae and phytoplankton are estimated by Button (1971) to produce 10^{13} g of hydrocarbons

per year. Thus it is not surprising that there are hydrocarbonoclastic groups of fungi. Ahearn and Meyer (1976) review these and many of their physiological characteristics.

In a study on the selective effect of oil on yeast populations in estuarine marshlands in Louisiana, Ahearn and Meyers (1972) were able to show a shift in yeast species toward the hydrocarbonoclastic species. Ahearn and Crow (1980) compared species and densities of yeasts isolated from North Sea waters before and after the Amoco Cadiz oil spill in 1976. Even though a hydrocarbonclastic yeast was more commonly isolated afterwards, relatively few fungi were isolated 12 days from the beginning of the accident. They suggested that high concentrations of aromatics may have been inhibitory on the yeast flora.

Very little is known about fungal degradation of polyurethane in marine habitats. Jones and LeCampion-Alsumard (1970a, b) reported several species of higher fungi growing on polyurethane-covered metal panels submerged in marine waters at Nice, France. Fungal hyphae were found to a depth of 1 mm on a 3 mm deep layer of polyurethane. The fruiting bodies or ascocarps increased in volume and resulted in the splitting and removal of the surface layers. Filip (1979), in his investigations of fungal utilization of polyurethane as a sole nutrient source, reported that isocyanate almost completely disappears. Otherwise no other structural changes were found even though the two species of fungi penetrated the resilient foam tested.

Although the use of DDT has been greatly curtailed, it remains a widely distributed pollutant. In vitro studies of fungal interactions with DDT can provide background for understanding other chlorinated hydrocarbons. Hodkinson (1976) acknowledged that laboratory investigations have obvious limitations in the study of field problems. It is usually accepted that studies of pure cultures have the advantage of separating the responses of one species in specifically characterized conditions from the interactions of many organisms in a complex environment. DDT, as Hodkinson (1976) reviews, affects a wide range of fungi and alters many aspects of their physiological responses to nutrients. That DDT is persistent in nature has been attributed to the inability of microorganisms to degrade this chlorinated hydrocarbon molecule. Yet, Hodkinson (1976) cited a number of papers describing various aspects of DDT degradation by a number of fungi. Pfaender and Alexander (1972) proposed that the persistence of DDT in nature may indicate that both aerobic and anaerobic processes are necessary for complete degradation. They suggest that such fluctuations in oxygen concentration may not be frequent in some habitats. As with oil, a number of microbes are unable to utilize DDT or its metabolites when it is provided as the only carbon source. Anderson and Lichtenstein (1971) observed that the organisms decompose these compounds in a rich medium. Alexander (1967) suggested that for biodegradation to occur the following conditions were necessary: 1) an organism with the necessary catabolic systems must be present in the environment; 2) the compound must be available in a form which permits degradation to proceed; and, 3) the environmental conditions should be suitable for microbial proliferation and induction of the appropriate enzymes to bring about the desired reaction. It may be that this combination of factors is seldom achieved in nature.

Seagrasses. The role of fungi in the conversion of seagrasses into nutritive matter for other organisms is poorly known. Hughes (1975) and Kohlmeyer and Kohlmeyer (1979) reviewed the basic mycological studies of drift seagrasses. They generally characterized molds into three groups: a) those which are dominant; b) those which were found occasionally; and c) those which were uncommon. It is thought that mycological decomposition of seagrasses is brought about by yeasts

and terrestrial molds such as Cephalosporium, Hormodendrum, and Penicillium (Suckow and Schwartz 1960). Labyrinthulids frequently have been isolated from the submerged leaves of Thalassia (Perkins 1973) and from material collected in Tampa Bay (Quick 1969). Newell and Fell (1980) reported the occurrence of several common fungi including zoosporic fungi previously not known to occur in submerged Thalassia leaves. They made an in vitro search for optimal conditions in seawater incubation systems for fungi occurring in these leaves. They found no single combination of factors yielded all of the naturally prevalent fungi. The results suggested that some higher fungi which have previously been isolated from drift Thalassia may play a minor role in the decomposition of submerged turtle grass (Newell and Fell 1980).

Mangroves. Mangroves are fairly common on the margins of Tampa Bay. Ulken (1978) reported finding three chytrids, Blyttiomyces laevis Sparrow, Endochytrium digitatum Karling and Phlyctochytrium sp. from the muds of Cockroach Bay. She suggested that these organisms were saprophytes and active in remineralization. Studies on Rhizophora mangle L. in Biscayne Bay by Fell, Master and Newell (Fell 1976; Fell and Master 1975, 1980; Fell and Newell 1981; Fell et al. 1975, 1980; Master and Fell 1977; Newell 1976) of the red mangrove degradation system now allow us to appreciate the role that fungi play in detrital food webs.

Fell (1976) suggested the following events. Subsequent to leaf senescence, leaves fall in the water and are rapidly colonized by microorganisms (fungi, bacteria and varieties of small invertebrates). The fungi convert the leaf materials to utilizable proteins. There is a sequence of fungal populations associated with general states of leaf decay, due to the nature of the remaining leaf compounds. In the early stages fungi which invade the leaf tissue use readily available carbon compounds, whereas later colonizers utilize the more complex carbon substances. In later studies, Fell and Masters (1980) designed a laboratory model which demonstrated that fungi were required for nitrogen immobilization. They reported decreases in C:N ratios of approximately 60% in red mangrove (R. mangle) leaves as aging and microbial succession ensued. Fell (1976) had anticipated that there was an interdependency of organisms in this decay process. There are a number of species of higher fungi described from roots, stems and leaves of mangroves. Kohlmeyer and Kohlmeyer (1979) have compiled this information with taxonomic keys and descriptions of these fungi.

Little is known about fungi which are pathogenic to mangroves. Olexa and Freeman (1978) described a gall disease on Rhizophora mangle caused by Cylindrocarpon didymum (Hartig) Wollenw. The distribution ranged from Levy County on the Gulf coast to Flagler County on the Atlantic coast. Tampa Bay was included. Barnard and Freeman (1982) reported that mortality was generally low but diseased trees are predisposed to wind breakage. Olexa and Freeman (1977) found Cercospora rhizophorae Creager, Anthostomella rhizomorphae (Kunze) Berl. & Vogl. and several saprophytic fungi consistently from red mangrove leaves. In the same study they surveyed for the leaf diseases at five locations in the Ten Thousand Islands of Florida and found less disease in disrupted areas, and therefore less litter production. They hastened to point out that decreased leaf fall by no means signified that a reduction in plant disease was beneficial to the system. They suggested that decreased leaf fall might serve as a detriment by depleting the system of a constant detrital nutrient source.

Algae. While a seeming majority of all higher marine fungi are known to occur on algae (Kohlmeyer and De Moulin 1981), knowledge of the pathogenic role of fungi of seaweeds and phytoplankton is sparse (Andrews 1976). Quick (1969) isolated several species of Thraustochytrium, Labyrinthula, Schizochytrium, and Labyrinthulomyxa from

the thalli of ten different seaweeds, including Enteromorpha, in Tampa Bay. Steidinger (unpublished) has observed Lagenisma coscinodisci Drebes (1974) in Palmeriana (=Hemidiscus) lardmaniarus, a large diatom from Tampa Bay.

Fungi and Sea Foam. On windy days millions of bubbles are produced from the film of organic materials and microorganisms occurring on the surface of the sea. This froth accumulates along the shore as sea foam. Among the various structural components of foam are fungal propagules (spores etc.). Wagner-Merner (1972) suggested that these arenicolous fungi in sea foam may reveal distributional information about coastal fungi. In a one-year survey of fungal spores in sea foam from four sites between Pine Island, Hernando County, and Bonita Beach, Florida, it appeared that distribution and diversity of fungi were influenced by location of the beaches in relation to marshes, mangroves, and estuaries. Foam from beaches in proximity to marshes had a much greater fungal species diversity than those farther away. It also appears that fungal propagules may be dispersed by sea foam blown along the shore and trapped in and among the shore plants and detritus.

CONCLUSIONS

In the foregoing discussion, a brief survey of a variety of fungi, their roles in marine environments and some taxonomic uncertainties have been presented. Perturbations by both man and nature in Tampa Bay bay can threaten the interdependency of organisms in the decay process. The result could easily bring about an epizooic or epiphytotic problem as summarized in Figure 3.

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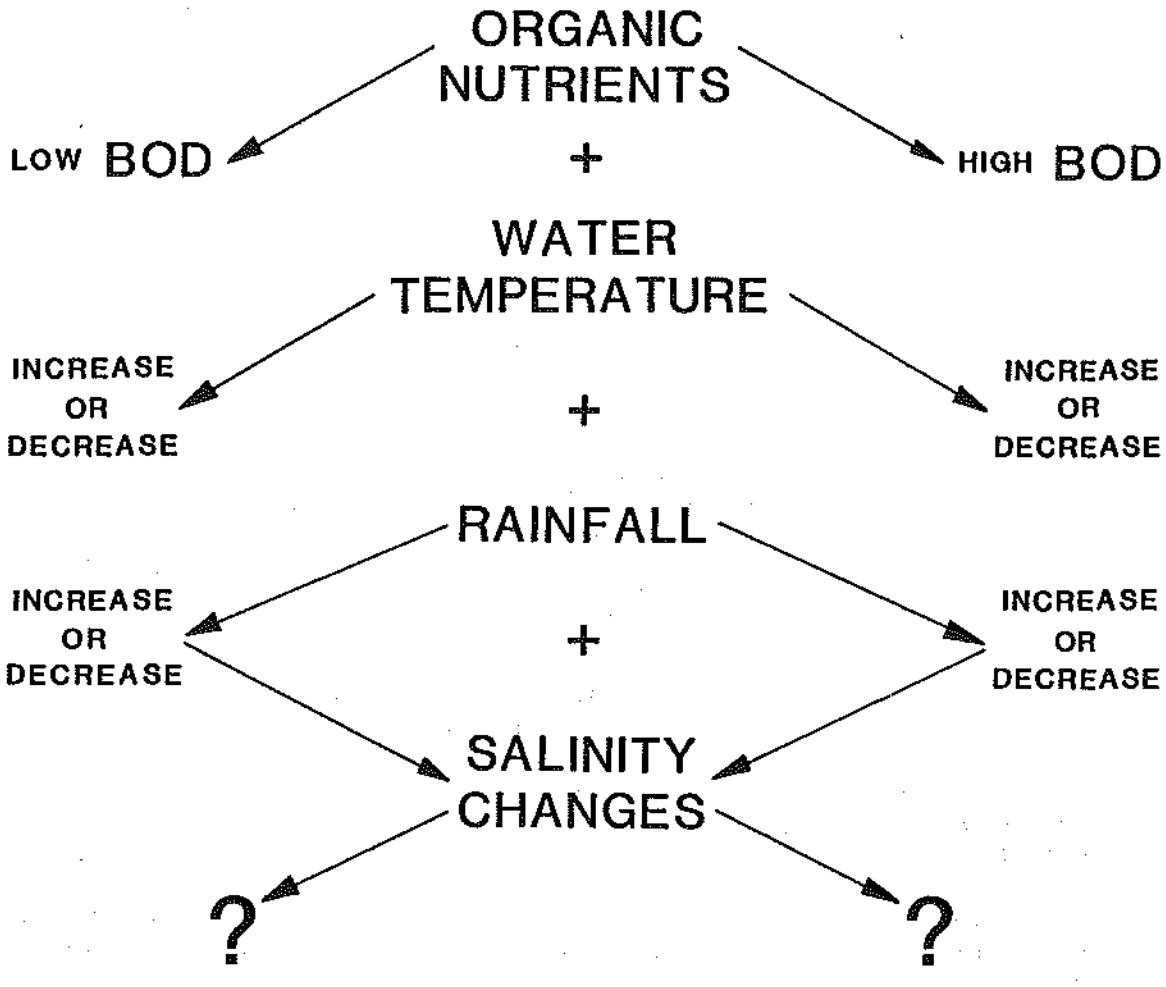

Figure 3. Environmental scheme for a potential mycological problem.

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THE ZOOPLANKTON OF TAMPA BAY: A REVIEW

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ABSTRACT

The surface zooplankton have been examined at forty-two locations throughout Tampa Bay during four seasonal surveys from fall of 1969 through summer of 1970. Thirty-seven taxa of holoplankton were identified. These were grouped according to abundance: Group I (greater than 1,000/m^3), Group II (100-1,000/m^3) and Group III (less than 100/m^3). Group I includes three species of copepods, Oithona colcarva, Acartia tonsa, and Paracalanus crassirostris, and the appendicularian Oikopleura dioica. A combination of these taxa accounted for an average of 60% of the total zooplankton biomass. Group II includes five species of copepods and one cladoceran. Together, these organisms comprised 5% of the total zooplankton biomass. Group III includes twenty-two additional species, most of which penetrated no further than mid-Tampa Bay. Half of the Group III species were copepods. Other abundant organisms include copepod nauplii and meroplanktonic larvae of benthic invertebrates. While four holoplankton species with primarily coastal rather than estuarine affinities did show statistically significant relations to higher salinity, most of the abundant zooplankton taxa were found throughout the Bay. With few exceptions, all zooplankton species had maximum levels of abundance in Tampa Bay during warmer seasons. The lack of significant relation between zooplankton biomass and chlorophyll a + phaeopigment levels indicates that there is ample phytoplankton food in the Bay water to sustain the zooplankton population. Calanoid and cyclopoid copepod species found in Tampa Bay have been shown to exhibit broad geographical ranges in estuarine waters of eastern North America. Most occur, at least seasonally, from Canada or New England to southern Florida or Puerto Rico. Thus, these species do not conform to the biogeographic provinces proposed by Hedgpeth, which suggest that Tampa Bay is the border between the Caribbean and Carolinian marine biogeographic provinces in the Gulf of Mexico. There are numerous unanswered questions concerning the zooplankton of Tampa Bay. Specifically, these include the feeding habits of abundant zooplankters in the Bay, and the utilization of these zooplankters as food by organisms at higher trophic levels.

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The paper of Hopkins (1977) represents the only comprehensive survey of the zooplankton of Tampa Bay. Hopkins examined the geographic distribution of zooplankton at 42 locations throughout the estuary (Fig. 1) during 4 quarterly surveys between autumn of 1969 and summer of 1970. Samples were collected in surface tows with 74 um mesh nets, and quantitative data on both abundance and biomass of zooplankton were presented. Biomass was in terms of dry weight and was calculated from size-weight regressions. Hopkins' survey was done in conjunction with phytoplankton, hydrographic and nutrient analyses which have been presented by Turner and Hopkins (1974).

The locations sampled for zooplankton were grouped into seven sections, based on geography and salinity (Fig. 1). Thirty-seven species of holoplankton were recorded, and these were divided into three groups based on average abundance: Group I, more than 1,000/m^3; Group II, 100-1,000/m^3; Group III, less than 100/m^3. Average numbers of total zooplankton ranged from 12,700 to 108,600/m^3 (Fig. 2A). Of these, post-naupliar copepods were most abundant (2,800-49,700/m^3), followed by Group I copepods (2,100-39,500/m^3) and copepod nauplii (5,000-33,500/m^3) (Fig. 2A).

Group I copepods include three species: Oithona colcarva, Acartia tonsa, and Paracalanus crassirostris (Fig. 2B). The only other species in Group I was the tunicate Oikopleura dioica (Fig. 2B). Together, the four Group I taxa averaged 60% and 38% of total zooplankton biomass and numbers respectively. Copepod nauplii averaged 29% of total zooplankton number. Seasonal patterns for total zooplankton, naupliar and post-naupliar copepods, and Group I taxa all revealed minimum levels of abundance in winter with maxima during warmer periods (either summer or fall) (Fig. 2A, B).

Group II includes five species of copepods (Oithona nana, Pseodo-diaptomus coronatus, Oithona simplex, Labidocera aestiva, Euterpina acutifrons) and the cladoceran Evadne tergestina (Fig. 3). The copepods were most abundant during warmer seasons, but the only period of substantial abundance of E. tergestina was May 1970 when a mean abundance of 1,300/m^3 was recorded (Fig. 3).

There were clear geographic trends in the abundance of some taxa. Group I species were recorded throughout the Bay and except for P. crassirostris in Hillsborough Bay, averaged greater than 1,000/m^3 for the year in all Bay sections. Post-naupliar copepods, Group I copepods (particularly O. colcarva and A. tonsa), copepod nauplii and O. dioica were most abundant in lower salinity embayments such as Old Tampa Bay and the Manatee River (Fig. 4). These same taxa were recorded at minimum abundance levels in the more open higher salinity waters of Mid- and Lower Tampa Bay (Fig. 4). The Group II copepod P. coronatus exhibited a geographical distribution similar to most Group I taxa (Fig. 5). This distribution, with primary surface abundance in shallow low salinity regions, supports Jacobs' (1961) observation that P. coronatus appears associated with the bottom, and is best cultured in lower salinity water. Unlike P. coronatus, most other Group II species (particularly O. nana, O. simplex and L. aestiva) were most abundant in higher salinity waters of Mid- and Lower Tampa Bays, and Boca Ciega Bay (Figs. 4 and 5). The cladoceran E. tergestina (Group II) was abundant only in Old Tampa Bay and Upper Tampa Bay.

Group III included 22 species: 11 copepods, 2 cladocerans, 1 decapod, 2 chaetognaths, 4 tunicates, 1 siphonophore, and 1 trachymedusa (Table 1). With 2 exceptions, these species were collected most frequently, or only, during warmer seasons. Exceptions were Centropages hamatus and Podon polyphemoides, which were found only in winter. Both these species have primarily cold water affinities, and are found in North American estuarine and coastal waters as far north as Canada (Turner 1981; White 1979). In terms of geographical distributions in Tampa Bay,

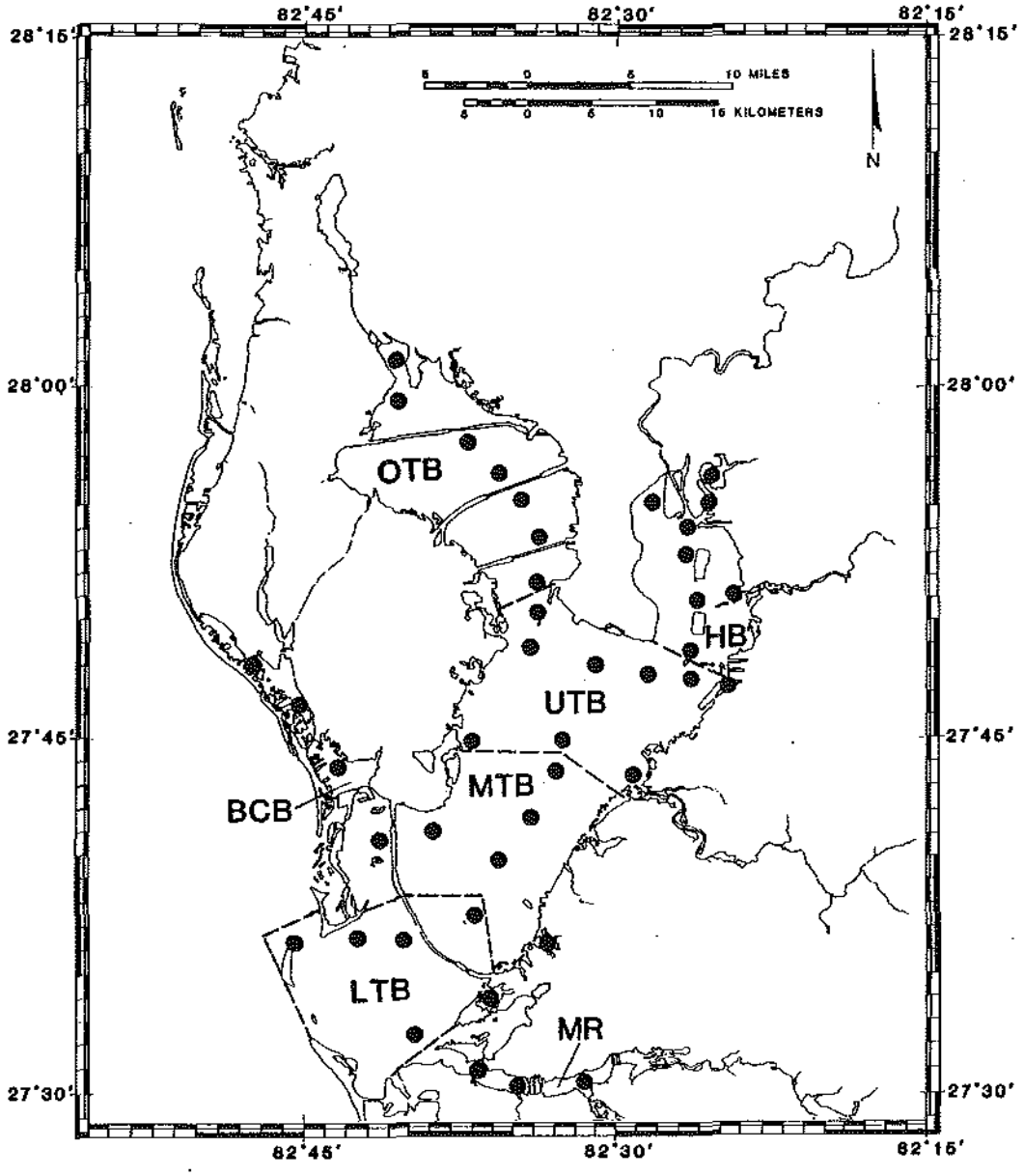

Figure 1. Sampling stations for zooplankton in Tampa Bay, divided into regions according to salinity and geography: OTB - Old Tampa Bay; HB - Hillsborough Bay; UTB - Upper Tampa Bay; MTB - Middle Tampa Bay; LTB - Lower Tampa Bay; BCB - Boca Ciega Bay; MR - Manatee River.

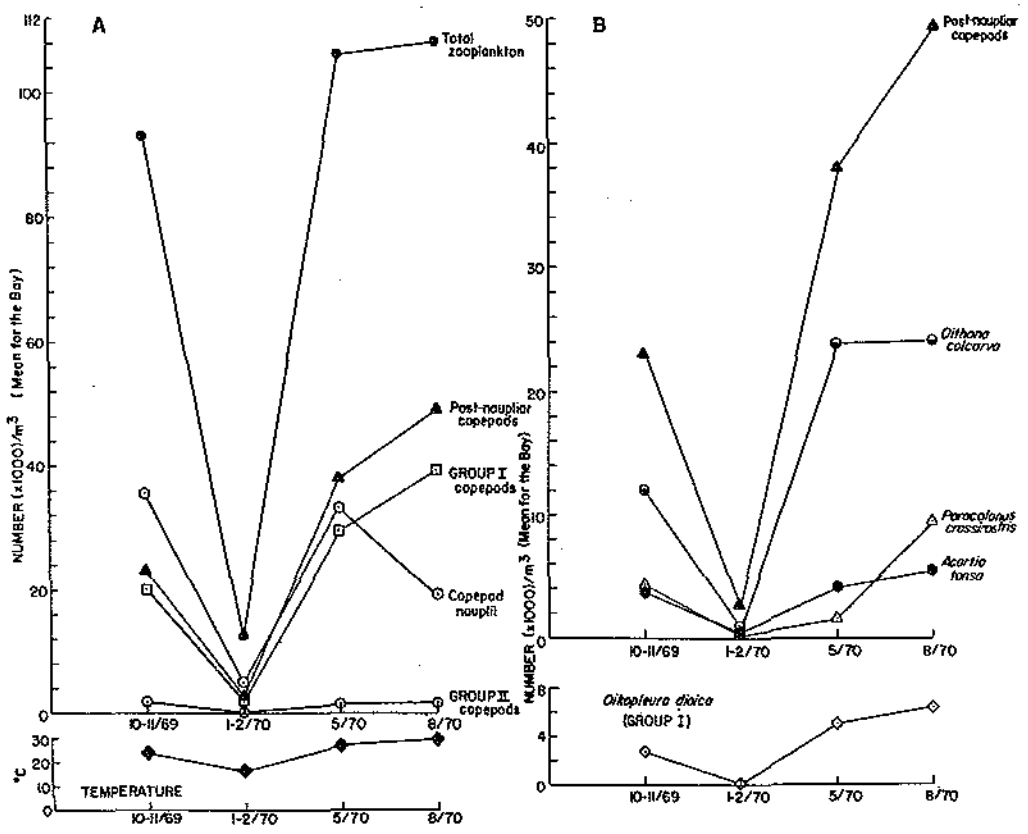

Figure 2. Seasonal abundance means for abundant zooplankters. A - abundance levels of total zooplankton, post-naupliar copepods, Group I copepods, copepod nauplii, and Group II copepods. Mean temperature for each sampling period. B - Abundance levels of post-naupliar copepods, and the four Group I taxa.

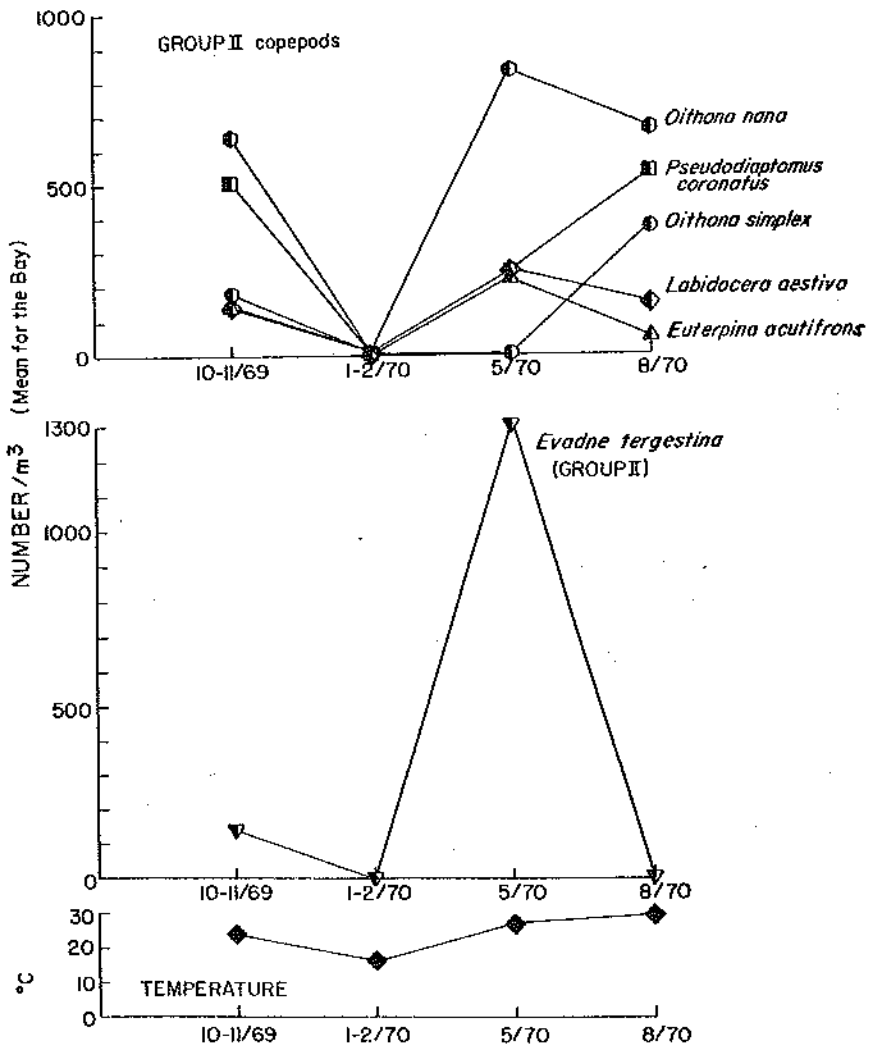

Figure 3. Seasonal abundance means for Group II taxa, and mean temperature for each sampling period.

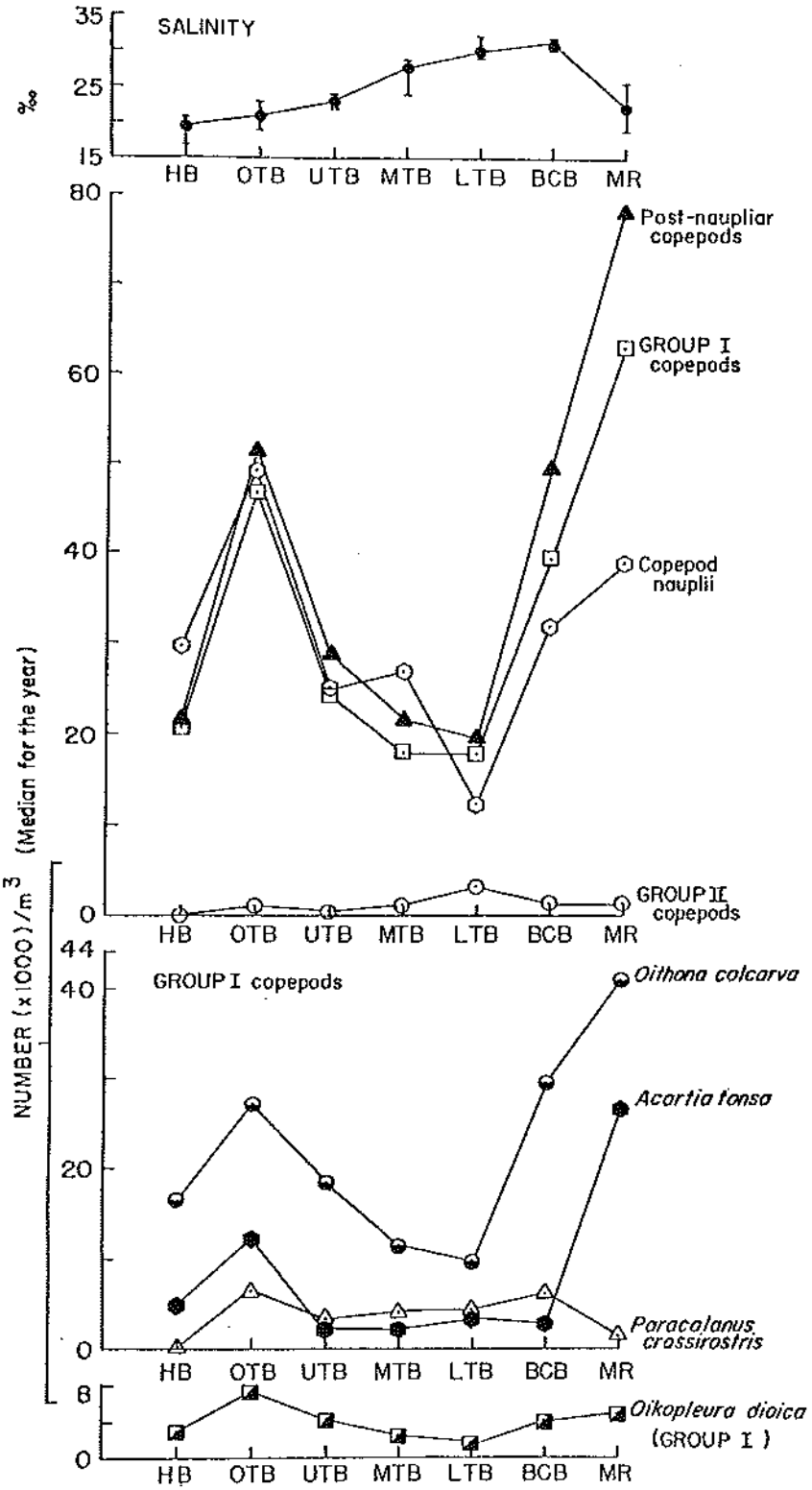

Figure 4. Distributions by region of mean temperature (vertical bars are ranges), and mean levels of abundance of post-naupliar copepods, Group I copepods, copepod nauplii, Group II copepods, and individual Group I taxa.

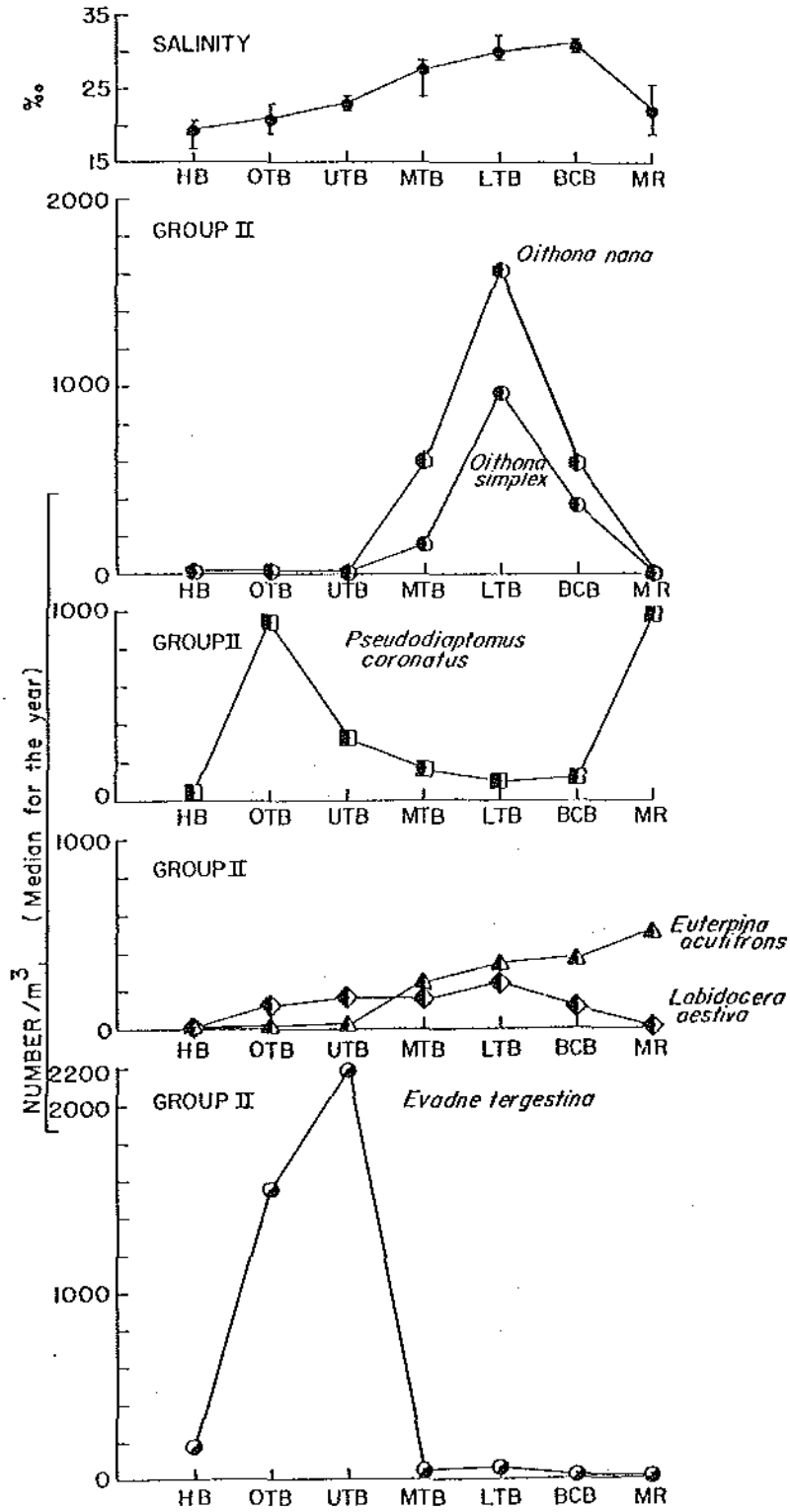

Figure 5. Distributions by region of mean temperature (vertical bars are ranges), and mean levels of abundance of Group II taxa.

Table I. Group III organisms (less than 100/m^3).

Copepods:

Eucalanus pileatus
Paracalanus quasimodo
Temora turbinata
Centropages hamatus
Centropages velificatus
Oncaea curta
Oncaea venusta
Corycaeus amazonicus
Corycaeus americanus
Corycaeus giesbrechti
Microstella rosea

Cladocerans:

Penilia avirostris
Podon polyphemoides

Decapods:

Lucifer faxoni

Chaetognaths:

Sagitta tenuis
Sagitta hispida

Tunicates:

Oikopleura longicaudata
Oikopleura fusiformis
Appendicularia sicula
Doliolum gegenbauri

Siphonophores:

Muggiaea kochi

Trachymedusae:

Liriope tetraphylla

Centropages velificatus, C. hamatus, Penilia avirostris, Lucifer faxoni, Liriope tetraphylla, Sagitta tenuis and S. hispidus penetrated as far as Old Tampa and Hillsborough Bays. All other Group III species penetrated no further than mid-Tampa Bay.

Meroplanktonic larvae of benthic invertebrates (Table 2) averaged 19% of total zooplankton number, and 8% of total biomass. Areas of maximum abundance varied among group, but all meroplankton were most abundant during warmer periods. Fish eggs were principally collected in fall and spring throughout the estuary, but with two exceptions, did not exceed 500/m^3. During other seasons, less than 90 fish eggs/m^3 were collected.

It is apparent from a comparison of biomass means (Table 3) that the zooplankton of Tampa Bay is dominated by only a few species. Three Group I copepods (A. tonsa, O. colcarva and P crassirostris) together comprised 56% of total zooplankton biomass. The 5 species of Group II copepods, and all other post-naupliar copepods each comprised about 3% of total biomass. Copepod nauplii, most of which were probably those of A. tonsa and O. colcarva, comprised about 6% of total biomass. The relatively diverse assemblage of meroplankters comprised only about 8% of total biomass. The category listed in Table 3 as "other zooplankton" comprised about 18% of total biomass. This high value is larely due to the inclusion of medusae in this category. Mean zooplankton biomass in Tampa Bay (39.6 mg dry weight/m^3) compares favorably with values obtained with fine mesh nets and dry weight determinations on individual zooplankters in other Gulf coast and southeastern United States Atlantic estuaries (Table 4).

A comparison of geographic trends in zooplankton number and biomass (Fig. 6A) reveals largely similar trends. Values for both parameters were highest in the Manatee River, followed by Old Tampa Bay. Minimum values were found

Table 2. Meroplankton organisms.

Group I (>1,000/m^3)	Group II (100-1,000/m^3)
bivalve larvae	echinoderm larvae
barnacle larvae	bryozoan larvae
polychaete larvae	decapod larvae
gastropod larvae	

Group III (<100/m^3)	Fish Eggs
polyclad larvae	with two exceptions,
phoronid larvae	less than 500/m^3
brachiopod larvae	
enteropneust larvae	
ascidian larvae	
cephalochordate larvae	

Table 3. Biomass contributions of various components of the zooplankton in Tampa Bay.

Taxon or group	mg dry weight/m^3	Percent
Acartia tonsa	11.87	30.01
Oithona colcarva	7.92	20.02
Paracalanus crassirostris	2.20	5.56
Oikopleura dioica	1.85	4.68
Evadne tergestina	0.91	2.30
Pseudodiaptomus coronatus	0.33	0.83
Labidocera aestiva	0.29	0.73
Oithona nana	0.26	0.66
Euterpina acutifrons	0.16	0.40
Oithona simplex	0.14	0.35
Other copepods (post-naupliar)	1.11	2.81
Copepod nauplii	2.36	5.97
Meroplankton	3.05	7.71
Other zooplankton	7.11	17.97

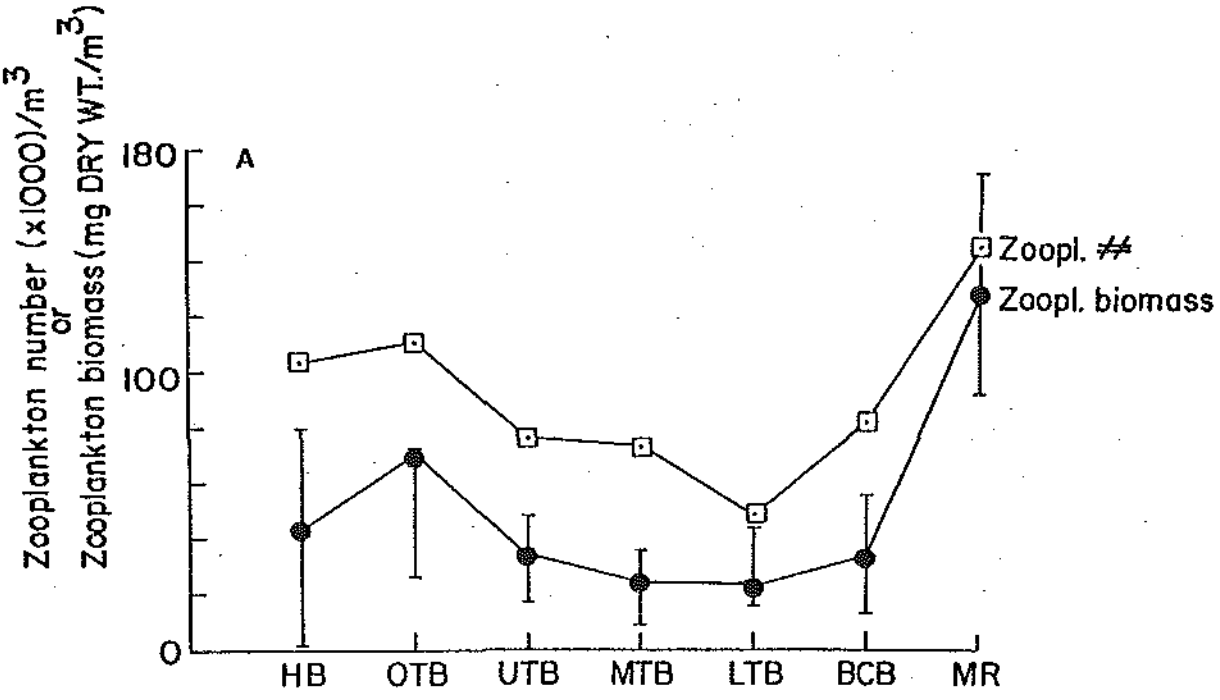

Figure 6A. Distributions by region of mean zooplankton number and mean zooplankton biomass (vertical bars represent ranges).

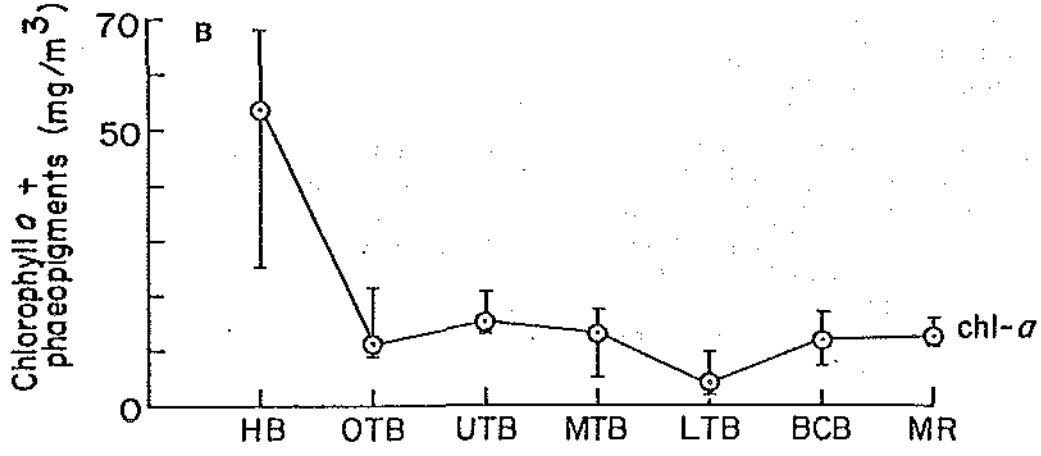

Figure 6B. Distributions by region of chlorophyll a + phaeopigments (vertical bars represent ranges).

Table 4. Comparison of mean zooplankton biomass in Tampa Bay with that in other Gulf of Mexico and southeastern Atlantic estuaries.

Location (Reference)	mesh size (um)	Zooplankton biomass (mg dry weight/m^3)
St. Andrew Bay, Florida (Hopkins 1966)	153	42.8
Anclote River estuary, Florida (Weiss 1978)	64	44.3
Tampa Bay, Florida (Hopkins 1977)	74	39.6
Newport River estuary, North Carolina (Thayer et al. 1974)	153	17.5
North Inlet, South Carolina (Lonsdale and Coull 1977)	153	16.1

at the mouth of the estuary.

Means and ranges of chlorophyll a + phaeopigments (Fig. 6B) exhibited relatively even distributions throughout the estuary, with the exception of Hillsborough Bay. The eutrophic condition of Hillsborough Bay is associated with high nitrogen and phosphorus levels due to a combination of runoff and anthropogenic inputs (Turner and Hopkins 1974).

The high chlorophyll and phytoplankton cell density values recorded for Tampa Bay (Turner and Hopkins 1974), together with lack of any significant relation between chlorophyll and the ten most abundant holoplankton species in the estuary (Hopkins 1977), indicates that there is ample phytoplankton food in the Bay waters to sustain the zooplankton population.

Relationships between the distributions of abundant holoplankters and salinity (Table 5) reveal that three copepods (O. simplex, O. nana and E. acutifrons) with primarily coastal rather than estuarine affinities (Gonzalez and Bowman 1965) were significantly related to higher salinity. A fourth copepod, P. crassirostris, was also significantly related, although it was abundant throughout the Bay. P. crassirostris has similarly been found to be abundant in other estuaries from Florida (Hopkins 1966) to Long Island, New York (Turner, in press), and appears to be indigenous to estuarine waters (Bowman 1971; Gonzalez and Bowman 1965).

The copepods of orders Calanoida and Cyclopoida which are found in Tampa Bay have been shown to exhibit broad geographical ranges in estuarine waters of eastern North America (Turner 1981; Table 6). Most occur, at least seasonally, from Canada or New England to southern Florida or Puerto Rico. The only abundant copepod in Tampa Bay not listed in Table 5 is Euterpina acutifrons (Harpacticoida) (Turner 1981 did not deal with harpacticoids). This species has worldwide distribution in both tropical/subtropical (Gonzalez and Bowman 1965; Haq 1972) and temperate (Moreira et al. 1982; Lebour 1918) waters. The lack of biogeographic distinctiveness of the zooplankton of Tampa Bay is further revealed by observations that the three copepod species which together comprised 56% of total biomass (A. tonsa, O. colcarva and

Table 5. Relationships between the distributions of abundant zooplankters and salinity. Values are t-tests of the significance of the regression coefficient. $t_{.01}$ = **, n = 41. Mean values for each station over the four surveys were used.

Dependent variable	Independent variable (salinity)
Acartia tonsa	1.58
Evadne tergestina	1.40
Pseudodiaptomus coronatus	-1.53
Oikopleura dioica	-1.44
Labidocera aestiva	1.55
Oithona colcarva	-2.18
Paracalanus crassirostris	2.47**
Oithona simplex	4.62**
Euterpina acutifrons	5.17**
Oithona nana	6.42**

P. crassirostris) were also numerical dominants in estuarine zooplankton studies from the lower Laguna Madre, Texas (Breuer 1962; see also Bowman 1975) to, during summer, Peconic Bay, New York (Turner, in press). While the relative abundance of zooplankton species in an estuary relates partly to the temperature and salinity regime, as well as topography and circulation of an estuary (Jeffries 1967), the zooplankton species assemblage in Tampa Bay is largely similar to assemblages in other physiographically different Gulf of Mexico estuaries such as the Anclote River estuary (Weiss 1978), Alligator Harbor (Grice 1956) and St. Andrew Bay (Hopkins 1966).

Hedgpeth (1953) proposed that Tampa Bay is the approximate boundary between the Carolinian (Cape Hatteras to Cape Canaveral, plus northern Gulf of Mexico) and the Caribbean (Tampa Bay and Cape Canaveral south through the Caribbean) marine biogeographic provinces. While this boundary may apply to many macroinvertebrate species (Hedgpeth 1953), it is clearly not applicable to estuarine copepods with geographic ranges as wide as those for the species found in Tampa Bay.

There are numerous unanswered questions concerning the zooplankton of Tampa Bay. For instance, the information obtained thus far is based on a single year (1969-70) of sampling at quarterly intervals. We know nothing of the variability of zooplankton in Tampa Bay over monthly, weekly, daily, or tidal cycle time intervals. Also, the results to date are from samples collected at the surface only. There is no information on variability of vertical distributions. Both horizontal and vertical temporal variability of zooplankton has been shown to be substantial in certain other estuarine studies (Lee and McAlice 1979; Minello and Matthews 1981). In some cases there may be substantial variability on the tidal cycle time scale (Hopkins 1963; Weiss 1978).

Year-to-year fluctuations of marine zooplankton levels have been related to climatic and hydrographic variations in very few instances (examples include Peterson and Miller 1975; Russell et al. 1971). It would be interesting to compare the plankton of Tampa Bay over several annual cycles which include drought and rainy years. Large scale pulses of low salinity or fresh water may inundate estuarine waters. Examples include the flood in the San Francisco Bay area in 1862 (Hedgpeth 1979) and the passage of a tropical storm through the Chesapeake Bay region in 1972 (Boesch et al. 1976). In both cases, the result was drastic

Table 6. Estuarine ranges in eastern North America of calanoid and cyclopoid copepods collected in Tampa Bay (data from Turner 1981).

Taxon	Northern Record	Southern Record
GROUP I		
Oithona colcarva	Woods Hole (41°30')	Florida Keys (25°)
Acartia tonsa	Miramichi Estuary (47°30')	Puerto Rico (18°)
Paracalanus crassirostris	Block Island Sound (41°20')	Puerto Rico (18°)
GROUP II		
Pseudodiaptomus coronatus	Miramichi Estuary (47°30')	Biscayne Bay (25°)
Oithona nana	Pensacola Bay (30°30')	Puerto Rico (18°)
Oithona simplex	" "	" "
Labidocera aestiva	Gulf of St. Lawrence (48°40')	Florida Keys (24°30')
GROUP III		
Centropages hamatus	Labrador (56°30')	Tampa Bay (27°30')
Centropages velificatus	Delaware Bay (38°50')	Puerto Rico (18°)
Temora turbinata	Block Island Sound (41°20')	Puerto Rico (18°)
Paracalanus quasimodo	Beaufort, North Carolina (35°)*	Puerto Rico (18°)
Eucalanus pileatus	Beaufort, North Carolina (35°)*	Laguna Madre, Texas (25°)
Oncaea venusta	Block Island Sound (41°20')	Puerto Rico (18°)
Corycaeus americanus	Delaware Bay (38°50')	Florida Keys (25°)
Corycaeus giesbrechti	St. Andrew Bay, Florida (30°)	Florida Keys (25°)
Corycaeus amazonicus	Beaufort, North Carolina (35°)*	Puerto Rico (18°)

*Personal observations (JTT)

reduction of the salinity of estuarine waters. Also, intrusion of offshore water with higher than normal salinity appears related to outbreaks of red tide in Tampa Bay (Steidinger and Ingle 1972). On-shelf intrusions of the Gulf of Mexico Loop Current would be expected to transport oceanic zooplankters into coastal waters, particularly during summer (Hopkins et al. 1981). This mechanism may partly explain the co-occurrence of maximum holoplankton diversity and salinity in the Anclote River estuary during summer (Weiss 1978).

Present information on Tampa Bay zooplankton encompasses only organisms large enough to be collected by 74 um mesh nets. There are no published studies on the microzooplankton, particularly the protozooplankton, of Tampa Bay. These organisms appear extremely abundant and energetically important in other areas (Beers and Stewart 1969; Heinbokel and Beers 1979; Capriulo and Carpenter 1980; Smetacek 1981).

The trophodynamics of Tampa Bay zooplankton and the organisms which feed upon them are not well defined. While there is a fair amount of information from laboratory studies to indicate that the copepod Acartia tonsa is omnivorous, eating a variety of phytoplankton, zooplankton and detrital foods (examples include Conover 1956; Reeve and Walter 1977; Lonsdale et al. 1979; Heinle et al. 1977), there is yet no published information on the feeding habits of the two next most abundant zooplankters in Tampa Bay (Oithona colcarva and Paracalanus crassirostris). However, investigations currently in progress reveal that in the northern Gulf of Mexico and in coastal waters of North Carolina, these two species as well as many others common in Tampa Bay ingest a variety of phytoplankton and zooplankton foods (Turner, unpublished data). It is unknown whether any of these or other copepods substantially ingest the Florida red tide dinoflagellate. Investigations in New England and Canadian waters reveal that the local red tide dinoflagellate is ingested by several zooplankters (White 1979, 1980, 1981; Turner and Anderson, in preparation), but in one Cape Cod embayment, the impact of zooplankton on red tide dynamics appears minimal (Turner and Anderson, in preparation).

The feeding habits of other non-copepod zooplankters abundant in Tampa Bay are also poorly understood. For instance, the cladoceran Evadne tergestina becomes sporadically abundant in Tampa Bay. Although a few Soviet studies (summarized by Conover 1978) suggest that marine cladocerans in the Black Sea incorporate radioactively labeled bacterioplankton, specifics of marine cladoceran feeding are largely lacking. The tunicate Oikopleura dioica has been shown to feed upon microorganisms (King et al. 1980; King 1982), but much more work remains to be done. There are no quantitative data on ctenophores in Tampa Bay because the abundant species, Mnemiopsis mccredyi, disintegrates upon formalin preservation. Nonetheless, Mnemiopsis fragments were present in many of Hopkins' (1977) samples, and this organism is often visibly abundant in Tampa Bay. Mnemiopsis is a voracious predator upon copepods and other zooplankton, and its predation impact has been shown to be substantial in other estuaries (see review by Reeve and Walter 1978).

Many of the important copepod species in Tampa Bay have been shown to be frequent forage items for larval fishes in shelf waters of the northern Gulf of Mexico (J. J. Govoni, National Marine Fisheries Service, Beaufort, N.C., personal communication). Also, Oikopleura dioica is an important food item for larvae of certain fish species in European waters (Shelbourne 1962). The roles of zooplankton in larval fish food webs in Tampa Bay have thus far remained uninvestigated. Also, the impact of intrazooplankton predation by, for example, chaetognaths and medusae is unknown.

In summary, while there is reasonable baseline information on the occurrence, distribution and abundance

of some zooplankton components of Tampa Bay, we are far from a comprehensive understanding of the ecology of the pelagic community of the estuary. The same can be said for most other estuaries of the world.

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THE MEROPLANKTON OF TAMPA BAY

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ABSTRACT

Information on the planktonic, early developmental stages of fish and invertebrates (meroplankton) has been collected in a variety of studies conducted in the Tampa Bay area over the last 20 years. Early, largely qualitative investigations documented the importance of the bay system as a spawning site and nursery for species important to Gulf of Mexico fisheries. More recent studies have provided quantitative estimates of relative abundance, seasonality, and to some extent, spatial distribution of meroplanktonic organisms in the estuarine and coastal waters of the area. However, because of "state of the art" limitations to the study of meroplankton organisms, as well as the restricted areal coverage of the quantitative investigations, additional data collection is needed before a comprehensive assessment can be made of the relative value of the various subareas of the bay system as spawning and nursery grounds.

INTRODUCTION

Meroplankton, the planktonic, early developmental stages of fish and invertebrates, is an important component of estuarine and coastal ecosystems. This period of planktonic existence is a critical time in the life history of these organisms. Natural mortality during this period is high, but growth is rapid and dispersal from local spawning areas is accomplished.

Meroplankton organisms include species important as forage as well as those of direct commercial importance to man. It has been documented that estuarine-dependent species account for approximately 90% of the total commercial catch in the Gulf of Mexico (Skud and Wilson 1960). In the early 1960s, Bureau of Commercial Fisheries investigators found that 23 species of major importance in Gulf fisheries inhabit the Tampa Bay system during their early developmental stages (Sykes and Finucane 1965).

Early studies of Tampa Bay meroplankton were largely qualitative but documented the importance of the bay system as a spawning site and nursery area for species important to Gulf fisheries. Eldred et al. (1965) investigated the seasonal distribution of penaeid larvae in Boca Ciega and lower Tampa Bays. Finucane (1966, 1967) presented information on the dominant fish eggs and larvae and their relative abundance in various parts of the bay system. Kelly and Dragovich (1967), in a study of the macrozooplankton, provided additional information on the distribution and seasonal abundance of meroplankton in Tampa Bay.

Recent studies have provided quantitative estimates of relative abundance, seasonality and, to some extent, spatial distribution of meroplankton organisms in the estuary. A study of zooplankton within the bay by Hopkins (1977), although concerned primarily with holoplankton, also

presented information on meroplankton seasonality and distribution. Several studies conducted to assess the impact of power plant entrainment on planktonic stages of fish and benthic invertebrates have detailed seasonal trends and relative abundance of meroplankton in lower Hillsborough and upper Tampa Bays (Phillips et al. 1977; Blanchet et al. 1977; Phillips and Blanchet 1980a, b) and in Old Tampa Bay (Weiss et al. 1979).

REVIEW

A variety of studies during the past twenty years have contributed to the knowledge of Tampa Bay meroplankton (Table 1). These studies were widely separated in time and usually of limited areal extent within the bay. Most of these studies focused on a single species or group of species rather than total meroplankton. Early studies dealt primarily with species of commercial importance, while more recent efforts were concerned with power plant associated impacts on specific components of the meroplankton. For these reasons, it is convenient to divide the meroplankton into two groups for purposes of discussion - invertebrate meroplankton and ichthyoplankton.

Invertebrate Meroplankton. Invertebrate meroplankton includes the planktonic early developmental stages of various species of worms, molluscs, echinoderms and crustaceans. Larvae of the decapod crustaceans, particularly those of the commercially important pink shrimp (Penaeus duorarum) and stone crab (Menippe mercenaria) have been studied more extensively than those of other groups.

During the mid-1950s, several studies were conducted to investigate the biology, ecology and distribution of juvenile and adult pink shrimp. In 1957-1958, Florida Board of Conservation personnel found that pink shrimp spawned from February to November, with peak spawning during the spring and summer (Eldred et al. 1961). Spawning and larval development occur in the offshore waters and postlarvae are recruited to estuarine nursery grounds for juvenile development.

Initial investigations of the distribution of penaeid larval and postlarval stages in the bay area during 1962-1963 (Eldred et al. 1965) found that spawning occurs in Gulf waters 10-40 miles offshore. From collections made in lower Tampa Bay and Boca Ciega Bay, it was suggested that pink shrimp do not spawn in inshore Tampa Bay waters but are recruited to the bay as postlarvae. In addition, it was revealed that although recruitment varied from year to year it was greatest during summer months. In a study of macrozooplankton throughout the bay system, P. duorarum postlarvae were found to be most abundant in the summer (Kelly and Dragovich 1967), with greatest numbers in Boca Ciega Bay. Pink shrimp postlarvae were collected from May through November 1978, in a quantitative meroplankton study conducted in Old Tampa Bay (Weiss et al. 1979). Peak densities of 2.6 postlarvae per 100 cubic meters were reported during August. Meroplankton studies in lower Hillsborough and upper Tampa Bays during 1979 reported occurrence of postlarvae from June through December with a July peak of 4.7 postlarvae per 100 cubic meters (Phillips and Blanchet 1980a).

Larvae of the penaeid shrimps Sicyonia spp. and Trachypenaeus spp. have also been collected from stations located at the entrance to Boca Ciega and Tampa Bays and adjacent coastal waters (Eldred et al. 1965; Kelly and Dragovich 1967). Sicyonia brevirostris, the largest and most important commercial rock shrimp in Florida waters (Williams 1965; Cobb et al. 1973), is thought to be largely confined to the middle portion of the central west Florida shelf (Cobb et al. 1973); however, Eldred (1959) and Joyce (1965) concluded that this species is not dependent on estuarine nursery grounds during its life cycle. Adults and subadults of this species have been taken from Gulf waters 10-40 miles (6-21 fathoms) offshore from Tampa Bay (Eldred et al. 1965). Other species known to occur in the Tampa Bay area are S. typica and S.

Table 1. Major meroplankton studies conducted in the Tampa Bay area.

LOCATION (reference)	PERIOD	METHODS	MAJOR MEROPLANKTON TAXA
14 stations, Tampa Bay systems and offshore to 10 miles (Kelly and Dragovich 1967)	Monthly, Sep. 1961 to Aug. 1962	0.5m, 1.024mm mesh plankton nets	Porcellanid Larvae - 27% Brachyuran Larvae - 10% Fish Eggs - 1% Fish Larvae - <1% Anchovies Seatrout Spot Menhaden Penaeid Shrimp - <1% Pink shrimp Sicyonia spp. Trachypenaeus spp.
Lower Tampa Bay and adjacent coastal waters (Eldred et al. 1965)	Bimonthly, Sep. 1961 to Jan. 1964	0.3m diameter, 569 um mesh plankton nets; day/night	Pink shrimp Sicyonia spp. Trachypenaeus spp.
10 stations within Tampa Bay and adjacent coastal waters (Finucane 1966, 1967)	1963-1965	High speed plankton sampler	Fish Eggs Anchovies Drum Herrings Soles Silversides Fish Larvae Anchovies Seatrout Spot Rough silversides Menhaden
42 stations within Tampa Bay system (Hopkins 1977)	Quarterly, 1969-1970	0.3m diameter, 76 um mesh plankton nets	Meroplankton 19% of numbers 8% of biomass Pelecypod Cirriped Polychaete Gastropod

Table 1. continued.

LOCATION (reference)	PERIOD	METHODS	MAJOR MEROPLANKTON TAXA
11 stations in Big Bend area of Upper Tampa Bay (Phillips et al. 1977, Blanchet et al. 1977)	Biweekly, Jan. 1976 to Mar. 1977	1m diameter, 363 um mesh plankton nets; day/night	Fish Eggs 12 families Anchovies - 73% Drum - 26% Fish Larvae 22 families, 41 species Anchovies - 84% Drum - 4% Invertebrates 105 taxa Decapods - 94% Pinnixa sayana Polyonyx gibbesi Upogebia affinis Xanthid crabs
5 stations within Upper Old Tampa Bay and Safety Harbor (Weiss and Wilkens 1979)	Biweekly, Mar. 1978 to Nov. 1978	1m diameter 505 um mesh plankton nets; dawn, mid-day, dusk, midnight; planktonic stages of fish and commercially important invertebrates	53 Fish Taxa, 30 identified to species Fish Eggs Anchovies - 82% Drum - 15% Other -< 1% Fish Larvae Anchovies - 83% Gobies Rough silversides
5 stations in Big Bend area of Upper Tampa Bay (Phillips and Blanchet 1980)	Biweekly, Feb. 1979 to Feb. 1980	1m diameter, 505 um mesh plankton nets; day/night; select group of RIS of fish and commercially important invertebrates; estimates of all taxa collected from randomly selected samples collected monthly.	Fish Eggs Bay anchovy - 50% Drum - 48% Fish Larvae Bay anchovy - 74% Scaled sardine - 16% Drum Invertebrates Xanthid crabs - 40% Pinnixa sayana - 35% Upogebia affinis - 8% Stone crab - 5%

laevigata (Dragovich and Kelly 1964; Eldred et al. 1965) and two species of the genus Trachypenaeus, T. constrictus and T. similis (Dragovich and Kelly 1964; Saloman 1964; Eldred et al. 1965; Zimmerman et al. 1972).

While Trachypenaeus spp. are not specifically sought commercially, they, along with other noncommercial penaeid species, may occur in commercial catches. Eldred (1959) noted the presence of substantial quantities of T. similis in boxes of commercially marked, medium-sized shrimp labelled "pink shrimp". Eldred (1959) also noted that species of Trachypenaeus are important to the fisheries of several foreign countries. Adults of these species may also occasionally occur in bait shrimp catches (Inglis and Chin 1966).

During 1961-1963, spawning of Sicyonia spp. occurred in waters off Tampa Bay from February or March to December. Larvae were present from March to November, with greatest densities occurring during the summer months. Postlarvae were present from May to November.

The seasonal distribution of early larvae suggested that spawning of Trachypenaeus spp. occurred from February through November, with peaks occurring in August and September. Larvae were taken inshore primarily from March to October. Postlarvae were present inshore from April to November and were in greatest abundance from August to October.

The commercially important stone crab, Menippe mercenaria, is common in the Tampa Bay area. In 1976, the combined landings from the three counties surrounding the bay (Pinellas, Hillsborough and Manatee) were reported to be 190,408 pounds, valued at $168,014 (Florida Department of Natural Resources 1977). Blanchet et al. (1977) reported the presence of M. mercenaria zoeae during all months of 1976 in lower Hillsborough Bay (Fig. 1). Peak densities occurred during spring and summer months with greatest densities of 536 zoeae per 100 cubic meters during September. First stage zoeae were most abundant (78% of all stone crab larvae collected) and could indicate that spawning took place locally. Weiss et al. (1979) collected stone crab zoeae from April through October in Old Tampa Bay with greatest densities of 323 per 100 cubic meters occurring in May. Phillips and Blanchet (1980a) found zoeal stages from March through November 1979, in lower Hillsborough and upper Tampa Bays. Peak densities also occurred during May (556 per 100 cubic meters). Large numbers of Stage I zoeae indicated that spawning was occurring within the study area.

Kelly and Dragovich (1967) conducted the first comprehensive study of spatial and temporal distribution of zooplankton organisms in Tampa Bay and adjacent coastal waters. Monthly collections were made at 14 locations within the bay system and 10 miles offshore from September 1961 to August 1962. Meroplankton accounted for 46.2% of all zooplankton collected. Porcellanid and brachyuran crab larvae were the dominant meroplankton organisms collected and accounted for 27% and 10% of total macrozooplankton numbers respectively. Larval porcellanids were most abundant during spring and at stations in upper Tampa Bay and at the mouth of Hillsborough Bay, while brachyuran larvae were most numerous in summer and fall and in upper Tampa Bay. Caridean shrimp and polychaete larvae each constituted 2.4% of the total number of zooplankton organisms collected during the study.

Quarterly zooplankton surveys at 42 locations within the bay during 1969-1970 revealed the relative importance of meroplankton organisms within the zooplankton community (Hopkins 1977). The meroplankton fraction averaged 15,400 individuals and 3 mg dry weight per cubic meter for the bay system and contributed, respectively, 19% and 8% of total zooplankton numbers and biomass collected. Meroplankton organisms were divided into three groups according to average numerical abundance: Group I, greater than 1,000/m^3; Group II, 100-1,000/m^3; and Group III, less than

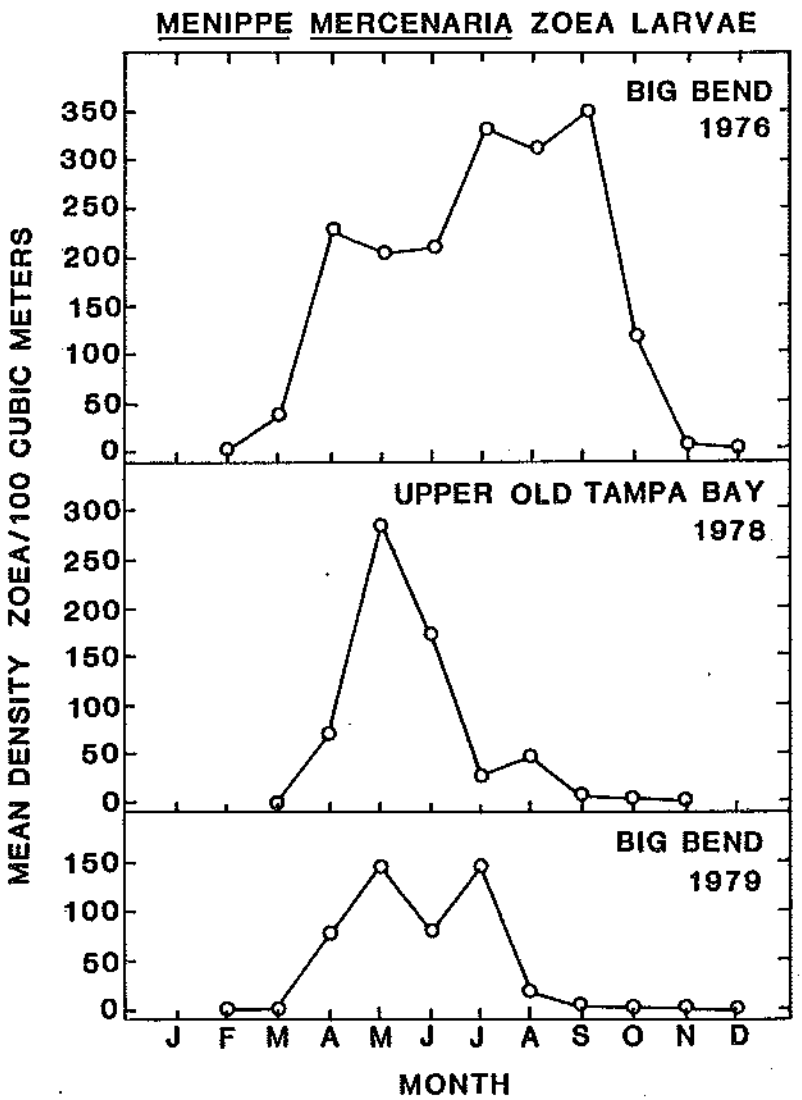

Figure 1. Mean density/100 cubic meters of Menippe mercenaria zoeae reported in three studies of Tampa Bay meroplankton.

100/m^3. Those organisms averaging more than 1,000 individuals per cubic meter included pelecypod, barnacle, polychaete, and gastropod larvae. Highest annual mean values for pelecypod veliger larvae occurred in upper Tampa Bay; for barnacle larvae, Old Tampa Bay and the Manatee River; for polychaete larvae, Boca Ciega Bay and Old Tampa Bay; and for gastropod larvae, lower Tampa Bay and the Manatee River. All members of Group I were least abundant during winter months. Group II consisted of echinoderm, bryozoan and decapod larvae. Echinoderm and bryozoan larvae were most abundant in Boca Ciega Bay while larval decapods were most numerous in upper Tampa Bay. Echinoderms and decapods were least abundant in winter samples and bryozoans least common during spring. Group III larvae, which were relatively rare in the collections, included larval stages of polyclad flatworms, phoronids, brachiopods, acorn worms, ascidians, and cephalochordates. Medusae of attached hydroids were occasionally taken. Most Group III larvae were in greatest abundance during the warm months.

Blanchet et al. (1977) collected meroplankton at ten stations in lower Hillsborough and upper Tampa Bays at approximately two week intervals from January 1976 through March 1977. A total of 105 invertebrate taxa, of which 86 were decapod crustaceans and 19 were miscellaneous forms from 7 phyla were reported. Peaks of abundance occurred in April and October. Larval decapods accounted for 94% of the invertebrate larvae taken in the warm months. During the winter, decapod larvae were rare and other larval taxa made up a large fraction of the catch. The pinnotherid crab, Pinnixa sayana, was the most abundant larval decapod in the collections, accounting for 34.7% of all organisms collected. Major spawning peaks of this species were evident during April and October, with a smaller peak occurring in July. Larvae of the porcellanid crab, Polyonyx gibbesi, were ranked second in abundance and accounted for 28.3% of all organisms collected. Large swarms of early zoeae were noted in the study area during the warm months. Larvae of the callianassid shrimp, Upogebia affinis, ranked third in abundance, were most common during the spring and early summer months. Larvae of this species made up 10.8% of all meroplankton organisms collected. The next most abundant decapod taxa taken were the xanthid crabs Neopanope texana and Hexapanopeus angustifrons. Peak spawning activity for both species apparently occurred during late summer and fall.

Phillips and Blanchet (1980b) collected monthly meroplankton samples in the intake canal of Tampa Electric Company's Big Bend Station from March through October 1979. The data collected gave a general idea of the presence and relative abundance of all meroplankton organisms occurring in the study area; however, the time interval between collections was too long to describe short-term distributional patterns. The invertebrate fraction of the meroplankton was dominated by larvae of decapod crustaceans. The most commonly collected larval taxa were, in order of decreasing abundance, the pinnotherid crab, Pinnixa sayana, which accounted for an average 35% of larval invertebrates; the xanthid crabs, Eurypanopeus depressus, 19%, and Hexapanopeus angustifrons, 9%; the callianassid shrimp, Upogebia affinis, 8%, and stone crab, 5%. As a group, xanthid crabs accounted for 40% of all larval invertebrates in the samples. Additional xanthid species commonly collected were Rhithropanopeus harrisii, Panopeus herbstii, and Neopanope texana. Postlarvae of pink shrimp accounted for less than 1% of total invertebrate meroplankton occurring in the samples. Other penaeid shrimp found included Sicyonia sp. and Trachypenaeus sp. Larvae of the brief squid also occurred in the samples.

Ichthyoplankton. The planktonic early developmental stages of fish, the eggs and larvae, constitute the ichthyoplankton. Initial investigations of

Tampa Bay ichthyoplankton were conducted at 10 stations throughout the bay system during 1963-1965 (Finucane 1966, 1967). Fish eggs were collected in greatest numbers at the mouth of the estuary and in adjacent coastal waters during February and in the upper reaches during May. A second pulse occurred in both areas during June and July. Eggs were essentially absent from the bay system from October through January. Eggs were predominantly anchovies, drum, herrings, soles and silversides. The occurrence of early egg stages in some of these groups indicated that spawning occurred within the estuary. Greatest densities of fish eggs occurred in Old Tampa Bay and Hillsborough Bay in the spring and summer with lowest densities during the winter. Fish larvae exhibited a similar pattern of seasonal abundance in Old Tampa Bay, but were rare in Hillsborough Bay throughout the year. Larvae were most abundant during June when anchovies, seatrout, spot, rough silversides, and menhaden dominated the catch.

Phillips et al. (1977) collected day and night ichthyoplankton samples at approximately two week intervals during 1976 and 1977 at ten stations in the vicinity of the Big Bend Power Plant near the mouth of Hillsborough Bay. Eggs from 12 families and larvae of 41 species from 22 families were recorded during the 15 month study. Additional studies conducted in a larger study area near the Power Plant in 1979 (Phillips and Blanchet 1980a) concentrated on investigating the abundance and distribution of six fish species (Table 2). Day and night samples were collected at two week intervals from February 1979 to February 1980. Monthly samples collected in the plant intake canal from March to October 1979 were examined for all fish eggs and larvae (Phillips and Blanchet 1980b). In addition to the six species chosen for intensive study, eggs and larvae of 16 species from 13 families were recorded in the monthly samples.

Weiss et al. (1979) sampled five stations in upper Old Tampa Bay and Safety Harbor from March to November 1978 as part of a monitoring program to assess the effects of cooling water withdrawal for the A. W. Higgins Power Plant. Samples were collected every six hours over a 24 hour period at two week intervals. A total of 53 fish taxa were taken in the collections, 30 of which were identified to species. Seven types of eggs could be identified to species level, although a variety of egg types were noted.

In the studies cited above, the greatest densities of eggs and larvae occurred during the spring and summer months (Fig. 2). Anchovy and drum eggs and anchovy larvae (primarily Anchoa mitchilli) dominated the collections (Table 2). Anchovy eggs and early larvae were collected from March through October (Fig. 3) during all three years, indicating a protracted spawning season for the species in Tampa Bay. Greatest egg densities occurred in April or May each year but remained high throughout the summer months in both 1976 and 1979. In 1978, egg densities exhibited a bimodal pattern with lowest numbers occurring in July. Anchovy larvae exhibited a similar bimodal pattern in each of the three years with numbers diminished during June. Peak larval densities occurred during July in 1976 and 1979 and during May in 1978.

Several species of sciaenids (drums) are important to the commercial and sport fisheries of the bay area. These include the spotted seatrout (Cynoscion nebulosus), sand seatrout (C. arenarius), kingfish (Menticirrhus spp.), black drum (Pogonias cromis), and red drum (Sciaenops ocellatus). Sciaenid eggs were the second most abundant group of eggs collected in each of the three studies, ranging from 15% to almost 49% of all eggs collected (Table 3). At least seven species of sciaenids occur within Tampa Bay, and because of the difficulty of identifying sciaenid eggs to species, several species are undoubtedly represented in the collections. Sciaenid eggs were reported to be most abundant from April through September with peak densities during May in each of the three studies (Fig. 3). Sciaenid larvae were

Table 2. Species chosen for concentrated study at Big Bend during 1979-1980. (From Phillips and Blanchet 1980a)

SCIENTIFIC NAME	COMMON NAME
Invertebrates	
Crassostrea virginica	Eastern oyster
Penaeus duorarum	Pink shrimp
Callinectes sapidus	Blue crab
Menippe mercenaria	Stone crab
Fishes	
Harengula jaguana	Scaled sardine
Anchoa mitchilli	Bay anchovy
Menidia beryllina	Tidewater silverside
Bairdiella chrysoura	Silver perch
Cynoscion nebulosus	Spotted seatrout
Pogonias cromis	Black drum

Table 3. Dominant fish egg and larval taxa as percent of all eggs or larvae collected from three ichthyoplankton surveys in Tampa Bay.

	BIG BEND 1976		BIG BEND 1979		HIGGINS 1978	
Eggs						
	Engraulidae	73.1	Engraulidae	51.1	Engraulidae	82.2
	Sciaenidae	26.1	Sciaenidae	48.7	Sciaenidae	15.4
	Carangidae	0.4	Soleidae	0.1	Soleidae	1.1
Larvae						
	Anchoa spp.	87.4	*A. mitchilli*	74.4	*Anchoa* app.	83.6
	Sciaenidae	3.9	*H. jaguana*	16.3	Gobiidae	13.3
	Gobiidae	2.7	Sciaenidae	3.1	Sciaenidae	1.1
	Pomadasyidae	2.1	Blenniidae	1.5	Atherinidae	1.1
	Carangidae	1.1	*Prionotus* spp.	0.9	Blenniidae	0.3

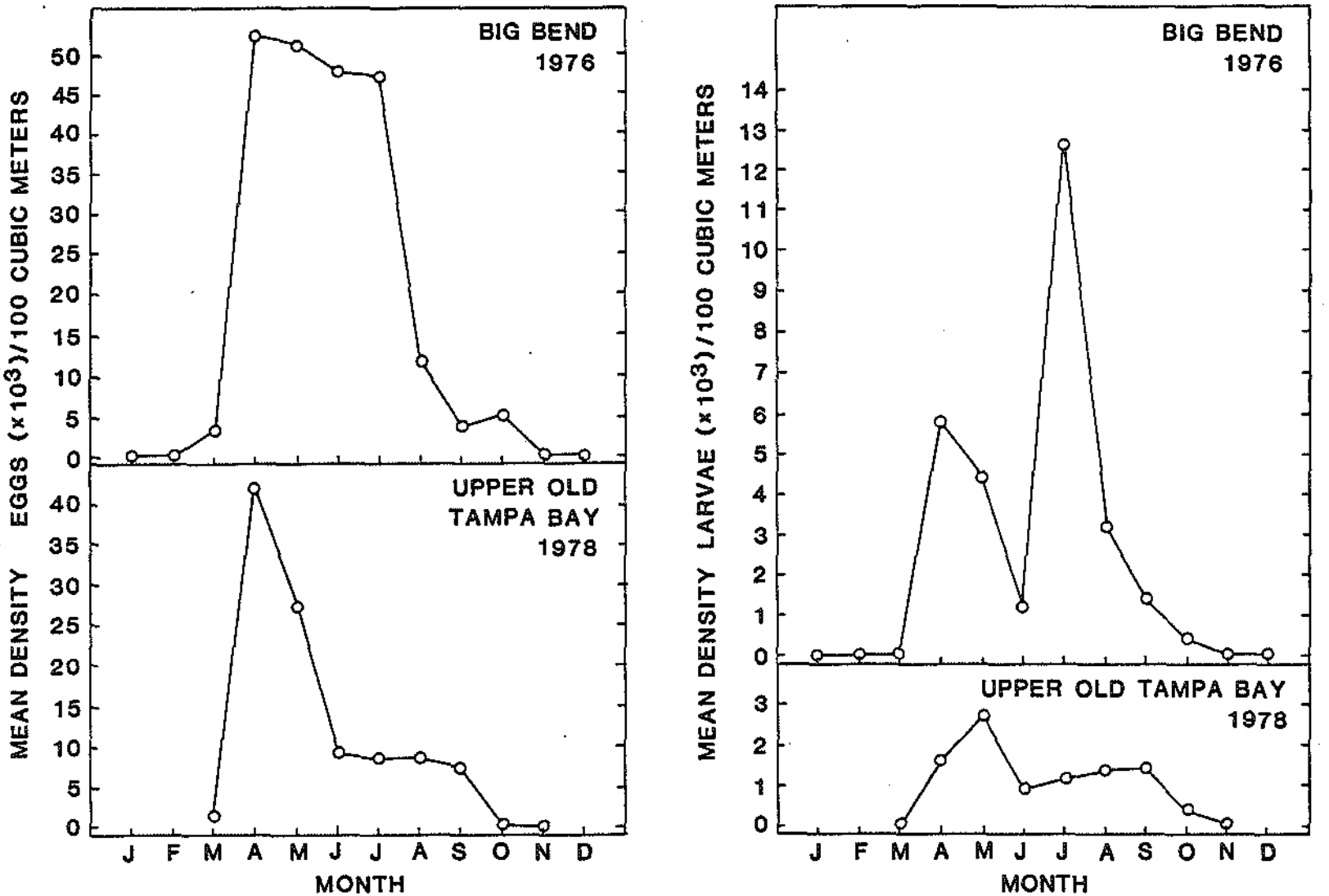

Figure 2. Mean densities of fish eggs and larvae at Big Bend in 1976 and in Upper Tampa Bay in 1978.

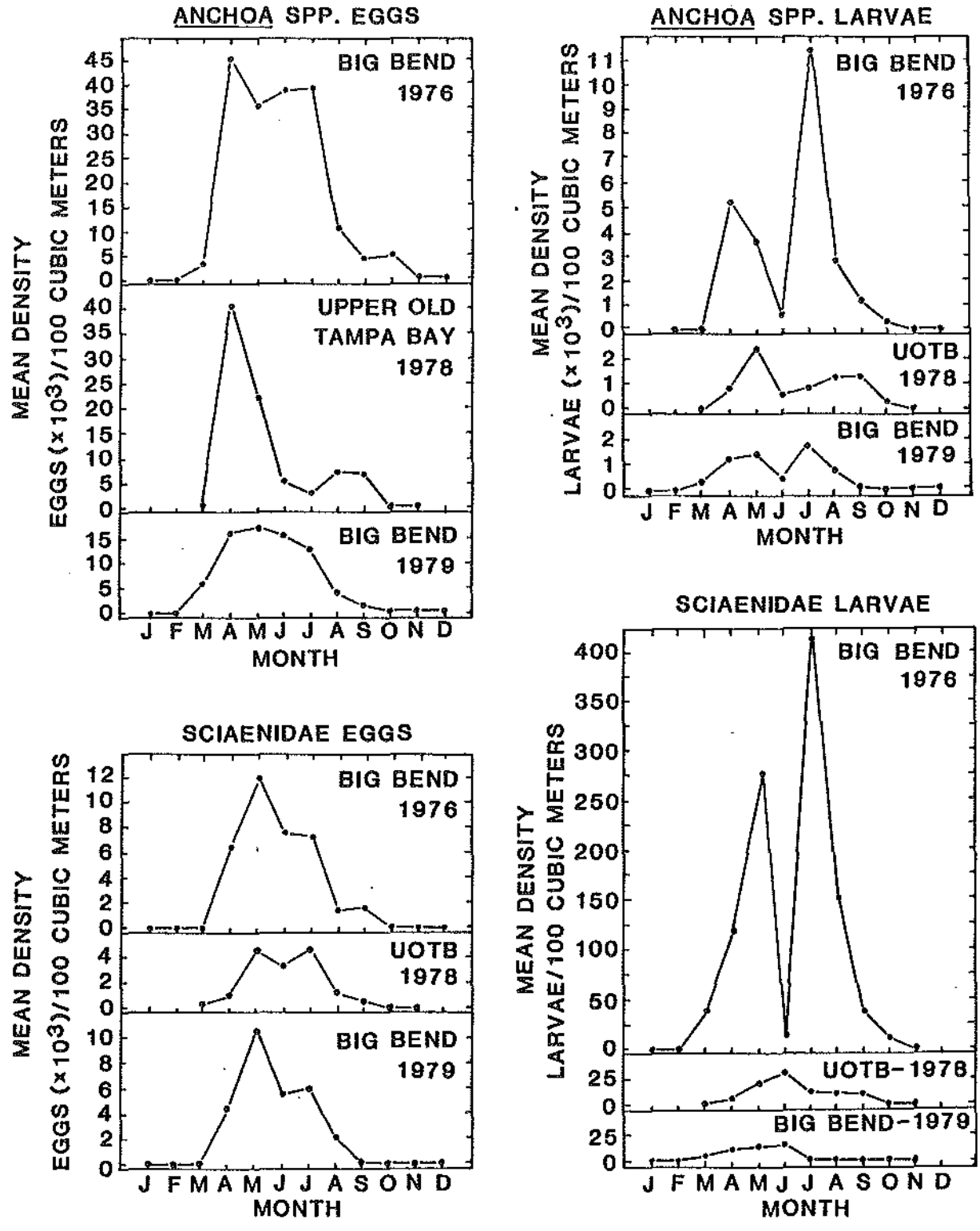

Figure 3. Mean densities of Anchoa spp. and Sciaenidae (drum) eggs and larvae reported in three studies of Tampa Bay ichthyoplankton.

also most abundant during spring and summer months. Peak densities occurred in July in 1976 at Big Bend, but during June in both 1978 and 1979. The bimodal pattern of larval abundance in 1976 may reflect peak spawning activity by different species.

Goby larvae were numerically important in the studies conducted in 1976 and 1978, accounting for 2.7% and 13.3% respectively of all larvae collected. Species represented in the ichthyoplankton included: frillfin goby (Bathygobius soporator), naked goby (Gobiosoma bosci), code goby (G. robustum), clown goby (Microgobius gulosus), and green goby (M. thalassinus).

Spring and summer collections also contained larvae of a number of other species including the scaled sardine, Harengula jaguana, sheepshead, Archosargus probatocephalus, pigfish, Orthopristis chrysoptera, and several carangids and blennies.

Winter samples were dominated by blenny and goby larvae, but numbers were usually low. Larvae of the pinfish (Lagodon rhomboides), menhaden (Brevoortia spp.), spot (Leiostomus xanthurus), and speckled worm eels (Myrophis punctatus) were taken in January and February at Big Bend in 1976 and 1979. These species spawn offshore in the Gulf of Mexico and are recruited into the upper reaches of Tampa Bay as late postlarvae.

SUMMARY

Studies of the meroplankton in the Tampa Bay area have indicated that the bay system plays a vital role in the life histories of many species of fish and benthic invertebrates. It is important both as a spawning site and as a nursery area for numerous estuarine or estuarine-dependent forms. Because of state-of-the-art problems in meroplankton taxonomy, however, studies have been generally restricted to ichthyoplankton and planktonic stages of decapod crustaceans, particularly those of commercial value. These studies have provided a limited amount of information regarding patterns of seasonal abundance for the dominant taxa in various subareas of the bay system.

In addition, ichthyoplankton studies have dealt primarily with pelagic eggs and larvae which are easily collected by conventionally towed plankton nets. Little information exists regarding the spawning and developmental history of species with demersal eggs and larvae. Species which spawn exclusively in the numerous grassbeds, oyster bars, or shallow beach zones in the bay system have not been investigated.

The extent and relative values of various portions of the bay as spawning and nursery grounds remain generally unknown because quantitative distributional meroplankton studies have been of limited areal coverage; up-to-date information on the distribution and abundance of adult fish and invertebrates is limited; and data on fecundity, natural mortality, growth and other population parameters are scant.

The Tampa Bay system is valuable as a spawning and nursery area because of the diversity of aquatic habitats such as seagrass beds, mangrove stands and tidal creeks, as well as good bay water quality. Habitat loss and degradation of water quality due to many years of development in the bay area have been extensively documented. Such activities as dredge and fill, the discharge of industrial and municipal wastes, and the use of large volumes of bay water for power plant cooling purposes have undoubtedly had adverse impacts on the adult and larval stages of fish and invertebrates. The magnitude of these impacts are unknown because long-term, synoptic meroplankton studies are lacking. Because of the potential for further degradation of valuable aquatic resources, all efforts should be made to identify the existing resources and to study the dynamics of population maintenance and production and the factors affecting population expansion and decline. As a first step toward these ends, baywide distributional studies of both adult and larval fish and invertebrate populations are recommended.

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VARIABILITY IN THE VERTICAL DISTRIBUTION OF ICHTHYOPLANKTON IN LOWER TAMPA BAY, FLORIDA

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ABSTRACT

Previous studies have demonstrated that many zooplankton taxa are able to effect landward transport into, and retention within, positive estuaries by regulating their vertical distribution. The present study was undertaken to determine whether or not ichthyoplankton in lower Tampa Bay, Florida, exhibit such regulatory abilities. An evaluation of the net non-tidal flow over four tidal cycles revealed that, during the summer rainy season, a sufficient degree of density stratification occurred so as to result in a tidally averaged, two-layered circulation pattern. From this information it is concluded that larval fish have a greater probability of achieving landward transport and/or estuarine retention by remaining near the bottom during all tidal phases. Fixed plankton nets were used to sample postlarval fishes from the surface, mid-depth and bottom over several tidal cycles during the spring and fall recruitment peaks. Results of factorial analysis of variance on abundance data showed that the majority of species were concentrated significantly (P less than or equal to 0.05) at some particular depth, indicating behavioral control of their vertical distribution. Surface samples were dominated by Opisthonema oglinum (Clupeidae), Anchoa hepsetus (Engraulidae), and Eucinostomus spp. (Gerreidae). Other surface dominants included the blennids Chasmodes saburrae and Hypleurochilus geminatus, both of which also showed a significant degree of positive phototropism. Mid-depth samples were dominated by the flatfishes Achirus lineatus (Soleidae) and Symphurus plagiusa (Cynoglossidae) as well as Chloroscombrus chrysurus (Carangidae) and Haemulon plumieri (Haemulidae). Bottom samples were primarily dominated by the sciaenids Menticirrhus spp., Cynoscion arenarius, and Sciaenops ocellatus, which also exhibited a significant photoperiod response, migrating to mid-depth at night. Other bottom dominants included Prionotus scitulus (Triglidae) and Gobiosoma robustum (Gobiidae). Preference for a more bottom oriented distribution during the larval stage of development, especially in the case of the sciaenids, may be correlated with a greater degree of dependency upon the estuarine nursery grounds of upper Tampa Bay.

INTRODUCTION

The abundance of food and shelter found in most estuaries provides such an excellent refuge for young fishes that the majority of the commercially important species occurring along the south Atlantic and Gulf coasts of the United States have evolved life history patterns in which the larval and juvenile stages depend upon estuarine habitat during early development (McHugh 1966; Shenker and Dean 1979). The life history strategies of these species generally follow a similar pattern. In most cases, the eggs are spawned offshore and give rise to pelagic larvae which somehow make their way into the low salinity waters of the estuaries. Here, the larvae settle out of the water column, develop into juveniles and grow, and eventually return to or towards the sea again as sexually mature adults. This life history

pattern is an extremely important phenomenon which, according to Gunter (1967), constitutes a general law regarding the fishes and most other large motile organisms inhabiting the estuaries of the south Atlantic and Gulf of Mexico.

The larval stage of development in fishes is the most critical period of time in the survival of individuals and hence, the stock and recruitment of populations (May 1974). Like other planktonic organisms, the weakly swimming pelagic larvae of fishes are primarily dependent on oceanic and tidal currents for their horizontal distribution (Bishai 1960; Harden Jones 1968), including the inshore transport from open ocean spawning waters to the estuarine nursery grounds (Haven 1957; Pearcy and Richards 1962; Graham 1972). However, a common hydrodynamic feature of the shallow, intensively flushed estuaries of the south Atlantic and Gulf coasts is a net seaward residual flow due to the input of freshwater from their drainage basins (Pritchard 1952). Such a circulation pattern should prevent, or at least inhibit, the entrance of offshore spawned fish larvae into the enclosed bays (Gunter 1967) as well as disperse those pelagic larvae spawned in the estuaries away from their adult populations, towards the sea (Sandifer 1975).

Many investigators have described the utilization, by various coastal and estuarine zooplankters, of the net landward flow in the lower layers of well stratified estuaries as one mechanism by which planktonic larvae could be recruited and retained (Rogers 1940; Carriker 1951; Bousefield 1955; Haven 1957; Pearcy and Richards 1962; Graham 1972; De Wolf 1974; Sandifer 1975; Turgeon 1976; Weinstein et al. 1980; Woolridge and Erasmus 1980; Cronin 1982). However, the problems of larval recruitment and retention become more acute in shallow, well-mixed estuaries which have strong tidal flows. With the exception of the Mississippi River system, the estuaries of the Gulf of Mexico are generally considered to be vertically homogeneous (Ross 1973). The presence of a classical tidally averaged two-layered circulation pattern has not been adequately demonstrated in these estuaries and hydrographic data suggest that such stratification could only occur during the rainy months of the year (Jones et al. 1965). Thus, Hoese (1965) considered the mass transport of young fish from Gulf waters into the upstream nursery grounds to be a major unsolved problem in marine science, and despite attempts since to elucidate the matter, the specific mechanisms by which larval fishes are recruited to, and concentrated in, well-mixed tidal estuaries remain poorly understood (Weinstein et al. 1980).

Although few studies have directly addressed the patterns of ichthyoplankton vertical distribution in estuaries, it seems clear that the position which the larvae occupy in the water column, and perhaps, their ability to regulate this position in response to relevant physical and/or chemical conditions, are important factors in any recruitment-retention mechanism (Weinstein et al. 1980). In the present study, the vertical distribution of postlarval fishes, and the variability associated with this distribution, was examined in the mouth of Tampa Bay, Florida, during the spring and fall recruitment peaks. Ichthyoplankton sampling was stratified by depth, photoperiod, and tidal direction. Thus, the purpose of the study was to depict postlarval fish behavior with respect to these strata in an attempt to discern the mechanisms responsible for their landward transport and/or retention within this estuary.

MATERIALS AND METHODS

Postlarval fishes were sampled biweekly, on spring tides, during the months of May and June and again during September and October of 1980. These months correspond to the bimodal annual recruitment peak of the estuarine ichthyofauna of southwest Florida (Wang and Raney 1971). Data from these two periods were analyzed separately as spring and fall data sets.

Samples were collected with three stationary, 0.5 m diameter, 0.5 mm mesh

conical plankton nets. The nets were each attached to 25 lb lead weights and suspended from the Sunshine Skyway Bridge where they were allowed to fish synoptically over the entire water column, at the surface, mid-depth, and one meter off the bottom. Depth at the sampling site was 10 meters. This site was located in the center, and deepest point, of the natural channel entering the mouth of Tampa Bay. Figure 1 shows the location of the sampling site relative to the surface velocities at each point over a complete tidal cycle (from Ross 1973).

To enable quantitative determination of postlarval fish densities, the volume of water filtered was measured with a General Oceanics model 2030 flowmeter fitted in the mouth of each net. The nets were fished during the peak velocities of both the flood and ebb phases of a tidal cycle until it was visually determined that the surface net was beginning to clog and lose its filtering efficiency. An attempt was made to filter a minimum volume of 100 m^3 to obtain each sample, but variable clogging conditions sometimes precluded this effort. Collections were preserved in 5% buffered formalin and transported to the laboratory where, under a dissecting microscope, all postlarval fishes were sorted from other plankters, measured for standard length to the nearest 0.1 mm, and identified to the lowest taxon possible.

Spring samples were collected only during daylight hours while fall samples were collected both during daytime and nighttime. This sampling scheme thus constituted a factorial design with the main effect classes being sample date, photoperiod (fall data set only), tidal current direction, and depth. The dependent variable in this design was the standardized density of postlarvae (no./100 m^3) of the various species analyzed. Factorial analyses of variance (ANOVA) were performed on data from only those species in each data set which ranked in the upper fifty percentile in abundance. Prior to analysis, data were logarithmically transformed (log x+1) in order to meet the homoscedasticity requirement of ANOVA. Since there was no replication for each combination of factors, it was necessary to utilize an independent estimate of the error mean square, which represented the error between nets, in the ANOVA procedures. This was determined from two sets of collections made during November of 1980 in which all three nets were simultaneously fished at the same depth, for each of the three sample depths, throughout the tidal phase. Logarithmically transformed density data from the most abundant species were subjected to one-way ANOVA, with depth as the only class, and the error mean square computed in this procedure was then used in the factorial ANOVA. In addition, the mean standard lengths of those species analyzed, and the Shannon diversity index value (H'), were calculated for each sample. Both of these variables were also subjected to one-way ANOVA with depth being the only class. A posteriori multiple comparison procedures (Duncans multiple range test, $P = 0.01$) were used to determine the main and interaction effects in all ANOVA procedures.

For those taxa in each data set which ranked in the upper fifty percentile in abundance, species group dendrograms were generated using the methods of Richardson and Stephenson (1978). Postlarval fish densities were summed over the other dimensions for each depth, transformed with a square root function, and then standardized as percentages to yield species x depth matrices. Bray-Curtis dissimilarity coefficients were calculated for each matrix and clustered by group average sorting. Selection of acceptable fusion levels for species groups was somewhat subjective based in part on intuitive knowledge of the data.

To gain some insight into the hydrodynamics of the study area the net non-tidal flow was measured at both the north and south sides of the natural channel during May and June of 1981 respectively. Three General Oceanics model 2030 flowmeters, each fitted with low threshold rotors (sensitive to 5

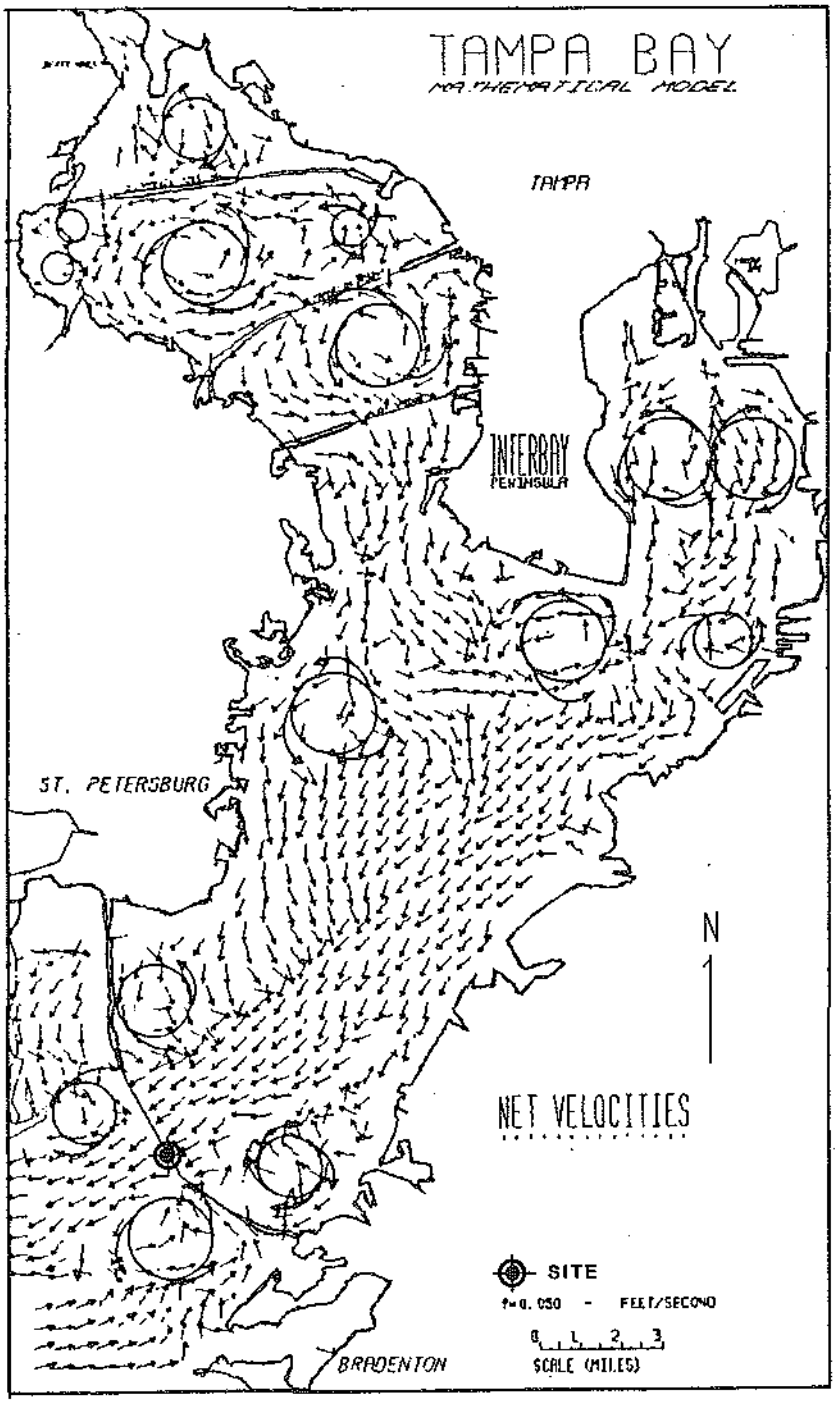

Figure 1. Location of sampling site relative to the net surface tidal current velocities at each point over a complete tidal cycle. (From Ross 1973).

cm/sec velocities) were arranged sequentially on a weighted line and suspended from the Sunshine Skyway Bridge to the sample depths of 1 meter, 5 meters, and 9 meters during slack tide. The meters were retrieved and read on four subsequent slack tides. From this arrangement the resultant distance that a parcel of water at the three sample depths would travel over two tidal cycles was calculated. In addition, temperature and salinity were measured from water samples collected concurrently at sample depths with a 2-liter Nisken bottle in order to discern any vertical density stratification. Temperature was measured in the field to the nearest 0.1°C, with a submersible thermometer, while salinity was measured to the nearest 0.1 °/oo in the laboratory with an Autosal model 8400 conductivity salinometer.

RESULTS

A total of 11,645 postlarval fishes were collected during the spring sampling period from which 34 species were identified. Only 30 species were identified from a total of 6,439 specimens collected during the fall sampling period. Tables 1 and 2 list, in phylogenetic order, the species collected in the spring and fall data sets, respectively. In the left hand column the total number of individuals of each species captured in a particular data set is shown. The next column ranks the species by their relative total mean densities. The total mean number of larvae per 100 m^3 represents the average standardized density of a species over all the samples collected at a given sample depth. These densities are then converted to relative percentages of the total mean density of that species, for comparison.

It is obvious from Tables 1 and 2 that few species, as planktonic larvae, were evenly distributed in the water column, but rather, the majority were segregated into some particular depth stratum. This phenomenon is more quantitatively displayed in Tables 3 and 4, which represent the analysis of variance summaries of the spring and fall data sets, respectively. Multiple comparison test results are shown below individual letter designations, along with the appropriate levels of significance.

In the spring data set, 11 of the 17 species analyzed showed a significant main depth effect with respect to their densities. The species found most often near the surface included Dactyloscopus sp. (Dactyloscopidae), Eucinostomus sp. (Gerreidae), Chasmodes saburrae (Blennidae), and Ioglossus calliurus (Gobiidae). The flatfishes Achirus lineatus (Soleidae) and Symphurus plagiusa (Cynoglassidae), as well as Haemulon plumieri (Haemulidae) were captured significantly more often at mid-depth. The bottom oriented group included the drums Menticirrhus sp. and Cynoscion arenarius (Sciaenidae), along with Prionotus scitulus (Triglidae) and Gobiosoma robustum (Gobiidae). No species exhibited a significant tide x depth interaction; that is, the phase of the tide had no measurable effect on postlarval fish vertical distribution. Tide as a main effect was also insignificant in all cases. However, two species, Anchoa hepsetus (Engraulidae) and P. scitulus, did exhibit significant differences with respect to sample date. This was interpreted as meaning that A. hepsetus was reaching its spawning peak in late May, while P. scitulus was only beginning its spawning season in late June.

Thirteen of the 17 species analyzed in the spring data set also displayed a significant depth effect with respect to their mean standard lengths. It is important to determine where the largest postlarvae of a species are concentrated in the water column, as this may indicate the depth of preference for that species. Presumably, the larger a larval fish becomes, the stronger and more active a swimmer it is, thus allowing it to better overcome the mixing effects of turbulence and achieve its desired vertical distribution. Only S. plagiusa and C. arenarius postlarvae were found to be significantly larger near the bottom. This distribution was also observed for both Menticirrhus

Table 1. Abundance data for all species collected in the spring sample set. Species are listed in phylogenetic order.

SPECIES	Total No.	Density Ranked Abundance	Total Mean No./ $100m^3$	Bottom Mean No./ $100m^3$	Mid-Depth Mean No./ $100m^3$	Surface Mean No./ $100m^3$	Bottom % of Total	Mid-Depth % of Total	Surface % of Total
Harengula jaguana	36	21	1.40	0.00	0.00	1.40	0	0	100
Opisthonema oglinum	4,012	1	175.50	29.93	35.80	109.77	17	20	63
Anchoa hepsetus	896	6	42.54	9.38	5.38	27.78	22	13	65
Ogilbia cayorum	5	27	0.20	0.00	0.00	0.20	0	0	100
Hyporhamphus unifasciatus	14	25	0.42	0.00	0.00	0.42	0	0	100
Strongylura marina	2	32	0.07	0.00	0.00	0.07	0	0	100
Membras martinica	71	19	2.42	0.25	0.00	2.17	10	0	90
Syngnathus sp.	33	18	3.09	2.15	0.78	0.16	70	25	5
Serraniculus pumilio	2	33	0.07	0.00	0.00	0.07	0	0	100
Serranus subligarius	4	30	0.15	0.00	0.04	0.11	0	27	73
Chloroscombrus chrysurus	562	7	38.34	9.16	22.87	6.31	24	60	16
Oligoplites saurus	187	11	16.89	10.89	2.98	3.02	64	18	18
Eucinostomus sp.	1,480	4	49.99	1.29	2.99	45.71	3	6	91
Haemulon plumieri	82	14	5.37	0.16	4.32	0.89	3	80	17
Archosargus probatocephalus	15	22	1.27	0.00	0.17	1.10	0	13	87
Cynoscion arenarius	395	9	32.12	21.53	10.54	0.05	67	33	0
Cynoscion nebulosus	96	12	9.13	6.04	2.56	0.53	66	28	6

Table 1 continued.

SPECIES	Total No.	Density Ranked Abundance	Total Mean No./ $100m^3$	Bottom Mean No./ $100m^3$	Mid-Depth Mean No./ $100m^3$	Surface Mean No./ $100m^3$	Bottom % of Total	Mid-Depth % of Total	Surface % of Total
Menticirrhus sp.	433	8	33.26	16.99	14.78	1.49	52	44	4
Chaetodipterus faber	23	20	1.67	0.47	1.14	0.06	28	68	4
Mugil curema	53	15	3.94	1.85	1.55	0.54	47	39	14
Dactyloscopus sp.	223	13	7.15	0.00	0.00	7.15	0	0	100
Chasmodes saburrae	869	10	29.44	1.48	1.73	26.23	5	6	89
Hypsoblennius hentzi	5	31	0.10	0.00	0.00	0.10	0	0	100
Hypleurochilus geminatus	25	23	0.83	0.00	0.00	0.83	0	0	100
Gobiosoma robustum	51	17	3.57	3.30	0.27	0.00	92	8	0
Bathygobius soporator	10	24	0.78	0.59	0.13	0.06	76	16	8
Ioglossus calliurus	68	16	3.58	0.05	1.93	1.60	1	54	45
Peprilus sp.	22	25	0.77	0.00	0.00	0.77	0	0	100
Prionotus scitulus	805	5	48.23	25.08	22.18	0.97	52	46	2
Achirus lineatus	461	3	59.12	18.62	19.45	0.80	48	50	2
Symphurus plagiusa	693	2	91.39	51.71	39.54	0.44	57	43	0
Monacanthus hispidus	4	29	0.16	0.00	0.16	0.00	0	100	0
Lactophrys quadricornis	7	27	0.33	0.11	0.22	0.00	33	67	0
Sphaeroides nephelus	1	34	0.04	0.00	0.04	0.00	0	100	0

Table 2. Abundance data for all species collected in the fall sample set. Species are listed in phylogenetic order.

Species	Total No.	Density Ranked Abundance	Total Mean No./ $100m^3$	Bottom Mean No./ $100m^3$	Mid-Depth Mean No./ $100m^3$	Surface Mean No./ $100m^3$	Bottom % of Total	Mid-Depth % of Total	Surface % of Total
Opisthonema oglinum	8	17	1.93	0.00	1.55	0.38	0	80	20
Anchoa hepsetus	1,640	1	259.20	93.95	136.42	28.83	36	53	11
Ogilbia cayorum	2	30	0.03	0.00	0.00	0.03	0	0	100
Hyporhamphus unifasciatus	2	29	0.04	0.00	0.00	0.04	0	0	100
Fundulus sp.	2	26	0.11	0.00	0.00	0.11	0	0	100
Membras martinica	36	18	1.21	0.00	0.00	1.21	0	0	100
Syngnathus floridae	18	16	2.11	1.11	0.89	0.11	52	42	6
Serraniculus pumilio	3	22	0.45	0.21	0.24	0.00	47	53	0
Rachycentron canadum	8	19	0.96	0.00	0.76	0.20	0	79	21
Chloroscombrus chrysurus	236	6	30.08	9.12	17.36	3.60	30	58	12
Oligoplites saurus	2	28	0.04	0.00	0.00	0.04	0	0	100
Eucinostomus sp.	3	27	0.10	0.00	0.00	0.10	0	0	100
Haemulon plumieri	35	15	3.51	0.85	2.09	0.57	24	60	16
Cynoscion nebulosus	51	13	5.06	2.93	1.84	0.29	58	36	6
Menticirrhus sp.	833	3	119.59	55.54	54.35	9.70	46	45	9
Sciaenops ocellatus	187	7	16.18	8.46	6.36	1.36	52	39	9
Chaetodipterus faber	7	23	0.41	0.03	0.13	0.25	7	32	61

Table 2 continued.

SPECIES	Total No.	Density Ranked Abundance	Total Mean No./$100m^3$	Bottom Mean No./$100m^3$	Mid-Depth Mean No./$100m^3$	Surface Mean No./$100m^3$	Bottom % of Total	Mid-Depth % of Total	Surface % of Total
Mugil cephalus	265	5	30.44	9.93	13.96	6.55	33	46	21
Dactyloscopus sp.	9	24	0.34	0.00	0.00	0.34	0	0	100
Chasmodes saburrae	103	14	5.05	0.97	1.37	2.71	19	27	54
Hypleurochilus geminatus	125	12	5.79	0.81	0.11	4.87	14	2	84
Gobiosoma robustum	843	4	100.36	65.60	29.97	4.79	65	30	5
Bathygobius soporator	6	21	0.55	0.29	0.06	0.20	53	11	36
Gobionellus sp.	54	10	9.65	6.05	3.29	0.31	63	34	3
Scomberomourus cavalla	1	25	0.33	0.00	0.33	0.00	0	100	0
Prionotus scitulus	1,578	2	224.07	106.19	96.67	21.21	48	43	9
Achirus lineatus	176	8	14.26	3.22	8.68	2.36	22	61	17
Symphurus plagiusa	67	11	6.91	1.58	4.47	0.86	23	65	12
Lactophrys quadricornis	125	9	11.45	3.42	3.45	4.58	30	30	40
Sphaeroides nephelus	10	20	0.95	0.67	0.08	0.20	71	8	21

Table 3. Summary of the analysis of variance procedures for the spring data set. Multiple comparison test results are shown below individual letter designations along with appropriate levels of significance.

SPECIES	H'	SL	Transformed {log(x+1)} Postlarvae/100 m^3 Date	Tide	Depth	Tide x Depth
Total species	B M S**	S B M***	(ns)	(ns)	(ns)	(ns)
Opisthonema oglinum	-	S M B***	(ns)	(ns)	(ns)	(ns)
Anchoa hepsetus	-	S B M***	2 4 3 1***	(ns)	(ns)	(ns)
Chloroscombrus chrysurus	-	S B M***	(ns)	(ns)	(ns)	(ns)
Oligoplites saurus	-	S M B***	(ns)	(ns)	(ns)	(ns)
Eucinostomus sp.	-	S B M***	(ns)	(ns)	S M B***	(ns)
Haemulon plumieri	-	S M B***	(ns)	(ns)	M S B*	(ns)
Cynoscion arenarius	-	B M S***	(ns)	(ns)	B M S***	(ns)
Cynoscion nebulosus	-	(ns)	(ns)	(ns)	(ns)	(ns)
Menticirrhus sp.	-	S B M*	(ns)	(ns)	B M S***	(ns)
Mugil curema	-	S M B**	(ns)	(ns)	(ns)	(ns)
Dactyloscopus sp.	-	S M B***	(ns)	(ns)	S M B***	(ns)
Chasmodes saburrae	-	(ns)	(ns)	(ns)	S M B***	(ns)
Gobiosoma robustum	-	S B M***	(ns)	(ns)	B M S**	(ns)
Ioglossus calliurus	-	S M B*	(ns)	(ns)	S M B***	(ns)
Prionotus scitulus	-	(ns)	4 3 2 1**	(ns)	B M S***	(ns)
Achirus lineatus	-	(ns)	(ns)	(ns)	M B S**	(ns)
Symphurus plagiusa	-	B M S***	(ns)	(ns)	M B S***	(ns)

Depths: Surface (S), Mid-depth (M), Bottom (B)
Tides: Flood (F), Ebb (E)
Dates: 15 May (1), 31 May (2), 13 June (3), 28 June (4)
ns - not significant at P = 0.05; * - $P \leq 0.05$;
** - $P \leq 0.025$; *** - $P \leq 0.01$.

Table 4. Summary of the analysis of variance procedures for the fall data set. Multiple comparison test results are shown below individual letter designations along with appropriate levels of significance.

Transformed {log(x+1)} Postlarvae/100 m^3

SPECIES	H'	$\overline{SL}$	Date	Photo-period	Tide	Depth	Photoperiod x Depth	Tide x Depth
Total species	M S B***	(ns)	1 2 3 4***	N>D***	E>F***	M B S***	(ns)	(ns)
Anchoa hepsetus	-	(ns)	1 2 3 4***	N>D***	(ns)	(ns)	(ns)	(ns)
Chloroscombrus chrysurus	-	(ns)	1 2 3 4***	N>D*	ns	M S B*	(ns)	(ns)
Haemulon plumieri	-	(ns)	(ns)	(ns)	(ns)	(ns)	D - M S B* N - B M S*	(ns)
Cynoscion nebulosus	-	(ns)	(ns)	(ns)	(ns)	(ns)	(ns)	(ns)
Menticirrhus sp.	-	(ns)	1 2 3 4***	(ns)	(ns)	M B S*	(ns)	(ns)
Sciaenops ocellatus	-	(ns)	2 3 4 1**	(ns)	(ns)	M B S*	D - B M S* N - M S B*	(ns)
Mugil cephalus	-	S B M***	2 1 4 3***	(ns)	(ns)	(ns)	(ns)	(ns)
Chasmodes saburrae	-	(ns)	(ns)	D>N*	(ns)	(ns)	D - S M B* N - B M S*	(ns)
Hypleurochilus geminatus	-	(ns)	(ns)	D>N**	(ns)	S M B*	D - S M B* N - M B S*	(ns)
Gobiosoma robustum	-	(ns)	(ns)	N>D***	(ns)	B M S***	(ns)	(ns)
Gobionellius sp.	-	(ns)	(ns)	N>D*	(ns)	(ns)	(ns)	(ns)
Prionotus scitulus	-	B S M*	1 2 3 4***	(ns)	(ns)	M B S***	(ns)	(ns)
Achirus lineatus	-	B S M***	(ns)	(ns)	(ns)	M S B**	(ns)	(ns)
Symphurus plagiusa	-	(ns)	(ns)	(ns)	(ns)	M B S**	(ns)	(ns)
Lactophrys quadricornis	-	(ns)	2 1 3 4***	(ns)	(ns)	(ns)	(ns)	(ns)

Depths: Surface (S), Mid-depth (M), Bottom (B)
Photoperiods: Day (D), Night (N)
Tides: Flood (F), Ebb (E)

Dates: 8-9 Sept (1); 23-24 Sept. (2); 8-9 Oct (3), 21-22 Oct (4)
ns - not significant at P = 0.05; * - $P \leq 0.05$; ** - $P \leq 0.0.025$; *** - $P \leq 0.01$.

sp. and G. robustum. However, due to the influence of a few very large individuals captured near the surface, the multiple comparison procedures yielded misleading results for these species. The postlarvae of the remaining species, including Opisthonema oglinum (Clupeidae), A. hepsetus, Chloroscombrus chrysurus, Oligoplites saurus (Carangidae), Eucinostomus sp., H. plumieri, Mugil curema (Mugilidae), Dactyloscopus sp., and I. calliurus were all found to be significantly larger near the surface.

Standard length data averaged for the total combined species in each sample also showed a significant trend, with the larger individuals being found near the surface.

With respect to the Shannon index of species diversity, the samples were found to be significantly more diverse moving from the surface to the bottom.

In the fall data set, 8 of the 15 species analyzed exhibited a significant main depth effect with respect to their densities. However, of those 8, 2 species also showed a significant photoperiod x depth interaction. When the interaction between two factors is significant, conclusions reached about the significance of the individual factor effects are not always valid (Sokal and Rohlf 1969). Nevertheless, the following observations can be drawn from Table 2.

The only exclusively bottom oriented species in the fall data set was G. robustum. The remaining species all showed a significant tendency toward a mid-depth distribution, especially the flatfishes A. lineatus and S. plagiusa, as well as C. chrysurus. Both Menticirrhus sp. and P. scitulus, however, exhibited more of a mid-bottom preference. Transformed density data calculated for the combined total species in each sample also revealed a significant mid-bottom orientation.

Four species were found to have a significant photoperiod x depth interaction; that is, the postlarvae of these species altered their vertical distribution in response to changes in the diurnal cycle. Haemulon plumieri was primarily mid-depth oriented during daylight hours, but during the nighttime it was found most often near the bottom. Sciaenops ocellatus (Sciaenidae), however, exhibited the reverse pattern. During the daytime, this species was concentrated near the bottom, while at night it was captured much more frequently at mid-depth. The most dramatic vertical migrations were exhibited by the blennies C. saburrae and Hypleurochilus geminatus. During daylight hours both species were strongly surface oriented. However, after nightfall both species were rarely captured at the surface, becoming primarily distributed near the bottom. The author has observed similar positive phototropism in blenny larvae cultured in aquaria, and it is interesting to see this behavioral response acknowledged in ecological field data.

With regard to density data from the combined total species, significantly more postlarvae were captured during the nighttime than during daylight hours. This was also specifically true for the gobies G. robustum and Gobionellus sp., as well as for A. hepsetus and C. chrysurus. Nevertheless, for the majority of species, daylight net avoidance was apparently negligible. Graham (1972) found daylight net avoidance to be a serious problem with herring larvae, and thus only sampled during darkness. The difference between these studies may be attributable to the relatively high current velocities and turbid waters of Tampa Bay. The significant photoperiod response exhibited by the gobies may have been due to a tendency for them to rest directly on the bottom during daylight hours. Weinstein et al. (1980) found this to be the case for postlarval flounders in the similarly turbid Cape Fear river estuary of North Carolina.

Tide, as a main effect, was only significant for the cumulative total species densities, with the greatest number of individuals being captured on the ebb phase. No single species exhibited a significant main tide effect; and, as in the spring dataset, no species

were shown to exhibit a signficant tide x depth interaction effect.

With respect to sample date, density data from 7 individual species, as well as from the combined total species, showed significant differences. The general trend displayed in the majority of cases was a progressive decrease in spawning activity throughout the fall sampling period. However, S. ocellatus and Mugil cephalus both showed sharp spawning peaks during late September and early October. These data agree with the body of literature dealing with the life histories of these two species.

Only 3 species in the fall data set exhibited a significant depth effect with respect to their mean standard lengths. Both P. scitulus and A. lineatus postlarvae were found to be considerably larger near the bottom, whereas M. cephalus individuals were significantly larger at the surface.

In contrast with the spring data set, the mid-depth and surface samples were found to have significantly greater species diversity than the bottom samples, in terms of the Shannon index. This shift in maximum species diversity, from the bottom to the mid-depth and surface, may be attributable to a general trend on the part of most species to rise in the water column at night.

The results of the numerical classification procedures for the spring and fall data sets are depicted as species dendrograms in Figures 2 and 3, respectively. The spring and fall data sets share a number of common distributional patterns. In Figure 2, Dactyloscopus sp. is shown to be most dissimilar from the other species. This is because it was captured exclusively at the surface, which was not the case for any other species. Groups 1 and 2 fuse at the next highest level of dissimilarity, below which sub-groups 1A, 1B, 2A and 2B are clustered. Group 1A includes only G. robustum, which appeared to be the only truly benthic species. Group 1B is made up of the sciaenids C. nebulosus, C. arenarius, Menticirrhus sp., as well as P. scitulus, M. curema, O. saurus, A. lineatus, and S. plagiusa. This group represents the bottom to mid-bottom oriented species. Group 2A is comprised of C. chrysurus, H. plumieri and I. calliurus, and includes those species which exhibited a primarily mid-depth distribution. Group 2B is composed of O. oglinum, A. hepsetus, C. saburrae, and Eucinostomus sp., and represents those species with a mid-surface preference.

In Figure 3, only two significant levels of fusion are apparent, resulting in three major species clusters. Group 1A is comprised of G. robustum, Gobionellus sp., C. arenarius, S. ocellatus, Menticirrhus sp., and P. scitulus. This group represents the bottom to mid-bottom distributed species and, as in the spring data set, was dominated by the gobiids, sciaenids, and triglids. Group 1B includes those species which were generally mid-depth oriented and shares in common with the spring data set H. plumieri and C. chrysurus, as well as a mugilid species, M. cephalus. In addition, this group also includes the flatfishes A. lineatus and S. plagiusa, and the engraulid A. hepsetus. The difference in the distribution of these three species between the two data sets was probably related to their respective photoperiod responses, with A. lineatus and S. plagiusa being somewhat negatively phototropic, and A. hepsetus being positively phototropic. Group 2 is composed of those species which exhibited a preference for a mid-surface to surface distribution and includes the ostraciid Lactophrys quadricornis and the blennids C. saburrae and H. geminatus, which similarly dominated this group in the spring data set. The combined results of the cluster analyses are summarized in Table 5.

Data generated by the hydrographic work yielded results which were interesting and quite unexpected. Throughout the present study significant vertical density stratification was never detected, as the water column appeared to be continuously well-mixed by the swift and turbulent tidal currents. However, when the net nontidal flow was evaluated over two tidal cycles at the three sample depths, a two-layered flow

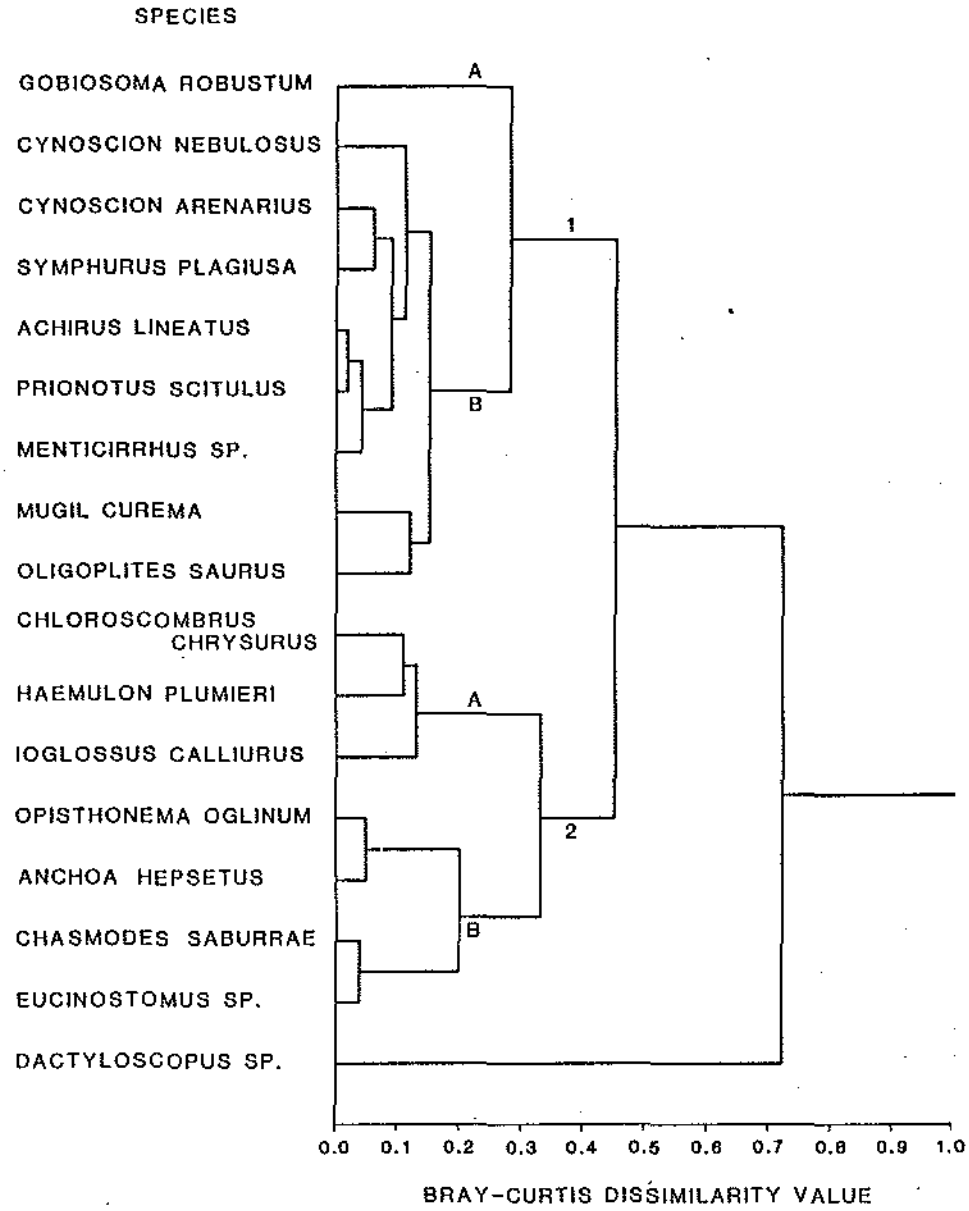

Figure 2. Results of the Bray-Curtis dissimilarity index for the spring data set depicted as a species group dendrogram. See text for a discussion of group designations.

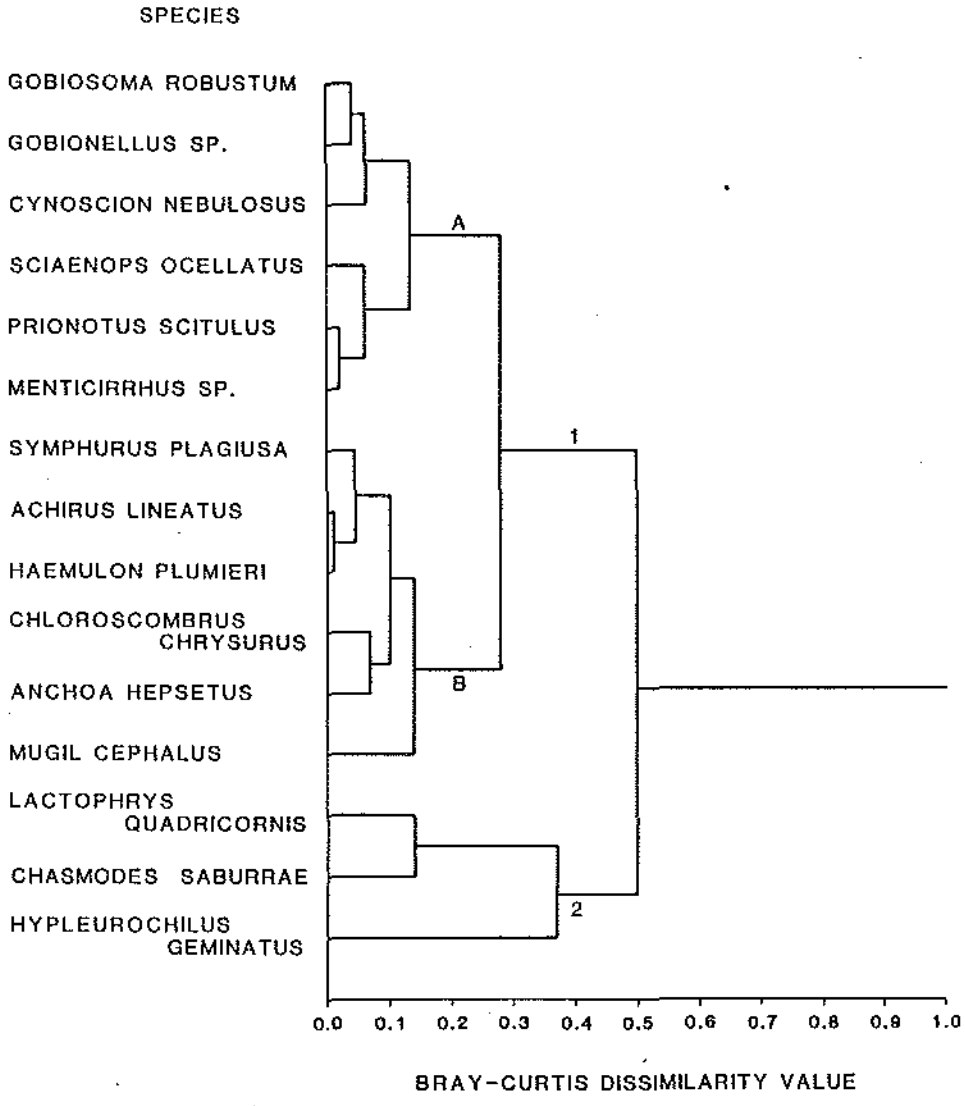

Figure 3. Results of the Bray-Curtis dissimilariy index for the fall data set depicted as a species group dendrogram. See text for a discussion of group designations.

Table 5. Tabular summary of the results of the cluster analyses for both the spring and fall data sets combined.

	SPRING	FALL
SURFACE		
Dactyloscopus sp.	x	-
Hypleurochilus geminatus	-	x
MID-SURFACE		
Opisthonema oglinum	x	-
Anchoa hepsetus	x	-
Eucinostomus sp.	x	-
Chasmodes saburrae	x	x
Lactophrys quadricornis	-	x
MID-DEPTH		
Anchoa hepsetus	-	x
Chloroscombrus chrysurus	x	x
Haemulon plumieri	x	x
Mugil cephalus	-	x
Ioglossus calliurus	x	-
Achirus lineatus	-	x
Symphurus plagiusa	-	x
MID-BOTTOM		
Oligoplites saurus	x	-
Cynoscion arenarius	x	-
Cynoscion nebulosus	x	x
Menticirrhus sp.	x	x
Sciaenops ocellatus	-	x
Mugil curema	x	-
Prionotus scitulus	x	x
Achirus lineatus	x	-
Symphurus plagiusa	x	-
BOTTOM		
Gobiosoma robustum	x	x
Gobionellus sp.	-	x

x = presence
- = absence

structure was shown to exist. In addition, the data indicated the presence of considerable lateral variation in the net flow velocity with depth. Figure 4 is a graphic depiction of the vertical profiles of the net tidal excursion from both the north and south sides of the tidal channel entering Tampa Bay.

Although such vertical profiles can be drastically altered by short term variations in wind conditions and/or freshwater input (Graham and Venno 1968; Pritchard 1978), it is the author's opinion that the results presented here are generally representative of the normal circulation pattern of lower Tampa Bay during the late spring and summer. According to Bowden (1967), vertical differences in salinity of as little as 0.1°/oo can result in a degree of density of stratification significant enough to enable considerable landward transport of salt along the bottom. Therefore, since 60% of the annual rainfall in the Tampa Bay watershed occurs between the months of June and September (Simon 1974), it seems reasonable that a tidally averaged, two-layered circulation pattern could be maintained throughout these months, even though such minor salinity variations may not have been detectable in the present study.

The coincidental presence of a two-layered system during the major spawning season of the estuarine ichthyofauna of southwest Florida has important implications concerning the recruitment-retention mechanisms employed by the young of these species. From Figure 4 it can be seen that after two complete semi-diurnal tidal cycles (i.e., 24 hours), a parcel of water one meter off the bottom, and the passive larvae contained in that parcel, would be transported about 0.5 km landward. At a depth of 5 meters, effectively no net horizontal transport would take place. A parcel of water at the surface, however, would be transported seaward a distance of 0.8 km.

DISCUSSION

The problem addressed in the present study is not whether larval fishes are recruited to, and retained within Tampa Bay; these facts are established by the presence of the postlarvae of the families Clupeidae, Carangidae, Sciaenidae, Sparidae and Mugilidae in the upper reaches (Kelly and Dragovich 1967; Phillips and Blanchet 1980), as species of these families are generally regarded as offshore or lower bay spawners. The real point at issue is whether evolved patterns of fish behavior contribute significantly to the process. Stated more simply, the question seems to resolve itself into whether it is active or passive transport that is taking place.

In relation to the amount of transport a planktonic larvae can achieve from water movements in the horizontal plane, that by swimming is negligible, whereas in a vertical plane, that by swimming may be very great (Bousefield 1955). Thus, many authors have proposed that the phenomenon of vertical migration may be an important behavioral mechanism influencing the landward transport and retention of various estuarine dependent zooplankters. If vertical migrations are properly phased with tidal cycles so as to result in a tendency to swim up into, or remain in the upper layers of the water column on a flooding tide, and to drop out of the water column near the bottom during an ebbing tide, a significant net landward transport can be achieved provided that tidal current velocities are reduced as the bottom is approached (i.e., boundary layer conditions). Harden Jones et al. (1978) termed this behavioral pattern "selective tidal stream transport," and Weihs (1978) was able to demonstrate energy savings of up to 90% for young plaice that utilized this mechanism during migration. The selective use of tidal currents may be especially important to those zooplankters inhabiting shallow, vertically homogeneous estuaries lacking

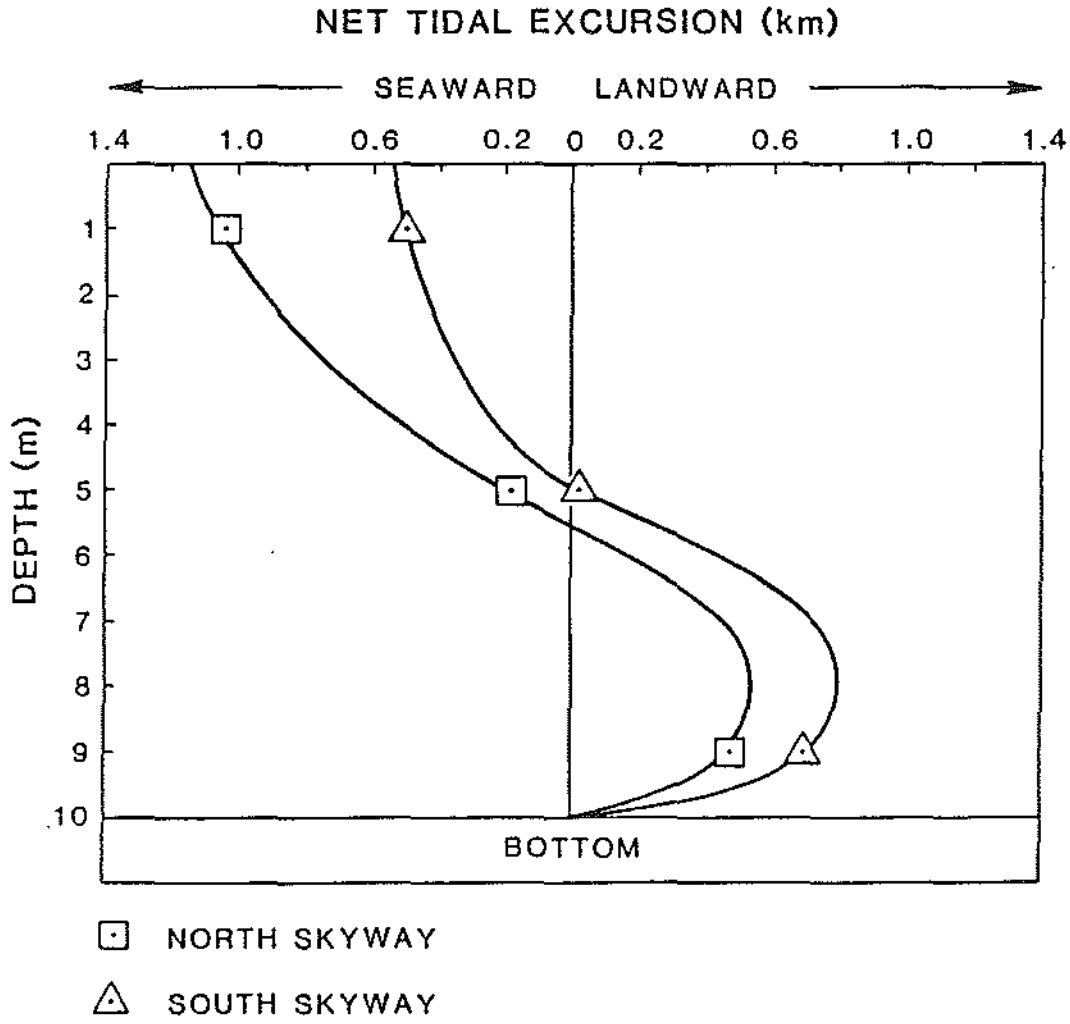

Figure 4. Net tidal excursion over one complete tidal cycle at the three sampling depths, shown in kilometers. The north and south Skyway sampling sites were both located at the 10 meter isobath on the respective sides of the natural channel entering Tampa Bay.

a landward flowing layer near the bottom (Weinstein et al. 1980). This behavioral response has been demonstrated in copepods (Woolridge and Erasmus 1980), oyster larvae (Carriker 1951; Bousefield 1955; Wood and Hargis 1971), crab larvae (Wheeler and Epifanio 1978; Cronin 1982), and fish larvae (Creutzberg 1961; Graham 1972; Weinstein et al. 1980). It has also been shown that in some organisms, active, tidally induced vertical migrations can be endogenously controlled with entrainment being synchronized by small scale changes in such factors as temperature, salinity, turbidity, and dissolved organic substances (Hughes 1972; Cronin and Forward 1979).

When the present study was first conceived, it was hypothesized that postlarval fishes in lower Tampa Bay would exhibit a behavioral pattern such as that described above; but none of the species analyzed were shown to have a significant tide x depth interaction, which would be indicative of selective tidal stream transport. However, the coincident occurrence of a tidally averaged two-layered circulation pattern throughout the duration of the major recruitment season would seem to negate the importance of such a behavioral response. The results of the present hydrographic work indicate that by simply spending more time in the lower layers of the water column during the rainy season, a larval fish could achieve a net catadromous displacement as well as be retained within this estuary.

In the present study, the majority of the species collected were, on the average, significantly concentrated at some particular depth. The existence of such non-random patterns of distribution in a well-mixed tidal estuary must somehow be determined and maintained by forces which act in opposition to the mixing effects of turbulence; but segregated vertical distributions do not necessarily invoke an active migratory effort on the part of larval fishes. For example, Emery and Stevenson (1957) postulated that since velocity, and therefore turbulence, is reduced as the bottom is approached, larvae would spend statistically more time in the lower layers of the estuary and, as a result, would be signficantly concentrated there. In this way, the authors contended, pelagic larvae could be passively retained within stratified estuaries. This hypothesis, however, seems untenable since field data has generally indicated that turbulence increases with depth in shallow, intensively flushed tidal estuaries (Gordon and Dohne 1973). In addition, in the present study, many species were found to be significantly concentrated at or near the surface.

It has also been suggested that the vertical stratification of larvae in the water column may simply be due to differences in their relative buoyancy in relation to the density of the surrounding water mass. Spaargaren (1980) was able to show that the distance the shrimp Crangon crangon was passively displaced landward was directly related to its sinking rate, which was determined by tidally controlled variations in ambient seawater density and viscosity. However, at any give point in lower Tampa Bay, significant tidally correlated variations in seawater density probably do not occur because of the relatively low freshwater input from tributaries, thus negating the relevancy of this hypothesis. Alternatively, Bousefield (1955) found the more buoyant earlier stages of oyster larvae concentrated in the seaward flowing surface waters of the Miramichi River estuary of New Brunswick, Canada; but as the larvae developed into the larger and more dense later stages, they sank into the landward flowing waters along the bottom and became concentrated there, and were thus retained. While such density related stratification may be an important factor affecting the vertical distribution of fish eggs and prolarvae, which generally contain relatively large buoyant oil globules, it seems unlikely that such forces could contribute significantly to the vertical segregation observed in the more dense and actively swimming postlarvae.

It may be possible to attribute disparities in the vertical distribution of larval fish to relative differences in their body configurations and the resultant resistance to turbulent drag. Gordon and Dohne (1973) found that Reynolds stress increased towards the bottom to a maximum value of about 5 dynes/cm^2 in the turbulent tidal flow of the Choptank River estuary of Maryland, which is bathymetrically comparable to Tampa Bay. Turbulent stresses of that magnitude would presumably be sufficient enough to cause significant upward vertical fluxes of larvae in the water column; but those species that were of a more streamlined configuration should be less susceptible to the mixing effects of turbulence, and thus, should spend statistically more time in the lower layers of the estuary, resulting in a greater probability for retention. To the author's knowledge, however, few studies have yielded comparative coefficients of drag for different species of larval fishes; none have attempted to relate such parameters to the ecology of those species.

When considering the turbulent nature of the strong tidal currents in lower Tampa Bay relative to the miniscule size of larval fishes, it seems as though an active vertical migratory component is needed to account for the degree of stratification exhibited by the majority of species, especially in light of the above arguments. Swimming in the vertical plane must be actively and continuously employed in order for larval fishes to gain and maintain a preferred position in the water column. The depth that a particular species tends to concentrate at is probably determined by long evolved patterns of behavior that, in most cases, are closely related to the life history of that species as an adult. For example, species that are restricted to benthic, estuarine habitats as adults also tend to be bottom oriented as larvae. In the present study this relationship is best exemplified by the triglid P. scitulus, the gobies G. robustum and Gobionellus sp., and the flatfishes A. lineatus and S. plagiusa, all of which showed a strong preference for a bottom distribution.

The degree of affinity that a postlarva has for the bottom may also be a useful index of that species' relative dependence upon estuarine habitat during its early development. The four species of the family Sciaenidae collected in the present study - including C. arenarius, C. nebulosus, Menticirrhus sp., and S. ocellatus - are all known to spawn in coastal areas or in high salinity bays (Jaanke 1971; Powles and Stender 1978); and yet these species represent a significant portion of the ichthyoplankton found in the lower salinity waters of upper Tampa Bay (Weiss et al. 1979), indicating a high degree of estuarine dependence. As postlarvae, these species were consistently found to be concentrated near the bottom. To a lesser degree, this relationship holds true for young mullet, M. cephalus and M. curema, whose offshore spawning is well documented (Anderson 1957; Arnold and Thompson 1958).

Conversely, those species which tended to maintain a surface distribution as postlarvae generally complete their life cycles in the higher salinity coastal waters and show little or no dependence on estuarine nursery areas. This is specifically true for the clupeid O. oglinum (Houde 1977), the engraulid A. hepsetus (Hoese 1965), the gerreid Eucinostomus sp. (Springer and Woodburn 1960), and the dactyloscopid Dactyloscopus sp. (probably D. moorei - Dawson 1982). The ecological significance of the strong phototropism exhibited by the blennies C. saburrae and H. geminatus is, however, more difficult to interpret. Neither of these species appears to be dependent upon estuarine habitat during their early life histories, but as adults they both occupy very restricted benthic niches in shallow coastal areas and lay demersal eggs which they nurture with parental care (Hildebrand and Cable 1938). Positive phototropism on the part of the postlarvae, which results in a primarily

surface distribution throughout their spawning season, may be an important mechanism aiding in the dispersal of the young, and thus, the genetic flow of these species.

Alternately, for those species whose postlarvae were generally concentrated at mid-depth, it may be that they prefer to maintain or stabilize their position in the mouth of the estuary, actively avoiding transport in either the landward or seaward direction. An examination of the early life histories and adult distributions of both the pelagic carangid C. chrysurus (Gunter 1945) and the haemulid H. plumieri (Moe 1966) seems to indicate that such a relationship holds true for these species.

It is important to note that an active effort on the part of larval fishes to maintain a particular depth distribution does not necessarily suggest an instinctual migratory drive to seek, and be retained within, estuaries. In the case of those species which spawn offshore, or in the mouths of bays, the vast majority of eggs and larvae are undoubtedly carried away by longshore currents, or are flushed seaward and never make it into estuarine waters (Turner et al. 1979). The observed return of the young to the estuarine nursery grounds is probably best viewed as a strictly chance event which is only assisted by such vertical migrations rather than directed or controlled by them.

Once inside estuarine boundaries, however, larval fish appear to be able to effect a certain degree of control over the extent of their landward penetration and retention. As described above, the maintenance of a near bottom distribution in the deeper channels of Tampa Bay during the rainy season, when a two-layered circulation pattern is probably best developed, would theoretically enable postlarvae to accumulate in upstream estuarine waters. Penetration into the shallower grassbed and mangrove nursery grounds could be further augmented by strong lateral movements during slack tides. King (1971) was able to quantify such migrations for both larval redfish and flounder in a natural pass along the coast of Texas. But once distribution within the primary nursery areas has been attained, the tendency to seek boundary layers along the bottom during ebbing tides may, as Weinstein et al. (1980) have proposed, be the most important behavioral mechanism assuring the retention of larval fishes.

In closing, knowledge of the patterns of ichthyoplankton vertical distribution in estuaries may also have practical applications, especially in environmental assessment and impact work. With the aid of such data, for example, entrainment effects of power plants could be minimized by adjusting the intake design to depths least likely to impact upon the highest densities of resident important species in the entrained area.

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BENTHIC MACROINVERTEBRATES OF TAMPA BAY

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ABSTRACT

Existing literature (about 70 publications) on benthic macroinvertebrates from Tampa Bay are reviewed. Studies were diverse, consisting of investigations of commercially important species (such as Penaeus duorarum, pink shrimp; and Crassostrea virginica, American oysters), studies of seagrass associated fauna, and quantitative large-scale investigations of benthic infaunal communities. The objectives of these investigations were also diverse: life history studies; studies on recolonization and repopulation; and the evaluation of dredge/fill, sewage, phosphoric wastes and thermal effects. Overall, the studies have provided a broad (but spotty) characterization of the benthos of Tampa Bay. Some general conclusions (based upon these studies) are: 1) approximately 1,200 infaunal and epifaunal benthic species inhabit Tampa Bay; 2) seasonal fluctuations in the abundance and diversity of benthic macroinvertebrates are pronounced; 3) long-term cyclic defaunation (approximately 5 years) appears to occur on a regular basis; 4) seagrass beds have declined with a concomitant decrease in faunal diversity; 5) opportunistic and "pollution indicator" species are abundant at several locations of the Bay, particularly in Hillsborough Bay; 6) sediment type appears to be the controlling factor in determining faunal distribution in the Bay; 7) a general increase in species richness and a decrease in abundance is evident on a north to south gradient in the Bay. Changes in salinity and sediment type, the influence of the Gulf of Mexico in the southern reaches of the Bay and the lower incidence of pollution and habitat alteration in lower Tampa Bay are inferred as the causes for this gradient. Recommendations for future studies in the Bay include: 1) the understanding of cumulative impacts on benthic fauna from the variety of man-induced activities in the Bay; 2) feasibility evaluation of restoring lost seagrass beds and effective management plans for preserving existing seagrass beds; 3) quantitative, comprehensive and long-term studies of the Bay benthos to better understand (and formulate managment plans for) the long-term effects of urban runoff, domestic wastes and industrial discharges to the Bay.

LIVE BOTTOM COMMUNITIES OF TAMPA BAY

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ABSTRACT

Several live bottom communities have been located in Tampa Bay. One is a stenohaline community located in Lower Tampa Bay. This community consists of an assemblage of the sea whip Leptogorgia virgulata, the loggerhead sponge Spheciospongia vesparia, boring sponges (Cliona spp.), tunicates and various algae including Sargassum filipendulum and Caulerpa mexicana. These occur together on rock ledges to 1 m in height and up to 30 m^2 in area. A second euryhaline type of live bottom community has been observed in Old Tampa Bay on similar rock ledges. This community has the same general species composition except that the more stenohaline loggerhead sponge, S. filipendulum and C. mexicana are absent, apparently reflecting the lower and more variable salinities.

INTRODUCTION

Live bottom communities are areas containing biological assemblages of such sessile invertebrates as sea fans, sea whips, hydroids, anemones, ascidians, sponges, bryozoans, and hard corals living upon and attached to naturally occurring hard or rocky formations (Harris 1981). These areas have been described in various parts of the Gulf of Mexico, Atlantic, and the Florida Keys; however, there have been limited descriptions of live bottom communities in estuarine systems such as Tampa Bay. Dawson (1953) reported two hard bottom areas in Tampa Bay but no descriptions of the associated fauna or flora were included.

Live bottom communities are normally located within areas of narrow temperature and salinity fluctuation (i.e. stenothermal and stenohaline). However, physiological tolerances of some species associated with live bottom communities have allowed their intrusion into estuarine systems. Tampa Bay represents such an area, with temperatures of 8.8-35.1°C and salinities of 0.9-36.9 ppt (Simon 1974). In this report, two live bottom communities in Tampa Bay are qualitatively described.

METHODS AND MATERIALS

During the course of routine biological surveys of Tampa Bay in January 1981, large dark areas of bay bottom were observed from a boat in water depths (3 m) that do not normally support seagrasses (Lewis et al., this volume, Fig. 1). These areas were subsequently visited and two qualitative surveys were performed at each site in January and February 1981. A species list was compiled from visual analysis of underwater photographs and representative voucher specimens.

RESULTS

A qualitative species list of the Lower Tampa Bay live bottom community is given in Table 1. The boring sponge Cliona celata and the loggerhead sponge Spheciospongia vesparia were the dominant species of sponges although many other unidentified sponges were also present. The sea whip Leptogorgia virgulata was the most prominent cnidarian; the tube anemone Cerianthopsis americanus and the rock anemone Haloplenella sp. were also abundant. The starlet coral Siderastrea radians was less prevalent but significant since it represents the only hard coral

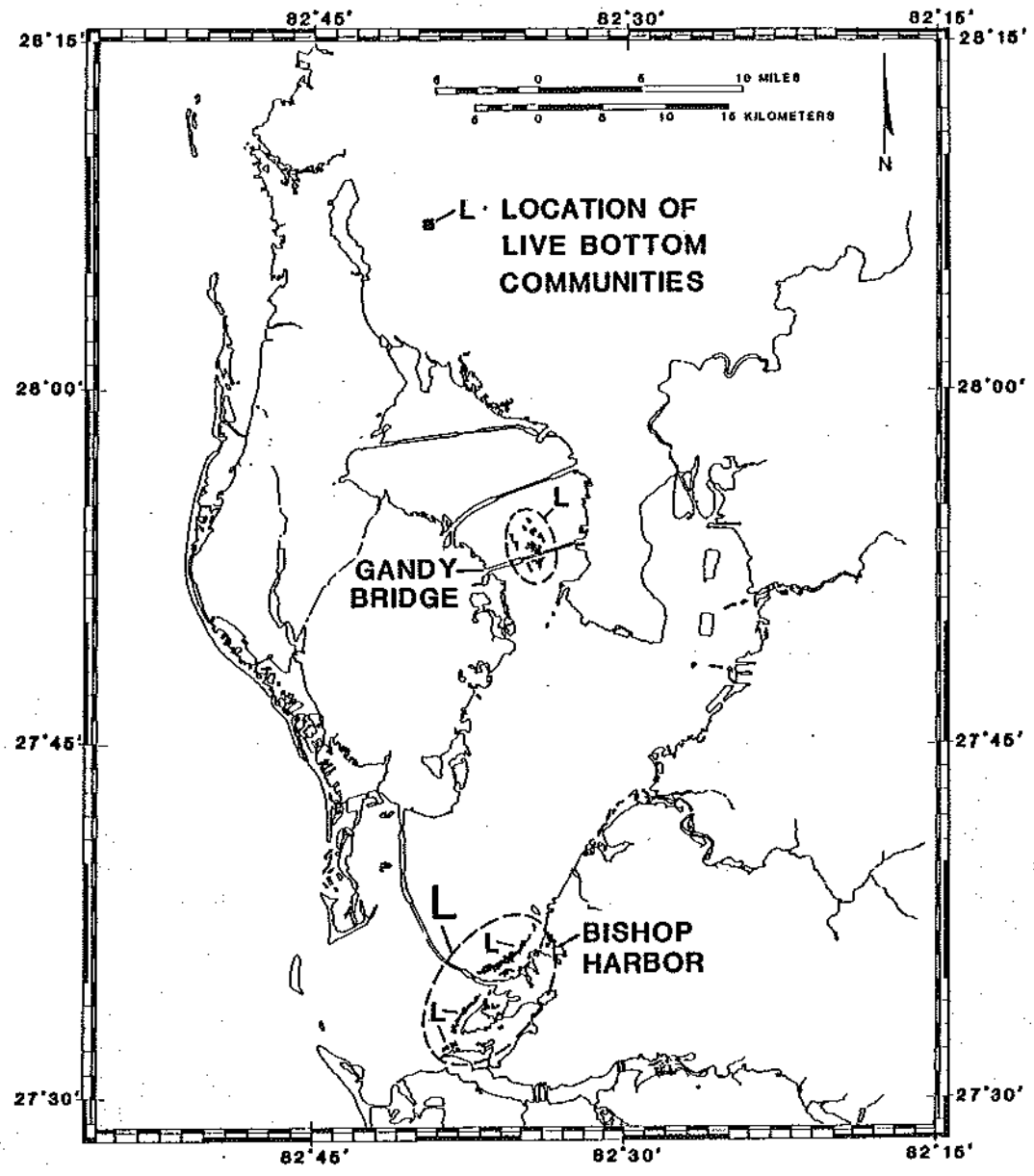

Figure 1. Location of live bottom communities in the Tampa Bay area.

Table 1. Species list, Lower Tampa Bay live bottom community.

PORIFERA	
Cliona celata	boring sponge
Spheciospongia vesparia	loggerhead sponge
CNIDARIA	
Leptogorgia virgulata	sea whip
Cerianthopsis americanus	tube anemone
Haloplenella sp.	rock anemone
Siderastrea radians	starlet coral
MOLLUSCA	
Thais haemostoma floridana	Florida rock snail
POLYCHAETA	
Dodecacaria concharum	boring polychaete
CRUSTACEA	
Alpheus sp.	snapping shrimp
Dardanus sp.	hermit crab
CHORDATA (Urochordata)	
Amaroucium stellatum	starred tunicate
CHORDATA (Vertebrata)	
Archosargus probatocephalus	sheepshead
Lagodon rhomboides	pinfish
Haemulon sp.	grunt
ALGAE	
Sargassum filipendulum	sargassum
Caulerpa mexicana	caulerpa

found in Tampa Bay. Sargassum filipendulum and Caulerpa mexicana represented the dominant algal species. Yearly temperatures range from 13.0 to 30.5°C and salinities from 25.7 to 32.4 ppt in this area (Hillsborough Co. Environmental Protection Commission 1972-1977).

Table 2 is a qualitative list of species occurring in the Old Tampa Bay live bottom community. This community was similar to the Lower Tampa Bay community although there was less apparent species diversity. Leptogorgia virgulata and boring sponges including Cliona celata were the dominant components of this community; the anemones Cerianthopsis americanus and Bundosoma sp. were also present. The caprellid amphipods Caprella penantis and C. equlibra were found associated with L. virgulata in large numbers (Lombardo and Lewis 1981; Caine 1983). Yearly temperatures range from 11.0 to 30.5°C and salinities from 17.7 to 30.7 ppt in this area (Hillsborough Co. Environmental Protection Commission 1972-1977).

Figure 2 is an underwater photograph taken at the Lower Tampa Bay site (Bishop Harbor). The two live bottom communities are illustrated in Figures 3 (Bishop Harbor) and 4, Old Tampa Bay (Gandy Bridge).

DISCUSSION

The importance of live bottom communities as habitats and food sources for a variety of invertebrate and vertebrate species has been well documented (Hedgpeth 1954; Grussendorf 1981; Gettleson 1981; Lissner 1981; Van Dolah and Burrell 1981; Wenner et al. 1983). The observed abundance of sheepshead (Archosargus probatocephalus), grunt (Haemulon sp.) and pinfish (Lagodon rhomboides) associated with these communities as well as other documented species of fish (Van Dolah and Burrell 1981) indicate their importance as a recreational or commercial resource. Because of the unique and sensitive nature of live bottom communities (Harris 1981), further study of Tampa Bay's communities is warranted. Mapping of these areas is of primary importance since these communities have never been previously documented in Tampa Bay and do not readily appear as images on aerial photography. Projects such as the possible submerged oil pipeline in Tampa Bay (M. O. Rinkel, pers. comm.) could disturb bay bottom areas in the vicinity of the Lower Tampa Bay site.

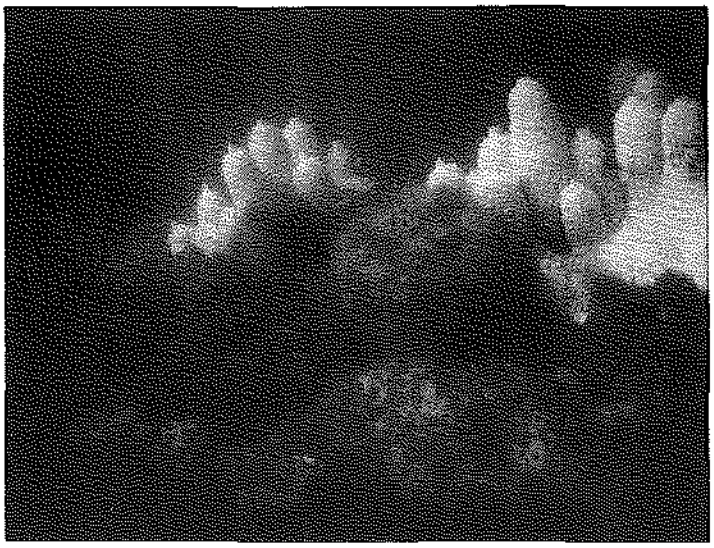

Figure 2. Underwater photograph of live bottom community at Bishop Harbor, Lower Tampa Bay

Table 2. Species list, Old Tampa Bay live bottom community.

PORIFERA	
Cliona celata	boring sponge
CNIDARIA	
Leptogorgia virgulata	sea whip
Cerianthopsis americanus	tube anemone
Bundosoma sp.	burrowing anemone
MOLLUSCA	
Thais haemostoma floridana	Florida rock snail
CRUSTACEA	
Caprella penantis	caprellid amphipod
Caprella equilibra	caprellid amphipod
Alpheus sp.	snapping shrimp
Pagurus pollicaris	flat-clawed hermit crab
CHORDATA (Urochordata)	
Styela sp.	sea squirt
CHORDATA (Vertebrata)	
Hypleurochilus geminatus	crested blenny
Syngnathus sp.	pipe fish
Lagodon rhomboides	pinfish

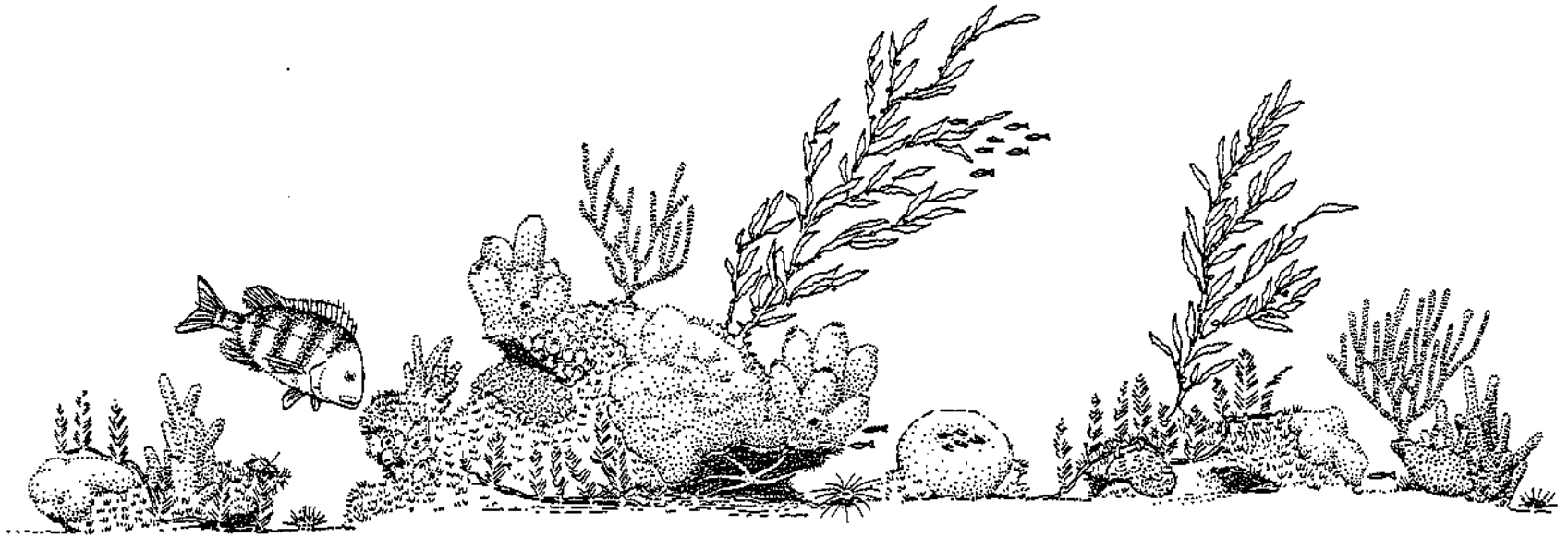

Figure 3. Illustration of live bottom community at Bishop Harbor, Lower Tampa Bay.

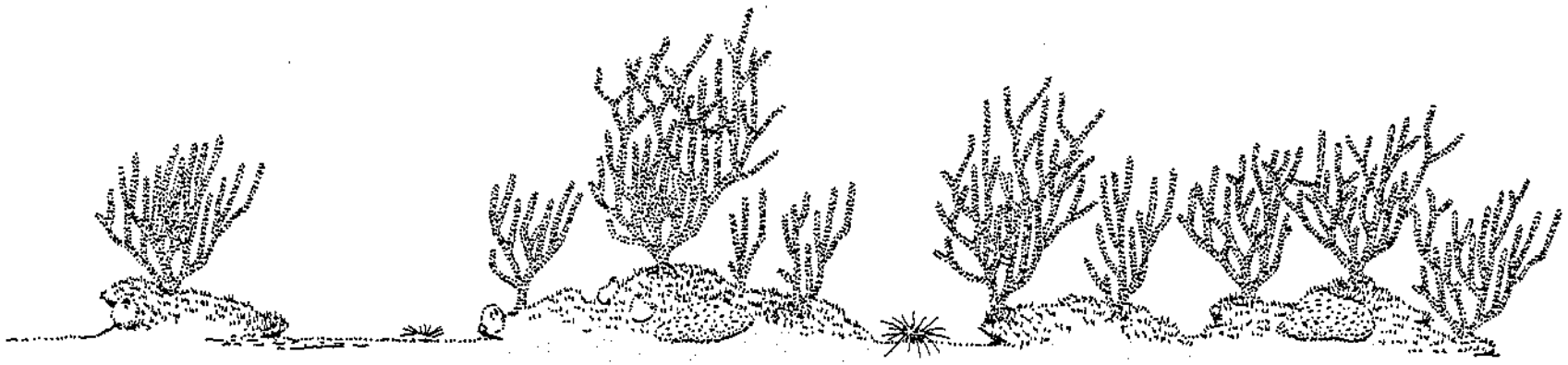

Figure 4. Illustration of live bottom community at Gandy Bridge, Old Tampa Bay.

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A SURVEY OF THE DISTRIBUTION AND MIGRATION OF THE FISHES IN TAMPA BAY

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ABSTRACT

This paper provides a review of the fishery investigations that have been conducted in the Tampa Bay area. Most of the investigations of the community structure, distribution and migration of the fishes have been conducted within the past 25 years in discrete areas within the Bay. This review indicates that much of the Bay has been sampled at one time or another and that adequate data are available to discuss the temporal and spatial changes that occur in the fish community in Tampa Bay. At least 203 species of fishes have been reported in the Tampa Bay area (as defined in this report) and many of these have important sport and/or commercial value. The importance of Tampa Bay as a nursery for immature fishes is evident from the data reviewed, and the distribution of juvenile species within the estuary is discussed. Like many estuaries, Tampa Bay supports a diverse community of resident and transient fishes that is dominated (in terms of relative abundance) by a small percentage of the common species. Seasonal changes in relative abundance and diversity are evident throughout the Bay as most species are collected during the spring and summer, and relatively few are collected in winter. This review also discusses the relationship beween estuarine habitats and fishery resources, the detrimental consequences associated with habitat destruction, and recommendations for future studies.

INTRODUCTION

Numerous studies conducted during the last 25 years have provided essential information regarding the community structure, distribution and migration of the fishes in Tampa Bay. Much of this information has been published in technical reports and is often difficult to retrieve. Therefore, the purpose of this paper is to provide a single reference source for and a general review of the historical literature on fishes from Tampa Bay. Since this review is intended to be somewhat general, the reader is referred to the References section to obtain sources which will provide additional information. The References section contains numerous reports that are not cited in the text. A list of the fishes collected in Tampa Bay is presented in the Appendix.

Study Area. Most investigations in Tampa Bay have been conducted within the last 25 years. Many studies were site-specific; rarely did a single investigation include sampling stations throughout the Bay. Nonetheless, samples from most sections of the Bay have been collected at one time or another.

The data reviewed were collected within the general subdivisions of Tampa Bay, and the lower reaches of the major tributaries discharging into the Bay. Data from other areas were also used on a limited basis. The coastal beaches along Pinellas County and the area just offshore of the beaches and the barrier

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islands at the mouth of the Bay support many fishes that are common in both the Gulf and the estuary. Data collected from these areas provide valuable information regarding the seasonal inshore-offshore patterns of migration of marine and estuarine fishes. The general areas from which fish community samples have been collected are presented in Figure 1.

Limitations. Several factors may affect the accuracy of the results in any fishery study (see for example, Kjelson and Colby 1977). The duration of investigations is often less than two years and typically no more than 12-14 months, a time insufficient to observe natural cyclic changes that occur, so misconceptions regarding the abundance and species composition of the fish community may be formed.

Juvenile or immature fishes routinely are collected in estuaries. Their abundance depends upon successful recruitment which is controlled by a variety of environmental factors. Samples collected during a year or period of poor recruitment will tend to be biased toward low relative abundance.

The variability in sampling gear and methodology used by selected investigators in Tampa Bay is outlined in Table 1. Trawls and seines were the predominant gear employed; however, there was little consistency in mesh size, net dimensions and number of replicates collected at each station. Both trawls and seines are selective for juvenile or immature specimens and those species that frequent shoreline or demersal habitats. Other species are often poorly represented in samples collected with a limited array of gear.

Little information is available regarding the number of stations and the number of replicate samples that should be collected to "adequately" sample a fish community. One or two seine and trawl hauls are usually collected at each station, although the number may vary among the investigators (Table 1). The number of trawl samples (replicates) required to adequately sample a community with patchy distribution has received more attention. Taylor (1953) showed that a high variance was associated with mean catches per tow and suggested that a reduction in variance could be achieved by reducing the duration of each tow. Roessler (1965) determined that 2-minute tows yielded maximum efficiency. Roessler and Tabb (1974) used seven short tows at each of twenty stations to determine the effects of thermal discharge into an area of Biscayne Bay. Livingston (1975, 1976) and Livingston et al. (1977) also determined that repetitive short tows efficiently sampled a heterogeneous community. Additional information regarding the use of trawls and subsequent analysis of the data collected is contained in Barnes and Bagenal (1951), Stickney (1976) and Mearns and Allen (1978).

The natural fluctuations in community structure in response to tidal and diel cycles often are not considered when samples are collected. Shallow habitats (sand bars, sloping beaches, grass flats and mangrove forests) may be inadequately sampled if collections occur only during low tide. If samples are collected only during daylight hours, the results will be biased toward lower abundance and possibly inaccurate descriptions of species composition.

Environmental perturbations (red tide blooms, unseasonably low or high water temperatures, etc.) may cause catastrophic fish kills which may selectively eliminate certain species or entire communities. Although such kills are cyclic, "natural" occurrences, they may bias the results of short-term fishery investigations.

It is important to note that fish populations and communities are generally discussed in terms of relative, rather than absolute, abundance since the latter is difficult, if not impossible, to determine in an open, dynamic system such as an estuary. Nonetheless, significant information on the fishery resources of a system can be obtained from relative abundance data, especially when those data are collected over long periods of time and integrated with data

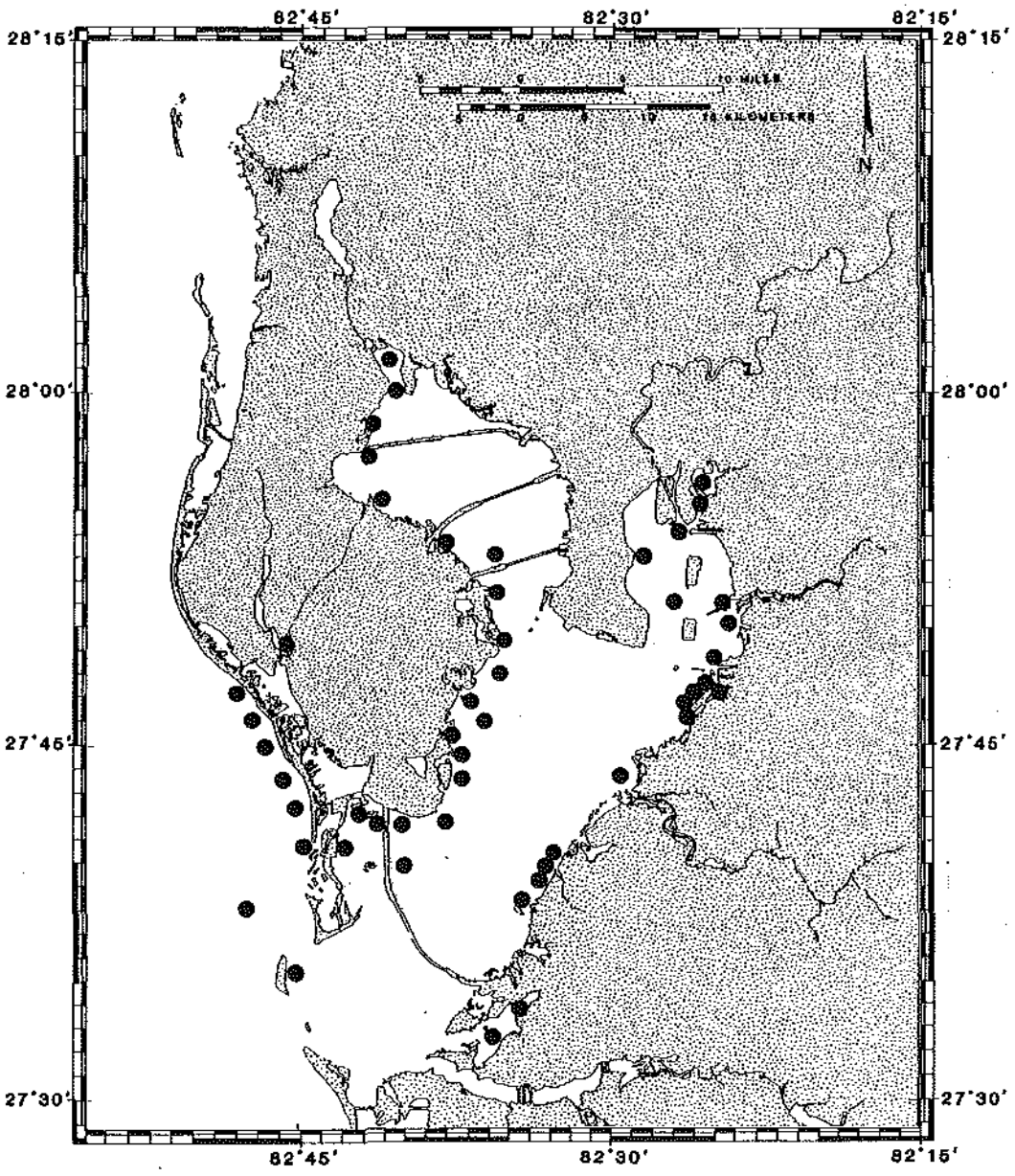

Figure 1. Areas that have been sampled during investigations of fish communities in Tampa Bay.

Table 1. Examples of the variation in sampling methodology among selected investigators who have collected samples from Tampa Bay.

Investigator(s)	Study Period (Months)	Number of Stations	Seine Dimensions	Trawl Dimensions	Other	Number of Replicates
Springer and Woodburn 1960	14	3	50' x 4'			var.
		2		1' x 3' roller frame		1-2
		2			push net	var.
Comp 1977	15	6	150' x 6'			2
		7		10' otter		2
Comp 1980	12	4	150' x 6'			1
		5		10' otter		2
McNulty et al. 1974	12	1	100' x 6'			1
		1		16'		1
Schleuter and Price (unpub.)	14	1	25'			5-6
Sykes and Finucane 1965	15	8	30', 50', 70'			1
		16		10', 16'		1
		var.			cast net	var.
					push net	
Moe and Martin 1965	7	9		16'		1-2
Salomon and Naughton 1979	12	9	100' x 6'			2

concerning the distribution, migration and species composition of the community being studied.

LITERATURE REVIEW

The literature on the fishes of Tampa Bay has not, until now, been reviewed and compiled in one source. The Bay's physical characteristics and its associated flora and fauna have been summarized in general reviews by Olson and Morrill (1955) and Simon (1974). Ingle and Hamilton (1973) reviewed selected references from the Tampa Bay area and summarized the fishery investigations that were being conducted in the Big Bend and Port Manatee areas.

Other review and discussion papers highlight marine fishes in general and some of the literature cited in those papers is pertinent to Tampa Bay. For example, Briggs (1958) provided a list of Florida fishes and a discussion of their distribution. Woodburn (1965) listed references on fishery resource problems in the Tampa Bay area. Ingle (1969) produced a list containing hundreds of publications that discuss marine resources that are found in Florida waters. Similarly, Nakamura et al. (1980) provided 302 references specifically dealing with fishes found in Gulf of Mexico estuaries.

FISHES AND THE ESTUARINE ENVIRONMENT

While a review of general estuarine ecology is beyond the scope of this paper, the relationship between estuaries and fishery production is of interest and will be discussed briefly. Additional and more detailed information on this subject has been provided by Skud and Wilson (1960), Hedgpeth (1966), Gunter (1967), Haedrich and Hall (1976) and Powell (1977), among others.

Partitioning of the fauna in estuaries is evident and often is related to salinity. As environmental parameters vary significantly from "optimum" conditions, a decrease in the number of species usually occurs (Gunter 1967). In estuaries, the number of fish species (particularly marine species) will decrease along a gradient of high to low salinity (Gunter 1967; Vernberg and Vernberg 1976). Those species that primarily exist in estuaries are able to tolerate extreme seasonal and diel fluctuations in temperature and salinity. Marine and estuarine fishes will be found near the mouth of an estuary while the fauna in the central and upper reaches will be predominantly estuarine. A salinity of 5-8°/oo generally will separate estuarine fishes from those typically associated with fresh water.

Estuaries support all life stages of a fish community. It has been estimated that up to 97.5% of the commercial fishery resources in the Gulf of Mexico and over 90% of the sport or recreational species in the United States depend upon estuaries during all or part of their life cycle (Skud and Wilson 1960; Gunter 1967; Reintjes 1970).

Successful recruitment of many species ultimately depends upon the availability of estuarine nurseries because it is here that fishes mature and eventually enter the adult population. The progeny of Gulf-spawned species are passively transported into the estuary in tidal currents or by actively following a salinity gradient. Once in the estuary, the young fishes congregate on shallow sand flats, in grass beds and mangrove forests, which provide physical protection from predators. Many predators cannot tolerate conditions of low salinity and are therefore naturally excluded from prime nursery habitat. A high rate of primary production by suspended and attached algae results in an abundant food source for young (and some adult) fishes. Other nutrient sources include detritus and various dissolved and suspended constituents which enter the estuary via direct land runoff and river discharge.

The timing of spawning in the Gulf and the subsequent movement of the young into estuaries is critical and usually coincides with the period of highest estuarine primary production. Summer production in Gulf coast estuaries may be as much as 1.5 times

greater than winter production (Skud and Wilson 1960); since most Gulf coast fishes spawn in the spring and summer, an abundant food supply for the young is assured. When the young fishes, spawned during the spring and summer, mature and begin to migrate from the shallow, protected areas, they are replaced by larvae and juveniles spawned during the late summer and fall. The arrival in the estuary of these species often coincides with a seasonal decline in primary production, but the secondary spawn (late summer - fall) usually involves fewer species than the primary spawn (spring - summer) so there will be a concomitant decrease in the demand for nutrient resources in the nurseries. Therefore, estuaries can support a variety of species essentially on a year-round basis. The maintenance and proliferation within the estuary of a diverse assemblage of species is assured by this partitioning of available habitat and nutrient resources. The seasonal use of the Tampa Bay estuary by selected species is graphically depicted in Figure 2. The estuary is utilized by several species as a nursery from late winter through early summer and fall.

Length-frequency data are often used to determine the extent of nursery utilization by juvenile fishes in an estuary. Tables 2 and 3 (from Comp 1977) provide examples for two common estuarine species, pinfish (Lagodon rhomboides) and spot (Leiostomus xanthurus). Juvenile pinfish first appeared in the catches in February 1976 (Table 2) and remained in the Big Bend area through September when they apparently began their seasonal migration toward the Gulf. Moe and Martin (1965) indicated that, based on length-frequency data, the pinfish they collected in December 1962 offshore of the mouth of Tampa Bay were those individuals that had recently migrated from Tampa Bay proper. Following a winter spawn in the Gulf and lower Bay, the larval and juvenile pinfish migrate into the nursery areas in the Bay (Table 2).

Spot (Leiostomus xanthurus) exhibit similar patterns of migration into and out of the estuary. The length-frequency data provided in Table 3 and by Springer and Woodburn (1960) indicate that the juvenile spot, following a fall-winter spawn in the Gulf, enter the estuary in late winter. They rapidly develop, then when they attain a size of approximately 80 mm, migrate to the deeper areas of the Bay and ultimately toward the Gulf during the fall.

Sykes and Finucane (1966), in their study of the distribution of immature commercial species in Tampa Bay, document the movement and growth of spot throughout the Bay. Their data are summarized in Table 4 where it is shown that an influx of juvenile spot began during the winter months. Rapid growth was evident as shown by the progressive increase in the minimum size of the fish collected during the year. For example, the smallest specimens contained in the winter samples ranged between 12 and 18 mm while those collected the following fall ranged between 66 and 95 mm (Table 3).

The seasonal migration patterns of these two and other juvenile fishes is well-documented in literature from Tampa Bay and from other estuaries. The reader is referred to the literature cited in this section and in the References section for more detailed information.

SPECIFIC STUDIES BY AREA

Coastal Areas/Lower Tampa Bay. For a period of 8 months in 1962 and 1963, Moe and Martin (1965) examined the fishes collected during shrimping operations offshore of Pinellas County. Several of the nine stations that were sampled were in close proximity to Pinellas County beaches and to the mouth of Tampa Bay. The data collected at these stations corroborated the findings of investigators sampling in Tampa Bay. For example, the seasonal disappearance from Tampa Bay of migratory species often coincided with the appearance of the same species at offshore sites. Hence, the seasonal onshore-offshore movement of fishes was

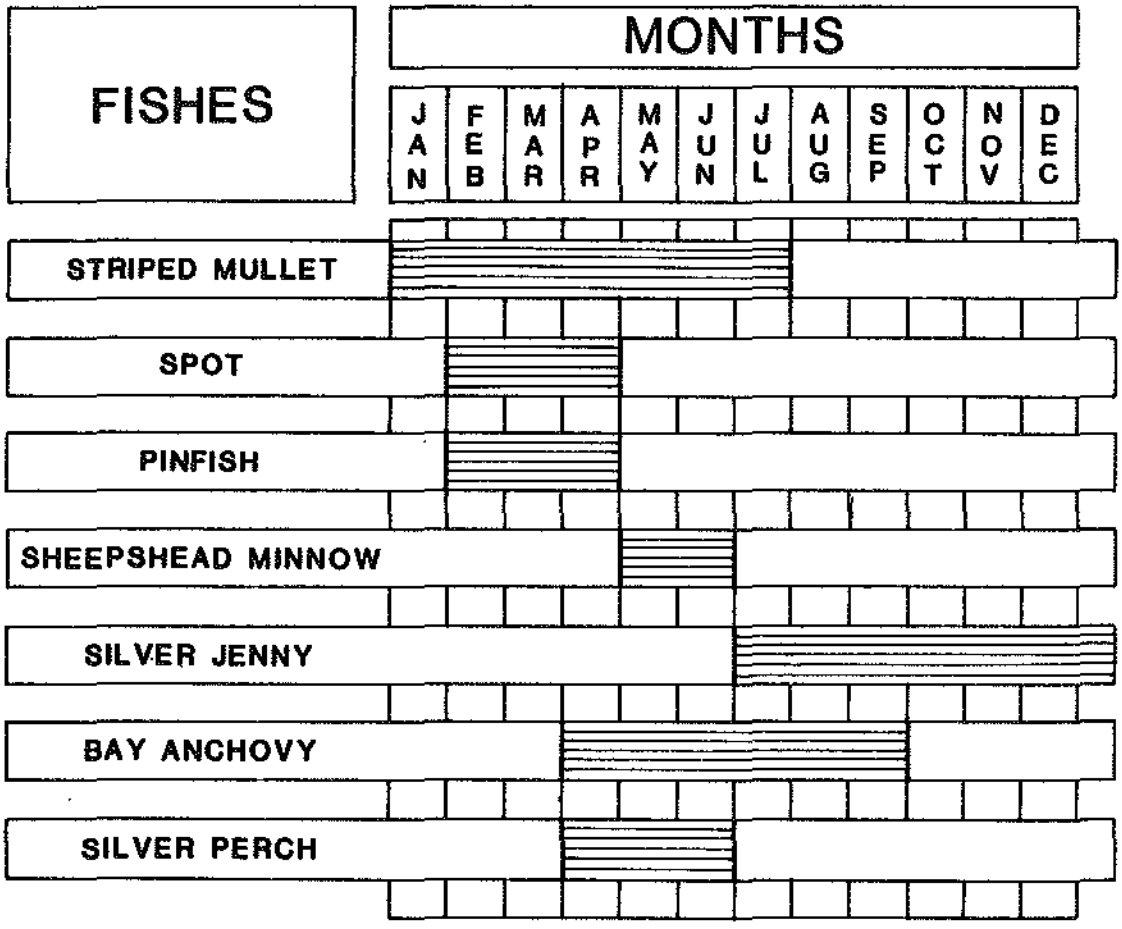

Figure 2. Seasonal distribution of selected juvenile fishes within the nursery areas of Tampa Bay.

Table 2. Length-frequency distribution of Lagodon rhomboides collected in the Apollo Beach area between January 1976 and March 1977.

Mid Class (mm)	Months 1976 J	F	M	A	M	J	J	A	S	O	N	D	1977 J	F	M
17		3	2												1
20		17	10												21
23		29													40
26		24	22												25
29		19	59	12											26
32		7	38	25			1								7
35		1	4	30	1										3
38			2	38	1										
41				55	1										
44				43	7										
47				23	14										
50				6	35										
53					34	6	1	1							
56					41	11									
59				1	37	10	1	1							
62					21	18	9						1		
65					14	14	18	7							
68					7	14	32	1					1		
71					2	12	21	3							
74					2	7	31	5							
77						4	12	7							
80					1		24	4	2						
83							22	3	1						
86							13	3	1						
89							16	2	2						
92						2	3		3						
98							2		2						
101							2	1	6	1					
104									1						
107									1						
110									2						
113									1						
119									2						
125									1						
128								1							
137								1							
Totals	0	100	137	237	218	98	215	41	27	1	0	0	2	0	105

Table 3. Length-frequency distribution of Leiostomus xanthurus collected in the Apollo Beach area between January 1976 and March 1977.

Mid Class (mm)	Months 1976 J	F	M	A	M	J	J	A	S	O	N	D	1977 J	F	M
17														12	
20														6	1
23		1	2												1
26		2	5												8
29			5												18
32			21												41
35			2												39
38				3											31
41				2											16
44				18											11
47				26											16
50				20											9
53				5	1										14
56				4	2										1
59				2	5										1
62				1	10										
65					11										
68					12										
71					10										
74					12										
77					11										
80					20										
83					19										
86					18										
89					11										
92					5										
95					4										
98					3										
101					2										
104					2										
Totals	0	3	35	81	157	0	0	0	0	0	0	0	0	18	207

Table 4. Distribution by season and area of immature spot (Leiostomus xanthurus) in Tampa Bay. (From Sykes and Finucane 1966).

Area	Winter	Spring	Summer	Fall
lower Tampa Bay				
Number	88	823	47	10
Size range (mm)	12-147	21-143	61-142	94-130
central Tampa Bay				
Number	256	176	21	13
Size range (mm)	17-30	24-60	64-130	86-125
Old Tampa Bay				
Number	1,279	3,170	486	262
Size range (mm)	12-135	21-139	40-137	66-133
Hillsborough Bay				
Number	12	367	25	3
Size range (mm)	18-30	27-137	70-135	95-110

verified. A detailed account of the most abundant species collected is presented and the report also contains a complete list of the fishes sampled and pertinent temperature and salinity data.

The fishes along the coastal beaches in Pinellas County were surveyed by Fable and Saloman (1974) during their investigation of the recreational fishery on three piers, and by Saloman and Naughton (1979) who conducted a systematic survey of the littoral fishes at nine seine stations between Long Key and Clearwater Pass. Data obtained from both studies aid in understanding the migratory movements of shoreline fishes; the latter report provides a description of the diversity, seasonality and relative abundance of the fishes in the littoral zone. A list of species observed and/or collected is presented in both reports.

McNulty et al. (1974) collected monthly seine and trawl data from five areas along Florida's Gulf coast (Figure 3) including Maximo Point located in lower Tampa Bay. These data provided a basis for comparing the fish fauna among a variety of coastal areas and the data collected from Maximo Point added to the baseline information for Tampa Bay. Species lists, temperature and salinity data, length-weight data and relative abundance figures for male, female and juvenile fishes are given in the report.

The most comprehensive report on the fishes of lower Tampa Bay was prepared by Springer and Woodburn (1960). Approximately 80 species collected from lower Tampa Bay are discussed in detail and information on a total of 253 species collected or observed in the Tampa Bay area is also provided. Length-frequency data and patterns of migration, distribution and relative abundance of numerous species are discussed in this report. Springer and Woodburn (1960) frequently refer to historical literature in their report and the reader is referred to their literature cited section for more details on this subject.

Additional reports on the fishes in lower Tampa Bay include those by Moe (1964) who observed at the Sunshine Skyway Bridge the fishes killed by a red tide bloom in 1963; by Woodburn (1959, 1962) who conducted brief surveys of marine fauna near the P. L. Bartow Power Plant in Pinellas County and near John's Pass, Boca Ciega Bay; and by Rinckey and Saloman (1964) who observed a fish kill in this area that

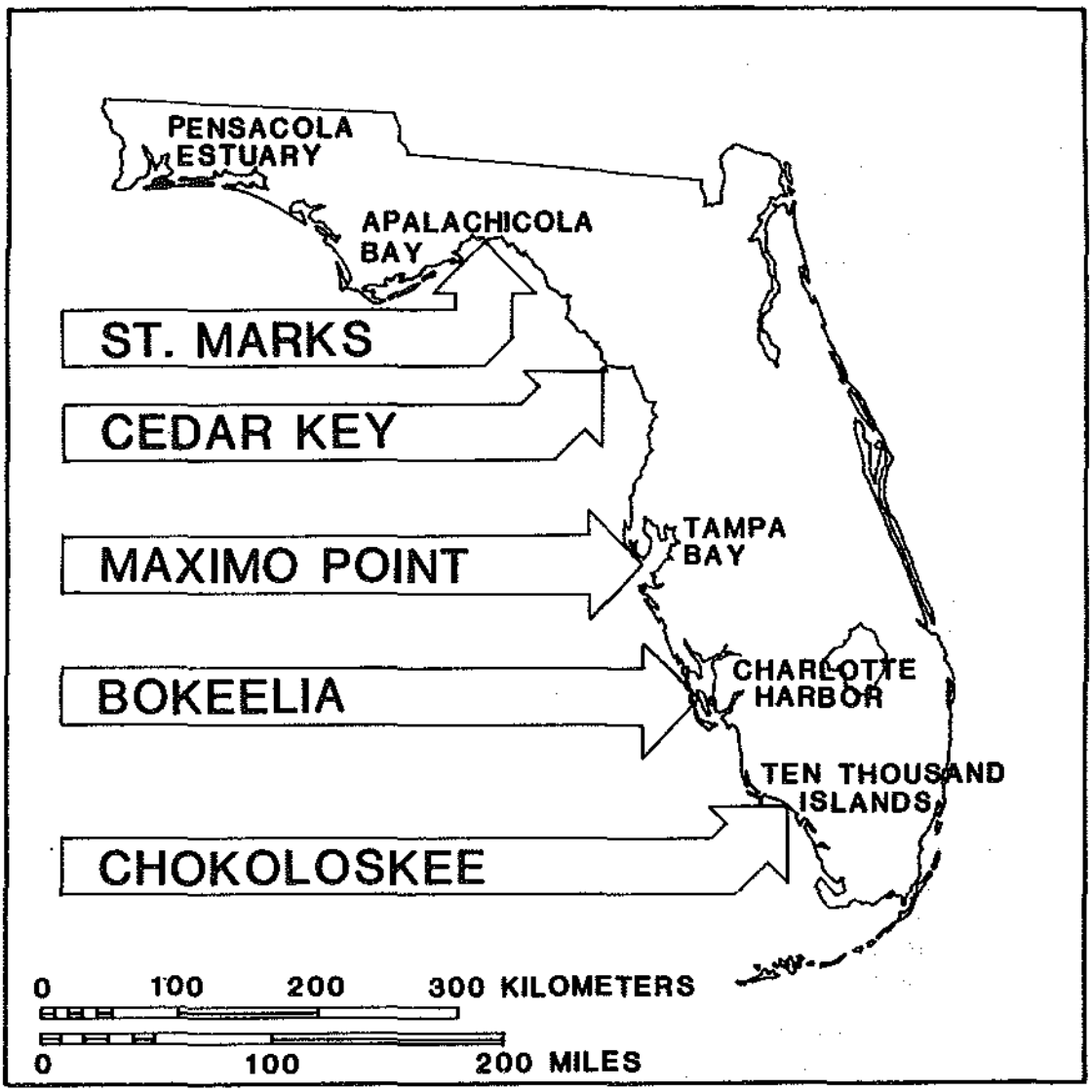

Figure 3. Major sampling locations along the west coast of Florida.

resulted from unseasonably low water temperatures.

Central Tampa Bay. Between November 1973 and May 1974, Dames and Moore (1975) investigated the fish fauna in the Little Manatee and Alafia Rivers. Samples were collected three times at six stations on each river with gill nets, hoop nets, traps, seines and an electroshocker. In the Alafia, samples were collected from the mouth of the river upstream to freshwater sites in the north and south prongs. Little Manatee River samples were collected from the mouth to a freshwater site located approximately seven miles downstream from the headwaters of the river.

Species lists (by station) and length data are provided and the size of the fishes collected confirms that the rivers, to some extent, function as nurseries. Of the 57 species of fishes collected in the Alafia River, 35 were typically marine-estuarine inhabitants and 29 of the 59 species collected in the Little Manatee River were marine-estuarine species. Even though the sampling program was somewhat abbreviated and some taxonomic problems were discovered, the report nonetheless provides an adequate and much-needed description of the fish community in both rivers.

In 1970, ecological studies were initiated in the vicinity of Tampa Electric Company's (TECO) Big Bend Power Station and, with the exception of 1978, fishery information was collected in this area through February 1981. Between 1970 and 1977, Conservation Consultants, Inc. (CCI) collected fishery data that are contained in a series of 27 quarterly reports each of which presents raw data (usually by station), a species list, and a brief summary of observations. Detailed tables that summarize the seasonal relative abundance of all fishes collected at Big Bend between 1970 and 1975 are presented in CCI 1976, Appendix 5-A. Prior to 1976, samples were collected somewhat intermittently and the sampling stations were often changed during the study. Therefore, although the sampling efforts prior to 1976 resulted in a general data base, the results must be cautiously interpreted due to some limitations in sampling methodology and taxonomy.

In 1976 and 1977, CCI conducted an intensive 15-month environmental impact study in the Big Bend area; the trawl and seine section of this study was described by Comp and Morris (1976). Station locations and sampling methodologies were established and adhered to and in-depth analyses were presented in quarterly reports 23 through 26. Each report presented by station a composite species list of all fishes collected, and raw data including temperature and salinity values and lengths and weights of the fishes collected. An assessment of the impact of power plant operation on the fish comunity near Big Bend is contained in a report by Comp (1977) which summarizes and analyzes the results of the 15-month survey and provides a systematic account of the abundant species in the area.

Between February 1979 and February 1980, Mote Marine Laboratory conducted a study similar in scope and methodology to the 1976-77 TECO study. Although all fishes collected were enumerated, detailed data were gathered and discussed only for selected abundant or commercially important species. A final report on this study (Comp 1980) describes sampling methodology, discusses the seasonal changes and distribution of selected species and presents a list of all species collected with seines, trawls and on the traveling screens at the power plant cooling water intake.

Henningsen (1984) sampled the fish community in the Big Bend area between July 1979 and February 1981. The preliminary data analyzed to date indicate that the patterns of relative abundance, distribution and seasonality are similar to those previously discussed in other technical reports and publications.

The above-referenced reports constitute many volumes of fishery data which precludes the presentation of a

detailed summary in this review. The reader is referred to specific quarterly and/or final reports for detailed information.

McKay Bay. Few surveys of the fishes in Hillsborough or McKay Bays have been conducted to date. Sykes and Finucane (1966) collected fishes in Hillsborough Bay during their investigation of the occurrence of immature commercial fishes in Tampa Bay. Lewis and Courser (1972) described in detail the McKay Bay system and provided information regarding its associated flora and fauna. A good discussion of the importance of mangrove forests and tidal marsh areas to fishery resources is provided in their report.

Between May 1977 and August 1978, Schlueter and Price (unpublished) collected fishery data from one seine station in McKay Bay. The report contains a species list that outlines by month the relative abundance of the 30 species of fishes that were collected and a discussion of the relationship between the distribution and abundance of the fishes and the freshwater flow to the Bay. A detailed systematic account of the growth and migration of selected abundant species is also provided.

Old Tampa Bay. The few fishery-related investigations that have been conducted in Old Tampa Bay include the study by Sykes and Finucane (1966) which will be discussed later in more detail, and the study by Springer and Woodburn (1960) who sampled two trawl sites in Old Tampa Bay and reported that 57 species of fishes were collected in this area.

Additional reports were produced by Rinckey and Saloman (1964) who described a fish kill in Old Tampa Bay that resulted from unseasonably low water temperatures in December 1963, and by Higman and Ellis (1955) who briefly described the sport and commercial fishing activity in Old Tampa Bay.

BAY-WIDE SPECIFIC LIFE HISTORY STUDIES

Sykes and Finucane (1966) sampled two seine and four trawl stations in each of four areas in Tampa Bay (lower Tampa Bay, central Tampa Bay, Hillsborough Bay and Old Tampa Bay) to determine the extent of the abundance and distribution of immature commercially important species. A total of 20 commercially important fishes were found to inhabit the Tampa Bay system during their early life stages. Non-commercial immature species were also collected and are briefly discussed in this report.

The report includes summary tables which present an overview of the catches by season and area. A qualitative review of the distribution of the species indicated that although many of the species were collected throughout the Bay, 57% of the total catch occurred in Old Tampa Bay. Conversely, samples collected in Hillsborough Bay, an area that exhibits a similar pattern of salinity distribution as Old Tampa Bay, accounted for only 8% of the total catch. Since the salinity ranges in both bays is ideally suited for many immature species, both habitats would be expected to support similar fish communities. However, dissimilar results for the two areas were obtained and Sykes and Finucane (1966) concluded that the disparity in apparent abundance is due to a loss of suitable habitat in Hillsborough Bay because of artificial alterations.

The general distribution and life history patterns of the commercially important Florida pompano (Trachinotus carolinus) and a closely related species (Trachinotus falcatus) are given by Finucane (1969) who collected numerous samples throughout Tampa Bay. A review of the spawning habits, growth and food preference of these species is presented along with a discussion of the relationship between the distribution of these species and environmental parameters such as temperature,

salinity, dissolved oxygen and pH.

Martin and Finucane (1968) collected longnose killifish (Fundulus similis) at 18 stations located throughout Tampa Bay for the purpose of discerning the life history, spawning behavior, development and general ecology and distribution of the species. Fundulus similis is, as evidenced by the results of this and numerous other studies, the most abundant cyprinodont in Tampa Bay. Although it is found throughout the system, most are concentrated from central Tampa Bay northward to Old Tampa and Hillsborough Bays.

Detailed life history information on the code goby (Gobiosoma robustum) in Tampa Bay is provided by Springer and McErlean (1961). Results indicated that this species spawns twice each year (early spring to early summer and late summer to fall) and that the young rapidly mature and reproduce. The entire life cycle of this species usually occurs within one year.

Finucane et al. (1964) provided an account of the fish kill associated with the red tide bloom in April 1963. The study also monitored the subsequent recovery of the fish community for a five month period. This particular outbreak was mainly confined to lower and central Tampa Bay and, for comparative purposes, Finucane et al. (1964) sampled areas within and out of the confines of the bloom. Results indicated that 56 species of fishes were adversely affected by the red tide outbreak. A list of the species killed during this bloom and a discussion of the dominant species affected are given in the report.

SPECIES COMPOSITION

Springer and Woodburn (1960), in their study of the fishes of the Tampa Bay area, reported that 253 species have been collected or observed in the region. Additional data presented by Springer (1961), Moe and Martin (1965) and Powell et al. (1972) extended the total to well over 300 species although that number includes many offshore inhabitants that would not likely be found in or near Tampa Bay proper. Since this review focuses on the fishes in Tampa Bay, the above and other data were further refined and a list was compiled which includes only those species collected or observed within the confines of Tampa Bay as defined earlier in this report. Limited editorial license was used when compiling the list since the identity of a few species as reported in the literature is questionable and the exact point of collection for some specimens reported by Powell et al. (1972) is unclear.

Based on the best available information, 203 species of fishes have been reported in Tampa Bay and nearby coastal areas. Of that number, 125 species are considered common inhabitants of the Bay while the remainder are considered rare or uncommon as they are infrequently collected or observed. These designations are somewhat arbitrary since the efficient collection of all representative species depends upon adequate sampling of all habitats with a variety of gear. This limitation often belies the accurate determination of even the relative abundance of certain species. It is likely that many other species than have been reported to date exist in Tampa Bay.

Other estuaries along Florida's Gulf coast have been studied in some detail and all appear to support a wide variety of species. To the south, Gunter and Hall (1965) collected 107 species of fishes from the Caloosahatchee estuary during a three year study and Wang and Raney (1971) collected 125 species in Charlotte Harbor during a one year study between 1968 and 1969. Wang and Raney (1971) extended their total to 246 species after they reviewed additional fisheries data from Charlotte Harbor and the fish reference collection of the Mote Marine Laboratory. Their total of 246 species probably includes some species that were collected outside of the estuary.

Studies conducted in estuaries north of Tampa Bay include those by Reid (1954) who collected 122 fishes near Cedar Key during a one year study;

Livingston et al. (1977) who collected 79 species of fishes in the Apalachicola Bay system during a three year study; and Cooley (1978) who reported that at least 187 species are found in the Pensacola estuarine system. Because of reasons previously stated it is likely that the actual number of species present in each system exceeds the number reported by these and other investigators.

Generally, the number of species in an estuary declines with decreasing salinity. This trend is to a certain extent seen in Tampa Bay although the limitations previously discussed preclude absolute comparisons from one study or area to the next. Lower Tampa Bay generally provides suitable habitat for both marine and estuarine species so it is reasonable to assume that more species will be collected or observed there than in any other section of the Bay. Conversely, the upper bays and river mouths provide, due to extreme fluctuations in salinity, a more specialized habitat that would therefore be expected to support fewer species.

In Boca Ciega and lower Tampa Bay samples, Springer and Woodburn (1960) reported the presence of 127 species and 57 species in Old Tampa Bay. Similarly, a 15-month study conducted by Comp (1977) at Big Bend accounted for 56 species while at McKay Bay, Schlueter and Price (unpublished) collected 30 species during a 14 month study in 1977 and 1978. Only 35 and 29 species were collected from the mouths of the Alafia and Little Manatee Rivers, respectively, during three sampling periods conducted between November 1973 and May 1974 by Dames and Moore (1975).

The species composition in Tampa Bay, as in most Gulf coast estuaries, is highly diverse although ten or fewer individuals generally constitute the majority of the catch in terms of relative abundance. These species are often numerically dominant throughout the estuary although their "rank" may change in different areas of a system in response to a variety of environmental factors such as salinity, temperature and habitat type. Table 5 illustrates the change in dominance of abundant species collected from a variety of areas within the Bay. The fish community along coastal beaches (Saloman and Naughton 1979) and at Maximo Point (McNulty et al. 1974) is dominated by typically marine fishes. Farther up the estuary at Big Bend (Comp 1977) and McKay Bay (Schlueter and Price, unpublished), changes in dominance are evident as typically estuarine species are more abundant.

The species composition is remarkably similar among estuaries on Florida's west coast. McNulty et al. (1974) collected monthly fishery samples at five Gulf coast areas shown in Figure 3. The nine most abundant species collected from all five areas are given in Table 6. These species are very similar to the abundant species reported from a variety of areas within Tampa Bay (Table 5) and from other estuaries (see for example Gunter and Hall 1965; Wang and Raney 1971; Cooley 1978 and others).

The species listed in Table 5 constitute in terms of relative abundance between 88% and 98% of the total catch for the studies cited. Numerical dominance by a few species is a typical occurrence in most estuaries. In McNulty et al.'s (1974) study of five areas along the Gulf coast (Figure 3) nine species that constituted 90% of the total catch were collected. In the Caloosahatchee area, Gunter and Hall (1965) collected eight species that constituted 75% of the catch; in Cedar Key (Reid 1954) five species constituted 79% of the total catch and in Pensacola (Cooley 1978) four species constituted 76% of the catch.

IDENTIFICATION KEYS

There are numerous publications available which will aid in the identification of fishes collected in the Tampa Bay area. The following brief review is intended to provide the reader with the general sources of information.

Jordan and Evermann (1896-1900) provided extensive taxonomic information for most of the fishes likely to be

Table 5. Dominant species, in order of abundance, collected in selected areas of Tampa Bay, and the percentage of the catch represented by those species.

		PERCENT OF CATCH
COASTAL BEACHES: (Saloman and Naughton 1979)	Scaled sardine Striped anchovy Bay anchovy Tidewater silverside Gulf kingfish Atlantic thread herring Northern kingfish Florida pompano Permit Cuban anchovy	98
MAXIMO POINT: (McNulty et al. 1974)	Silver jenny Pinfish Tidewater silverside Spotfin mojarra Longnose killifish Silver perch Pigfish Bay anchovy	88
BIG BEND: (Comp 1977)	Tidewater silverside Bay anchovy Longnose killifish Spotfin mojarra Striped mullet Sheepshead minnow Silver jenny Rough silverside Scaled sardine Pinfish	91
MCKAY BAY: (Schleuter and Price, unpub.)	Tidewater silverside Striped mullet Longnose killifish Bay anchovy Spot Scaled sardine Pinfish	92

Table 6. Composite list of dominant species, in order of abundance, collected by McNulty et al. (1974) in five selected areas (St. Marks, Cedar Key, Maximo Point, Bokeelia and Chokoloskee).

Pinfish	Lagodon rhomboides
Bay anchovy	Anchoa mitchilli
Tidewater silverside	Menidia peninsulae
Silver jenny	Eucinostomus gula
Spotfin mojarra	Eucinostomus argenteus
Pigfish	Orthopristis chrysoptera
Silver perch	Bairdiella chrysoura
Longnose killifish	Fundulus similis
Goldspotted killifish	Floridichthys carpio

encountered in Tampa Bay. The highly detailed descriptions of the fishes are especially useful when general identification keys do not provide sufficient information to identify a given species. Keys published more recently include those by Hoese and Moore (1977) who provide an excellent key to local fishes with color plates of most species described; Walls (1975), who also provides color plates of selected species with descriptions; Cliburn (1976); Dahlberg (1976); and Parker (1978).

ANTHROPOGENIC IMPACTS ON FISHERY RESOURCES

The impact on fishery resources resulting from habitat destruction is an important concern in all estuaries in the United States. Estuaries provide invaluable nursery habitat for numerous sport, commercial and forage species and significant losses of habitat may result in decreases in fishery resources.

A symposium sponsored by the American Fisheries Society (AFS) provided a forum for the presentation of papers dealing with the relationships between estuaries and fishes. The proceedings of this symposium were published by AFS in 1966.

Woods Hole Oceanographic Institution (1976) published a similar compendium of papers that discuss a myriad of estuarine processes and environmental concerns. Kumpf (1977) published a report that describes in detail the economic consequences of pollution on marine and estuarine species. Studies conducted in Florida in areas other than Tampa Bay that discuss the consequences of habitat destruction include those by Lindall (1973) and the U.S. Department of the Interior (1974).

The cause and effect relationships between habitat destruction and loss of fishery resources have been shown in several areas within Tampa Bay. In a study discussed elsewhere in this report, Sykes and Finucane (1966) discovered that fewer immature fishes utilized Hillsborough Bay as a nursery than utilized Old Tampa Bay, although both areas provided the range of salinity preferred by many species of juvenile fishes. The conclusion of the study was that the introduction of industrial and domestic wastes to Hillsborough Bay, coupled with man-induced habitat loss, virtually eliminated that area's capability to function as a nursery for commercial, sport and forage species.

The loss of habitat as a result of dredging and filling activities in Boca Ciega Bay along with the concomitant loss of fishery resources has been well-documented (for example: Smith 1966; Saloman 1965 and Sykes 1971). As early as 1956, Hutton et al. (1956) predicted that up to 90% of the bait shrimp area in Boca Ciega Bay would be eliminated by proposed dredge and fill activities. Figure 4, from Saloman (1965), shows the extent of dredge and fill operations in Boca Ciega Bay through 1963 along with the proposed (at that time) fill areas. The economic loss to the bait shrimp industry operating in Boca Ciega and

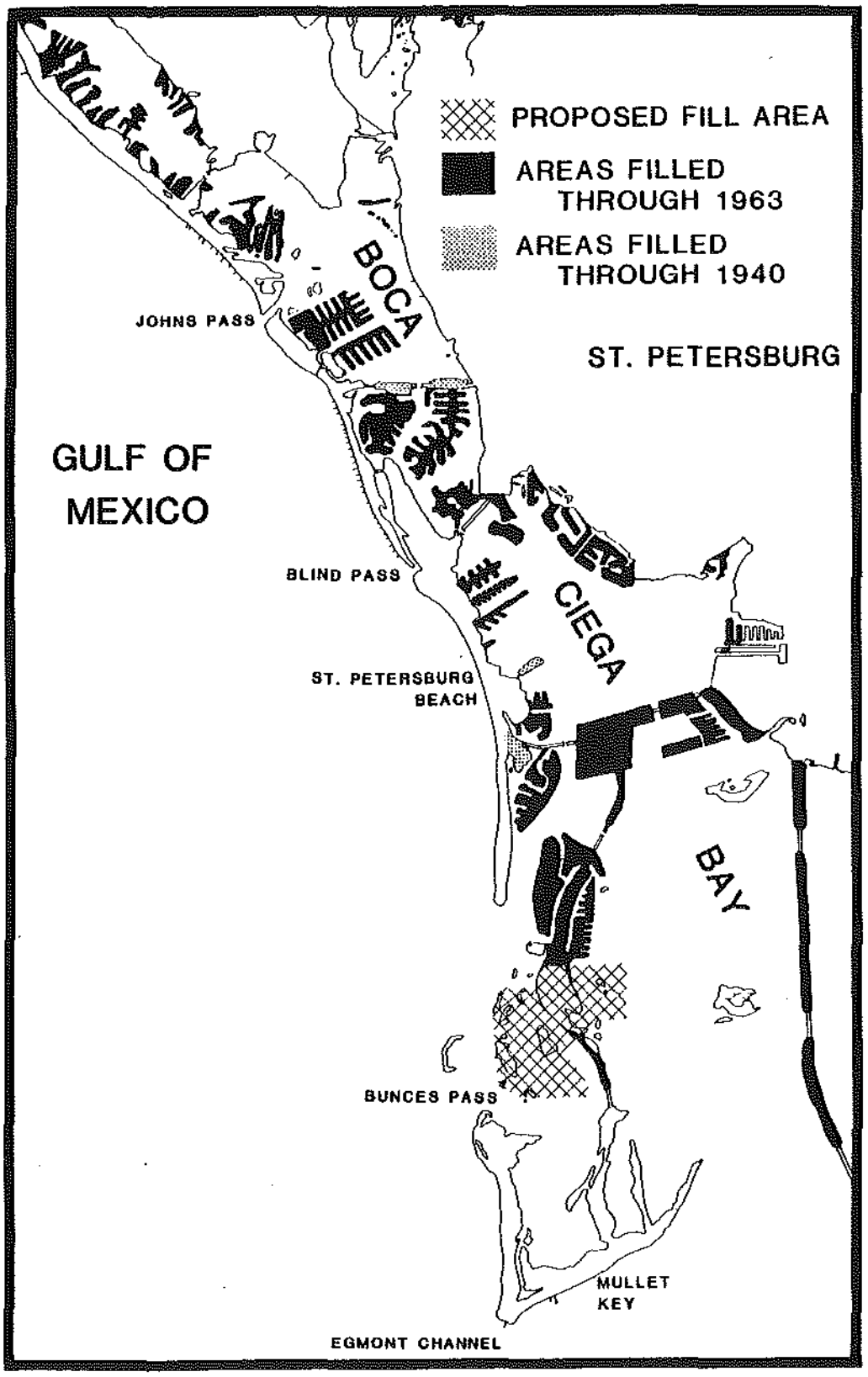

Figure 4. Completed (through 1963) and proposed dredge and fill sites in Boca Ciega Bay (from Saloman 1965).

Tampa Bay as a result of habitat reduction is discussed in Saloman (1965).

Another controversial issue is the construction of dead-end access or "finger" canals. Shortly after these canals are constructed and opened to a larger body of water, they often support a diverse community of fishes and invertebrates. Later, many species, especially demersal fishes, are excluded from these canals as a result of a precipitous decline in dissolved oxygen which is usually attributed to a lack of sufficient circulation within the canals. Therefore, these canals generally do not provide a favorable habitat for desirable aquatic flora or fauna, although some exceptions have been noted. For example, Kinch (1979) studied the ichthyofauna in a five year old canal system in Marco Island and found the fish community here to be basically similar to that found in natural surrounding areas.

Conversely, Lindall et al. (1973) and Lindall et al. (1975) found that over time significant changes occurred in the fish community in a west Tampa Bay canal system. The results of these two studies are summarized in Table 7. Two months after the canal system was constructed, Lindall et al. (1973) collected fish samples by trawling within the canals between August 1970 and August 1971. Table 7 shows that during this sampling period over 10,000 fishes were collected and that four of the 32 species collected constituted 96% of the catch. Bay anchovies (Anchoa mitchilli) were most abundant (75% of the fish catch), followed by spotfin mojarras (Eucinostomus argenteus), spot (Leiostomus xanthurus) and silver jenneys (Eucinostomus gula) which collectively constituted an additional 21% of the catch. During a follow-up study conducted between October 1971 and September 1972, Lindall et al. (1975) collected roughly the same number of fishes and species but there was a significant change in species composition and dominance. Bay anchovies constituted 95% of the catch and the three other species that were previously abundant only accounted for 0.2% of the catch made during the subsequent study.

Additional information on this controversial matter can be obtained by referring to the literature cited in this section and by reviewing the literature contained elsewhere in this volume.

SUMMARY

The Tampa Bay estuarine system supports a diverse community of larval, juvenile and adult fishes and a substantial data base regarding the temporal and spatial changes in the distribution, relative abundance and migration of the community and individual species has been established over the last 25 years. The results of numerous investigations have indicated that Tampa Bay supports at least 203 species of fishes, many of which have important sport and/or commercial value. The species composition in the Bay is similar to fish communities in other Gulf coast estuaries in structure and percentage of dominant species.

One of the most important functions of the system is to provide nursery areas for larval and juvenile fishes and many species utilize Tampa Bay during their early life stages. Records of seasonal migration and distribution indicate that most spawning occurs during the spring and early summer in the nearby Gulf and thoughout much of Tampa Bay. A second peak of less intensity occurs during the fall and usually involves fewer species than the spring-summer spawn. During and following these spawning periods, the larval and juvenile fishes migrate to the shallow, protected areas of the estuary where they will mature.

The seasonal movements of adult fishes are similar to those of the juveniles in that peaks in relative abundance generally occur in the spring through early fall. Decreases in relative abundance are apparent with the onset of colder water temperature in December through February when many species apparently migrate to the Gulf or to the deeper areas of the Bay.

Table 7. Data from Lindall et al. (1973) and Lindall et al. (1975) showing the change in species dominance in a canal system in Tampa Bay.

	AUG 1970 - AUG 1971	OCT 1971 - SEP 1972
No. Fishes:	10,017	9,342
No. Species:	32	34
No. Dominant:	4	1
Percent Catch (fishes):	96%	95%
Bay anchovy	75%	95%
Spotfin mojarra, Spot, Silver jenny	21%	0.2%

This general pattern of migration does not, however, involve all species as some live out their entire life cycle within the confines of the estuary. These "estuarine" species are usually found in areas with low or highly fluctuating salinities. Fluctuations in salinity pose certain physiological stresses on aquatic flora and fauna so fewer species of fishes are usually found in the upper reaches of the estuary than in the more saline "marine" sections of the Bay. Habitat type also governs the relative abundance and species diversity in other areas in the Bay. For example, shallow, protected habitats usually support larger numbers of individuals but fewer numbers of species than open bay or beach habitats. Those species which specifically utilize the shallow areas as a nursery along with a few small resident species constitute the majority of the catch made in these areas. Conversely, a variety of migratory species and numerous species that cyclically feed along open beach areas constitute the majority of the catches made in these habitats.

Dredging and filling activities have had a deleterious impact on the Bay area fish community, especially in Boca Ciega Bay. The construction of access or "finger" canals has produced habitats that are not conducive to the maintenance or proliferation of fish communities. The loss of estuarine habitat is one of the main concerns in the Tampa Bay area because numerous species depend upon the availability of nurseries for their survival and eventual recruitment into the adult population. Loss of habitat combined with several seasons of poor recruitment could cause a serious decline in the fishery resources in the Bay.

Due to the sampling limitations previously discussed, only gross changes in abundance could have been detected over time. The data reviewed in this report suggests that such a change has not occurred in Tampa Bay. Similarly, the species composition as described in the most recent reports appears to be very similar to that described in earlier publications. However, most of the recent studies have been restricted to relatively small areas of the Bay, so the results obtained cannot be extrapolated and used to determine the stability of the fish abundance or community structure throughout the Bay.

RECOMMENDATIONS

The spatial and temporal patterns of relative abundance, distribution and migration of the fishes in Tampa Bay have been well established. Estimates of absolute abundance are lacking due to the inherent limitations associated with fishery studies conducted in open, dynamic systems such as Tampa Bay. To obtain an estimate of the absolute

abundance of even selected species would require a time-consuming, labor-intensive survey that would probably not provide the desired results due to the limitations previously discussed.

It is recommended therefore, that an indirect approach be taken toward monitoring fish stability and/or production within the Bay. Such an approach will involve locating, then monitoring, the community structure (and perhaps, relative abundance) within the major nurseries in Tampa Bay. Information on the seasonal use of several nurseries in the Bay is provided in the literature reviewed in this report; however, to best understand the extent of utilization the location of all nurseries should be identified.

Once the locations of the major nurseries have been established, steps can be taken to insure that these areas are preserved since, as shown in previous reports, a loss of critical estuarine habitat can result in a loss of fishery resources. To prevent this occurrence, it is imperative that the grass flats, shallow beaches, embayments and mangrove forests in Tampa Bay be protected from unnatural or harmful alterations.

In addition, the freshwater flow requirements to the estuary should be determined since the dilution effect caused by river discharge is necessary for the survival of numerous species. The increasing demand for water supplied by the rivers will undoubtedly result in an eventual decrease in flow to the estuary. Such a reduction in flow could deleteriously affect the estuarine resources in the Bay, so it is imperative that a balance between the need for freshwater in the estuary and for other uses be established.

In summary, alterations to critical estuarine habitats threaten to decrease the productivity of fishes within the Bay. Even though this review has indicated that Tampa Bay continues to support a diverse community of fishes, it is recommended that plans to protect the valuable resources in Tampa Bay be devised and implemented in the very near future.

ACKNOWLEDGMENTS

I would like to thank the organizers of BASIS for their recognition of the need to provide a source in which the vast amount of information on the resources of Tampa Bay can be compiled and disseminated. Thanks are also extended to Mr. Bill Tatum, Executive Director of the Southwest Florida Water Management District, for his support of BASIS. Ms. Mary Parks, the librarian at the Mote Marine Laboratory was, as always, very helpful and obtained some of the literature cited in this report. The assistance of the library staff at the Florida Department of Natural Resources Marine Research Laboratory was also appreciated. The original manuscript was typed by Ms. Kay Klinzing and the original figures were drafted by Mr. Dean Rusk and their help is sincerely acknowledged. Finally, I would like to thank all of the people, too numerous to mention by name, who enthusiastically provided assistance whenever it was needed.

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APPENDIX

COMPOSITE LIST OF SPECIES REPORTED FROM TAMPA BAY

The most recent nomenclature adopted by Robins et al. (1980) is cited in this list and several changes in generic and/or specific names have occurred since Bailey et al. (1970) edited the last list of accepted nomenclature for fishes. The generic and/or specific names previously used in the references that were reviewed when compiling the Tampa Bay list are in parentheses under the proper new nomenclature.

Key:

- M - These are predominantly marine species.
- E - These are predominantly estuarine species.
- F - These are predominantly freshwater species that are incidentally collected near freshwater sources in Tampa Bay. All would be considered "uncommon" components of the Tampa Bay fish community.
- M-E - Species designated as both marine and estuarine commonly utilize both types of habitats or they are migratory species that utilize the estuary during some part of their life cycle.
- U - These species are uncommon or rare in fishery collection or observations in Tampa Bay.

The key refers to habitats or areas in which the fishes are most commonly collected in Tampa Bay. The "marine" species are usually collected from lower Tampa Bay, along coastal beaches, or just offshore of coastal beaches. Those designated as "estuarine" are usually collected from central Tampa Bay, Hillsborough and Old Tampa Bay, or at river mouths.

		M	E	F	U
Ginglymostoma cirratum	nurse shark	X			
Rhincodon typus	whale shark	X			X*
Carcharodon carcharias	white shark	X			X
Odontaspis taurus (Charcharias taurus)	sand tiger	X			X
Carcharhinus acronotus	blacknose shark	X			
Carcharhinus leucas	bull shark	X			
Carcharhinus limbatus	blacktip shark	X	X		
Carcharhinus obscurus (Eulamia floridana)	dusky shark	X			
Carcharhinus plumbeus (Eulamia milberti) (Carcharhinus milberti)	sandbar shark	X			X
Negaprion brevirostris	lemon shark	X			X
Sphyrna mokarran	great hammerhead	X			X
Sphyrna tiburo	bonnethead	X	X		
Pristis pectinata (Pristis pectinatus)	smalltooth sawfish	X	X		X
Rhinobatos lentiginosus	Atlantic guitarfish	X			
Dasyatis americana	southern stingray	X	X		
Dasyatis sabina	Atlantic stingray	X	X		X

*one dead specimen observed in Hillsborough Bay in 1977.

		M	E	F	U
Dasyatis sayi	bluntnose stingray	X	X		
Gymnura micrura	smooth butterfly ray	X	X		
Aetobatus narinari	spotted eagle ray	X			
Rhinoptera bonasus	cownose ray	X	X		
Manta birostris	Atlantic manta	X			
Acipenser (oxyrhynchus?)	Atlantic sturgeon		X		X
Lepisosteus osseus	longnose gar			X	X
Lepisosteus platyrhincus	Florida gar			X	X
Elops saurus	ladyfish	X	X		
Megalops atlanticus (Megalops atlantica)	tarpon	X	X		
Albula vulpes	bonefish	X			
Anguilla rostrata	American eel	X	X		X
Gymnothorax saxicola	ocellated moray	X			X
Bascanichthys bascanium (Bascanichthys teres)	sooty eel	X			X
Echiophis intertinctus (Mystriophis intertinctus) (Myrophis intertinctus)	spotted spoon-nose eel	X			X
Echiophis punctifer (Myrophis punctifer)	stippled spoon-nose eel	X			X
Myrophis punctatus	speckled worm eel	X	X		
Ophichthus gomesi	shrimp eel	X	X		
Ophichthus ocellatus	palespotted eel	X			X
Brevoortia patronus	gulf menhaden	X	X		
Brevoortia smithi	yellowfin menhaden	X			
Dorosoma cepedianum	gizzard shad			X	X
Dorosoma petense	threadfin shad		X	X	X
Harengula jaguana (Harengula pensacolae)	scaled sardine	X	X		
Opisthonema oglinum	Atlantic thread herring	X	X		
Sardinella aurita (Sardinella anchovia)	Spanish sardine	X			
Anchoa cubana	Cuban anchovy	X			
Anchoa hepsetus	striped anchovy	X	X		
Anchoa mitchilli	bay anchovy	X	X		
Synodus foetens	inshore lizardfish	X	X		
Ictalurus nebulosus	brown bullhead			X	X
Arius felis (Galeichthys felis)	hardhead catfish	X	X		
Bagre marinus	gafftopsail catfish	X	X		
Opsanus beta	gulf toadfish	X	X		
Opsanus pardus	leopard toadfish	X			
Porichthys plectrodon (Porichthys porosissimus)	Atlantic midshipman	X	X		
Gobiesox strumosus	skilletfish	X	X		
Halieutichthys aculeatus	pancake batfish	X			X
Ogcocephalus radiatus	polka-dot batfish	X	X		
Ogcocephalus sp.		X	X		
Urophycis floridana (Urophycis floridanus)	southern lake	X	X		
Ophidion beani	longnose cusk-eel	X			X

		M	E	F	U
Ophidion grayi	blotched cusk-eel	X			X
Ophidion welshi	crested cusk-eel	X			X
Hemiramphus brasiliensis	ballyhoo	X			X
Hyporhamphus unifasciatus	halfbeak	X	X		
Strongylura marina	Atlantic needle fish	X			X
Strongylura notata	redfin needlefish	X	X		
Strongylura timucu	timucu	X	X		
Tylosurus crocodilus (Strongylura raphidoma)	houndfish	X			X
Adinia xenica	diamond killifish		X		
Cyprinodon variegatus	sheepshead minnow		X		
Floridichthys carpio	goldspotted killifish		X		
Fundulus confluentus	marsh killifish		X		
Fundulus grandis	gulf killifish		X		
Fundulus seminolis	Seminole killifish			X	X
Fundulus similis	longnose killifish		X		
Lucania parva	rainwater killifish		X		
Gambusia affinis	mosquitofish		X		
Poecilia latipinna (Molliensa latipinna)	sailfin molly		X		
Membras martinica	rough silverside		X		
Menidia peninsulae (Menidia beryllina)	tidewater silverside		X		
Regalecus glesne	oarfish	X			X
Hippocampus erectus (Hippocampus hudsonius)	lined seahorse		X		
Hippocampus zosterae	dwarf seahorse		X		
Micrognathus criniger (Micrognathus crinigerus)	fringed pipefish		X		
Syngnathus floridae	dusky pipefish		X		
Syngnathus louisianae	chain pipefish		X		
Syngnathus scovelli	gulf pipefish		X		
Centropomus undecimalis	snook	X	X		
Centropristis striata (Centropristes melanus)	black sea bass	X			X
Diplectrum formosum	sand perch	X			
Epinephelus itajara (Promicrops itajara)	jewfish	X	X		
Epinephelus morio	red grouper	X			X
Mycteroperea microlepis	gag	X			
Serranus subligarius (Serranellus subligarius)	belted sandfish	X			X
Rypticus saponaceous	greater soapfish	X			X
Lepomis macrochirus	bluegill			X	X
Micropterus salmoides	largemouth bass			X	X
Astrapogon alutus (Apogonichthys alutus)	bronze cardinalfish	X			X
Pomatomus saltatrix	bluefish	X	X		
Rachycentron canadum	cobia	X	X		
Echeneis naucrates	sharksucker	X	X		
Remora remora	remora	X	X		
Caranx crysos	blue runner	X			

		M	E	F	U
Caranx hippos	crevalle jack	X	X		
Caranx latus	horse-eye jack		X		X
Chloroscombrus chrysurus	Atlantic bumper	X	X		
Hemicaranx amblyrhyncus	bluntnose jack	X			X
Oligoplites saurus	leatherjacket	X	X		
Selene setapinnis (Vomer setapinnis)	Atlantic moonfish	X			X
Selene vomer	lookdown	X			
Trachinotus carolinus	Florida pompano	X	X		
Trachinotus falcatus	permit	X	X		
Trachinotus goodei	palometa	X			
Lutjanus apodus	schoolmaster	X			X
Lutjanus griseus	gray snapper	X	X		
Lutjanus synagris	lane snapper	X	X		
Lobotes surinamensis	tripletail	X	X		
Diapterus auratus (Diapterus olisthostomus)	Irish pompano	X			X
Diapterus plumeiri	striped mojarra		X		
Eucinostomus argenteus	spotfin mojarra	X	X		
Eucinostomus gula	silver jenny	X	X		
Gerres cinereus	yellowfin mojarra		X		X
Haemulon aurolineatum	tomtate	X			X
Haemulon plumieri	white grunt	X			
Orthopristis chrysoptera (Orthopristis chrysopterus)	pigfish	X	X		
Archosargus probatocephalus	sheepshead	X	X		
Calamus arctifrons	grass porgy	X			X
Diplodus holbrooki	spottail pinfish	X			
Lagodon rhomboides	pinfish	X	X		
Bairdiella chrysoura (Bairdiella chrysura)	silver perch	X	X		
Cynoscion arenarius	sand seatrout	X	X		
Cynoscion nebulosus	spotted seatrout	X	X		
Equetus acuminatus	high-hat	X			X
Equetus umbrosus	cubbyu	X			X
Leiostomus xanthurus	spot	X	X		
Menticirrhus americanus	southern kingfish	X	X		
Menticirrhus littoralis	gulf kingfish	X			
Menticirrhus saxatilis (Menticirrhus focaliger)	northern kingfish	X	X		
Micropogonias undulatus (Micropogon undulatus)	Atlantic croaker		X		
Pogonias cromis	black drum	X	X		
Sciaenops ocellatus (Sciaenops ocellata)	red drum	X	X		
Pseudupeneus maculatus	spotted goatfish	X			X
Kyphosus sectatrix	Bermuda chub	X			X
Chaetodipterus faber	Atlantic spadefish	X	X		
Tilapia melanotheron	blackchin tilapia		X		
Halichoeres bivittatus	slippery dick	X			X
Lachnolaimus maximus	hogfish	X			X

		M	E	F	U
Nicholsina usta	emerald parrotfish	X			
Mugil cephalus	striped mullet	X	X		
Mugil curema	white mullet	X	X		
Mugil trichodon	fantail mullet	X	X		
Sphyraena barracuda	great barracuda	X	X		
Sphyraena borealis	northern sennet	X			X
Sphyraena guachancho	guachanche	X			X
Polydactylus octonemus	Atlantic threadfin	X			X
Opistognathus lonchurus	moustache jawfish	X			X
Dactyloscopus tridigitatus	sand stargazer	X			X
Astroscops y-graecum	southern stargazer	X	X		
Paraclinus fasciatus	banded blenny		X		X
Paraclinus marmoratus	marbled blenny		X		X
Chasmodes bosquianus	striped blenny	X			X
Chasmodes saburrae	Florida blenny	X	X		
Hypleurochilus geminatus	crested blenny	X			X
Hypsoblennius hentzi	feather blenny	X	X		
Lupinoblennius nicholsi (Blennius nicholsi)	highfin blenny	X			X
Parablennius marmoreus (Blennius marmoreus)	seaweed blenny	X			X
Dormitator maculatus	fat sleeper			X	X
Bathygobius soporator	frillfin goby		X		
Gobionellus boleosoma	darter goby		X		
Gobionellus hastatus	sharptail goby		X		
Gobiosoma bosci	naked goby		X		
Gobiosoma longipala	twoscale goby		X		X
Gobiosoma macrodon	tiger goby	X	X		X
Gobiosoma robustum	code goby		X		
Microgobius gulosus	clown goby		X		
Microgobius thalassinus	green goby		X		
Trichiurus lepturus	Atlantic cutlassfish	X			
Scomberomorus caralla	king mackerel	X			X
Scomberomorus maculatus	Spanish mackerel	X	X		
Peprilus alepidotus	harvestfish	X			X
Peprilus triacanthus (Poronotus triacanthus)	butterfish	X			X
Scorpaena brasiliensis	barbfish	X			X
Bellator militaris	horned searobin	X			X
Prionotus roseus	bluespotted searobin	X			X
Prionotus rubio	blackfin searobin	X			X
Prionotus scitulus	leopard searobin	X	X		
Prionotus tribulus	bighead searobin	X	X		
Ancylopsetta quadrocellata	ocellated flounder	X			X
Citharichthys macrops	spotted whiff	X			X
Etropus crossotus	fringed flounder	X			
Paralichthys albigutta	gulf flounder	X	X		
Syacium papillosum	dusky flounder	X			X
Achirus lineatus	lined sole	X	X		
Trinectes maculatus	hogchoker	X	X		
Symphurus plagiusa	blackcheek tonguefish	X	X		

		M	E	F	U
Aluterus schoepfi (Alutera schoepfi)	orange filefish	X			
Monacanthus ciliatus	fringed filefish	X	X		
Monacanthus hispidus (Stephanolepis hispidus)	planehead filefish	X	X		
Lactophrys quadricoinis (Acanthostracion tricornis)	scrawled cowfish	X	X		
Lactophrys trigonus	trunkfish	X	X		X
Lactophrys triqueter	smooth trunkfish	X			X
Lagocephalus laevigatus	smooth puffer	X	X		X
Sphoeroides nephelus	southern puffer	X	X		
Chilomyeterus schoepfi	striped burrfish	X	X		
Diodon holocanthus	balloonfish	X			X

Total Number of Species: 203

CURRENT STATUS AND RECENT TRENDS IN BIRD POPULATIONS OF TAMPA BAY

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ABSTRACT

The avifauna of Tampa Bay is dominated by representatives of four orders: Pelecaniformes (pelicans, cormorants, anhingas); Ciconiiformes (herons, ibis, spoonbills, storks); Anseriformes (waterfowl); and Charadriiformes (shorebirds, gulls and terns). Data from the literature, various breeding bird surveys, Christmas Bird Counts, and winter duck surveys are analyzed to determine status and recent trends in populations of birds inhabiting Tampa Bay. Breeding areas and other localities of particular importance to birds are identified; factors in population trends are discussed, and needs for further information are pointed out.

INTRODUCTION

Birds are an important component of the rich biota of the Tampa Bay estuarine system (Woolfenden and Schreiber 1973; Simon 1974). However, despite ornithological activity in the region for at least a century (Howell 1932) and protective action by federal and private wildlife agencies since 1905, no systematic review of the populations of bird species dependent on the bay system has been attempted. Woolfenden and Schreiber (1973) summarized much valuable information about birds of Tampa Bay, but their focus was on the much larger area of the eastern Gulf of Mexico. Dunstan and Lewis (1974), Lewis and Lewis (1978) and Schreiber and Schreiber (1978) characterized bird populations and plant succession of selected dredged material islands in Tampa Bay but did not attempt to assess the status of populations baywide. In recent years we and collaborators have attempted to visit nearly all breeding colonies in the area. In no single season have we yet succeeded in thoroughly surveying all sites, but enough information is available for us to attempt to summarize the status of breeding birds of Tampa Bay. In addition, annual winter inventories of McKay Bay and Safety Harbor birds, and winter waterfowl surveys carried out by the Florida Game and Freshwater Fish Commission allow some statements about winter bird populations, particularly shorebirds and waterfowl.

We have not attempted to discuss every species recorded in the Tampa Bay area nor even every breeder. Rather, our emphasis is on those species judged to be regular users of the bay system, and those of special interest due to rarity or unusually restricted distribution.

English and scientific names follow the 6th edition of the Check-list of North American Birds (American Ornithologists' Union 1983).

BREEDING BIRDS

Most of the species breeding in Tampa Bay occupy colonies on islands where they are secure from terrestrial predators. Large numbers of birds of

many species may breed at a single site, a situation that encourages survey efforts but presents problems of a special nature. Virtually all bird colonies have been surveyed during the last decade (e. g. Nesbitt et al. 1982), but the data obtained vary greatly with the method employed and the experience of observers. Several authors have reviewed census methods for colonial species (Buckley and Buckley 1976; McCrimmon 1976; King 1978; Portnoy 1978, 1980), and while we do not propose an additional review here, a brief description of methods is necessary.

Wherever possible, direct counts of nests or nesting birds were made. This method was most useful for large species nesting on top of the canopy, and ground-nesting species where nests or incubating adults were clearly visible. At some heronries, where site size and habitat profile allowed close approach and good visibility, nests of most species could be counted. Direct counts were made without entering the colony.

At large or dense heronries where counts were impossible or would cause disruption of nesting efforts, "flight line counts" were employed (Erwin and Ogden 1980, Erwin 1981). Because of some bias inherent in the method, flight line counts were supplemented with estimates based on broods or total number of young seen, particularly when censusing uncommon species.

Laughing Gulls were censused using a circular plot technique (Patton and Hanners 1984), except where vegetation was too shrubby (Port Manatee Spoil).

At rarely visited sites, especially Tarpon Key and Johns Pass, species that could not be counted directly were estimated by a careful walk-through of the colony.

At every colony we selected one or more methods on the basis of the biology of the species to be censused, their sensitivity to disturbance, and the habitat types present.

We identified 22 active bird colonies (Fig. 1, Table 1), and undoubtedly have overlooked some sites used by very small numbers of pairs or "ephemeral" species such as Least Terns, which move readily among sites and are extremely difficult to survey completely. In general, sites occupied by larids (see Table 1) contained sparsely vegetated sand or shell substrates, while pelecaniform and ciconiiform birds nested where shrubs or trees were available. Many of the sites were briefly characterized by Nesbitt et al. (1982) but several require further comment here.

Alafia Bank, comprised of two dredged material islands totalling about 20 ha, is a National Audubon Society sanctuary. Originally constructed in 1931, the islands have been modified by erosion, plant succession (Lewis and Lewis 1978) and recent spoil deposition, and offer a variety of habitats attractive to nesting birds. Part of the island is managed to provide suitable nesting habitat for terns and skimmers. In the late 1950s, Alafia Bank was the largest mixed-species colony in Florida, with 25,000 pairs of breeding birds (Ogden 1978a). By the late 1970s and early 1980s, numbers had decreased to 10-15,000 pairs, although it remains the largest colony in the state. Nesting diversity also may be unrivalled in Florida, with up to 20 species breeding annually.

Washburn Sanctuary (Terra Ceia Bird Key), a 3 ha natural mangrove island, has been protected by the National Audubon Society since 1939 and is the second largest mixed colony in the area.

Tarpon Key, a National Wildlife Refuge, is a large natural mangrove island used by large numbers of nesting Brown Pelicans and Double-crested Cormorants, and smaller numbers of herons, egrets and ibis. It is the "descendant" of the famous Maximo colony at Indian Key, 4.5 km north of Tarpon Key, noted by Scott (1887). With Alafia Bank and Washburn Sanctuary, it is one of the three largest mixed colonies of pelecaniforms, herons and ibis in the region.

The Johns Pass colony, first visited in 1880 by Scott (1887), remains active a century later. Most of the nesting birds

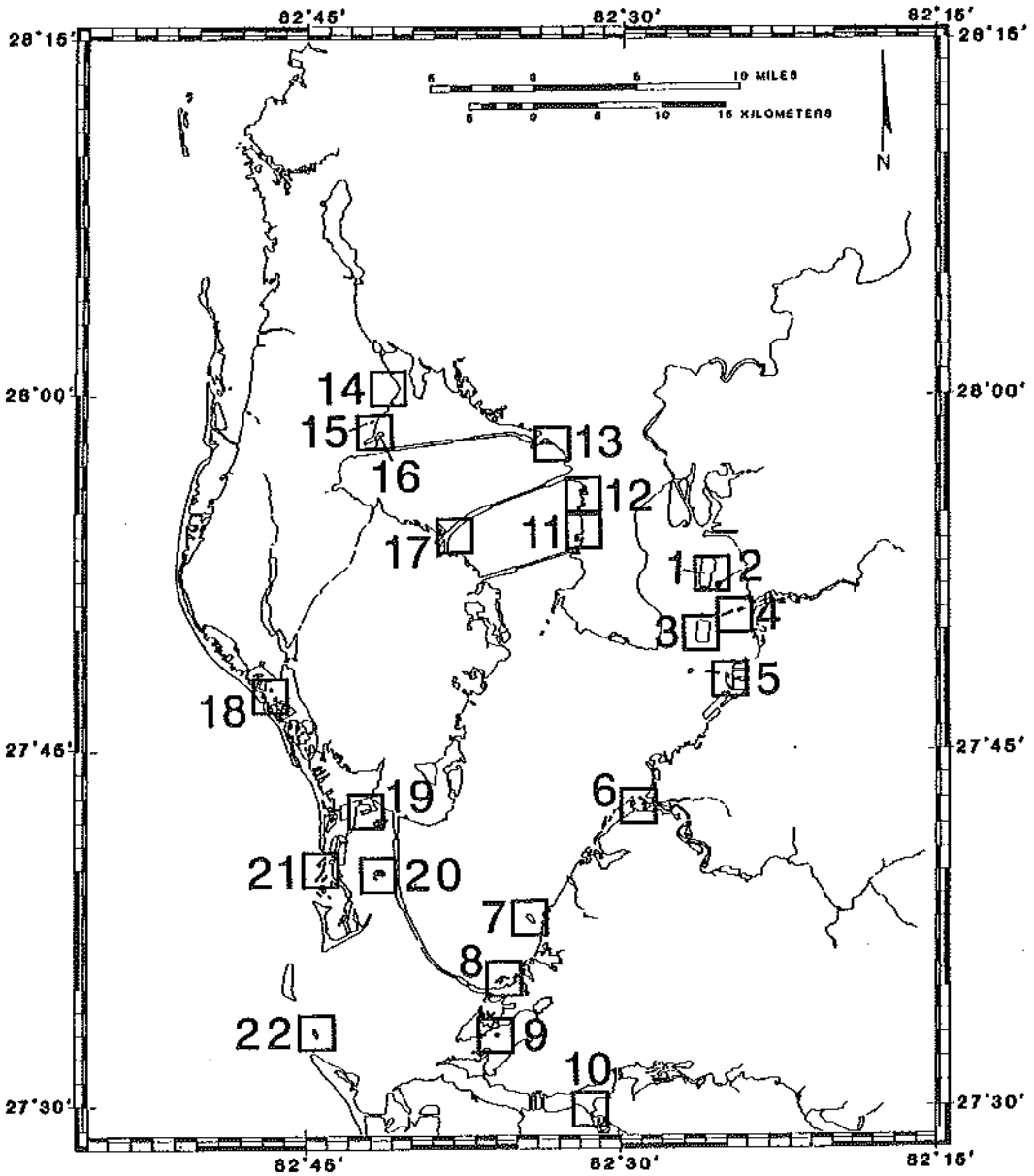

Figure 1. Bird colonies of Tampa Bay, 1980-84. (See Table 1).

Table 1. Bird colonies of Tampa Bay, 1980-1984 (from Fig. 1). All population estimates expressed as breeding pairs (= nests). P - Pelecaniformes; C - Ciconiiformes; L - Iarids.

Colony Number	Name	Nesting Species Taxa	Nesting Species Number	Total Population	Site Protected?	Source
1	Island 2D	L	5	20,000	no	Patton and Hanners, pers comm.; Paul, unpubl.
2	Fantasy Island	L	2	6-15,000	yes	Patton and Hanners 1984
3	Island 3D	L	7	500	no	Patton and Hanners, pers. comm.; Paul, unpubl.
4	Alafia Bank	PCL	20	10-15,000	yes	Nesbitt et al. 1982; Paul, unpubl.
5	Fishhook/TECO Spoil	L	2	30	no	Paul, unpubl.
6	Mouth of Little Manatee River	C	6	210	no	Nesbitt et al. 1982; Paul, unpubl.
7	Port Manatee Spoil	L	1	4,200	no	Patton and Hanners 1984
8	Two Brothers Island	C	1	0-9	no	Nesbitt et al. 1982
9	Washburn Sanctuary	PC	15	4,000	yes	Nesbitt et al. 1982; Paul, unpubl.
10	Mouth of Braden River	PC	9	500	no	Paul, unpubl.
11	Westshore	C	1	37	no	Paul, unpubl.
12	Sunset Park	C	1	35	no	Paul, unpubl.

Table 1 continued.

Colony Number	Name	Nesting Species Taxa	Nesting Species Number	Total Population	Site Protected?	Source
13	Wilson Property	C	1	5	no	R. R. Lewis, unpubl.
14	Philippe Park	C	1	30	yes	Paul, unpubl.
15	Alligator Lake	C	7	500+?	no	G. T. Bancroft, pers. comm.
16	Cooper's Point	C	1	8	no	Paul, unpubl.
17	Howard Frankland Causeway	L	1	100	no	Paul and Patton, unpubl.
18	Johns Pass	PC	5	350	no	Nesbitt et al. 1982
19	Bayway Spoil	L	2	15-30,000*	no	Patton and Hanners 1984
20	Tarpon Key	PC	10+	2,000+	yes	Paul, unpubl.
21	Shell Keys	L	1	100	no	Paul, unpubl.
22	Passage Key	L	6	7,500	yes	Patton and Hanners 1984; Paul, unpubl.

*Colony site lost to development after 1983 season.

are found on the smallest of the three islands just inside the mouth of the pass. Small numbers of pelicans, cormorants, and several herons occur. This colony has been less intensively surveyed than many in Tampa Bay.

Passage Key was established as a National Wildlife Refuge in 1905. At the time, herons nested in trees on the island (Howell 1932). No trees remain; only low, salt-tolerant vegetation exists on this small (approximately 1 ha) barrier island. Regular scouring by high tides and storms maintains habitats suitable for terns, skimmers, and Laughing Gulls.

Bayway Spoil, the largest Laughing Gull colony in the state and possibly the country in the 1970s and early 1980s (Patton, in prep.), was last used by breeding gulls in 1983. Construction activities rendered it unsuitable thereafter. Undoubtedly many of the gulls nesting in the newer Hillsborough Bay colonies have moved from Bayway.

Islands 2D and 3D were built in Hillsborough Bay in 1978 and 1982 respectively. Both exceed 200 ha in area. Least and Gull-billed Terns and Black Skimmers nested on 2D in 1978-81, but moved to 3D in 1982. In that same year Laughing Gulls began to nest on 2D, and within one year numbered about 20,000 pairs (S. R. Patton and L. A. Hanners, pers. comm.). As grasses spread on 3D the same shifts in nesting birds are to be expected.

Several colonies described by Scott (1887) are no longer active: in Old Tampa Bay, Papy's Bayou, Double Branch and Rocky Creek; in Hillsborough Bay, Green Key and Indian Key. Some of these sites were shot out by plume hunters in the last century (Scott 1887) but Indian Key was active in the 1920s (Bent and Copeland 1927) and late 1950s ("Pinellas Bird Key" of Ogden 1978a, who noted the colony to be the second largest in Florida), and Green Key was active until the 1960s.

Of the 22 sites identified in Table 1, all but six (nos. 11, 12, 13, 14, 16, 17) are islands. Five of the remainder are small dry-land colonies of Yellow-crowned Night-Herons or Great Blue Herons, two species which commonly select such sites. The last site is the beach-like shore of the Howard Frankland Causeway, where about 100 pairs of Black Skimmers nest annually.

Annotated List of Breeding Birds

1. Brown Pelican Pelecanus occidentalis. Because of its large size and habit of nesting on top of the canopy, Brown Pelicans are fairly easy to census. At the three major colonies (Tarpon Key, Alafia Bank, Washburn Sanctuary), nest counts supplemented by aerial survey data reveal a total of 2,000 or more breeding pairs annually through 1983. About 50-75 pairs breed at Johns Pass and the mouth of the Braden River for a baywide total of nearly 2,100 pairs. In 1984, the three major colonies all increased dramatically to 2,700-3,000 pairs, an unexpected development whose explanation is at present unknown. The Brown Pelican is increasing in Florida, with 8,500 pairs the best statewide estimate available (S. A. Nesbitt, pers. comm.). In Tampa Bay are two of the five largest colonies in the state, and nearly a third of the statewide population.

This is the best known of all species in the bay. A large literature on the biology of Brown Pelicans has developed on movements, behavior, growth, diet, pesticide residues, populations, and parasites. Many workers have obtained some or all of their data from Tampa Bay (e. g. Blus et al. 1974; Nesbitt et al. 1977, 1981; Humphrey et al. 1978; Schreiber 1979; Fogarty et al. 1981; Schreiber and Schreiber 1983, and references therein). See also the excellent review in Clapp et al. (1982a).

2. Double-crested Cormorant Phalacrocorax auritus. Double-crested Cormorants are abundant year-round residents of Tampa Bay, and breed at Alafia Bank, Tarpon Key, Washburn Sanctuary and Johns Pass. This species has been largely ignored locally, and the available data on breeding populations are incomplete and probably

underestimates as well. Clapp et al. (1982a) noted two colonies in Tampa Bay with more than 500 adults in 1976, presumably Alafia Bank and Washburn Sanctuary. But nest counts at Alafia Bank in 1984 by Paul indicated at least 500 pairs at that site alone, and it is likely that the breeding population baywide exceeds 1,000 pairs.

3. Anhinga Anhinga anhinga. Anhingas prefer freshwater feeding habitats but occasionally nest at coastal colonies. In Tampa Bay the breeding population probably does not exceed 100 pairs, with nearly all found at Tarpon Key and Washburn Sanctuary.

4. Great Blue Heron Ardea herodias. Great Blue Herons are common residents and widely distributed throughout the Tampa Bay area. They breed at all three major colonies and also at Johns Pass and several other small colonies (nos. 6, 8, 10, 13, 16). The total population is conservatively estimated to be 300 pairs. Great Blues are among the earliest species to nest, beginning as early as December, with most young fledging by April or May. A few pairs breed later.

5. Great Egret Casmerodius albus. Great Egrets are also common throughout the area, and breed at sites 4, 6, 9, 10, 15, 18 and 20. Total numbers may well be underestimated at 550 pairs. Ogden (1978a) suggested that Great Egret numbers have remained stable in Florida since the late 1950s. We lack data for previous years for Tampa Bay colonies.

6. Snowy Egret Egretta thula. Flight-line surveys at Washburn Sanctuary suggest a breeding population of 500-700 pairs in 1981-1984 (Paul, unpubl. data). This is one of the largest Snowy colonies in the state. Snowies also breed at six other sites (4, 6, 10, 15, 18, 20), with approximately 250 at Alafia Bank and possibly the same number at the remaining five colonies. Numbers at several of these sites are poorly known, however, and further survey is necessary. One thousand pairs is probably a conservative estimate. Rodgers (1980a) estimated nesting success over two years at Alafia Bank to be 2.0 young per nest (survival to 2 weeks).

Ogden (1978a, b) reported numbers at Tampa Bay sites to exceed 3,500 pairs, but by the mid-1970s the largest colony was 600 pairs at Alafia Bank. Our data indicate that the population decline is continuing.

7. Little Blue Heron Egretta caerulea. Little Blue Herons feed largely in fresh water, but may nest in coastal colonies. In Tampa Bay they nest at colonies 4, 6, 9, 10 and 15. Flight-line surveys at Alafia Bank and Washburn suggest 100-150 and 55 pairs respectively, with much smaller numbers believed to nest elsewhere. One thousand pairs were estimated in the late 1950s at Alafia Bank, but just 300 in the 1970s (Ogden 1978a). Two possible causes of the decline are the loss of freshwater wetlands to development of eastern Hillsborough County, and shooting by tropical fish farmers in the Gibsonton area (see Rodgers 1982). Nesting success in 1976-77 (1.5 2-week old young per nest) was also markedly lower than that of Snowies or Tricolored Herons, although clutch size was not (Rodgers 1980a, b).

8. Tricolored Heron Egretta tricolor. Tricolored Herons are widespread in the area, and breed at all the mixed heronries located (4, 6, 9, 10, 15, 18, 20). Numbers are best known for Alafia Bank and Washburn, totalling 450-500 pairs. Similar numbers may nest at Alligator Lake, but no survey has been conducted there (G. T. Bancroft, pers. comm.). Smaller numbers nest at the other sites but further survey efforts are necessary. The total Tampa Bay population is estimated to 1,000 pairs. It is not clear whether this species has declined since the 1950s; Ogden (1978c) reported an aerial survey estimate of 1,000-2,000 pairs.

9. Reddish Egret Egretta rufescens. Reddish Egrets formerly bred commonly in Tampa Bay. Scott (1887) found them in large numbers at Indian Key, and also at Johns Pass, Double Branch Creek, and Rocky Creek. They

were not known to breed in Tampa Bay this century until 1974, when found at Alafia Bank (Paul et al. 1975). They have nested there annually since, and subsequently have been found at the Washburn Sanctuary and Tarpon Key. The total population is now 30 pairs, or about 10% of the statewide population (Paul, in prep.). About 20 pairs breed at Alafia Bank.

10. Cattle Egret Bubulcus ibis. Cattle Egrets are abundant breeders at Alafia Bank and Washburn Sanctuary, with smaller numbers at Tarpon Key, Alligator Lake, Johns Pass, and the mouths of the Braden and Little Manatee Rivers. Many large colonies are in interior Florida as well (Nesbitt et al. 1982). First found nesting in Florida in 1953 (Sprunt 1954), the Cattle Egret now outnumbers all other herons in the state (Ogden 1978a). In the Tampa Bay area breeding numbers exceed 3,000 pairs. Cattle Egrets feed primarily on insects, not fish and other aquatic organisms, and therefore do not compete with other herons for food. At times, however, they may compete for nesting sites (Werschkul 1978).

11. Green-backed Heron Butorides striatus. The Green-backed Heron is rarely colonial but a few pairs breed at some of the colonies discussed here. It is widespread in Florida; no population estimate for the Tampa Bay population is possible.

12. Black-crowned Night-Heron Nycticorax nycticorax. Black-crowned Night-Herons are notoriously difficult to census. Largely nocturnal, they are not as obvious as other herons around the colony. They breed at the three major heronries and possibly at other Tampa Bay colonies, but data are inadequate to estimate an area population. About 40-50 pairs were estimated at both Alafia Bank and Washburn Sanctuary in 1983; smaller numbers are thought to occur at Tarpon Key. Estimates at Alafia Bank in the mid-1970s were much higher (300 pairs; Dunstan 1978a) and indicate a marked decline.

13. Yellow-crowned Night-Heron Nycticorax violaceus. Yellow-crowns feed largely on crustaceans, especially crabs, and therefore are probably less affected than Black-crowns by the loss of freshwater wetlands. They are also easier to survey, and more widespread. They may nest in large colonies, or in small groups away from other birds. Estimates at Alafia Bank in recent years are about 150-190 pairs, with 80-100 at Washburn Sanctuary and smaller numbers elsewhere (sites 6, 10, 18, 20). Small groups of 30-35 nests have also been found high in the oak trees of Philippe Park (site 14) and the pines of Sunset Park and Westshore (sites 12 and 13). From these dry-land colonies adults fly shoreward to forage along intertidal flats, creeks and drainage ditches. The total population exceeds 350 pairs, again indicating a decline since the 1970s when Dunstan estimated that many at Alafia Bank alone (Nesbitt et al. 1982).

14. White Ibis Eudocimus albus. The White Ibis is, after the Cattle Egret, the most common wader in Florida. In Tampa Bay a very large colony nests at Alafia Bank; in 1983, a year of ample rainfall and wet conditions, 10,200 pairs were estimated by the flight-line technique, or twice the population of the preceding year. Ogden et al. (1980) have suggested that many ciconiiform birds may curtail nesting efforts in dry years. Elsewhere in the area, 1,000-2,000 pairs breed annually at Washburn Sanctuary. Though some may breed at Tarpon Key and elsewhere, the total is probably fewer than 100 pairs. White Ibis feed in a wide variety of habitats, from suburban lawns to mangrove swamps, but despite this flexibility are decreasing here and elsewhere in the state due to development and drainage of wetlands (Kushlan 1978). At Alafia Bank, White Ibis numbers have declined at least 50% since the late 1950s (Ogden 1978a).

15. Glossy Ibis Plegadis falcinellus. Glossy Ibis apparently first nested in Tampa Bay in 1967 (Dunstan 1978b). Since then, numbers have increased at Alafia Bank to 200-250 pairs and to 80-100 at Washburn Sanctuary, and baywide numbers may currently be

stable. They are not known to breed at other Tampa Bay colonies. Glossies forage primarily in freshwater wetlands and wet pastures, areas at risk as development continues.

16. Roseate spoonbill Ajaia ajaja. Most Roseate Spoonbills found in Tampa Bay are post-breeding migrants from Florida Bay (Robertson et al. 1983), and are found in small scattered groups along protected mangrove shorelines. Prior to 1900, spoonbills apparently nested at Indian Key and Johns Pass (Allen 1942). They were reported again at Indian Key in 1912 (Howell 1932) but were not recorded breeding in the region again until 1975, when at least 7 nests were found at Alafia Bank (Dunstan 1976). They have nested annually since, and currently number 20-30 pairs. No other nesting is known in Florida north of Everglades National Park.

17. Osprey Pandion haliaetus. Osprey populations in the Tampa Bay region have been little studied, but casual observations indicate about 10 nests in the area of Cockroach Bay and the mouth of the Little Manatee River. A few others may occur, primarily from Bishops Harbor southwest to Terra Ceia Bay and along the western shore of Old Tampa Bay, but the total population probably does not exceed 25 breeding pairs. Ospreys are quite common in some parts of Florida (Howell 1932) but we are not aware of any indications that numbers in Tampa Bay have ever been large.

18. Bald Eagle Haliaeetus leucocephalus. As recently as the 1940s, a dense population of Bald Eagles occurred in the Tampa Bay area. Broley (1947) observed at least 66 nests in Pinellas, Hillsborough and Manatee Counties. Most of these were located close to the coast. As of 1984, 17 active nests are known (data from Florida Game and Fresh Water Fish Commission), a decline of at least 75%. Primary causes have been rapid urban development following World War II and the use of persistent pesticides, notably DDT (Peterson and Robertson 1978). Broley (1947) also noted the effects of logging of pine forests, which removed the large trees needed for suitable nest sites, and shooting. The Southern Bald Eagle is currently listed as endangered by federal authorities, and as threatened by the Florida Game and Fresh Water Fish Commission.

Development remains the most serious problem threatening local numbers of Bald Eagles. Current guidelines used by the U.S. Fish and Wildlife Service and Florida Game and Fresh Water Fish Commission (FWS, no date) recommend a primary buffer zone of 750' around each nest, within which nearly all human activities are discouraged. In some cases, however, land use decisions have been made in disregard of the guidelines or without knowledge of the presence of the nest. In such cases eagles have moved to new nest sites or disappeared.

Although none of the "coastal" nests occur in the mangrove zone or on islands within the Tampa Bay system as defined in this symposium, it should be pointed out that most eagles nesting within 3 km of the coast forage regularly along bay shores.

19. Snowy Plover Charadrius alexandrinus. A severely threatened species, Snowy Plovers have nearly vanished from the Gulf Coast of Florida (Woolfenden 1978). They are restricted to barrier beaches where few pairs now remain because of heavy human use. In Tampa Bay, the remaining beaches on Passage Key, Mullet Key and Shell Keys are too heavily used by humans for many plovers to persist. The large dredged material islands in Hillsborough Bay may provide habitat for a few pairs; on 14 June 1981 we saw seven Snowy Plovers on Island 2D (Paul 1981), while the following year two were seen on 3D.

20. Wilson's Plover Charadrius wilsonia. Wilson's Plovers breed in barren habitats at the back of the mangrove zone near the mean high water line, as well as on barrier islands, spoil islands and causeways. They are much more common than Snowy Plovers, but few data exist regarding local population size. In 1981 at least 30-40 pairs were

found on Island 2D. As vegetation has grown more dense on 2D, the plovers have moved to 3D but fewer have been found there. The baywide population probably exceeds 50 pairs but we have too few data to speculate further.

21. American Oystercatcher Haematopus palliatus. Oystercatchers were found nesting in the Tampa Bay area by Scott (1889) but they were considered rare by the early 1900s (Howell 1932). Kale (1978a) considered them increasing in recent years in Florida. In Tampa Bay, observations by Paul, Patton and Hanners indicate at least 35 pairs on Hillsborough Bay spoil islands, and 15 or more on islands near the bay mouth. In the entire bay system 60-75 pairs may be present.

22. Black-necked Stilt Himantopus mexicanus. Dinsmore (1977) reported on nesting Black-necked Stilts in McKay Bay. Investigations since then have been scanty but Paul found stilts nesting on Island 2D in 1981, 1982 and 1984, while S. R. Patton (pers. comm.) found nesting birds on 3D in 1984. The baywide population is unknown, but at those two sites there are a minimum of 30 pairs.

23. Willet Catoptrophorus semipalmatus. Willets are widely distributed and conspicuous breeders in most areas where salt marshes or grassy habitats just above the high tide line can be found. They exploit causeways and spoil islands readily. The population is probably not at risk, but its size is unknown.

24. Laughing Gull Larus atricilla. The Laughing Gull is the most common breeding bird of Tampa Bay. Patton and Hanners (1984) estimated 50,000 pairs at six colonies in Tampa Bay in 1981 and 1982. Since then most of the population has shifted to Hillsborough Bay colonies due to the loss of the Bayway colony, habitat changes at Passage Key, newly available habitats at Island 2D and now 3D, and possibly the closure of the Toytown Dump in St. Petersburg. Recently, Clapp et al. (1983) estimated the Florida Gulf Coast population of Laughing Gulls to be 58,540 birds, or 22% of the breeding population of the southeastern U.S. With about 100,000 birds now known locally, we now estimate that Tampa Bay Laughing Gulls comprise one-third of the entire breeding population of the Southeast.

25. Gull-billed Tern Sterna nilotica. A very few pairs nest annually, usually with Black Skimmers. In 1981, about 4 pairs were found on 2D (Paul 1981). In 1983, 3 nests were found in a skimmer colony on 3D, while in 1984 S. R. Patton (pers. comm.) found 10 nests there. Very little is known about this species locally.

26. Caspian Tern Sterna caspia. The first Florida nesting record of this tern was in 1962 on new fill for the Bayway in Boca Ciega (Woolfenden and Meyerriecks 1963). Since then most Caspian nesting attempts in the state have been in Tampa Bay (reviewed by Schreiber 1978). In 1981-83, 13-30 pairs nested annually at Alafia Bank and adjacent islands. Forty-five pairs nested on Island 3D in 1984, the most ever in Florida.

27. Royal Tern Sterna maxima. Royal Terns nest annually in Tampa Bay at one of two sites, Alafia Bank (1981-82) or Passage Key (1982-84). The population in 1981-83 was about 800 pairs, and exceeded 1,000 in 1984. With the recent erosion of other colony sites in Florida, this is one of two remaining in the state (see also Clapp et al. 1983).

28. Sandwich Tern Sterna sandvichensis. There are few Sandwich Tern nesting records in Florida this century (Kale 1978b). Since 1979, however, they have been found almost annually with Royals when they nested at Alafia Bank. At Passage Key they were harder to detect but probably nested there also. The largest number found was 8 pairs at Alafia Bank in 1982 (Paul 1982).

29. Least Tern Sterna antillarum. In recent years Least Terns have nested in a variety of locations in the Tampa Bay area, including McKay Bay, Alafia Bank, Islands 2D and 3D, a small spoil island in the TECO breakwater (site 5 in Fig. 1), Passage Key, Shell Keys, a small salt barren at the edge of Terra Ceia

Bay, an undeveloped residential lot on Anna Maria, and rooftops in St. Petersburg and Tampa. Colonies ranged in size from a few pairs to over 100, with the largest numbers on Island 3D in 1982 where two colonies totalled about 250 pairs. Least Terns move so readily between years, and even between nesting attempts, that it is difficult to carry out a comprehensive survey. It is likely that the baywide population is on the order of 300-500 pairs.

30. Black Skimmer Rynchops niger. Like Least Terns, Black Skimmers nest primarily on sand or shell beaches of spoil islands, causeways and natural barrier islands, and move readily from one site to another as conditions change. In recent years, skimmers nested at Islands 2D, 3D, Alafia Bank, Howard Frankland Causeway, Passage Key and Bayway Spoil. The best estimate of local populations was in 1983 when 800 pairs were found at five colonies (Paul 1983). Largest numbers were at 3D (400 pairs) and Passage Key (265).

Five additional species worthy of mention breed locally in mangroves: Clapper Rails (Rallus longirostris), Mangrove Cuckoos (Coccyzus minor), Gray Kingbirds (Tyrannus dominicensis), Black-whiskered Vireos (Vireo altiloquus), and Prairie Warblers (Dendroica discolor). Mangrove Cuckoos, the rarest of the five, are found annually on islands in Boca Ciega Bay. The other four species are more widely distributed along Tampa Bay mangrove shorelines. Though Gray Kingbirds may also nest in uplands beyond the mangroves, all five species are regarded as essentially coastal birds. Only the rail is relatively common locally. No estimates of population density are known to us.

WINTERING BIRDS

Ducks, shorebirds and many of the species listed above dominate the wintering bird populations of Tampa Bay. Notable wintering or nonbreeding populations of a few other species occur as well, and these are identified below.

1. Common Loon Gavia immer. Common Loons are widespread in the open waters of the bay system from November through March, but there are few data on the local population. Following an oil spill in Tampa Bay in 1970, a bird rescue operation handled about 500 loons, a "major fraction" of the local winter population (Clapp et al. 1982a, p. 64; Sims 1970).

2. Horned Grebe Podiceps auritus. Horned Grebes are commonly found in Tampa Bay in winter, with loose flocks frequenting waters off sandbars and single birds more widely distributed. Two hundred were handled in rescue operations following the 1970 oil spill (Sims 1970), but more can be seen during boat trips along bay shorelines and the total population may exceed 1,000 birds. No survey has ever been attempted, however, and that estimate is speculative.

3. American White Pelican Pelecanus erythrorhynchos. White Pelicans are found year-round in Hillsborough Bay but do not breed. Populations are largest in winter, with up to 400 counted in roosting flocks at Alafia Bank and Island 3D. White Pelicans also commonly use McKay and Terra Ceia Bays, and scattered sites in Old Tampa and Boca Ciega Bays.

4. Magnificent Frigatebird Fregata magnificens. Frigatebirds are common nonbreeding visitors from April to October, found chiefly in the lower portions of Tampa Bay. Two important roosts are known, Tarpon Key and Washburn Sanctuary. Up to 1,000 birds have been counted at Tarpon Key (Harrington et al. 1972), while at Washburn the roost normally numbers 200-300 (pers. obs.). Most frigatebirds seen at local roosts are males. Harrington et al. (1972) have suggested that the distribution of the sexes is influenced by wind conditions and wing loading.

5. Fish Crow Corvus ossifragus. Fish Crows are abundant permanent residents, and nest throughout the area - despite their treatment here as a non-breeder - including on Tampa Bay islands. They are persistent egg

predators in bird colonies. Following the breeding season Fish Crows roost in large flocks on these same islands. Numbers peak in winter: over 22,000 have been counted at Alafia Bank (Paul, in Stevenson 1982). The roost at Washburn exceeds 4,000 birds. Crows are known to roost at Tarpon Key but have not been counted.

Wintering Birds of McKay Bay and Safety Harbor

McKay Bay, the northeastern segment of Tampa Bay, is well known for harboring large numbers of maritime birds (Lewis and Courser 1972; Woolfenden and Schreiber 1973; Courser and Lewis 1975). For eleven years (1971-1981) during one half day in winter (late December or early January), all of the birds using the saltwater environments of McKay Bay have been counted by a single party of observers led by G. E. Woolfenden.

The count day was chosen months ahead of time, therefore no controls of important environmental variables were attempted. Perhaps the most important of these variables was tide. However, tidal effect was ameliorated in that all count periods lasted 6 or 7 hours (dawn until midday). Other environmental factors either did not occur (e. g. steady hard rain) or were trivial (e. g. cold, wind). However, below-normal temperatures farther north on the continent cause local changes (e. g. more wintering waterfowl during colder winters).

Human activities in and near McKay Bay have had great effects on the bird populations. Ditching and diking has occurred along most of the shoreline, and has altered habitats such as mangroves, salt marsh and tidal flats. Warm water effluent from the once operational, adjacent incinerator plant and the development of the Hookers Point sewage treatment facility also have affected the maritime birds of McKay Bay.

A summary of the eleven counts (Table 2) provides base data on species and numbers of birds using this locality in winter. Seventy-five species constitute the list (1 loon, 1 grebe, 2 pelicans, 1 cormorant, 9 herons, 1 stork, 2 ibises, 18 waterfowl, 3 raptors, 3 rails, 24 shorebirds, and 10 gull types). Just over half (38) of the 75 species were present and seen during all 11 counts. Almost one quarter (17 of 75) were recorded only one or two of the 11 counts.

Table 2 includes the average number of individuals of each species counted at McKay Bay based on the eleven censuses. The total of these means (24,510) shows that almost 25,000 marine birds are present in McKay Bay during any day in winter. Almost 80% of the individuals are of five species: 2 ducks (Lesser Scaup, Ruddy Duck) and 3 shorebirds (Dunlin, Short-billed Dowitcher, Western Sandpiper). Only a small percentage of the total number of scaup wintering on Tampa Bay ever occur in McKay Bay. In contrast, Ruddy Ducks are scarce elsewhere in Tampa Bay except during severe winters. The three shorebirds occur throughout Tampa Bay on tidal flats, but are most concentrated on the extensive, muddy flats of McKay Bay. Their numbers in Tampa Bay rival or surpass numbers elsewhere in North America in winter.

Other observations of wintering shorebirds suggest heavy use of intertidal mudflats along the eastern shore of Hillsborough Bay from the Alafia River mouth to the Kitchen (a small diverse embayment east of Green Key and north of Port Redwing) and Port Redwing. Daily movements of shorebirds in this area suggest that many return to McKay Bay at night or as tidal conditions change. A study of the winter ecology of shorebirds is needed to better understand the importance of the McKay - Hillsborough Bay area to these birds.

Censuses similar to those taken at McKay Bay have been conducted along a short segment of the western shore of Old Tampa Bay from Safety Harbor embayment to the Courtney Campbell Causeway. During five consecutive years (1977-1981) 50 species have been seen in the Safety Harbor area, all but

Table 2. The wintering maritime birds of McKay Bay and Safety Harbor: mean numbers and frequency of occurrence on Christmas Bird Counts, 1971-1981. t = mean less than 0.5.

SPECIES	MCKAY BAY (N=11) mean	MCKAY BAY (N=11) frequency	SAFETY HARBOR (N=5) mean	SAFETY HARBOR (N=5) frequency
Common Loon	t	1	7	5
Horned Grebe	9	11	201	5
American White Pelican	18	10	-	-
Brown Pelican	33	11	94	5
Double-crested Cormorant	42	11	498	5
Great Blue Heron	19	11	20	5
Great Egret	30	11	23	5
Snowy Egret	36	11	26	5
Little Blue Heron	24	11	30	5
Tricolored Heron	32	11	26	5
Reddish Egret	1	2	t	1
Green-backed Heron	4	11	5	5
Black-crowned Night-Heron	6	11	4	3
Yellow-crowned Night-Heron	13	11	23	5
White Ibis	108	11	222	1
Roseate Spoonbill	t	1	t	1
Wood Stork	10	11	3	5
Snow Goose	t	1	-	-
Green-winged Teal	346	11	-	-
American Black Duck	t	1	-	-
Mottled Duck	1	6	-	-
Mallard	1	3	-	-
Northern Pintail	145	10	t	1
Blue-winged Teal	150	11	-	-
Northern Shoveler	565	11	-	-
Gadwall	3	5	-	-
Eurasian Wigeon	t	2	-	-
American Wigeon	256	11	9	3
Canvasback	359	11	-	-
Redhead	1	2	-	-
Lesser Scaup	6,455	11	3,400	5
Oldsquaw	t	1	-	-
Surf Scoter	-	-	t	1
Bufflehead	t	1	5	1
Red-breasted Merganser	7	11	53	5
Ruddy Duck	1,359	11	182	1
Osprey	t	5	3	5
Bald Eagle	t	2	1	3
Northern Harrier	2	11	1	3
Clapper Rail	21	11	4	5
Sora	8	8	-	-
American Coot	290	11	-	-
Black-bellied Plover	146	11	76	5
Wilson's Plover	8	8	38	5
Semipalmated Plover	41	11	50	5
American Oystercatcher	t	1	4	3

Table 2 continued.

SPECIES	MCKAY BAY (N=11) mean	MCKAY BAY (N=11) frequency	SAFETY HARBOR (N=5) mean	SAFETY HARBOR (N=5) frequency
Black-necked Stilt	7	7	-	-
American Avocet	224	11	-	-
Greater Yellowlegs	22	11	2	3
Lesser Yellowlegs	134	11	t	2
Willet	49	11	50	5
Spotted Sandpiper	9	11	21	5
Whimbrel	1	5	-	-
Long-billed Curlew	t	3	-	-
Marbled Godwit	1	3	-	-
Ruddy Turnstone	2	4	43	5
Red Knot	124	7	335	5
Sanderling	t	2	21	5
Western Sandpiper	7,409	11	262	5
Least Sandpiper	301	10	105	5
White-rumped Sandpiper	t	1	-	-
Dunlin	2,025	11	3,280	5
Stilt Sandpiper	2	2	-	-
Short-billed Dowitcher	2,082	11	548	5
Long-billed Dowitcher	18	8	-	-
Wilson's Phalarope	t	1	-	-
Laughing Gull	809	11	440	5
Bonaparte's Gull	8	9	70	5
Ring-billed Gull	466	11	230	5
Herring Gull	49	11	52	5
Lesser Black-backed Gull	t	1	-	-
Caspian Tern	7	8	5	5
Royal Tern	4	7	19	5
Common Tern	t	1	-	-
Forster's Tern	90	11	70	5
Black Skimmer	115	10	73	5
Total	24,510		10,635	

one of which (Surf Scoter) are recorded for McKay Bay. Number of individuals present, 10,635, is less than half that found at McKay Bay. Seventy-four percent (37 of 50) of the species were present for all five counts; 12% (6 of 50) were seen only one or two times.

Wintering Waterfowl

The U.S. Fish and Wildlife Service and the Florida Game and Fresh Water Fish Commission conduct annual midwinter (January) waterfowl surveys in Tampa Bay. Aerial surveys are flown along standard transects around the margins of Tampa Bay, with the resulting data an index of the total bay area population but not a total census. Data for the period 1971-1981 are presented in Table 3.

Lesser Scaup was by far the most abundant, with Northern Shovelers, Ruddy Ducks, teal, and American Wigeon the most common of the remaining 13 species identified. Bellrose (1976) estimated numbers of Lesser Scaup wintering in Florida at nearly 285,000. Tampa Bay scaup were a large fraction of the state population at that time (Table 3). Index data, however, suggest a sharp decline after 1975. This decline was most serious in the scaup. Recent perturbations of the bay system, including the creation of Islands 2D and 3D, may have had an impact on waterfowl populations, particularly scaup which feed on molluscs and could have depended on portions of Hillsborough Bay now lost. However, Montalbano and Johnson (in press) have analyzed similar winter population survey data for Ring-necked Ducks in Florida and concluded that apparent declines were the result of variation in survey routes and effort. F. Montalbano (pers. comm.) has indicated his concern that the same may be true for other waterfowl species surveyed in winter in Florida, and pointed out that breeding surveys compiled by the U.S. Fish and Wildlife Service and Canadian Wildlife Service indicate a stable or increasing Lesser Scaup population over the last 30 years.

In Tampa Bay, a small shift in distribution of wintering waterfowl would be sufficient to cause significant changes in population indexes derived from aerial transect surveys. In the absence of additional data on breeding populations and on local and regional movements of wintering waterfowl, we cannot conclude that a serious decline has occurred, but we can call attention to the possibility. An evaluation of Tampa Bay waterfowl is urgently needed.

FACTORS AFFECTING POPULATIONS

A variety of factors, many already noted, influence bird abundance in Tampa Bay. This review cannot address all of them, but several deserve comment.

Red tides, a natural occurrence in the Gulf of Mexico, occasionally affect Tampa Bay waters. In 1974, a serious red tide was associated with mortality of several thousand waterfowl, primarily Lesser Scaup, in early 1974 (Schreiber et al. 1975; Forrester et al. 1977). Schreiber et al. (1975) were unable to assess the impact of losses on the area population without additional information.

A protozoan parasite was identified as the cause of mortality of Red Knots (Calidris canutus) at Johns Pass in 1973 (Woodard et al. 1977). Argasid ticks are known to occur in the nests of ground-nesting birds in the Gulf of Mexico (e. g. King et al. 1977), occasionally in concentrations leading to nest abandonment. To our knowledge, ticks have not yet been found in Tampa Bay colonies but they probably have not been sought.

Dredge and fill activites have had both beneficial and negative effects. Beach-nesting species have nested extensively on newly constructed islands, causeways, and shoreline fills, and in Hillsborough Bay spoil islands include the largest colonies of pelicans/herons/ibis (Alafia Bank) and gulls (Island 2D) in the state. Waterfowl and shorebirds use the protected waters and mudflats inside the large diked islands 2D and 3D, and new shorelines have offered opportunities to plant new marsh communities of value to

Table 3. Population trends in wintering waterfowl in Tampa Bay. Data from Florida Game and Fresh Water Fish Commission.

Year	Lesser Scaup	Other Species*
1971	95,600	1,600
1972	82,000	4,100
1973	103,700	1,600
1974	72,200	2,300
1975	105,900	2,000
1976	15,300	600
1977	62,900	1,500
1978	10,100	300
1979	8,400	400
1980	12,400	1,500
1981	19,900	2,200

*including Mottled Duck, Gadwall, American Wigeon, Green-winged Teal, Blue-winged Teal, Northern Shoveler, Northern Pintail, Redhead, Canvasback, Common Goldeneye, Ruddy Duck, Red-breasted Merganser and American Coot.

birds. On the other hand, large areas of coastal mangroves and intertidal wetlands have been lost, bay bottoms silted in or replaced by islands, and drainage patterns altered. Dredging and the construction of seawalls have probably also increased turbidity in the water column, a problem discussed elsewhere in this symposium.

Landfills are used extensively by gulls, which has probably contributed to increasing numbers of Laughing Gulls in Tampa Bay (Patton and Hanners 1984).

Tropical fish farms in the Gibsonton area provide a food source for a variety of fish-eating birds, including Little Blue Herons (Rodgers 1982), but foraging birds are sometimes shot. The impact of such mortality is unknown but may affect several species of herons nesting at Alafia Bank, as well as Double-crested Cormorants and Least Terns.

Pesticides and heavy metals are potential problems for birds feeding on organisms in Tampa Bay. The effects of pesticides on Brown Pelicans and some other species have been well documented but residue levels in Tampa Bay populations are poorly known. Heavy metal residues were the subject of a preliminary investigation in McKay Bay (Gude 1977) but more work is needed in view of the potential contaminant sources along heavily industrialized shorelines, especially in Hillsborough Bay.

Oil spills are potentially one of the most dramatic problems affecting bird populations. Nearly all species discussed here feed on fish or marine invertebrates, and loons, grebes, pelicans, ducks, gulls and terns all feed by partial or total immersion in water. Spills can cause bird mortality by direct contact or by ingestion during attempts to preen feathers or during foraging, and can kill prey species or coat intertidal vegetation and mudflats (see also Clapp et al. 1982a, b; 1983). Several studies have also shown that oiled birds can transfer oil to eggs during incubation, reducing hatching success (e. g. King and Lefever 1979; White et al. 1979; Parnell et al. 1984). Bird cleaning operations, though well-intentioned, probably prevent little mortality (Sims 1970). Recent exploration for oil and gas off the Florida Gulf coast has led to a comparison of the potential effects of onshore storage and handling facilities. Potential impacts on rare, threatened or

endangered plants and vertebrates are considered to be more severe if facilities are located in Charlotte Harbor than if located in Tampa Bay (McCoy 1981; Woolfenden 1983). This report identifies large populations of birds that may be at risk if oil and gas facilities are eventually constructed in Tampa Bay.

Lastly, it must be pointed out once again that drainage and alteration of wetlands are the single most important cause of declining populations of colonial birds. In south Florida, Robertson and Kushlan (1974) estimated a 90% decrease in numbers of 10 wading bird (ciconiiform) species since the 1930s. We lack data to estimate declines over the same period, but information presented in this paper suggests a decline of 50% or greater in just 25 years for the following species: Snowy Egret, Little Blue Heron, White Ibis, and possibly Black-crowned and Yellow-crowned Night-Herons.

SUMMARY

About 75,000 pairs of colonial birds, two-thirds of them Laughing Gulls, breed in Tampa Bay. Large populations of wintering birds also exploit bay resources, notably shorebirds and waterfowl. These populations have persisted despite significant and continuing alteration of shoreline habitats, bay bottom and freshwater wetlands. Recent population declines in many species suggest that, as elsewhere in Florida, progressive urbanization threatens to further reduce the carrying capacity of the Tampa Bay system for many species.

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MARINE MAMMALS, REPTILES, AND AMPHIBIANS OF TAMPA BAY AND ADJACENT COASTAL WATERS OF THE GULF OF MEXICO

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ABSTRACT

The purposes of this paper are twofold: 1) to name and describe the distribution of the species of mammals, reptiles, and amphibians found in Tampa Bay and in the Gulf of Maxico coastal waters adjacent to the Bay; and 2) to make recommendations for future research concerning those species that are endangered and for which few biological data exist. Twenty species of marine mammals have been reported in the survey area, but only two of these species, the bottlenose dolphin (Tursiops truncatus) and the West Indian manatee (Trichechus manatus), may be considered regular residents of the area. The few surveys conducted indicate a year-round population of over 100 bottlenose dolphins in the total survey area. The manatee population varies seasonally, with a maximum of almost 60 animals in the winter. The other species of marine mammals are all cetaceans that are only occasionally spotted at sea or found stranded. Three of the twenty marine mammal species found in the study area are endangered. The reptiles found in the survey area include several species of sea turtle, the mangrove water snake (Nerodia fasciata compressicauda), and the ornate diamondback terrapin (Malaclemys terrapin macrospilota). The species of sea turtle most commonly found in the area is the threatened loggerhead (Caretta caretta caretta) which nests (about 200 individuals) there; a Federally funded intensive survey of the sea turtles found in the South Atlantic and Gulf of Mexico is underway. The most common amphibian in the study area is the marine toad (Bufo marinus), which is not abundant. Studies aimed toward collection of data with applicability for management and conservation of the relatively unstudied, but rare, mammals and reptiles must be initiated. Studies in progress will be described and recommendations for future research will be made.

Certain species included in the Orders Mammalia, Reptilia, and Amphibia have received considerable interest for a variety of reasons: economic, physical appearance, endangered status, key role in the ecosystem, or simple curiosity. Despite such interest, adequate data are sadly lacking in many cases.

Our purposes are to 1) describe the distribution of reptiles, mammals, and amphibians in Tampa Bay and adjacent Gulf coastal waters, and 2) survey the past and current research done on these species, and to make recommendations for future endeavors. We have extended the survey area beyond Tampa Bay itself because many of the animals we are describing are very mobile; their presence anywhere near Tampa Bay strongly suggests that the Bay itself falls within their range.

The first group of animals that we will discuss is the marine mammals.

Several problems face marine mammal scientists. The mobility, speed and diving capabilities of the animals make them difficult and expensive to contact and follow. The animals are often submerged and, in murky coastal waters, they may be present but undetected. Present State and Federal funding levels have been inadequate, so that much of the marine mammal research that has been done to date in Florida has been voluntary. Consequently, any recommendations appearing in this paper concerning future marine mammal research are made with full awareness of their impossibility under current funding. Although a number of marine mammal species are occasionally seen alive or found stranded in the survey area (Moore 1953; Layne 1965; Caldwell and Caldwell 1973; Schmidly 1980), the only regular inhabitants are the West Indian manatee (Trichechus manatus) and the bottlenose dolphin (Tursiops truncatus).

The endangered West Indian manatee has been impacted by man throughout human residency in Florida (Odell and Reynolds 1979; Reynolds 1979; Brownell et al. 1981; Reynolds 1981). The manatee was described as "remarkably abundant" in Tampa Bay a little over a century ago (Maynard 1872). It was not until 1974, however, that an actual survey of manatees in this area was undertaken (Hartman 1974). Hartman reported that manatees were uncommon in Sarasota County, a little more plentiful in Manatee County, common in Hillsborough County, especially in the Little Manatee River, and very rare in Pinellas and Pasco Counties. He estimated a summer population of 40 animals in Tampa Bay itself, with an additional 35 animals scattered widely in the surrounding areas.

Hartman's (1974) rather cursory survey has since been augmented by two more thorough ones. Irvine et al. (1981 ms.) surveyed the Bay area from July - December 1979, and they found a maximum, during their December aerial survey, of 50 manatees in Tampa Bay, with only 14 manatees outside Tampa Bay. They found that the manatee numbers were lower in the warmer months.

Patton (1980) conducted a year-round survey of only the Bay itself, and found that manatee numbers varied seasonally, with a high of 55 animals in the winter. Patton (1980) demonstrated that the animals aggregated around artificial warm-water refugia in the winter, and that the animals dispersed during the summer, with many individuals being found in the Manatee and Little Manatee Rivers (Fig. 1). Descriptions of this winter aggregation of animals led to the designation of the Alafia River as a sanctuary under the Florida Manatee Sanctuary Act of 1980.

The only other research conducted on the Tampa Bay manatee population concerns animals recovered by the manatee carcass salvage network, part of the Southeastern United States Marine Mammal Stranding Network (see SEAN reports, 1980-1982, for locations of recent stranded animals). Twenty-two manatees have been recovered from the total survey area since 1974; 20 of these animals were recovered from the Bay or its tributaries (U.S. Fish and Wildlife Service, pers. comm., 1982).

Carcass salvage, while not a glamorous undertaking, is vital. From data accumulated from dead animals, scientists have learned about many aspects of manatee biology including causes of mortality, disease agents, heavy metal and pesticide sequestering, feeding habits, and the function and structure of the digestive tract. Data such as these complement field data to help provide a more comprehensive picture of the manatee.

It has long been recognized that conservation efforts must be taken to protect manatees (Bertram 1974). In other parts of Florida besides Tampa Bay, considerable scientific work has been done (Brownell and Ralls 1981; Odell and Reynolds 1980a) and considerable efforts in public awareness and law enforcement have paid off (Oberheu and Prather 1979; Willis

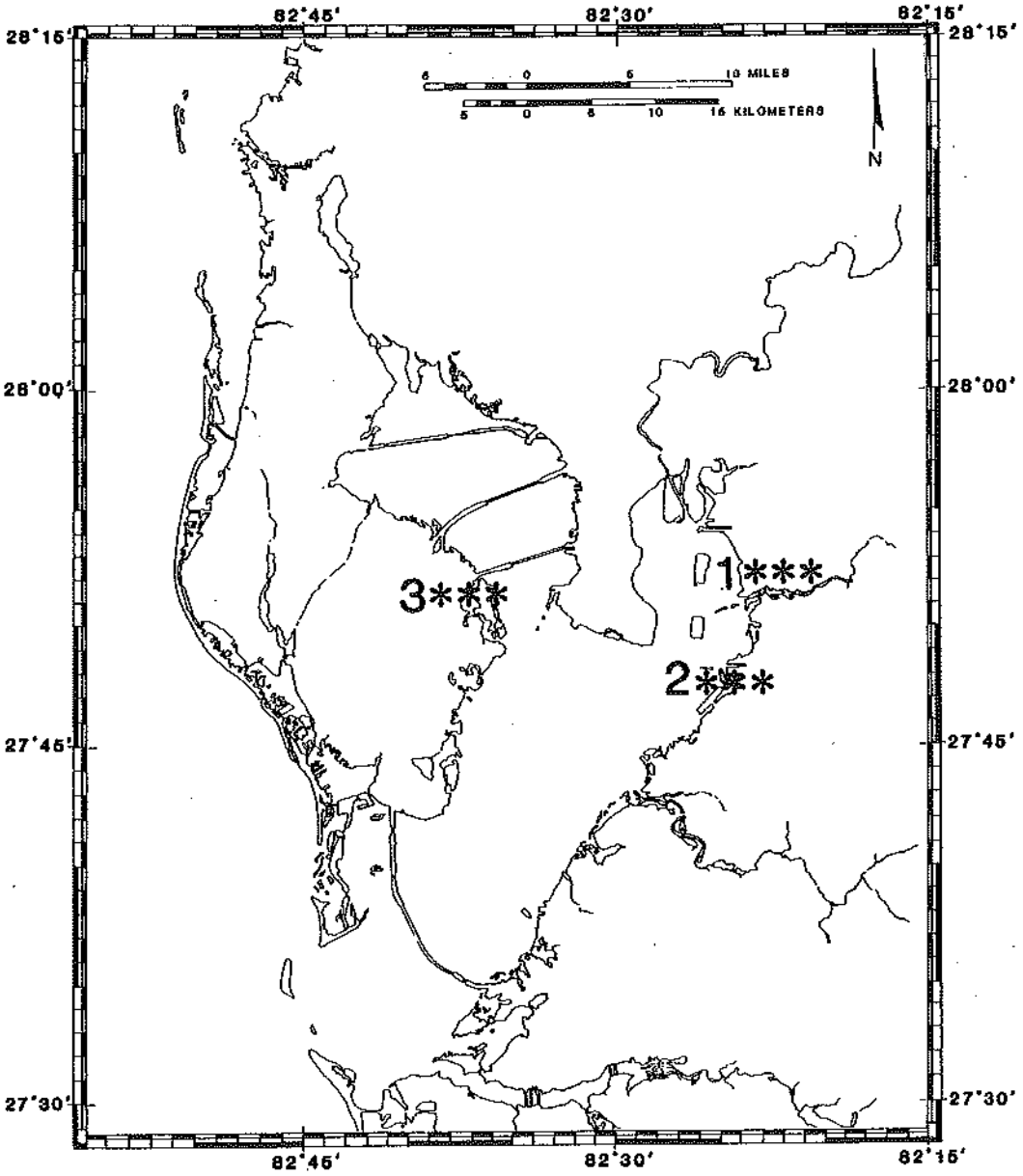

Figure 1. Locations within Tampa Bay that are marked with asterisks (***) indicate regions where manatees aggregate during cold weather. Location 1 is the Alafia River, where the Gardinier Phosphate Plant is located; location 2 is the site of the Tampa Electric Company's Big Bend plant; and location 3 is the site of Florida Power and Light's Bartow plant.

1979). Manatees in Tampa Bay should receive attention for several reasons:

1. Seasonally up to about 6% of the total established manatee population in Florida (about 1,000 animals) is present in the Bay;
2. A great deal of human activity (e.g., boating) that has been shown to be harmful to manatees occurs in the Bay. Further, the human population and human activity in the Bay area are increasing.
3. Tampa Bay could represent a migration route for the well-studied Crystal River manatees moving south.
4. The Tampa Bay manatee population has not been adequately studied to date.

Statewide, a comprehensive work plan has been established to direct research, educational, and legislative efforts concerning manatees (Rose et al. 1981). Additionally, a Manatee Advisory Committee, chaired by Dr. D. P. Domning, and a Save the Manatee campaign have been established. The goals of statewide programs are the same as for Tampa Bay itself, although the need for research in Tampa Bay is critical due to the lack of information on the population there. A holistic and coordinated approach using standardized methodology is needed in research to establish total numbers of manatees, their seasonal distribution, manatee behavior and movements, interactions with man, and effects of man that could impact manatees in the future. More money for carcass salvage, public education and enforcement of legislation must also be spent. Specific programs that should be funded include the following:

1. Comprehensive, repeated aerial surveys to establish abundance and distribution.
2. Behavioral studies (radio tracking) to record specifically what manatees do in the Bay.
3. Studies of potentially harmful human activities should be assessed. For example, the new span of the Sunshine Skyway Bridge is soon to be built. Monitors may notice direct impact of the project on manatees, but indirect impacts such as of underwater noise, pressure waves (if dynamite is used), and increased siltation should also be carefully examined and monitored.
4. Carcass salvage should receive more funding to insure that necropsies are done as soon as carcasses are found.
5. Funding to enhance public awareness as to human effects on manatees should be increased.
6. Finally, more money for signs warning boaters about manatees, as well as for hiring more enforcement personnel, should be allocated.

The other year-round marine mammal resident of Tampa Bay is the bottlenose dolphin. This species is not endangered, but, similar to the manatee, the bottlenose has not been thoroughly studied in Tampa Bay. Most dolphin research there has concerned population assessment via aerial surveys (Odell and Reynolds 1980b; Patton 1980; Irvine et al. 1981 ms.), although Dr. Richard Goldston and other authorized individuals have regularly performed necropsies on stranded specimens.

Odell and Reynolds (1980b) used line transect surveys to estimate the coastal bottlenose dolphin population in the survey area exclusive of Tampa Bay to be over 200 animals, which were found in small herds (mean = 2.87 to 5.97 animals/herd, depending on which section of coastline is considered). In the coastal zones, dolphins were equally likely to be found from the shoreline to a distance of 15 miles offshore. Tampa Bay itself was not surveyed by Odell and Reynolds (1980b).

Irvine et al. (1981 ms.) found that dolphin numbers in Tampa Bay and adjacent waters increased from July to November 1979, and that dolphin numbers appeared higher outside the Bay than within it. Irvine et al. (1981 ms.) offered no estimate of dolphin abundance

due to their inconsistent survey methods. Patton (1980) found a maximum of 23 dolphins in the Bay during any one aerial survey in 1979-1980, but his surveys, similar to those of Irvine et al. (1981 ms.) were not conducted in a way that allowed statistical verification of a dolphin population estimate for the Bay. Dolphin mortality in Tampa Bay is rather low compared to mortality levels in other parts of Florida such as the Indian River. Only 5 animals have been reported dead in the Bay area since January 1981 (SEAN 1981-1982).

Starting at the extreme southern end of Tampa Bay, but concentrated in Sarasota Bay, an intensive study of the movements and activities of bottlenose dolphins was conducted in 1975-1976 (Wells et al. 1980; Irvine et al. 1982). Fifty-seven dolphins were marked or fitted with radio tags and subsequently followed. The results indicated the following:

1. A localized herd, estimated at 102 animals, occupied a near-shore home range from southern Tampa Bay to a distance 40 km south. Possibly distinct herds, besides the one just mentioned, may exist in adjacent coastal waters.
2. The localized herd was typically split into small groups (mean = 4.8 animals/herd) having tight social bonds. The mother-calf bond was prolonged.
3. Calving occurred seasonally.

Considering that the bottlenose dolphin is one of the better known of the marine mammals, why are efforts being made to learn more about the species in Florida waters? First, as a carnivore at the top of a food web, the dolphin could be a good indicator species as to the health of the ecosystem. Additionally, Odell and Reynolds (1980b, p. 1) point out that "the major source of bottlenose dolphins has been the coastal waters of the southeastern United States, particularly Florida." The species is still collected in some parts of the state for use in oceanaria, providing that the oceanaria possess the appropriate permits. "It is possible for intensive collection in one particular area to deplete the population, particularly if the local herds have restricted home ranges and there is little interchange with other 'populations' " (Odell and Reynolds 1980b, p. 2). In view of the results of home range studies by Wells et al. (1980) and by Irvine et al. (1982), it would appear advantageous to increase scientific knowledge concerning the relatively unstudied dolphin population occupying most of Tampa Bay. At least five research priorities concerning the Tampa Bay dolphin population and other populations of dolphins near the Bay should be established:

1. Aerial surveys following standard methodology (see Leatherwood et al. 1978 or Eberhardt et al. 1979) should be done to adequately assess the populations in the Bay and adjacent areas.
2. Field studies of the population biology of the Tampa Bay dolphins should be done using techniques such as mark and recapture (Asper and Odell 1980) or natural scar patterns (Shane and Schmidley 1978) to identify individuals.
3. Field studies using techniques just described should be done on the already well-studied dolphin population of southern Tampa Bay and Sarasota Bay (Wells et al. 1980; Irvine et al. 1982).
4. Studies should ascertain which human activities in Tampa Bay could potentially impact dolphins there adversely. Steps should then be taken to monitor such activities and to minimize their detrimental effects. For example, reconstruction of the Sunshine Skyway Bridge could have adverse effects on dolphins for surprising reasons, such as excessive underwater noise causing the animals to be unable to communicate.
5. Funding should be increased to allow more and more thorough necropsies of stranded animals; to date, such

procedures have frequently been done gratis. Thorough necropsies can provide a wealth of information on the health of the population. Goldston (pers. comm, 1981) for example, has found the stomach parasite Braunina cordiformis, in stomachs of many Tampa Bay dolphins, but this parasite is rather rare in animals elsewhere in Florida.

Other marine mammals are occasionally spotted alive or found stranded in Tampa Bay and nearby waters. Unknown to many people, a thriving, shore-based whaling industry has existed in the nearby West Indies since 1875 (Rathjen and Sullivan 1970; Adams 1975; Caldwell and Caldwell 1975).

Schmidley (1980) states that there is a rich marine mammal fauna consisting of 35 species that presently occur or historically occurred along the southeastern coast of the United States or in the Gulf of Mexico. Schmidley (1980) provides an excellent literature review of the marine mammal strandings and sightings from the Tampa Bay area, and SEAN (1980-1982) reports events that have occurred since Schmidley's (1980) paper.

Using Schmidley (1980) and SEAN (1980-1982), the marine mammal occurrences (other than Tursiops truncatus and Trichechus manatus) in the survey area can be summarized (Table 1). No specimens for which identifications were tentative are included in Table 1. Two of the 18 species listed, Megaptera novaeangliae and Physeter catodon, are currently endangered (U.S. Dept. of the Interior 1980).

Research currently being done on stranded marine mammals mainly entails necropsies of dead animals and attempted rehabilitation at oceanaria (e.g., Sea World of Florida, Miami Seaquarium, Marineland) for living specimens. Despite inadequate funding for such operations, a wealth of data has been collected through the coordinated efforts of members of the Southeastern United States Marine Mammal Stranding Network. Personnel are now available and lines of communication established so that animals are treated or necropsied very soon after stranding (Reynolds et al. 1981).

The result of such efficiency is a great gain in knowledge concerning species for which, historically, there were few data. For example, Kogia breviceps, once considered to be very rare, has stranded several times around Tampa Bay, and it has, in fact, been shown to be the second most commonly stranded cetacean in Florida, second only to the bottlenose dolphin (Odell et al. 1981); valuable biological data now exist for this "very rare" species.

Besides increasing the funding to and efficiency of the stranding network, priority should be placed on aerial and boat surveys to ascertain the number of animals and their distribution for each cetacean species found in the Gulf, offshore of Tampa Bay. Scientific observers could, perhaps, be allowed to travel aboard and spot marine mammals from tankers crossing the Gulf, thereby eliminating the cost of outfitting a cruise designed simply to collect data.

Above all, a holistic viewpoint should be maintained when dealing with the marine mammals. Man can impact these animals in a number of ways other than direct commercial harvest, and, as pointed out by Geraci and St. Aubin (1980) and Holden (1975), some of the impacts can be somewhat subtle.

The presence of several species of sea turtle within the study area has been recognized for some time (Carr 1952). Five species may be found: the Atlantic loggerhead, Caretta caretta caretta, the Atlantic ridley, Lepidochelys kempii, the Atlantic leatherback, Dermochelys coriaceia (McDiarmid 1978), the Atlantic hawksbill, Eretmochelys imbricata imbricata (Huff et al. 1980), and the Atlantic green turtle, Chelonia mydas mydas (Carr and Caldwell 1956). All of these species are endangered, except the loggerhead, which is threatened (U.S. Dept. of the Interior 1980). Only two species nest within the study area;

Table 1. Marine mammals sighted or stranded in Tampa Bay and in Gulf of Mexico coastal waters between Pasco and Sarasota counties. Numbers represent events, not total number of animals involved. From Schmidley (1980) and SEAN (1980-1982).*

Species	Number of Strandings	Number of Sightings
Balaenoptera edeni	1	0
Megaptera novaeangliae	0	1
Physeter catodon	1	0
Kogia breviceps	5	0
Kogia simus	1	0
Ziphius cavirostris	2	0
Feresa attenuata	1	0
Pseudorca crassidens	0	1
Orcinus orca	0	1
Globicephala macrorhynchus	7	1
Steno bredanensis	1	0
Delphinus delphis	0	1
Grampus griseus	1	0
Stenella frontalis	0	1
Stenella plagiodon	3	1**
Stenella coeruleoalba	1	0**
Stenella longirostris	2	0
Stenella clymene	1	0

*Table 1 does not include strandings or sightings of Tursiops truncatus or of Trichechus manatus.

**indicates species for which numerous sightings have been made offshore of the survey area.

loggerheads use the area frequently, and in 1980, the Longboat Key Turtle Watch Group reported that a hawksbill had nested on Longboat Key (Huff et al. 1980).

The loggerhead is the most likely sea turtle to be seen in the study area (Irvine et al. 1981 ms.). The total United States population of loggerheads numbers at least 25,000 animals, of which an estimated 90% inhabit Florida waters (McDiarmid 1978). Recent nesting records for loggerheads in Sarasota and Pinellas Counties are as follows: 245 nests in 1979, 153 nests in 1980, and 231 nests in 1981 (Huff 1979; Huff et al. 1980; Huff et al. 1981). The lower count in 1980 was attributed to a shorter length of beach being surveyed on Manasota Key that year. The beaches that the loggerheads use most include Manasota Key, Casey Key, and Egmont Key (Huff 1979; Huff et al. 1980; Huff et al. 1981).

At present, volunteer Turtle Watch groups on Longboat, Casey, and Manasota Keys monitor nesting locations, move or incubate nests when necessary, tag female turtles, and release nestlings. Some groups provide detailed measurements to an on-going cooperative research program between the Florida Department of Natural Resources and the U.S. Fish and Wildlife Service.

Mote Marine Laboratory has recently tried to organize the independent Turtle Watch groups in the area, to provide a mutual forum for communications, cooperation, and support. One of Mote's immediate concerns is to organize staff and local volunteers to make certain that there are no gaps in surveys of nesting turtles. The Mote Lab hopes to provide educational, research, and rescue and rehabilitation support in the future (Mapes, pers. comm., 1982).

Other sea turtle research includes a recently funded (by the National Marine Fisheries Service, NMFS) effort to survey nesting beaches and pelagic turtles in the southeastern United States. This study focuses on the coastal zone from Cape Hatteras to the Dry Tortugas, but it also includes annual nesting beach surveys in the Gulf of Mexico, including Tampa Bay. It is hoped that funding of the project might be increased to allow more intensive surveys of the Gulf.

NMFS also has recently funded a Southeastern United States sea turtle carcass salvage program, modeled after and administered by the personnel who administer the marine mammal carcass salvage program for the same geographic region. It is hoped that the turtle salvage program will be as successful as the marine mammal program has been in defining causes of mortality and in providing large amounts of valuable data on the general biology of the animals. As with the marine mammals, salvaged sea turtles are inventoried by SEAN (all issues).

Additional action is necessary to effectively conserve and manage sea turtles found in the Tampa Bay region. Specific subjects requiring attention are:

1. Basic research to enumerate Gulf turtle populations, describe their movements, pinpoint feeding and nesting areas, and describe habitat requirements at all phases of the life cycle. To collect these data, frequent, standard surveys (e.g. aerial surveys, mark and recapture, radio tagging) should be done.
2. Protection of existing nesting beaches in an undeveloped state. Protection should also include prevention of predation on nests.
3. Continued legal protection of turtles and enforcement of protective laws.
4. Causes of mortality, as determined by necropsies. As already mentioned, sea turtle necropsies would provide a great deal of ancillary biological information that is useful for management.
5. Incubation of eggs and captive rearing and release of young turtles. Morreale et al. (1982) point out that improper incubation temperatures can result in a skewed sex ratio of young, reducing the benefit to wild

turtle populations of release of such young.

6. Monitoring effects of man that either presently could have an effect on sea turtles (e.g., disposal offshore of dredged materials; pollution) or that could impact the animals in the future (e.g., increased boating; construction).

Besides the species already discussed, there are other reptiles that are typically brackish water inhabitants. Neill (1958) indicates that the two primary species found in Tampa Bay are the brackish race of the southern water snake, called the mangrove water snake, Nerodia fasciata compressicauda, and the brackish ornate diamondback terrapin, Malaclemys terrapin macrospilota. The amphibian one is most likely to encounter in brackish water is the marine toad, Bufo marinus, but this species is not restricted to this habitat. Other reptiles and amphibians that are found incidentally in brackish or salt water include the alligator, Alligator mississipiensis, cottonmouths, Agkistrodon piscivorus piscivorus, and tree frogs (Neill 1958).

No distributional studies of the mangrove water snake or of the ornate diamondback terrapin (the only truly brackish species among those listed above) are underway at present (Kochman, pers. comm., 1982). However, both of these species regularly inhabit mangrove swamps, which have become reduced in the Bay area. Comprehensive surveys should, therefore, be made of the distribution, abundance, and habitat requirements of these species. Only with these data available can authoritative statements as to the effects of man's activities be made. Neither the mangrove water snake nor the ornate diamondback terrapin is endangered; hopefully, that status will not be attained by either species.

In conclusion, for most species of marine mammals, reptiles and amphibians found in the Tampa Bay area, an extremely undesirable situation exists: the status of the species is uncertain, few biological data are available, and man impacts the environment in a great number of ways, some obvious and some subtle. In a situation such as this, it is recommended that a cautious approach be used in initiating human projects or activities, and that as much data as possible be accumulated in order to best assess the effects of such projects or activities on the animals in question. Where so many variables are unknown or are poorly understood, it is best to be somewhat overcautious since errors in judgement could result in the eradication of a species from the Tampa Bay area.

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TAMPA BAY: THE END OF THE LINE?

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INTRODUCTION

Much controversy exists as to where the boundary between warm temperate ("Carolinian Province") and tropical marine ("Caribbean Province") organisms occur on the Gulf coast of Florida. Some authors have considered the entire Gulf to be tropical (e.g. Ekman 1953; Van Name 1954; Taylor 1955; Schilder 1956; Hall 1964) or ecotonal for tropical and temperate biotas (Lyons and Collard 1974). Others have suggested that a temperate/tropical demarcation exists at Cedar Key (Warmke and Abbott 1961; Coomans 1962), Cape Romano (Pulley 1952; Briggs 1974) or Tampa Bay (Hedgpeth 1953; Rehder 1954; Earle 1969; Humm 1969).

Distinct physical, geological or biological characteristics may be invoked to explain possible floral/faunal range terminations at Tampa Bay. Tampa Bay lies at the northern edge of a geomorphic division referred to as the Central Barrier Coastal Zone (Brooks 1973). Some of the disjunct distributions of marine organisms may be a result of the geologic emergence of peninsular Florida in late Pleistocene times (Abele 1970). Furthermore, Tampa Bay has been reported to serve as a southern temperature/salinity boundary to an area that extends northward to Cape San Blas (Jones et al. 1973). Temperature/salinity profiles collected in areas north of Tampa Bay demonstrate a simple salinity pattern with some evidence of nearshore runoff and eddy structure, while a complex area of rings or cells of salinity distributions, indicating the interface between the Loop current and shelf water, has been noted south of the Tampa Bay region (Jones et al. 1973). Finally, mangrove estuaries replace salt marsh estuaries of the northwestern coast of Florida near Tampa Bay (Provost 1972).

Our objective is to critically examine the suggestion that Tampa Bay serves as a marine biogeographic boundary, by using quantitative techniques. Below we report on the application of these techniques to the species' distribution of five taxa: fishes, decapods, gastropods, bivalves and polychaetes.

DATA

We chose to analyze species distributions of fishes, decapods, gastropods, bivalves, and polychaetes because presence/absence data were readily available for locations both north and south of Tampa Bay. Species lists for individual taxa were compiled from a subset of 8 sites along the western coast of Florida: Pensacola/Panama City, Alligator Harbor, Cedar Key, Anclote Key, Tampa Bay, Sarasota Bay, Charlotte Harbor, and Florida Bay (Fig. 1) and a species x location matrix constructed. We filled in certain gaps in the matrix: 1) when a species was not reported from one site that fell between two adjoining sites where it was recorded, and 2) when a species was known from the Keys and was reported from locations between Florida Bay and Alligator Harbor, but not in Florida Bay. Making such modifications did not greatly affect our conclusions.

Table 1 summarizes the sources of information used for each taxa. Only those organisms identified to species and found in less than 10 m of water were included in our survey. A graphical illustration of all species data for individual taxa and sites is presented in Figure 2.

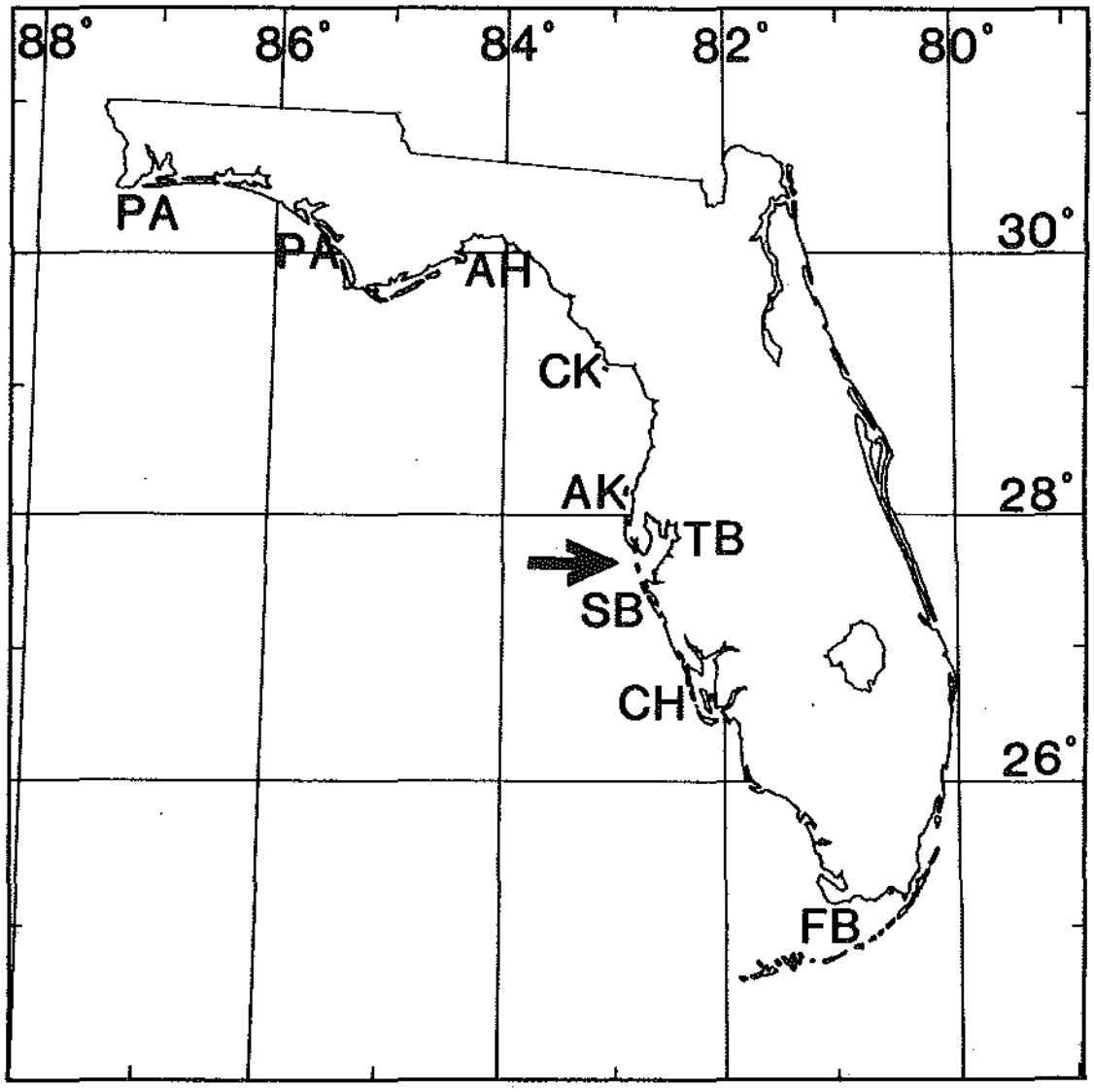


Figure 1. Map of Florida, showing the eight locations for which distributional data were compiled (see text for further explanation). PA = Pensacola/Panama City; AH = Alligator Harbor; CK = Cedar Key; AK = Anclote Key; TB = Tampa Bay; SB = Sarasota Bay; CH = Charlotte Harbor; FB = Florida Bay. The arrow indicates Egmont Key.

Table 1. References used to compile distributional information on the five taxa used in our analyses.

References	Taxa				
	POLY-CHAETES	GASTRO-PODS	BIVALVES	DECAPODS	FISHES
Bloom (in press)	x				
Perkins & Savage 1975	x				
Taylor 1961	x				
Mahadevan et al. 1981	x	x	x		
Taylor 1973	x	x	x		
Tiffany 1974	x	x	x		
Dragovich & Kelly 1964	x	x	x	x	
Hall & Lindall 1974	x	x	x	x	
Simon (unpubl.)	x	x	x	x	
Estevez 1981	x	x	x	x	x
Menzel 1971	x	x	x	x	x
Mahadevan 1981	x			x	
Lykes & Hall 1970		x	x		
Taylor et al. 1970		x	x		
Tabb & Manning 1961		x	x	x	
Abele 1970				x	
Hulings 1961				x	
McNulty 1974				x	
Rouse 1970				x	
Snedaker 1974				x	
Codey 1978				x	x
Grimes 1971				x	x
Gunter & Hall 1965				x	x
Berry 1957					x
Berry 1958					x
Caldwell 1954					x
Caldwell 1955					x
Caldwell 1957					x
Clark 1971					x
Godcharles & Jaap 1973					x
Grimes & Mountain 1971					x
Hastings 1979					x
Joseph & Yeager 1956					x
Kilby 1955					x
Lindall et al. 1975					x
Livingston et al. 1977					x
Moe & Martin 1965					x
Powell et al. 1972					x
Reid 1954					x
Roessler 1970					x
Springer 1961					x
Springer & Woodburn 1960					x
Sykes 1966					x
Yerger 1961					x
Zilberberg 1966					x

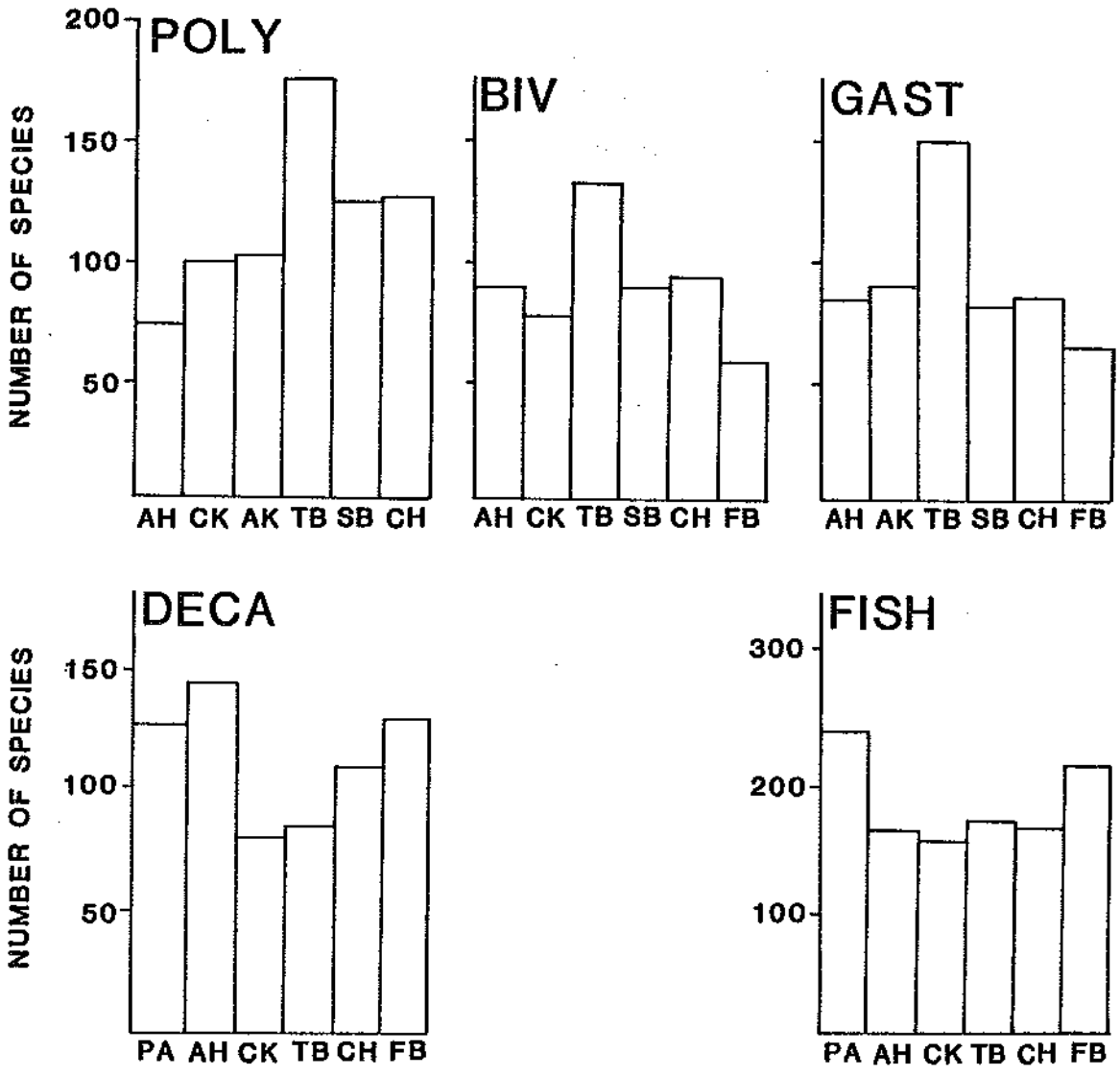


Figure 2. Numbers of species of polychaetes, bivalves, gastropods, decapods, and fish recorded from each of the sites for which we compiled distributional information.

DATA ANALYSIS

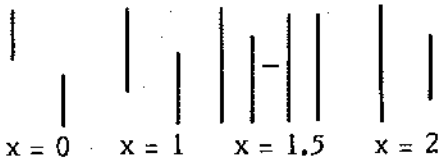
The positions of putative boundaries typically are determined by intuition. A researcher with considerable accumulated knowledge on the group of organisms in question uses such knowledge to identify disjunctions in species' distributions. This procedure is appropriate, perhaps even desirable, as a starting point. The guesses produced in this fashion should yield eventually to more rigorous quantification, however.

Examples of quantitative determination of boundaries in the distributions of marine orgaisms are few. Pielou (1977) introduced a simple technique for locating boundaries, and illustrated it using algal distributions. We will describe the technique below. Horn and Allen (1978) used cluster analysis, based upon Canberra-metric dissimilarity, to examine distributions of California coastal marine fishes. On the west coast of Florida, Hayden and Dolan (1976) used cluster analysis to locate a general marine faunal boundary somewhere between Pensacola and Tampa Bay. The nature of the data these authors used, as well as their clustering technique, prevented a more precise location of the boundary.

To analyze the potential role of Tampa Bay as a marine biotic boundary, we chose two separate methods. By using two methods, we hoped to be able to cross-check our conclusions. As well, neither of the methods chosen, Peilou's (1977) end-point technique or Raup and Crick's (1979) probabilistic similarity technique, has been used extensively, and therefore little is known of potential pitfalls in the application of each. Both methods are described in detail in the papers cited above; therefore we will present only a brief outline of them.

Pielou's (1977) end-point technique is used to determine if a series of species' distributions occur along a gradient independently of one another. If the distributions are not arranged independently, but end-points tend to co-occur along the gradient, then these "boundaries" will be spotted with the technique. Note that we used the unconditional hypothesis (H1) in our analysis, which does not take into account the range lengths of the species. We proceeded as follows:

(1) Assign a value to each pair of species' ranges, according to the scheme:



(2) Compute an observed Σx.

(3) Compute an expected Σx by calculating:

$$E(\Sigma x) = S(S-1)/2$$

where S = number of ranges.

(4) Compute a variance by calculating:

$$Var(\Sigma x) = S(S^2-1)/9$$

(5) Compare observed and expected values, and if they differ, examine the data more closely to account for the deviation.

This technique can be used only for species with uninterrupted ranges; therefore, the number of species employed in our analysis was less than the total number for which we had distributional information.

Raup and Crick's (1970) probabilistic similarity index determines if the taxonomic similarities among geographical locations are different than one would expect had the species been assigned to the locations randomly. Most "boundaries" should appear as "breaks" in a sequence of higher-than-expected similarities. We used the following analysis, much of which required the aid of a computer:

(1) Randomly assign each of S species to Y locations, where Y is the number of locations at which the species actually occurs.

(2) Repeat step (1) 20 times, tallying the number of species in common between all locations each time.
(3) Use the Monte Carlo simulation to generate an expected number of species in common and a variance.
(4) Compare observed and expected values, and examine the data to explain any deviations. Note that one could employ cluster analysis here, but we chose not to do so.

One should realize that either of these techniques can indicate differences in species distributions, and thus boundaries, but not the nature of the boundary. For the problem examined here, for example: a boundary at Tampa Bay may be detected, but it may not separate necessarily temperate and tropical provinces. Other criteria must be used to judge the affinities of faunas and floras.

RESULTS

Table 2 displays the results of applying Pielou's (1977) end-point technique to our data. The table illustrates that for all five taxonomic groupings, the calculated sum of x exceeds the expected sum of x. This result must derive from the presence of a great deal of overlap among species' distributions. Indeed, upon closer examination, the data revealed three common types of species' distributions:

(1) Species ranging through all locations (occurred for all five taxonomic groupings).
(2) Species confined to Tampa Bay (polychaetes, gastropods, bivalves).
(3) Species confined to the Panhandle (crabs).

The results indicate, therefore, no biotic boundary per se at Tampa Bay. The large number of ubiquitous species would tend to obscure any subtle divisions among species' distributions which might exixt, however. The analysis did reveal distinct species compositions in Tampa Bay and the Panhandle, at least for some taxa. These patterns, which have been noted previously, should be examined further.

The results of our analysis using Raup and Crick's (1979) probabilistic similarity index are more involved. Table 3 displays the similarity matrices among locations for the five taxonomic groupings. Careful inspection of these matrices reveals the following generalizations:

(1) Geographically adjacent locations tend to be more similar than expected (this observation is true for fish, decapods, and polychaetes).
(2) The Panhandle and the southern portion of the peninsula are less similar than expected (fish, decapods, polychaetes, bivalves).

Table 2. Results of the analysis of species' distributions using Pielou's (1977) endpoint technique.

	Fishes	Decapods	Polychaetes	Gastropods	Bivalves
$E(\Sigma x)$	27966	14706	24090	9870	10731
$Var(\Sigma x)$	1.48×10^6	5.65×10^5	1.18×10^6	3.11×10^5	3.53×10^5
Σx	48739.5*	21337.5*	32276.5*	15367.5*	14129.5*

*p less than 0.05

Table 3. Results of the analysis of species' distributions using Raup and Crick's (1979) probabilistic similarity technique. + = observed similarity greater than expected; - = observed similarity less than expected; 0 = observed and expected similarities not different (p = 0.05).

POLYCHAETES

	AH	CK	AK	TB	SB	CH
AH		0	0	-	-	-
CK			+	0	0	-
AK				0	0	0
TB					+	0
SB						+

GASTROPODS

	AH	AK	TB	SB	CH	FB
AH		+	0	0	0	0
AK			0	0	0	0
TB				0	-	-
SB					+	0
CH						-

BIVALVES

	AH	AK	TB	SB	CH	FB
AH		+	-	0	-	-
AK			0	+	0	0
TB				0	-	0
SB					0	0
CH						0

DECAPODS

	PA	AH	CK	TB	CH	FB
PA		0	0	-	-	-
AH			+	0	-	0
CK				+	+	+
TB					+	0
CH						+

FISH

	PA	AH	CK	TB	CH	FB
PA		0	0	-	-	0
AH			+	+	+	-
CK				+	+	0
TB					+	0
CH						0

(3) Tampa Bay is less similar than expected to surrounding locations (gastropods, bivalves).
(4) Anclote Key is more similar than expected to locations further north (polychaetes, gastropods, bivalves).
(5) Florida Bay is less similar than expected to locations further north (fish, gastropods).

It can be seen that the first three generalizations are very similar to the ones generated by Pielou's (1977) end-point technique (above). Note, however, that the list of taxa to which each applies in the two analyses are not identical. Again, the evidence that Tampa Bay is a biotic boundary is minimal. It may be so for polychaetes (see Table 3), but the large number of "endemics" there clouds interpretation. The last two generalizations indicate geographical locations where the search for biotic boundaries in the eastern Gulf of Mexico might be centered, at least for the taxa considered here: between Florida Bay and Charlotte Harbor (hereafter referred to as "Cape Romano" for purposes of comparison with other studies), and in the vicinity of Anclote Key. Note that these two locations have been mentioned as boundaries before (see Introduction).

CONCLUSIONS

Although we found little evidence that Tampa Bay serves as a boundary for tropical species of fishes, decapods, polychaetes, gastropods, or bivalves, examination of the problem should not be discontinued. Better data, as well as data from other locations, may indicate a different pattern than the one we have found. In addition, for other taxonomic groups, Tampa Bay may indeed serve as the northern terminus for a significant number of tropical species (see, for example, the contribution by Dawes in this volume). Clearly, more systematic collections of species all along the coast of western Florida are needed to provide the raw material for quantitative analysis. The need for additional collections is emphasized by the fact that one of our analyses has tentatively defined the vicinity of Anclote Key as a boundary between groups of species; yet the marine fauna of the coast between Tampa Bay and Alligator Harbor is perhaps the least known in western Florida.

Lyons and Collard (1974) identified faunal boundaries near where we have, based upon their analysis of a large number of dredge and trawl hauls. They emphasized bottom characteristics in erecting geographic subdivisions among benthic invertebrate communities. We concur for the tentative boundary near Anclote Key, but are not convinced that the boundary at Cape Romano is real.

To us, a "boundary" should indicate a barrier to movement: something that prevents passage. If organisms end up on the other side of the "boundary" simply by taking an alternative pathway, then no boundary existed. Consider Figure 3. A sharp drop in similarity may be noted between Florida Bay and Charlotte Harbor, for the four taxa for which we had appropriate data. The drop reinforces the conclusion that a boundary exists there. Yet, it also may be noted that for three of the taxa, similarities rise in the Panhandle. Many of the species that dropped out at Cape Romano reappear in the northern Gulf. The only conclusion to draw is that these species are not following the coast northward from Florida Bay, but are moving offshore somewhere near Cape Romano, outside the 10 m depth limit we set for our analyses. Our conclusion is reinforced by the fact that, at least for fish, many of the species in question have been captured on offshore reefs (Fig. 4). As well, the offshore Loop Current is known to carry species with tropical affinities into northern Gulf waters (see Lyons 1979). Such considerations indicate the complexities and subtleties involved in constructing rather arbitrary boundaries along shores.

The kinds of decisions that must be made in erecting boundaries are illustrated even better by our tabulations of distributional data. At the same time, certain aspects of the tabulation

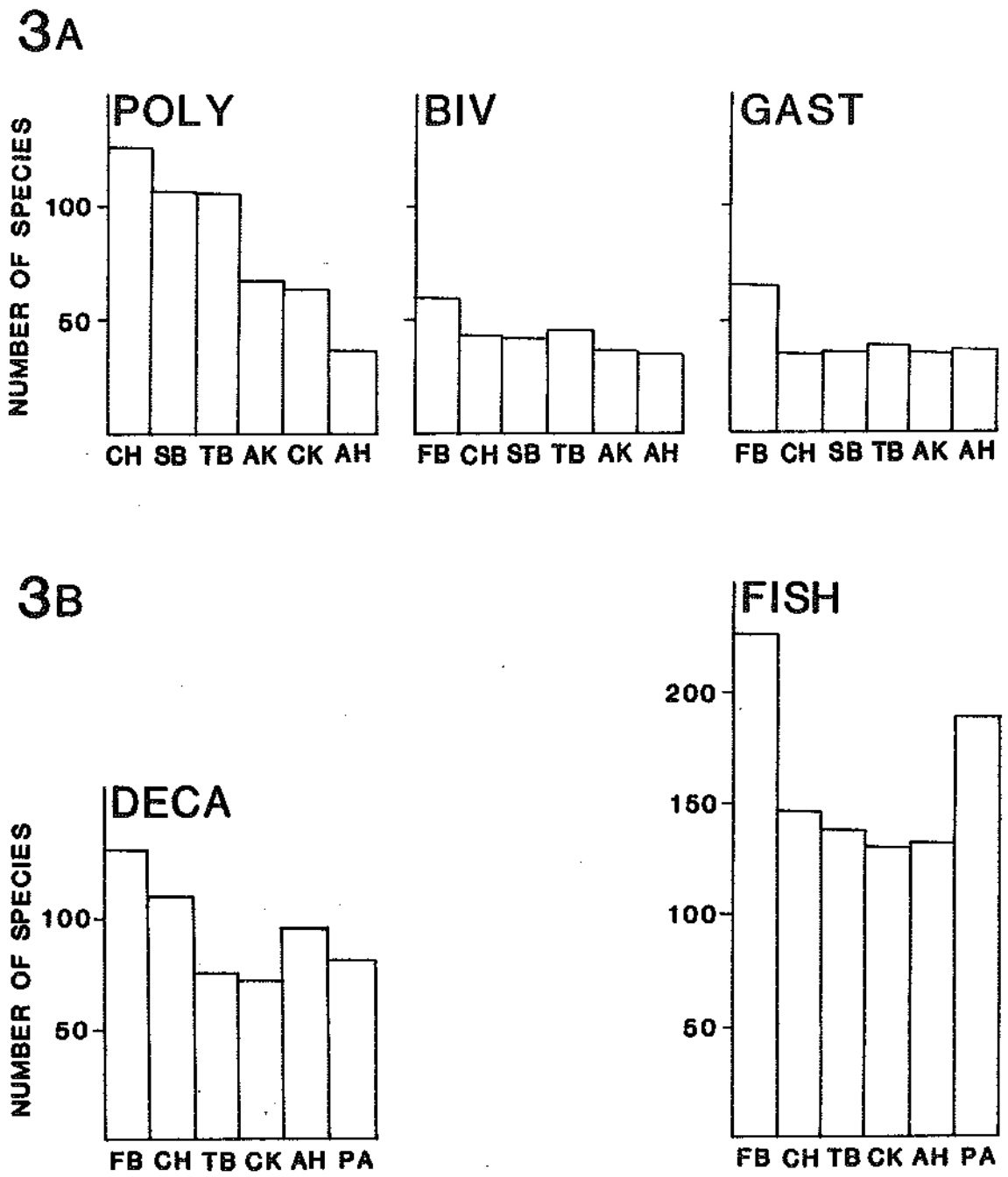


Figure 3. The number of species recorded at each location which also occur at the southernmost location.

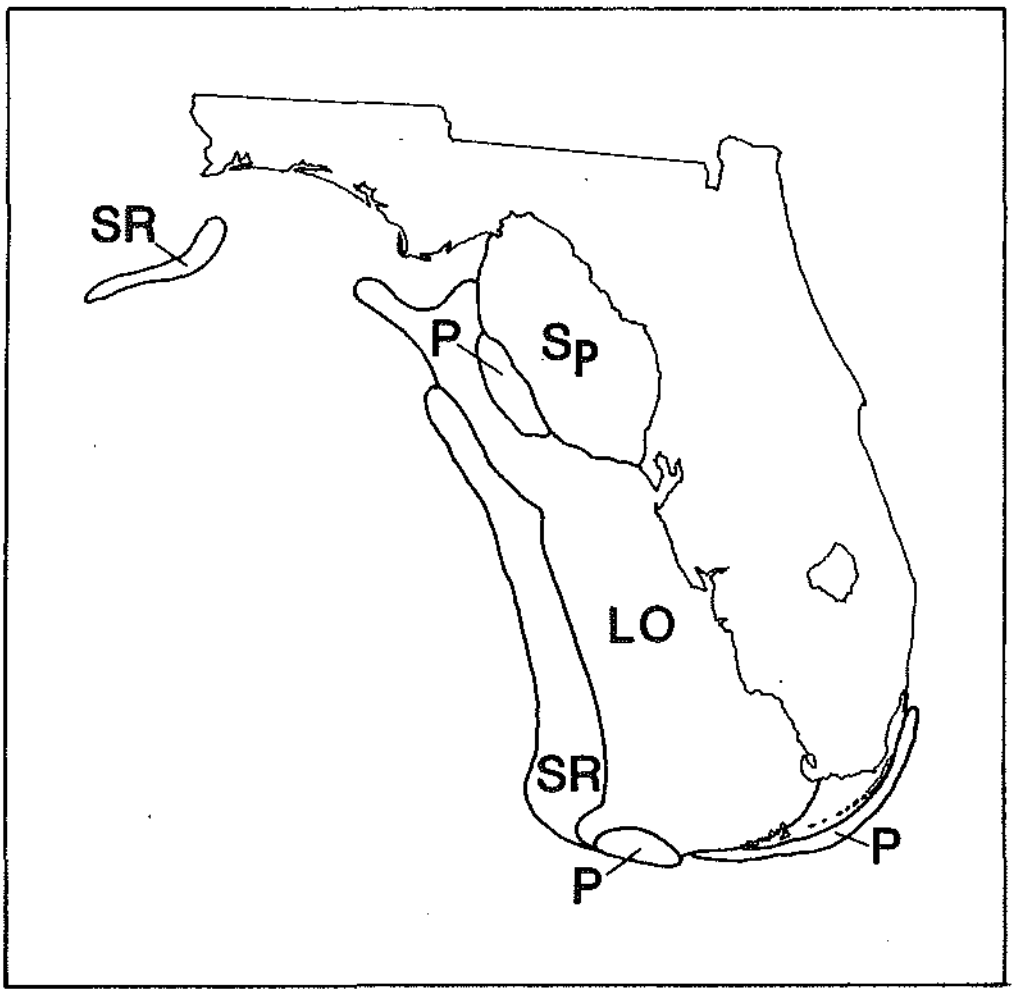


Figure 4. Map of the eastern Gulf of Mexico, showing the location of offshore reefs (from Brooks 1973). LO = scattered limestone outcrops, coral patterns and heads; P = Pleistocene reefs rejuvenated with hermatypic corals and algae; SP = scattered chert outcrops with sponges, Oculina, and Sideraster; SR = shelf edge reefs, coralline algae and deep water coral.

procedure again reinforce our conclusion about the importance of offshore dispersal routes for Florida Bay species. For example, when compiling data on fish in Tampa Bay, we noticed that a number of records were from Egmont Key (Fig. 1) but nowhere else in the Bay. Many of these records were of species also recorded in Florida Bay, but not in between the two locations. Including such records in our analyses would have substantially altered similarities among locations; we did not include them. We decided that Egmont Key was functioning as a "trap" for fish that otherwise would be well offshore. Such conclusions may not be agreed upon by other researchers. If not, they may make any appropriate adjustments to the data and rerun the analyses. In fact, we would encourage them to do so.

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THE STATUS OF KNOWLEDGE OF PREHISTORIC ARCHAEOLOGY IN THE TAMPA BAY AREA

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INTRODUCTION

Willey and Sabloff (1980) have divided the history of American archaeology into four periods. These periods represent histories of attitudes, concepts and methods, trends in ideas, and accomplishments, which can be framed into periods. Although they work well to compare regional growths in the development of scientific thought on a gross level, they do not represent any specific area. A period may be ushered in by ideas and results of excavations at one site or area, while the rest of the Americas may lag far behind. Sadly, this has been the case for Florida and the Tampa Bay region.

This paper reviews the growth in knowledge of the prehistory of the Tampa Bay region using the New World as a comparison. It is necessarily restricted to the immediate Bay environs, and the specific types of sites located there, but the consideraton of a larger spatial entity would not significantly affect the results.

The Speculative Period

The first period, according to Willey and Sabloff (1980: 12-33) is referred to as the Speculative and dates from 1492 to 1840. The period is characterized by an almost complete absence of literature, at least for the Tampa Bay region, and, as the term indicates, what information is available is totally speculative -- not being based on scientific investigations.

Although archaeological exploration had begun at the major mound sites in North America by the early nineteenth century, the lack of such spectacular sites in the Tampa Bay region and the lateness of historic settlement, are primarily responsible for a total absence of any account of any similar exploration here. That is not to say that there was none, but that no accounts were published. Ethnographic acounts of the Indians are almost totally absent also and this dearth of information has made cultural interpretation from archaeological data all the more difficult.

Archaeology was an avocation and did not become a profession until much later. Although Americans did not associate the large and complex sites with what they considered a barbaric race, they speculated on the origin of both and the lack of any scientific base brought imaginative speculation indeed.

Some early settlers in the area could not but recognize the temple mounds and large shell middens as artificial constructions, and, in fact, an early map of Fort Brooke, established in 1824, labels a mound within the cantonment as an Indian mound. Nevertheless. it was to be the 1870s before any descriptions of excavations occur and before we are able to read of the excavator's thoughts on these sites.

The Classificatory-Descriptive Period

The second period is referred to as the Classificatory-Descriptive, and dates from 1840 to 1914 (Willey and Sabloff 1980: 34-87). This period is characterized by the systematic description of sites and artifacts and the discovery that archaeological types had meanings although these meanings were not always understood.

It was the age of Darwin, of Huxley, and of Spencer. In American archaeology, it was the age of Stephens, Catherwood, Squirer and Davis, all of whose drawings and illustrations are works of art. However, in the case of

Squirer and Davis, the "Moundbuilders" were still viewed as a separate race from American Indians. The "lost race of Moundbuilders" myth did not end until the late 1890s with the work of Cyrus Thomas, although men such as Samuel Haven and Henry R. Schoolcraft had rejected the idea as early as the 1850s.

The first professional archaeological work in Florida began during this period with the work of Jeffries Wyman and S. T. Walker in the 1860s, 1870s and 1880s, neither of which excavated under the "Moundbuilder" misconception. Wyman was a well-known natural scientist and the first curator of the Harvard Peabody Museum (Willey and Sabloff 1980), but he did not excavate sites in the Tampa Bay region. Neither did S. T. Walker, an amateur, who did good archaeology for the time (Willey 1949). This does not mean that the distance between professional and avocational archaeology was any less than today, however. One only has to use the Tampa Bay region as an example.

The first published accounts of archaeological sites within the immediate Tampa Bay environs is that of J. H. Allen (1846) and T. A. Conrad (1846) who described several large shell middens at the mouth of the Manatee River in the mid-1840s. Both thought they were the result of natural wave action (Willey 1949). In fact, Allen states (1846) "their immense quantity precludes the idea of their having been accumulated by the aborigines of the country." It was over 20 years, in 1869, before we have another account of shell mounds associated with Tampa Bay. These were the descriptions by R. E. C. Sterns (1870, 1872).

The first account of any prehistoric cultural materials resulting from archaeological investigations in the immediate Bay area is that of Lieutenant A. W. Vogeles in 1876. Vogeles mentions a series of shell middens "commencing on the southern seashore, on the military reservation of Fort Brooke, and extending to the Hillsborough River" (1879, pp. 9-10). Further, he stated "During the Florida War this series was complete, but at present it consists only of a large mound on the military reservation" (1879, p. 10). This is what is referred to as the Fort Brooke Mound (8-Hi-13A). He mentions another site which was located "immediately outside the reservation," but which had been destroyed. It is not known if it was a sand or shell burial mound, but was described as a mound. A third mound was located "near the site of the present town market" (1879, p. 10) and "At the foot of the ... mound in the clay banks of a small stream which flows into the river we find chippings of flint implements" (1879, p. 10). He described what is evidently the Fort Brooke mound as being "about fifteen feet in height, with a diameter at its base of about fifty feet" (1879, p. 10). Vogeles dug into the mound in 1876 and found 2 skeletons, as well as some artifacts, hearths and animal bones. Cremated human remains were also found, but instead of viewing them as such, Vogeles interpreted the aboriginal inhabitants as "a race of cannibals" (1879, p. 11). The artifacts mentioned consisted of projectile points and pottery. The shapes of the projectile points were not given, thus we cannot type them or date them, but some vague descriptions of the ceramics were given which would lead us to believe they are Weedon Island - Safety Harbor Period in time. Vogeles' excavations at the Fort Brooke mound had been previously mentioned by W. W. Calkins who reported digging activities at several mounds in Florida (Calkins 1878). This mound is thought to have been located where the Bay Cadillac building stands today in downtown Tampa.

S. T. Walker, in 1880, also described the mound which he referred to as the "Vogdes' Mound" (1880, p. 413). Walker, however, had only an earlier description of the mound written by Vogeles which had appeared in the Tampa Sunland and Tribune on November 18, 1876. In his later article (1879), Vogeles did give mound dimensions which are quoted above, but these are quite different than Walker's measurements. Walker, who was, as stated earlier, a

good archaeologist for the 1880s, criticized Vogeles' work, especially his interpretation of cannibalism. Indeed, interpretations of this sort should have ended with the Speculative period 50 years earlier. Walker's criticisms of Vogeles' imagination are just. Walker stated (1880, p. 411):

> I will further state that it is not a shell mound proper, but is built of alternate layers of sand and shell, like all the domiciliary mounds hitherto described. The measurements, which he (Vogeles) neglected to give, are: length, 108 feet; width, 100 feet; height, 7 to 9 feet. The sand was obtained close at hand from excavations along the western base ... Partial cremation, which I have shown to have been common in the region, will relieve the aborigines of the unnecessary charge of cannibalism.

It is also important to note that Walker's description (1880) would lead one to believe that the mound was a temple mound, not a burial mound -- a significant difference when interpreting the site on a cultural level. As stated earlier, Walker was the first to look at the Tampa Bay sites in a scientific manner. It would be another 20 years before another did.

In the 1880s, J. Shepard briefly described the shell middens on Rocky Point, the Culbreath Bayou site, the Bull Frog Creek mound and the Fort Brooke mound. However, in relation to the Fort Brooke mound, he mentioned "two ancient earth mounds which have been dug into considerably" (1886, p. 906). The second mound may have actually been the remnants of the shell midden area described by Vogeles. He also noted stone artifacts exposed at low tide at Ballast Point and a "long ridge of shells" (1886, p. 906), evidently a shell midden, a little back from the bay shore near Ballast Point.

Although Walker was perhaps the better archaeologist, it was Clarence B. Moore who is associated with classificatory-descriptive archaeology in Florida and the Tampa Bay region. Moore worked throughout Florida for around 30 years, beginning in the late 1890s, but his work in the Tampa Bay region occurred mainly during the year 1900. Moore attacked the larger sand or shell and sand temple and burial mounds, digging sites at Pinellas Point, Maximo Point, mounds at the mouth of and up to 5 miles up Bull Frog Creek, mounds at the mouth of the Little Manatee River and up the Manatee River, on Tierra Ceia Island (Moore 1900) and on Long Key (Moore 1903).

Moore's numerous publications, though coming closest to classificatory-descriptive archaeology in Florida, fall short for the period. They consist primarily of descriptions. He tended to lump rather than split, or emphasized similarities rather than differences and his conclusions dealt "with minor problems of distribution of selected objects" (Willey 1949, p. 25). Thus ceramic typologies, so important in prehistory and basic to classificatory-descriptive archaeology, failed to emerge. It was W. H. Holmes (1894), using Moore's ceramic collections, who established classificatory-descriptive archaeology in Florida, although he never excavated here.

The beginning of scientific geology and evolutionary studies were the stimuli that gave rise to systematic archaeology in the New World. The old mold of sheerly speculative thought was broken and the careful recording, description and classification, so necessary for archaeological interpretation, was begun. Too, much more field work was being done, techniques of excavation were being developed and not the least important was the academic alliance archaeology made with anthropology (Willey and Sabloff 1980). Its weakest point was a lack of chronological control of the dimensions of archaeological data, especially through stratigraphy (Willey and Sabloff 1980).

The Classificatory-Historical Period

The third period is referred to as the Classificatory-Historical and dates

from 1914 to 1960. Although the ordering of events in time, that is chronology, was the concern of this entire lengthy period, the latter half, from 1940 to 1960, saw the beginning of new research goals and strategies in archaeology -- mainly a concern with context and function (Willey and Sabloff 1980).

Excavations that paid attention to stratigraphy were the main means of extracting temporal information from the data. Studies in seriation evolved as a means of putting data into a temporal framework.

The ultimate objective in American archaeology during the Classificatory-Historical period, it seems, was to draw one big chart, showing the complete cultural sequence in all cultural areas and to show how each temporal sequence was related to its geographical neighbors by comparing similar time frames. To put it more politely, the goals were "culture-historical syntheses of New World regions and areas" (Willey and Sabloff 1980, p. 83.). Lastly, it should be mentioned that even better methods of excavation (Willey and Sabloff 1980) and the advent of radiocarbon dating in the late 1940s were both a major boost toward the Classificatory-Historical goals.

The last two decades of this period were "a time of ferment and transition" (Willey and Sabloff 1980, p. 130). It was a time of experimental trends. "These trends concerned context and function -- and hinted at process" (Willey and Sabloff 1980, p. 130). This new trend of interest in context and function holds three primary themes. These are: first, that artifacts are a result of socio-cultural behavior; second, an interest in settlement patterning; and third, an interest in the relationship between culture and environment (Willey and Sabloff 1980). These themes were stimulated and assisted by other fields such as ethnology, geology, botany, biology, chemistry, metallurgy and physics.

Although the time of 1940 to 1960 is infinitely more interesting than the earlier part of this period, perhaps because one sees the beginnings of the modern foundations of archaeology, little space can be devoted to its formulation and significance, nor to the personalities involved.

Florida breaks into the Classificatory-Historical Period with work at several Bay related sites. In the early 1920s, Fewkes (1924) dug at the Weedon Island site and Stirling worked at the Safety Harbor site in the late 1920s (Stirling 1930, 1931). The Federal Emergency Relief Administration, under the direction of the Smithsonian Institution, supported work at inland sites in the middle 1930s. This program was later taken over by the Florida Geological Survey with J. C. Simpson as Field Director (Stirling 1935; Simpson 1937, 1939). Although only one of the sites worked on is really coastal (Cockroach Key), information contained in the interior mounds was relevant to interpreting inland-coastal settlement systems and chronology -- just as it is today. Several sites, including Palma Sola, Shaw's Point (Stirling 1930, 1931) and Perico Island (Stirling 1935) were examined at about the same time. The results were typical for this period -- a description of the cultural materials (although sometimes quite vague), and an attempt to place these sites into their proper chronological position within Florida's prehistory.

While this work was being done by people who were professionals, other digging was being done by people who were not. For example, a burial mound, the precise location unknown, but probably not far from downtown Tampa, was dug in the 1920s by two local residents. It was reported by Joseph Hall in 1928, who referred to it as the Tampa Mound. Hall's descriptions of the burial formation and skeletal remains are not very credible. He evidently did not observe the excavations, and his description is taken from the excavators' rather elaborate and excessive imaginations. He states, "The burial formation (was) in circles and squares with the central figure standing up in the

center and the others in a circle of 12 around him" (Hall 1928, p. 2). A total of 39 individuals were reported uncovered. Hall compares these to another mound near Ruskin and wrote, "In this mound were the remains of 65 people kneeling in a circle around a giant standing up in the center over eight feet tall" (1928, p. 2). His description of the skeletal material is as bad. He describes human skulls with horns, states they belong to many races, that they had teeth in places where humans do not have teeth today, and compares them to Homo erectus, who lived one-half million years ago (Hall 1928).

Indeed, he stated in reference to one of the skulls, "This unique specimen alone is enough to bring world-wide fame to ... Tampa among scientists all over the world who will be interested and will come to town to see and investigate this remarkable type of skull" (Hall 1928, p. 5). His descriptions of the ceramics would lead one to believe that they were Weedon Island - Safety Harbor Period in time, although he compared them to Mesoamerica and Egypt. Worked lithic material and shell were also evidently found in the mound.

As stated earlier, the exact location of this mound is not known, but Hall stated the Weedon Island mounds (located on the western shore of Tampa Bay in Pinellas County due west of the Port Tampa area), were "located about 10 miles from the Tampa mound" (1928, p. 1). The mound had not been completely excavated at the time the article was published and its fate is unknown.

The World War II era saw little activity, but in the late 1940s the Safety Harbor site received its most thorough excavations (Griffin and Bullen 1950). In the 1950s work proceeded at the Perico Island (Bullen 1950), Terra Ceia (Bullen 1951), Harbor Key (Bullen et al. 1952) and Rocky Point (Plowden 1955) sites.

A Classificatory-Historical framework was first established for Florida in the middle 1930s by M. W. Stirling (1936). Stirling outlined four major cultural areas and discussed the chronological relationship between Weedon Island and Safety Harbor cultures. Though this relationship was not based on stratigraphic data, it was essentially correct. Later, Willey (1945) and Goggin (1947) refined and expanded these temporal and spatial concepts. Goggin's framework has been used unmodified until recent times, but even the recent refinements are not substantial. Even now, it forms the basis for Classificatory-Historical components in studies of Florida archaeology.

The Explanatory Period

The last period is referred to as the Explanatory and dates from around 1960 to the present. It is dominated by aspirations stated by proponents of the "new" archaeology. Although one cannot yet view the accomplishments of this period with any historical perspective, it is possible to discuss its impact on archaeology throughout the nation and more specifically the Tampa Bay area.

The "new" archaeology has as its goal the explanation of cultural processes, but it also has its roots in the Cultural-Historical approach. Indeed, this was a necessary stage in the development of processual archaeology. What is really "new" is the influence of philosophers of science and general systems theory. Archaeologists began to examine the complex relationship between human societies and their sub-cultural systems and their environment (Fagan 1981). Further, they began to use research designs and test archaeological data against formal hypotheses. Statistical methods and computers were necessary to order large quantities of data. Deductive rather than the older inductive approach was used as archaeologists sought to construct general laws to explain specific behaviorisms.

Although one sees hints of processual archaeology in Willey's Archaeology of the Florida Gulf Coast (1949) which was published during the last period, or in Sears' study of the Weedon Island site (1971) about 10 years ago, the archaeology of the Tampa Bay

area remained steadfastly in a Classificatory-Historical stage. Numerous sites, including Pinellas Point (Goodyear 1968), Fish Creek (Karklins 1970), Palm River (Karklins 1968), Tierra Verde (Sears 1967) and Apollo Beach (Warren 1968) were examined and data published in the 1960s. None of it, however, in any way reaches an explanatory level.

It was not until around 1975 that one sees a movement toward change and this change is related to two factors. The first is the passage of historic preservation legislation on a federal and state level, and its implementation. The second consists of a number of pleas from academic archaeologists to turn this mandated archaeological research into a theoretical oriented work.

Approximately a million dollars a year has been spent during the last three years doing archaeology in Hillsborough County. Most of this has gone for excavation at inland sites or survey on inland tracts of land areas not previously developed. The immediate Bay area has, to a great extent, had its archaeological context destroyed. However, there are several examples of excavation and survey which would fall within the goals of the Explanatory stage. Excavations in Ybor City (Ellis 1977), at Fort Brooke (Piper and Piper 1980; Piper et al. 1981b), and Maximo Park (Williams 1979), and surveys associated with the Crosstown Expressway (Piper et al. 1981a), the proposed 49th Street Bridge (Gluckman et al. 1980), the Upper Tampa Bay Park site (Gluckman et al. 1978), and Egmont Key (Grange 1977) are examples of studies with stated, explicit research questions and the collection of data aimed specifically to answer these questions. Except at the Ybor City and Fort Brooke sites in downtown Tampa, no excavation has occurred in the last 10 years at any Tampa Bay associated site that lends itself to questions about the relationship between prehistoric or historic peoples and Tampa Bay. What is clear, however, is that excavation and surveys at sites in inland areas and the more limited number of investigations of sites in the immediate Bay area have reached a state of sophistication worthy of the Explanatory stage in the rest of the Americas. It is ironic, however, that the imminent destruction of these sites is the impetus, as well as the source of funding for, these investigations.

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PREHISTORIC COASTAL ADAPTATION IN THE TAMPA BAY REGION

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Beginning in the 1840s, a variety of naturalists, doctors, military officers, and antiquarians began publishing accounts regarding the aboriginal mounds located around the periphery of Tampa Bay. The earliest known accounts, by Conrad (1846) and Allen (1846), two malacologists accompanying a U.S. Navy surveying expedition, described the extensive shell sites at the mouth of the Manatee River. Conrad (1846, p. 44) noted that the mounds "much (resembled) those of artificial construction, and ... would deceive any unpractised eye." Allen (1846) stated that "their immense quantity precludes the idea of their having been accumulated by the aborigines of the country," and both men decided the mounds were the result of wave action. This was in spite of the fact that some five years earlier Vanuxem had correctly called attention to the artificial nature of many very large deposits of oyster shells on Chesapeake Bay (cited in Foster 1874). As Warren (1964, p. 229) has subsequently pointed out, "as any of us know who are oyster enthusiasts, it takes a lot of oysters to fill a hungry person and most of the oyster is shell anyway."

While Daniel Brinton passed through Tampa Bay on his trip of 1856-57 (Brinton 1859), it was not until 1869 that limited test excavations were recorded for the area. These were by Stearns (1872) at Point Pinellas. He pointed out that the shells found were of the same species living in the neighboring waters, chiefly consisting of oysters, conchs and scallops, and reported his findings to the California Academy of Sciences. Interest in the shellmounds had been generated by the 1868 excavations of freshwater shellmounds on the St. Johns River by Jeffries Wyman, first curator of the Peabody Museum (Wyman 1875).

In 1876, U.S. Army Lt. A. W. Vogeles conducted excavations in the largest of several shellmounds on the military reservation of Fort Brooke in Tampa. It may be noted that his detailed descriptions of its contents include, in however limited a fashion, the first zooarchaeological analysis in this area: he wrote that the "animal remains consisted of the bones of the dog, a claw of the common crab, and a human tibia burned and split" (cited in Walker 1880a, p. 413).

In the spring and summer of 1879, S. T. Walker of Clearwater began his preliminary explorations of coastal sites from Clearwater Harbor around Tampa Bay to the mouth of the Manatee River (1880a, b; 1883). He prepared ground plans and conducted excavations at the Bullfrog Creek, Cockroach Bay, and Shaws Point sites. In 1886, Shepard surface collected at Rocky Point, Fort Brooke, Culbreath Bayou, Ballast Point, and the Bullfrog Creek sites, noting that the latter had been reduced in size by lime-making activities (Shepard 1886).

In 1900 and again in 1903, Clarence B. Moore conducted extensive surveys and excavations in the Tampa Bay area from his steam-powered houseboat, "The Gopher" (1900, 1905). He footnoted in one report in the Journal of the Academy of Natural Sciences of Philadelphia that the "great shell deposit on Bullfrog Creek ... has since been entirely demolished to furnish material for streets of the town of St. Petersburg. It was reported that in the removal of the deposit nothing of interest was found" (1905, p. 304, n. 1). This evaluation of the site reflects Moore's chief interest, the contents of the area's sand burial mounds. He had previously excavated among the freshwater shellmounds of the St. Johns River where "little is found in comparison with the vast quantities of debris to be handled, and the relics of

the wretched makers of the shellheaps offer but a poor incentive in comparison to the more alluring results to be attained in other portions of the country." (1894, p. 25). Moore, like many others, had failed to appreciate the wealth of data pertaining to environmental and cultural adaptation inherent in the shellmiddens being used for roadfill and other purposes.

Today there are over 60 prehistoric archaeological sites recorded around the immediate interior of Tampa Bay from Maximo Point in Pinellas County to Shaws Point in Manatee County. Additional sites are known but not yet professionally recorded from the coastal zone. Aboriginal occupations represented include the Paleo-Indian through Seminole cultural periods. Bullen (1955) first introduced the idea of the potential existence of sites of Pleistocene man submerged within Tampa Bay by the rise of sea level. Work by Warren (1962, 1964, 1965, 1966) and Goodyear and Warren (1972) has shown that at least portions of the shell deposits bordering now sunken river channels in Tampa Bay were middens left by Paleo-Indian and Archaic period peoples.

Eustatic sea level changes have largely shaped the morphology and ecology of Tampa Bay. Questions regarding the duration and extent of the marine regressions and transgressions of the glacial eras are generally answered by two schools of thought. While both ascribe to a relatively rapid rise in sea level subsequent to the termination of the Wisconsin stage, Fairbridge (1974) concludes that the eustatic rise reached its present height 6,000 years ago and subsequently fluctuated above and below that point. The consensus among others (Coleman and Smith 1964; Flint 1957; Scholl et al. 1969) is that sea level was 3 to 8 meters lower at 5,000 years before present (BP) and has since risen gradually at a decreasing rate. But even among those in general agreement, opinions differ as to the relative effects of subsidence as opposed to eustatism on the location of the shoreline. Edwards and Merrill (1977) are of the opinion that the shelf area of the Gulf of Mexico uplifted during the Holocene. Scholl and Stuiver (1967) feel that the geomorphic and geological evidence supports tectonic stability for Florida during this period and possibly since Miocene times.

It is not the intention here to review the various and conflicting studies regarding sea level on the Gulf coast, but rather to point out the continuing problems of resolution. Most recently, Brooks (1981) has added another variable to further complicate the picture; he has just described a major geological fault cutting across Florida from Melbourne to Cedar Key through Lake Apopka. It may be that all previous researchers have been in error in treating the Floridan peninsula as a single tectonic unit. Rather, south Florida may have acted somewhat independently, making impossible exact comparisons between such work as that of Coleman and Smith (1964) in coastal Louisiana and that of Scholl (1964) in the Everglades.

As sea level rose to cover the relatively level stretches of continental shelf, brackish conditions formed within the combined lower reaches of the Hillsborough, Little Manatee and Manatee Rivers, and the beginnings of today's Tampa Bay macro-estuary thus provided habitat for oysters and other shellfish. In surface collections made at the shellyards of the three companies which had been actively dredging material from deposits in Tampa Bay and in shell roads and parking lots paved from the same sources, Goodyear and Warren (1972) recovered portions of five Suwannee projectile points. Bullen (1975) places these at the close of the Paleo-Indian period, c. 9,000 years B.C.

When sea level rises rapidly, river valleys are drowned and estuaries form (Edwards and Merrill 1977). In the presence of a longshore current, a barrier spit may develop on the seaward side of remaining channels (Curray 1960), thus facilitating estuarine development through regulation of a brackish regime. During the 2,000 years following

4,000 years BP, a series of severe droughts occurred in south Florida (Gleason et al. 1974). It is known that "alternating wet and dry periods are favorable to sawgrass growth, as compared to the growth of aquatic plants and swamps or hammocks which prefer more stable water conditions" (Davis 1943, p. 253). Given these points and the recognized growth of oyster beds in association with saltgrass marshes, and the relatively recent appearance of Rhizophora mangle (Estevez, pers. comm.), it is hypothesized here that the Tampa Bay environment consisted of extensive upper marshes of Cladium sp., grading into areas of Spartina spp. and Juncus spp. containing oyster beds. Subsequent sea level rise, moderation of climate, and colonization by Rhizophora mangle from south Florida has resulted in successional changes reflected in today's environment of extensive mangrove swamps, which environment is less conducive to the growth of Crassostrea virginica.

Goodyear and Warren (1972, p. 55) noted that the "oyster shell ... dredged from Tampa Bay ... was at least 99% Crassostrea virginica." Shells of other species, including those of Busycon spp., Mercenaria campechiensis, Atrina rigida, Oliva sayana, and Strombus alatus were only sparsely represented. Optimum salinity for oysters is 22°/oo, with the minimum value at 11°/oo (Brennan 1974). Various conchs which prey upon oysters require higher salinities, their depredations usually occurring during periods of drought when freshwater inflow of streams is diminished (Ingle and Whitfield 1968). Scholars must await in situ archaeological excavations in what remains of the submerged Tampa Bay shellmiddens before more precise statements can be made regarding the paleoenvironment and early aboriginal adaptation to it, but it may be pointed out that test excavations made by the author in coastal Manatee County shellmiddens and by Beriault (1982) in similar sites in coastal Collier County have revealed essentially monospecific layers of C. virginica at and below the present water table, with more mixed assemblages of shellfish species occurring in succeeding and more recent strata.

Interest in the study of coastal shellmiddens has developed considerably since Japetus Steenstrup's work in the early 1800s among middens in Denmark and along the shore of the Baltic Sea (Morse 1925). It was Steenstrup who coined the term "kjokkenmodding," or "kitchen midden," to describe these deposits of cultural refuse. New World adaptation to coastal environments has largely been seen to follow as a result of subsistence pressures due to the extinction between 12,000-6,000 years BP of the Pleistocene megafauna and the concurrent creation of estuaries by sea level rise. New and extensive resources were created which could be easily gathered. With the larger animals extinct and the environment subjected to the perturbations of adustment to the energy budget presented by non-glacial conditions, a more diverse mosaic existed and human subsistence was dependent upon hunting a greater variety of smaller animal species and gathering edible plantstuffs. The white-tailed deer became the most important terrestrial meat source in many areas of the New World.

In this regard, points made by Leakey (Leakey and Lewin 1978) on the basis of work by Lee (1965) among the !Kung bushmen are well taken: in the !Kung diet, meat, hunted by the men, accounts for slightly over 30% of the food, with the remainder of the diet consisting of plant materials collected by women. Therefore, it is more accurate to refer to such a subsistence mode as gathering-hunting, rather than hunting-gathering, though, as Leakey has noted (1978, p. 108), "inertia, tinged perhaps with a little male chauvinism, may well protect the old inaccurate name for some time to come."

The relative importance of shellfish and other marine species to the total diet of coastal peoples continues to be a matter of debate. The impressive size of many of the shellmiddens argues

for intensive utilization, but as previously noted, most of a shellfish is indeed shell, and this component of prehistoric coastal diets may be vastly overestimated by simple, visual examinations. Caloric values of the various components present, based upon determinations of minimum numbers of individuals converted to meat weights (Prange et al. 1979), is currently the preferred method of zooarchaeological analysis (Wing and Brown 1979). This approach, however, is biased toward the vertebrate and invertebrate components, floral elements being rarely preserved.

Osborn (1977, pp. 160-161), among others, has argued that "marine food resources are inferior to terrestrial resources, especially mammals, both in terms of human labor investment and in terms of protein yield," and that the post-Pleistocene shift in subsistence strategies from terrestrial to marine foods (Binford 1968) "did not occur in most areas of the world until inland human populations increased to levels approaching carrying capacity ... of the environment." While it is true that fish and shellfish are an excellent source of calcium, iodine, electrolytes, other minerals, and protein, they are indeed very low in calories. The numbers of kilocalories per kilogram of flesh for shellfish and fish are 800 and 1,370 respectively; the figure for both birds and mammals is 3,000 (Meehan 1977a). But as Yesner (1980, p. 733) has pointed out, nutritional yields are only half of the dietary picture: "The other half involves the relative 'costs' of coastal resource exploitation in terms of required time and energy investments per unit of nutritional yield." Regarding shellfishing, Yesner (1980. p. 733) notes that "in spite of the lower caloric yield ... it should be remembered that minimal technology is needed for all members of the population to engage in this activity" and in regard to fishing that its caloric yield may "be greater than that of terrestrial mammal hunting ... and within the range of extensive horticulture." So while both the caloric yield per kilogram of flesh and the prestige value of a deer were substantially larger than those of shellfish, it is probable that the prehistoric peoples of Tampa Bay were more dependent upon the coastal activities of the women, children, and old men than upon those of the young warriors hunting game in the interior.

On the basis of field work among the native Anvara of Australia, Meehan (1977a, b) found that while at no time during the year did shellfish contribute more than 30% to the total diet, both shellfishing and fishing activities took place far more frequently than any other subsistence activity. Proximity to shellfish beds was a major consideration in the location of camps, with gathering of mollusks involving the participation of "a broad spectrum of the population both in terms of age, physical fitness, and skill" (1977b, p. 524). The activity "required no special physical strength nor skill, nor the expenditure of much energy" (1977b, p. 524). Shellfish were highly valued; tribes living in the interior would make special trips to the coast expressly for the purpose of eating them. As Meehan noted in the title of one of her papers, "man does not live by calories alone" (1977b).

The majority of identifiable artifacts recovered by Goodyear and Warren from the oyster shell dredged from Tampa Bay are of the Archaic period, c. 6500-1200 B.C. Additional Archaic projectile points have been found in spoil materials dredged from Boca Ciega, Terra Ceia, and Old Tampa Bays (Warren 1965, Karklins 1970), and from Bishop Harbor (Burger 1979). During the Transitional period of 1200-500 B.C. (Bullen 1959), people continued to use the presently submerged shellmiddens; Goodyear and Warren (1972) recovered five pottery sherds which suggest that this may have been the final period of their occupation. Similar and later period sherds in greater numbers have been recovered from spoil dredged from shallower areas nearer the present shores of the Bay. This reflects a movement landward of living sites as the water level slowly approached its present position. Many of the coastal

site deposits extend below the present water table.

It is not the intention here to give a period by period account of coastal adaptation around Tampa Bay, complete with site distributions and content analyses. That is not only beyond the scope of this paper, but also presently impossible due to a paucity of data from controlled excavations and dated contexts. Rather, a general overview of estuarine subsistence strategies and technologies practiced in Tampa Bay and south Florida in general will be presented in order to acquaint the audience both with what is known and what is suspected.

In the words of Marrinan and Wing (1980, p. 9), "A combination of local environmental conditions, cultural biases, and the level of technology influences the prehistoric use of resources." Aboriginal coastal populations practiced broad-spectrum procurement by the extraction of resources from a variety of adjoining environments. Therefore, it is not actually possible to consider coastal adaptation without recognizing the inputs from adjoining interior areas. This is particularly apparent in a consideration of lithic technologies. While Ballast Point on the shore of the Interbay Peninsula has long been recognized as a source of silicified coral -- having been noted early by Conrad (1846) and Shepard (1886) -- chert resources appear to have been more heavily utilized at interior locations on the Hillsborough and Alafia Rivers. It should be pointed out, however, that other coastal sites apparently were utilized, as dredged materials at Fish Creek and Apollo Beach have shown. As well, coastal outcroppings of the Hawthorne formation containing chert nodules may have been generally present, but are now submerged and not apparent to investigators.

Interior areas also supplied a variety of floral and faunal foodstuffs. Among the latter are included deer, bear, raccoon, rabbit, turkey, opossum, bobcat, gopher tortoise, a large variety of freshwater turtles, snakes, alligator, amphibians, hawks and owls. Subsequent to the introduction of agriculture, interior areas, having soils more suitable for such endeavors, supplied cultivars. While a list of wild floral species utilized must be largely problematical, it might include hickory nuts, acorns, smilax roots, a large variety of berries, palm hearts, persimmons, pokeweed, cattail roots, fern fiddleheads, and various edible tubers and bulbs.

The estuarine areas supplied a great variety of aquatic, terrestrial, and avian species. Shellfish included oysters, clams, scallops, cockles and conchs. Crustaceans included blue and stone crabs, and the echinoderms are represented in the middens by fragments of sea urchin tests. Sea catfishes, jack, drum, sheepshead, trout, mullet, snook, rays and various sharks -- all the major species that spend some part of their life cycles in an estuarine environment -- are found in the shellmiddens. Reptiles consist of diamond-backed terrapin, alligator, and the various marine turtle species. Regarding marine mammals, various skeletal elements of the bottle-nosed dolphin have been recovered.

Among terrestrial vertebrates, the raccoon is an invariable strandlooper whose bones are well represented in coastal sites. On one occasion the author has discovered a portion of the mandible of a domestic dog; Wing (1978) has suggested that some tropical groups may have supplemented their diet by use of this domesticate.

Avian species may include all the common shorebirds seen today. Migratory species of duck were hunted, providing insight into the seasonality of site occupations. It may be that certain bird species represented in the middens were a feather, rather than a food, source.

Edible coastal strand vegetation that would have been available includes seagrape, saltwort, Spanish bayonet, saltweed, glasswort, samphire, purslane, seablite, and palm hearts and berries. As well, a variety of edible marine flora existed.

The technology of procurement in an area devoid of fine-grained, hard stone relied heavily upon the utilization of the readily available shell. A tool type appearing during the Archaic period within the assemblage of mostly lithic items was the celt, an adze-like implement fashioned from the lip of the Strombus gigas conch in imitation of stone prototypes traded south from stone-bearing regions. While celts were also made from the relatively thinner lip and body sections of various of the Busycon species, Strombus gigas celts have also been found in Tampa Bay sites; these reflect trade from south Florida, as the species is essentially Caribbean in its distribution.

Undoubtedly the most commonly recognized shell tools are the hammers and picks made from Busycon spp. and less often, from Pleuroploca gigantea conchs. The former were initially classified by Goggin into morphological/functional types (Goggin and Sommer 1949). Current work by Ste. Claire (1982) on edge wear analysis and processes of natural shell erosion may serve to refine Goggin's typology.

Additional percussion tools were made from the perforated shells of Melongena corona and Strombus pugilis/alatus. The latter was first identified as an artifact by Rau in 1876, who considered the pierced shell to have been suspended as an ornament. However, after considering the size of the two holes made in the body and the weight of the shell, he noted that it may have been used as a net sinker (Rau 1876). This was a very interesting observation, as often large numbers of the pierced shells are found which, if considered to be once-hafted hammers, are unbroken. The author has often wondered at the numbers of these still functional hammers when faced with a comparable number of mostly broken Busycon tools. Their battered distal ends could reflect their previous use as hammers, or if Rau's suspicions be correct, be merely the conscious aboriginal removal of a potentially snagging portion of a net sinker. The perforated Melongena artifacts may have served the same function.

A great variety of cutting, piercing, and pounding tools were fashioned from shell, particularly from the columellae of the larger conchs. The columellae also served as material for elongate plummets or pendants, which could have served both ornamental and utilitarian functions. The body of Busycon shells with columellae removed became functional dippers or bowls, complete with handles. Various other tools were fashioned of shell, but the above serves to illustrate the major types. As Griffin (1952, p. 48) remarked, "without shellfish for food, (the Florida Indian's) diet would have been more restricted; without shells from which to fashion artifacts his tool kit would have been less adequate."

A variety of tools were made of animal, and on occasion, of human bone. Deer antlers provided pressure flakers for chert working, deer bones materials for awls, socketed projectile points, and the archaeologically infamous bone bipoints. These latter are normally about 10 centimeters in length, highly polished, and often very sharp at both ends. They have been variously described as part of the foreshaft of spears, basketry fids, hair pins, leisters, and barbs from compound fishing hooks.

While finds of organic materials have been rare in the Tampa Bay area, Cushing's 1895 discoveries in the anaerobic mucks of Key Marco provide a rare insight into the aboriginal arts of cord and net making (Cushing 1897). Masses of netting and cordage were discovered, some of the former still attached to its original wooden floats. While Marrinan and Wing (1980) noted that the gauge or type of material may not have been the best for efficient capture of mullet, historical accounts of the sheer numbers of fish in the bays and estuaries indicate that practically any type of net would have rapidly rewarded its makers.

Wooden fishweirs were noted on the Atlantic coast of Florida by the early French explorers. On the Gulf side, "the

Indians ... had constructed on the Bay of Espiritu Santo (Tampa Bay) large inclosures of rough stone in order to obtain skates and many other fish which came into them at high tide, and when it receded were trapped there almost on dry land" (Garcilaso 1723, cited in Swanton 1946, p. 334).

Clearly, life in the coastal zone presented ample opportunities for subsistence via the aboriginal technologies. A subtropical environment rich in estuarine and marine resources resulted in a case of "environmental liberation", rather than limitation (Goggin and Sturtevant 1964, p. 180) for the protohistoric Calusa of south Florida. The resource base was of such magnitude and availability that the nonagricultural Calusa became a stratified society comparable in complexity to fully agricultural societies elsewhere. While the coeval, protohistoric Timacua of Tampa Bay were less dependent upon fish and shellfish, being cultivators of maize, beans, and squash, that they at least partially continued the estuarine subsistence strategies of earlier peoples is recognized by their presence on large coastal shellmounds at the time of the Spanish entradas.

The prehistoric coastal sites of Tampa Bay present archaeologists and ecologists with an interesting array of potential research questions along both theoretical and methodological avenues. Following is a partial list for consideration:

1. What are the major reasons for the adaptive shift to coastal resources? Was it largely due to interior population pressures or to particular cultural biases? Does the later shift to interior agriculture reflect overexploitation of estuarine resources?
2. How did early populations adapt to the successional changes effected by the rise of sea level? What is the history of sea level change in Tampa Bay? Is the Tampa Bay-as-salt marsh theory proposed herein an accurate portrayal of the paleoenvironment? How recently did Rhizophora mangle appear in the Bay and how rapidly did it spread? Regarding such paleoenvironmental reconstructions, little use has yet been made in the Tampa Bay area of techniques utilizing data obtainable from larval mollusks, plant phytoliths, pollen, and marine diatoms.
3. What are the discernable effects of human predation on shellfish populations? While the historical disappearance of the scallop Aequipecten concentricus has been attributed to changes in water quality, what are the causes of the relative disappearance of Strombus pugilis/alatus from Tampa Bay? The small Strombus conchs are often found in large numbers in the shellmiddens, but are no longer found in the surrounding waters. Work by Swadling (1976) on anthropogenic effects on prehistoric shellfish populations in New Zealand and Papua New Guinea has shown definite evidence of morphological changes with the advent of human predation.
4. In the field of demography, what are the relative merits of the application of the Nelson-Gifford scheme or of the structural/ecological approach of Willey and McGimsey (Ambrose 1967) to questions of aboriginal population size? Recent work on the effect of arsenic on sperm motility indicates that people dependent upon a seafood diet have more male offspring. Can evidence of this effect be found in the remains of Tampa Bay's aboriginal population structure? What are the cultural implications of such an effect? Parenthetically, it may be half-seriously proposed here that perhaps the reason the protohistoric people of South Florida were called the "Calusa," which means the "fierce people" (Smith 1861, p. 6) was due to a lack of females, which necessitated warfare in order to obtain them.
5. How do shellmiddens form and how do they grow? Early investigators,

including Walker (1880b) and Stearns (1872) had their own theories. Growth and morphology are important considerations in light of the apparent lack of stratigraphy in many shell sites and the desire of the excavator to obtain representative samples. Important points have been raised by Brennan (1977) regarding the contemporaneity (or lack thereof) of cultural contents and the matrix in which they are found. The effects of historic human, prehistoric human and natural disturbance, mixing, and displacement of materials -- indeed, the entire field of taphonomy and attendent information loss needs to be seriously addressed.

6. How useful are Wing's (1977) concepts of resource constellations? The potential for refinement exists, possibly leading toward controlled systems analyses of particular man-environment interactions.
7. Ste. Claire (1982) and the author are currently engaged in experimental studies of shell tool manufacture and use wear. Given the tendency for shell to erode both within sites and in exposed contexts, can a chronology of specific tool types be established? To what degree can the results of modern experimental work be legitimately applied to determinations of paleo-function of shell tools?
8. A recent consideration of the author's has been the effects of hurricanes and particularly of red tides upon the composition of faunal assemblages in coastal sites. Is it possible to discern such events in the archaeological record after they have been added to sites by natural and/or human depositional processes? Could an osteological signature for such events be determined? Given the regularity of such events (Estevez 1981), ample opportunities exist for experimental, if not particularly appetizing, work.
9. Major questions still exist regarding seasonal vs sedentary occupation of archaeological sites. While important work has been done elsewhere with growth annuli in various mollusks and fishes, south Florida lacks the clearly defined seasons of more temperate areas. What is the potential for calibrating such growth data in the Tampa Bay area?
10. Many questions arise relating to archaeological technique and follow from the points previously made. Given the lack of apparent stratigraphy in many shellmiddens, what is the best method of excavation? While the technology is expensive, subsurface interface radar may reveal existing strata not clearly discernable to the eye of the excavator. A basic shortcoming of many previous investigations has been the absence of pumping equipment in the field kit, resulting in termination of excavations at the water table rather than at culturally sterile deposits. And it is just such sub-water table deposits which may hold the answers to many of the questions posed herein.

Sample adequacy is a continuing problem -- and not just for archaeologists. How large should column samples be and how many should be taken? What is the best screen size, or should sorting tables be used instead? What comprises an adequate faunal sample?

Much of archaeological reconstruction is dependent upon tightly dated contexts. The relative chronologies of the early years were replaced after Libby's (1952) discovery of radiocarbon dating. But the geology of Tampa Bay and other areas of Florida poses certain restrictions on appropriate samples. Due to the presence of limestone outcroppings and the attendant dissolution of calcium carbonate into the water column, use of shell for radiocarbon dating should be avoided, as the shell may be contaminated to varying degrees by the living organism's incorporation of older carbon into its structure.

The above concerns and the paper in general have served to illustrate the

scientific potential of coastal archaeological sites in the Tampa Bay area for studies of cultural and ecological succession in West Florida. Research needs are both theoretical and methodological. Hypotheses regarding aboriginal subsistence strategies, settlement patterning, and seasonality/ scheduling practices may be tested by controlled excavation techniques. However, for comparability, standard criteria must be established. Until data recovery techniques are standardized and directed by a regional research design, individual efforts by archaeologists in academic and contract positions will be disjointed and only serve to further diminish an already deteriorated cultural resource base.

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THE UNDERWATER ARCHAEOLOGICAL RESOURCES OF TAMPA BAY

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INTRODUCTION

This paper will cover four main topics. It will begin with a brief review of the underwater archaeology of Tampa Bay and the Central Florida Gulf Coast. The second section of the paper will present a model for the prediction of underwater site locations, condition and significance. The third topic is a discussion of the kinds of non-archaeological data needed in order to undertake underwater archaeological research in Tampa Bay. The last topic to be covered will be the value of archaeological sites and data to the nonarchaeologists. As this paper is aimed primarily at the nonarchaeologist, it will concentrate on presenting general information which will sensitize those doing research in the Bay to the possible presence of submerged archaeological sites.

PREVIOUS WORK

The earliest finds of submerged human materials from Florida's west coast have gone unrecorded. Rumors of artifact finds from underwater sites in the Gulf as well as from west coast rivers, springs and sinkholes, are very persistent. Few, if any, of these second and third hand reports have resulted in site locations or even visits by underwater archaeologists.

The problem is that while the reports are probably true, no one seems to know who actually made such finds or where the finds were made. It is not very helpful to have a diver tell you that he has heard of a diver who found stone tools five miles offshore in the Gulf.

What we do know about the underwater archaeology of the west coast comes mainly from four sites. Two of these sites were found in springs near Venice. One site is a partially submerged shell midden at Venice Beach and the fourth site is in the Hillsborough River east of the University of South Florida.

The Warm Mineral Springs site and the Little Salt Spring site are the best known. These sites were first reported by a local diver (Royal and Clark 1960) in the late 1950s. Relatively large amounts of human skeletal material, artifacts, food debris and paleoenvironmental data have been recovered from these sites. Radiocarbon dates suggest an occupation which occurred between 9,000 and 13,000 BP (Clausen et al. 1979). Geological data confirm that the occupied parts of the springs were intermittently dry during lowered sea level stands (Cockrell and Murphy 1978).

The Venice Beach site is a Gulf edge shell midden which has been partially drowned. The land parts of the site extend for some 460 meters along the beach. The underwater part of the site is about fifteen meters offshore and about two meters underwater. The depth of the offshore midden deposit is about 83 centimeters. Carbon 14 dates indicate that the upper portions of the underwater site were occupied at about 2,000 BP. This site is located along a drowned river channel. Data relative to sea level fluctuations, local geomorphology, past environmental conditions and prehistoric subsistence were recovered (Ruppe 1980).

The site in the Hillsborough River was salvaged during the early summer of 1981. The site will be heavily impacted by the construction of the I-275 bypass around Tampa. The site is just downstream from a prehistoric chert quarry and is marked by the presence of extinct megafauna remains including what may be the partly articulated remains of one of the elephant forms.

Though preliminary reports have been completed on this work, they are not yet available in published form. The site appears to have been heavily disturbed and may represent secondary deposition.

From our perspective, the value of these sites lies in what they can tell us about the underwater archaeology of Tampa Bay. This is: 1) sites which date between about 13,000 and 2,000 BP should exist in Tampa Bay; 2) these sites are likely to be in good condition with excellent preservation of archaeological and nonarchaeological data; 3) these sites are likely to contain data not available at presently known land sites; and 4) these sites will probably be where we would expect that they would be located and will be of a type consistent with land sites of the period.

In addition, these sites have returned data which confirm known and suspected changes in the natural environment. But, they contradict some of the published sea level change information for the west coast.

PREVIOUS WORK

No underwater archaeological work has been done in Tampa Bay. However, we know that there are sites in the Bay and we know a few things about these sites.

The knowledge about sites in the Bay comes almost exclusively from the study of shell dredging spoil. In 1964 the presence of submerged shell middens in Upper Tampa Bay was recognized (Warren 1964). This recognition was based on the presence of artifacts in shell driveways and in shell road fill which could be tied to shell deposits in the Bay. Two years later, data on a dredge spoil site composed primarily of lithic tools and debris was published (Warren 1968). This site was located on Caladesi Causeway. In 1972 a more complete examination of these dredge spoil sites was published (Goodyear and Warren 1972). In 1980 information was published on a dredge spoil site from Boca Ciega Bay (Goodyear et al. 1980).

The information on these dredge sites largely confirms what is known from other west coast sites: 1) sites dating from about 13,000 to 2,000 BP exist in the Bay; 2) the most usual location for known sites in the Bay is along submerged river channels; 3) the dredge spoil sites suggest that we are dealing with naturally drowned sites; and 4) shell midden and lithic workshop sites are known to occur in the Bay. Even though the data are less complete than we would like, they do indicate that Tampa Bay is probably rich in underwater sites.

SITE FORMATION PROCESSES

Underwater archaeological sites are formed through natural and/or cultural processes. The natural processes are: submergence due to tectonic movement, isostatic recovery and sea level change; and, the erosion of a land site into a body of water and/or the movement by water of previously deposited materials. The cultural processes are: the deliberate or accidental deposition of cultural material into a body of water; the movement of material previously deposited in water by human activities such as dredging, and the building of structures in a body of water.

Each of these processes of site formation will have had a somewhat different effect on the resultant underwater site. The main variables from an archaeological perspective are primary versus secondary or tertiary deposition, and the effect of the water acting on sites and materials.

A variety of logical assumptions can be made about underwater archaeological sites from the information available on site formation processes and from the information on the kinds of sites which likely exist underwater. For example, there is a low probability that sand burial mounds exist in Tampa Bay because such sites were not being constructed in the area when the Bay was dry. If such a site did exist, the unconsolidated nature of the sand matrix would suggest a low probability for the site having survived

submergence.

This kind of reasoning allows the construction of a model which can predict, in general terms, site location, condition, and value or significance. The model is based on an underwater site classification system.

A CLASSIFICATION OF UNDERWATER SITES

This classification system was first proposed by John Goggin (1960). Since the publication of Goggin's article, the system has been somewhat expanded (Gluckman and Peebles 1974; Gluckman 1980).

The system proposes six categories or types of underwater sites. These are: 1) refuse sites, 2) redepositional sites, 3) drowned sites, 4) ceremonial sites, 5) sites built in water, and 6) shipwrecks.

Refuse Sites. The refuse site was described by Goggin (1960) as an underwater site formed from the deliberate deposition of cultural material (refuse or garbage) into a body of water. Refuse site formation can also result from loss of cultural material at a landing, anchorage or watering place. The refuse site is essentially an underwater midden.

Redepositional Sites. The redepositional site is one formed by the redepositing of archaeological material. The redeposition may be due to the erosion of a land site into a body of water or from the movement of previously deposited material by currents, waves, etc. (Gluckman 1967). Human factors, such as dredging, are also a factor in redeposition.

Drowned Sites. Goggin (1960, pp. 351-352) referred to drowned sites as "submerged sites of former human habitation." There are two varieties of drowned sites. These are sites which have gone underwater due to natural causes and sites which have been drowned by the construction of water impoundment structures.

Ceremonial Sites. What is here termed a ceremonial site has also been referred to as "shrines or places of offering and interments" (Goggin 1960, p. 352) and a "shrine or sacred locality" (Holmquist and Wheeler 1964, p. 2). Each of the three terms would appear to be equally descriptive of the activities involved in site formation. Ceremonial site is used here because it is somewhat broader in context and somewhat less cumbersome to use. In each case, the reference is to a site formed underwater through a single act or series of activities which are ceremonial or religious in nature or intent.

Sites Constructed in Water. When this type of site has been mentioned in the literature, it was usually considered as another variety of drowned site. However, the formation process is distinctly different from drowning. This type of site would include piers, wharfs and other harbor installations as well as fishtraps and weirs. Anything constructed in water which leaves structural remains would fall into this category.

Shipwrecks. As shipwrecks are phenomena of the historic period, they will not be discussed in this paper.

We know that prehistoric peoples who lived in the Bay area used small watercraft like canoes. Unfortunately, the canoes (log dugouts) which have been found in Florida represent isolated finds. There are not yet enough data to predict location, condition or signficance.

It is logical to assume that small prehistoric watercraft were used on and around the Bay. We know very little about how such craft were made or used. Thus, we can expect that they might be found almost any place in the Bay. At this time, it is most likely that prehistoric watercraft will be found by chance rather than through systematic search efforts.

SITE LOCATION

Refuse Sites. There are several factors which are important in predicting refuse site locations. The first factor is that refuse sites will be related to land sites. The expected relationship is in the immediate vicinity of a land site. If this

is not the case, location prediction can only follow definition of water-related refuse disposal patterns.

The second factor is that refuse sites can only be expected to form in a suitable body of water. A suitable body of water must be loosely defined as one in which refuse or garbage would be deposited or artifacts lost. It is less likely that garbage will be deposited in very shallow or tidal waters. If the water is difficult to reach, due to swamps, mangroves or the like, it will also be less suitable. Refuse sites would not normally be expected to form from losses in shallow clear water.

The third factor is site function. Sites which function to produce little or no garbage are not likely to produce recognizable refuse sites. If a site functions so as to produce mostly, or only, refuse which will not be preserved underwater, there will be no refuse sites.

Redepositional Sites. The elements which are involved in the prediction of redepositional site location are erosion of land sites into water and/or the movement of artifacts by water.

Redepositional sites will most commonly be found downstream of land sites. The distance downstream will depend on the ability of the water to carry artifacts. The natural principles which govern the movement of material by water come into effect when predicting the location of this type of site. This means that in order to predict locations, the specifics of a particular body of water must be understood.

Few observations are available concerning the movement of artifacts by water. Observations made in various Florida rivers indicate that material does not move very far downstream and that it tends to follow the rules of water sorting.

Recent bottom disturbance is another factor which must be considered in predicting redepositional site locations. Water-based development activities, particularly dredging, will redeposit material from underwater sites.

Drowned Sites. As it is unlikely that water impoundment structures were built in the Bay, only naturally drowned sites will be discussed.

Naturally drowned sites are best located using the variables which land archaeologists have determined influence site location choices. These are such things as distance to fresh water, presence of food resources, high well-drained land areas, and sources of lithic materials. This means that we would expect to find sites along drowned river channels and near, or around, any other sources of fresh water which were available when parts of the Bay were dry. We would also expect to find sites near sources of lithic material and at locations where shellfish and other marine resources are available.

Ceremonial Sites. Ceremonial sites are the most difficult type of underwater site to locate. We tend not to know a great deal about the ceremonial and ritual aspects of prehistoric lifeways. What is known is usually not enough to model this aspect of cultural behavior. Most of the few known underwater sites which fit into the ceremonial type were found by accident.

The most useful clues to the location of this type of site are likely to come from ethnographic and ethnohistorical data. Beyond this, the archaeologist can do little more than formulate hypotheses relating this category of behavior to water. It seems logical to hypothesize that most such behavior will not leave remains on land. An obvious exception would be ceremonial structures, such as mounds, in the immediate vicinity of water. Even though proximity does not guarantee a relationship, the probability is there.

Sites Built in Water. The location of some sites built in water are predictable from their function. Harbors and ports can be expected to contain this type of site. Even where records are not available to aid in location, the relationship between form, function and location are sufficiently predictable for most location purposes. But, unless the port, harbor or landing has been

abandoned, the continuous construction and reconstruction typical of such facilities can make location of older structures difficult.

Other varieties of this type of site will also exhibit the form-function-location relationships. Structures such as lighthouses, bridges and dams are only going to be found in specific kinds of locations. Their function, to a large degree, dictates their form and location. Given some understanding of their function and the technology required and available, both form and location become predictable factors in the equation.

The location of prehistoric sites built in water can also be predicted from a knowledge of their function. Precision of prediction, however, is likely to be far less than can be expected for Historic period sites. This will be the case because the most numerous kinds of prehistoric site should be fishtraps and weirs. While many of these sites are known, few studies of location patterning have been undertaken. Research relating form with age (Johnston and Cassanoy 1978) and historic descriptions and depictions such as John White's watercolor of a weir made between 1585 and 1587 (Lorant 1946) are available and helpful. This kind of information alone will not allow the prediction of site locations. But, this information with topographic information and data on the habits of the fish species taken will allow the prediction of places where these sites are most likely to be found. Where better data are present, more precise prediction can be attempted.

CONDITION AND SIGNIFICANCE

The condition of underwater sites will be dependent on the amount of damage done to the site during formation and/or major submergence. As site significance is largely a function of site condition, it also will be affected by this factor. In the most general terms, the more protected a site is during the formation process, the greater the likelihood that the site will be in good condition. The better the condition, the more likely it is that the site will be significant.

The significance of a site will be dependent on the quality and quantity of potentially recoverable data. In archaeological terms this usually means the presence of undisturbed context and associations.

On this basis a number of things can be pointed out about site condition and significance:

1. The more protection a site has against water damage, the better its condition will be.
2. Site significance will depend on the presence of context and association data.
3. Some types of sites will be more significant than others. For example, refuse and redepositional sites are the result of secondary and tertiary deposition. They will not often show intact context and associations. Consequently, refuse and redepositional sites will almost always be less significant than other types of sites.
4. Site significance will also be keyed to scarcity and age. Thus, drowned sites, ceremonial sites, and sites built in water are likely to be significant even if they are in poor condition. We have very little data about such sites so any data recovered could be of value.

We can expect to find all of the various types of sites in Tampa Bay. The Bay offers a relatively protected site formation situation which means that sites in the Bay should be in good condition.

As the Bay seems to contain sites representing the earliest known human occupations in Florida, and probably kinds of sites not found on land, we can expect very significant sites in the Bay.

It should be obvious from the preceding that large amounts of nonarchaeological data are needed if the model is to be operationalized. The most important of these data needs are discussed as follows.

1. Sea level change information: we need to know which parts of the Bay were dry during periods when the new land could have been occupied by humans. Our present information indicates that the period from about 13,000 BP to present is of major interest. However, we do not know when the first people entered Florida. Because of this, we should probably be concerned with at least the past 20,000 years.
2. Bathymetric charts of the Bay: as our ability to predict underwater site locations is very dependent on being able to relate past site location choices with topography, good bathymetry is essential. To be archaeologically useful, the contour intervals should be as close as is practical. The best interval would be about 1/3 of a meter. Anything over a meter would not show the low relief which would be expected of sites in the Bay.
3. Environmental reconstructions: the more we know about past environments, the easier it becomes to match subsistence and settlement patterns with physical location choices. If we know what the general environment was like during a given time and how that environment changed, we can dramatically refine our predictions. The more specific the environmental data, the more likely it is that we can understand why people made certain choices. Thus, we would like to know what plants and animals were present, what the carrying capacities were, patterns of seasonality and any other information which would allow us to consider patterns of human adaptation to the natural environment.
4. The definition of high probability areas: we know that all peoples at all times needed water, food and raw materials. We also know that when the resources necessary to meet these needs cluster in a given location, it is highly probable that people occupied that location. We need to define such locations within the Bay. The most ideal of these locations would be within several hundred meters of a permanent fresh water source, be high and well drained, be in the immediate vicinity of permanent or seasonal food resources and have ready access to a source of high grade lithic material. By concentrating sea level change research, bathymetric charting and environmental reconstructions toward the definition of high probablility areas, we should be able to locate underwater sites. This would also obviate part of the need to collect such information for the entire Bay.
5. Extinct megafauna beds and shell bank locations: there is a tentative but positive correlation between extinct megafauna sites and early archaeological sites. Thus fossil locations are often good clues to the location of archaeological sites. We know that some of the shell deposits in the Bay are archaeological sites. By matching shell deposits with high probability locations, we should be able to find underwater midden sites.
6. Remote sensing research: underwater archaeologists are very much aware that remote sensing offers the best possibility of quickly and economically locating sites. The instruments most commonly used in an archaeological context are the magnetometer, side scan sonar and the sub-bottom profiler. What we do not know is what the various kinds of underwater archaeological sites will look like on a given remote sensing print-out. That is, we know almost nothing about site signatures. What is needed are research projects aimed at defining the capabilities of remote sensing instrumentation with respect to the location and charting of underwater archaeological sites.
7. Impact assessment network: we know that impacts to the Bay have already foreclosed some research possibilities. We also know that future impacts will compound the present situation. Many of us are involved

with impact assessment and mitigation projets. But, none of us have the network of contacts, the time or the expertise to know about and deal with all potential impacts. If we formed a network of scientists who could trade information and expertise and were willing to offer services of this kind to public and private entities, we would have taken a major step in helping to manage the destruction.

Having just outlined several generations of research needed by archaeologists from other scientists, it seems appropriate to conclude by discussing what archaeologists can do for these researchers. To this end, a number of the contributions that archaeologists can make to other fields are discussed below.

1. Dating: archaeologists have constructed temporal schemes which cover the last 10,000 to 12,000 years. These chronologies can be tied to artifact types with a precision of several hundred to several thousand years. And, given the proper artifacts, the dates can be assigned immediately. Archaeological sites are prime locations for the material needed to provide certain kinds of radiometric and other absolute dates. For example, charcoal, bone and shell are available for Carbon 14 dating and materials for acid racemization dating may be present. In addition, archaeological sites commonly contain the data needed to cross check dates and dating techniques. In short, archaeologists can provide relatively precise indicators from a highly controlled context, which can allow dating of such disparate elements as old strand lines and Pleistocene extinction.
2. Baseline environmental data: because of the age expected of some sites in the Bay, these sites could serve as temporal baselines for the study of change. Materials collected from these sites could be subjected to analysis from which the rate and extent of a wide variety of chemical and physical changes could be determined.
3. Environmental reconstructions: underwater sites, particularly shell middens, tend to be rich in what archaeologists call ecofacts. This would include bone, shell, fish scales and pollen. From such material, reconstructions of climate, floral and faunal populations and in some instances, even topography are possible.

   Ruppe found at the Venice Beach site that oyster size and species had changed through time. In part, the differences were due to salinity tolerance. From this he was able to suggest that the opening and closing of inlets would lead to salinity changes in the lagoon environment and that this might be the reason for the size and species change in the oysters present in the midden (Ruppe 1980).
4. Money: underwater archaeology is highly visible and scientifically sexy research. In these days of increasingly tight research funds, piggybacking that kind of research can be advantageous.

Given the data needs required for underwater work in the Bay, there should be no difficulty in finding valid problems to explore which involve archaeology. Equally, adding archaeological problems to other types of research should not be difficult.

There are some obvious conclusions which can be drawn about the underwater archaeological resources of Tampa Bay:

1. There are sites in the Bay.
2. Some of the sites are of considerable antiquity.
3. The sites in the Bay are probably in good condition.
4. The sites in the Bay are archaeologically important because they can supply data not available from land sites.

5. Locating and working sites in the Bay will require multidisciplinary research.
6. There is some urgency attached to dealing with the sites in the Bay. If moves are not made in the near future to manage the impact to Bay bottom sites, they will be lost.

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THE FRONTIER AND TAMPA BAY

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The first Europeans to reach the United States came in search of gold. The settlers of Virginia in 1607 found it difficult to plant crops or trade with the Indians for they were very busy hunting for gold. Such was the same situation with the Spaniards who had come to Tampa Bay nearly eighty years previously. Two Spaniards had found the keys to virtually inexhaustible vaults of gold in Mexico (Hernan Cortez) and in Peru (Pizarro), and other Spaniards seeking to duplicate their efforts came to the western shore of the Floridian peninsula.

The first of these expolorers or conquistadors was Panfilo de Narvaez, who was given a patent by the King of Spain to settle Florida. After sailing from Santo Domingo on April 4, 1528, he arrived on the shores of Tampa Bay with 400 men. Finding only gold trinkets here, Narvaez and his men departed for Apalache, or the area about Tallahassee, where the Indians told him gold might be found (Tebeau 1971).

In 1539 a much larger expedition led by Hernando De Soto sailed from Cuba, landing on the shores of Tampa Bay on May 30, 1539. It was De Soto who gave the name of Bahia del Espiritu Santo, or Bay of the Holy Spirit, to Tampa Bay. He, like Narvaez, looked for gold in the area. Not finding it, he moved to the north where there were actual gold fields in Georgia, and where the natives had fashioned some small finds into ornaments. But there was not enough to satisfy the Spaniards of De Soto, who moved on to the Mississippi River (Lewis 1907). Thus to these two Spanish conquerors, Tampa Bay represented a gateway to wealth where they could enter, anchor their ship, and move inland to where the gold seemed to be. Unfortunately, there was no treasure in Florida and the gateway served only as a starting point for a long, fruitless trip into the interior of America.

A different type of personality came in 1549 when Father Luis Cancer de Barbastro sought to make Christians of the Indians. Due to the bad treatment given to the Indians by De Soto and Narvaez, Father Cancer, a Dominican priest, was killed as he waded ashore somewhere on Tampa Bay (Kenny 1970).

In order to protect the gold shipments from Mexico and Peru from being seized by English and French buccaneers, Spain established a permanent base at St. Augustine in 1565 and made plans to establish outposts on the west coast of Florida. In 1567 Pedro Menendez de Aviles, founder of St. Augustine, visited the area about present day Fort Myers and established San Antonio near Mound Key in the territory of the Calusa Indians. Next he came to Tampa Bay and established a small post in the Tocobaga Indian dominions (Kerrigan 1965). Both San Antonio and Tocobaga only lasted for short times -- San Antonio for six years and Tocobaga a month, for the Indians soon destroyed both places, driving the Spaniards away. Thus the attempt of the Spanish to found a colony on Tampa Bay, possibly at Safety Harbor, failed due to the hostility of the Tocobaga Indians.

One Spaniard named Hernando de Escalante Fontaneda was captured by the Calusa Indians when his ship was wrecked and lived among them for nearly twenty years. When he rejoined his fellow Spaniards, he wrote and published his memoirs, which gave a good insight into Southern Florida Indian life. Besides telling about Indian life, Fontaneda listed 22 Calusa settlements as key Indian towns, including one designated Tampa (True 1945). On a map drawn in 1601 by Herrera, the bay known to De Soto as the Bay of the Holy Spirit was designated

Tampa Bay (Grismer 1950). The naming of this bay as Tampa may have been correct if such a village existed here, or it probably was a mistake. Anyway, the name stuck.

During the 17th century, there were contacts between the Spanish and Indians at Tampa Bay, but these encounters were limited to trading sessions. In 1612, Lieutenant Juan Rodriguez de Cartayo presented the Tocobaga Indians with gifts and then sailed to Charlotte Harbor and Estero Bay (Grismer 1950). These trading expeditions did not last long, for diseases including smallpox and measles introduced by Narvaez, De Soto and the others, killed off many of the Indians living along the shores of Tampa Bay. Those who survived either migrated elsewhere or were captured by slave hunters from South Carolina (Covington 1968); soon there were no Indians here.

Sometime during the 17th century, the natives of Cuba discovered that the west coast of Florida contained vast quantities of edible fish. Soon as many as 200 vessels frequented the coast from Key West to Mobile. It was claimed that the first fishing vessels had come to Key West and the Miami area, and then others had moved up the Gulf coast. Usually the fleets arrived at the coast from Havana in the fall, making the coastal islands their base of operations where camps were established, nets were repaired, and the crews of each vessel (approximately 20 men each) made their temporary homes (Covington 1959). Fish gathered by the netting operations included trout, grouper, red snapper and sheepshead. Mullet caught in the nets were stripped of their roe or eggs and then tossed overboard. The fish caught were preserved by salt brought from Cayo Sal in Cuba, or by the smoke of burning corn cobs and shucks. Althought the fishermen were centered at Charlotte Harbor, there possibly were camps located on Egmont and Mullet Keys.

Some fishermen, not wanting to take the trip back to Havana in the spring of each year, decided to remain on the coastal islands or mainland. There they supported themselves by selling fresh produce from their gardens to the crews when they came back to the fishing camps. Some of the first orange groves along Tampa Bay were developed by these Cuban fishermen. Of course they had no legal title to the land, for no one informed the authorities at St. Augustine (Anon. 1940).

In the 1750s, the first wandering bands of Seminole Indians moved into the bay area. The men had come from camps in northern Florida in search of deer, whose skins they carried back to the trading posts in northern Florida and southern Georgia where they were exchanged for civilized products including rifles, pots, knives and clothing. These Indians stayed inland on their hunts, only rarely visiting the coast, but after contacts were made with the Cubans, the visits became more frequent. Some Indians were taken to Cuba for brief visits on the fishing vessels. Others were trained as seamen and began working on the vessels. Some Seminole women becames mates of the fishermen and children of these unions were taken to Cuba for baptism and education (Covington 1954).

The governor of Florida interested the King of Spain in the Florida timber industry and in 1756 issued orders stipulating that the timber of the peninsula might be cut for use as masts and spars. The naval shipyard at Havana dispatched Juan Baptista Franco in 1756 on a search for suitable timber. He found Tampa Bay to be "a large bay with three extensive mouths at its entrance with sufficient depth in all of them for any large ship." Landing and exploring the area for 22 days, he found two rivers (Hillsborough and Palm Rivers), abundant and adequate forests, and much wildlife (Arnade 1968).

In 1757 Franco came back to Tampa Bay with Francisco Maria Celi, who made a full scale exploration of the bay. Celi charted the various parts of the bay, giving the depths of the water in a scholarly fashion. A longboat was used by Celi to explore the Hillsborough

River, and he and his men proceeded as far as the falls in present Hillsborough State Park. As Franco had done, Celi praised the rich timber resources, but neither report was followed by action (Ware, no date).

During this period, the first maps of Tampa Bay were made available. Due to the soundings and observations made by Celi, the first detailed map was made in 1757. It shows no Indian settlements, but the Hillsborough and Palm Rivers were named as San Julian Arriaga and Franco. Old Tampa Bay and Hillsborough Bay were designated Estero Grande de Girior and Ensenada de Aquirre (Arnade, no date). The two names that have lasted throughout the years are Pinellas Point (Punta Pinal de Xinenez) and Boca Ciega (Boca Zieqa).

Another map appeared roughly at the same time with two versions -- one English and the other Spanish. Noted on this map are the two rivers, islands in the bay, and various depths of the water. Two places along Tampa Bay are identified as los trabajos (the works) and El Quemado. Zarazote is noted as the Sarasota of today (Covington 1961).

In the 20-year period from 1763 to 1783 England owned Florida and some good maps of the area were produced. The English appointed surveyors and map makers who produced adequate maps covering much of coastal Florida. It is believed that George Gauld did the soundings and made the sketches for the English map of Tampa Bay. Although Thomas Jefferys, geographer to the King of England, produced the first adequate English map of Tampa Bay based upon earlier Spanish, French and English maps, it was Gauld who first provided the name of Egmont Key and Hillsborough Bay to sites within Tampa Bay. These sites were named in honor of members of the Council governing the colonies. In the same manner, Charlotte Harbor was named in honor of the Queen of England.

William Roberts, who wrote the first lengthy account in English of Florida in 1763, calling Tampa Bay Bahia del Espiritu Santo as De Soto had done, said it was a "large and noble bay extending above twenty leagues in length and six in breadth where broadest having from five to seven fathom water except at the eastern outlet" (Roberts 1763). One part of Bahia del Espiritu Santo was called Tampa Bay by Roberts. It is known to us today as Old Tampa Bay.

When the Spanish regained Florida, Bernardo de Galvez sent Jose de Evia to inspect the coast from Tampa to Tampico. In September 1783, Evia sailed from Havana, making a detailed examination of the coast starting at the Keys. After examining Charlotte Harbor, Evia reached Tampa Bay in October but due to strong winds, came back again in November. He noted Mullet and Egmont Keys known to the Spanish as Castor and Pollux Keys, and met with Creek and Choctaw Indians who had come to Tampa to hunt deer and trade the skins to the English traders at Pensacola and St. Augustine for firearms, powder, balls and flannel. This examination by Evia was not a detailed one. However, Evia believed that the maps and charts he made of the bays were more accurate than the English ones (Holmes 1965).

In 1793 Vicente Folch y Juan was sent to check Tampa Bay to see if it was adequate for the establishment of a trading post and settlement. Folch, coming to Tampa Bay in the fall of 1793, was able to unearth more details about the bay than any previous visitor. He found four rivers leading into the bay -- three of them navigable by large vessels. The trees along the rivers seemed adequate for construction of houses and the land, although poor, could produce crops of vegetables, corn, cotton and tobacco (Holmes 1965).

Two Indian villages, Cascavela and Analtylaica, were sited at Tampa Bay and the inhabitants were delighted to learn that a trading post would be located nearby. Due to lack of a nearby post they were forced to carry their skins to St. Augustine, St. Marks or Pensacola, where they exchanged them for many items including saddles, pins and glass beads. Based upon his examination of the coast, Folch

recommended that a garrison be stationed in Tampa. The Spanish may have followed up Folch's suggestion but there is no available record that a post was established. In 1817 an English trader by the name of Arbuthnot may have established a post at Tampa Bay.

During the winter of 1799-1800 Andrew Ellicott, who was surveying the border between Spanish Florida and the United States, made a trip by sea from St. Marks to the St. Mary's River. Due to a heavy storm, the ship on which Ellicott was travelling was forced to anchor near the mouth of the Anclote River off St. Clement's Point. These points were known by their present day names at this early date. When the wind moderated, the ship hoisted anchor and sailed by Hillsborough Bay, Spiritu Santo or Bay Tampa -- he called it by all these names (Ellicott 1962).

By 1824 when the Americans first moved into Tampa Bay, there was little really known of the area. The keys, Mullet and Egmont, were well known and had been noted by virtually every visitor. The Cuban fishermen had used the lower portions of the Pinellas peninsula and some smaller islands at the mouth of Tampa Bay but little else. The mouths of several rivers had been explored, but only the Hillsborough in 1757 had been thoroughly examined. All the others, including the Manatee, Little Manatee, Braden, Alafia and Anclote, were virtually unknown. The details of the areas around modern day St. Petersburg, Clearwater, Tampa, Bradenton and Sarasota were not known at all except that they contained abundant forests and wildlife.

In 1818 Richard Hackley and the Duke of Alagon signed an agreement for the acquisition of much of central Florida from the King of Spain. Subsequently, Hackley acquired the Duke's portion and sent S. S. Seymour in 1822 to examine Tampa Bay. Entering the bay known at that time as Bahia del Espiritu Santo, his ship moved past Old Tampa Bay, edged by Buffalo Bluff and Mangrove Bluff on the right. He noted the Hillsborough, Manatee and Alafia Rivers and sailed 10 miles up the Hillsborough (Seymour 1922). He saw no Indians but encountered one Indian-Black who had lived in the area for 5 years. There were no Cuban fishing activities being maintained in the bay but Seymour learned that there had been some on the keys at the mouth of the bay until the United States acquired Florida in 1821.

In November 1823, Richard Hackley sent his 25-year old son, Robert, to establish a plantation at Tampa Bay. When young Hackley landed at present day downtown Tampa, he found no white settlers but only Indians, alligators and wolves. The work force of 16 men began to clear the land, assemble a frame building carried along from New York, take care of the cattle, hogs and chickens, and help clear the thick underbrush.

There was an Indian village at Thonotosassa and an excellent chance that more Indians and blacks would move into the area. Under the terms of the Treaty of Moultrie Creek signed in September 1823, the bulk of the Seminole population was to move from northern to central Florida. Some former slaves who had fled to freedom in Spanish Florida from the United States began to move away from the northern part of Florida to parts of the peninsula where white control had not been extended (Anon. 1956). They tended to live on islands along the coast which could have included islands near Bradenton and Sarasota. In contrast, the Indians established their villages inland because the treaty prohibited contacts with Cubans from along the coast. Of course, some blacks did live in segregated villages with the inland Seminoles.

With the creation of an Indian reservation in central Florida, it was necessary to erect a fort on Tampa Bay to prevent any contacts between the Indians and Cuban traders or fishermen. Accordingly, troops commanded by Colonel George Brooke were dispatched from Pensacola to establish a fort. James Gadsden, who had been examining the area, recommended to Brooke that

the site of Hackley's plantation at the juncture of Hillsborough Bay and River might be the best location. Gadsden had contacted Brooke by placing a signal on a point on the Interbay Peninsula which still bears his name (Grismer 1950). The troops moved on to the Hackley plantation and although the foreman protested, the house was used as officers' quarters. When Robert Hackley returned from New Orleans, he protested the action of Brooke. Ultimately a lawsuit was filed but the Hackleys lost in court.

Lieutenant George McCall, who was a member of the first group of soldiers to occupy the Tampa Bay military post which became known as Fort Brooke, wrote letters to his father telling about life in Florida. He called the entire bay Espiritu Santo, the western arm Tampa Bay and the eastern arm Hillsborough Bay. McCall visited both Mullet and Egmont Keys, noting the growth of cedar on Egmont, deer on Mullet and large numbers of oysters covering the floor of the bay. McCall claimed it to be the best oyster bed on the continent. About Fort Brooke the troops cleared the underbrush but left the fine growth of live oaks to shade the buildings which were being constructed of pine lumber.

The soldiers found the bay fishing to be wonderful. Twice a week boat crews hauled seines through the water catching full loads of redfish, sheepshead, drum, flounder, sole and mullet. The catch was thrown on the wharf and the cooks moved in to get a supply for their men to carry away in a wheel barrow. The remainder was given to the Indians or buried in the garden for compost (McCall 1868).

Although in 1830 the Federal Government claimed a tract of land 16 miles by 16 miles square for the Fort Brooke Military Reservation, settlers moved onto the reserve and lands outside it, hoping to claim land under the Pre-emption Law of 1826, a sort of Squatters Sovereignty (Covington 1980). William G. Saunders established a general store at Fort Brooke in 1828. Other businesses, including a shipyard, laundries, blacksmith shop, and rooming houses opened along the eastern banks of the Hillsborough River. William Bunce operated a fishing "rancho" off Pinellas peninsula at a place that became known today as Bunce's Pass, but later the rancho was moved to Palm Harbor just off Sarasota. Count Odette Philippi settled at Safety Harbor and established a plantation that contained citrus groves and cotton fields.

In 1834, the County of Hillsborough, which included the land from Dade City to the Caloosahatchee River and all of Tampa Bay, was established. Tampa was designated as the county seat but evidence was not clear as to the time and place that a courthouse was erected.

After the conclusion of the Second Seminole War, Congress passed the Armed Occupation Act in the hope that the settlement of the land between Gainesville and Charlotte Harbor would stimulate the rush of settlers into the wilderness and, if the remaining Seminoles in Florida were thinking about starting another war, they would be deterred by the frontier folk each living in scattered cabins that might be deemed virtual fortresses that could be captured only with the loss of many Indians. Some pioneers did take advantage of the act, which provided for the granting of 160 acres of land to the head of a family or single man who erected a house, cultivated 5 acres and lived on the land for 4 years. Virtually none of the land abutting on Tampa Bay was eligible for settlement under provisions of the act for it prohibited settlement within 2 miles of the coastline. Yet, there were many applications from persons who settled near or on the bay (Covington 1961). Robert Jackson and 13 others settled on the Alafia River, Henry Lindsey and dozens of others on the Manatee River, and some along the Hillsborough. In present day Pinellas County, Maximo Herandez settled on the tip of the peninsula or Maximo Point, Joseph Silva and John Levich at Boca Ciega, and 7 persons at Clearwater Harbor near Fort Harrison.

The rich soil of the Manatee River Valley attracted many settlers either under the terms of the Armed Occupation Act or by purchase of large tracts from the Federal Government. Josiah Gates opened a hotel at the present site of Bradenton under the terms of the Armed Occupation Act. Large tracts of land suitable for the production of sugar cane were purchased by persons from Tallahassee, including Hector and Joseph Braden, Robert and William Gamble, and Pinckney and John Craig. Since some 45 persons had desired land in the valley of the Manatee River, it was the first section along Tampa Bay that was surveyed in 1843.

By 1840, the Tampa Bay area had no incorporated towns, one county, and 452 persons, including 356 persons at Fort Brooke, 81 white settlers, 2 free blacks and 13 slaves. Since Fort Brooke dominated the bay, there was some shipping for the requirements of the post, and the inhabitants lived in a small unincorporated town within the bounds of the government land. Egmont Key Lighthouse had been erected during the Second Seminole War to guide ships into Tampa Bay. The frontier folk had settled along the mouths of the rivers and the bay because water was the available and dependable means of transport. Although much of the land was suitable for the growing of citrus and some strawberries, and the bay teemed with a rich supply of fish and oysters, and there was also a rich supply of phosphate in the valleys, not much of these resources could be utilized until better transportation in the form of railroads and harbor deepening could be realized.

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HISTORY OF THE PORT OF TAMPA

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ABSTRACT

The Port of Tampa has served as a vital transportation link for the west central Florida region since the early nineteenth century. It evolved initially as a gateway for agricultural products flowing to and from Cuba. Improvements to the natural harbor began with the discovery of phosphate in the region and the first Congressional authorization in the 1880s. During the past 100 years, channel dimensions have repeatedly been enlarged, the size of ships calling on the port has increased, and the annual tonnage transiting the Port has increased from 1 million tons in 1920 to 50 million tons in 1980. The several separate private and public improvement projects which have culminated in the current 43-foot project are traced, including some analysis of disposal strategies.

INTRODUCTION

The history of the City of Tampa is linked closely with the development of its port. Tampa's position as the financial and industrial hub of the Southeast is clearly a direct result of the availability of a deepwater harbor and efficient port terminals. However, because Tampa is located in a largely tourist- and retirement-oriented region, many area residents have little appreciation of the importance of the port. The development of the present port has involved numerous separate dredging projects extending over a period of approximately 100 years. These have been funded by both the federal government and private sources and have resulted in a network of almost 80 miles of deepwater channels. In addition, hundreds of acres of bay bottom have been filled to construct waterside terminal areas and, more recently, spoil disposal islands.

The purpose of this paper is to trace both the economic development of the port and these many port-related dredging projects as a form of "development time clock" against which trends in physical and biological parameters, as well as other forms of coastal development, can be set.

CARGO AND VESSEL HISTORY

Naval engagements involving Fort Brooke, Tampa's predecessor, date back to 1824. During the Civil War, the bay was the scene of engagements between federal forces and blockade runners. However, Tampa's role as a true port came into being only following the Civil War. Initial cargoes were primarily related to local agriculture consisting of lumber, cross-ties, and cattle all being shipped to Cuba.

The discovery of phosphate in the Bone Valley region of Polk County in the 1880s dramatically changed the future of the port and changed entirely the cargo mix on which the port is based. The impact of the phosphate industry is clearly pointed out by early tonnage figures. In 1889, the docks at Tampa handled approximately 27,000 tons of primarily agricultural goods. In 1891, the phosphate terminal located at Port Tampa had handled 136,000 tons. This difference points out a very important motivation for many of the port improvement projects which followed -- intense competition between port interests located in the city of Tampa and the railroad and Port Tampa facilities of Henry Plant.

Between 1910 and the early 1920s, annual tonnage stabilized at around 1.5 million tons. Outbound phosphate rock comprised about 75% of this total. Port tonnages since 1920 are shown in Figure 1. A slow increase in annual tonnage continued until around 1950, after which there began a sharp increase in annual tonnages which has continued to the present level of 50 million tons per year.

Tampa presently ranks 7th through 10th in the country, depending on which criteria one uses to judge the relative size of ports. Ninety-seven percent of Tampa's total tonnage is bulk cargo, and the vast majority of exports remains phosphate rock and phosphate products. Imports are primarily fuels such as gasoline and coal, along with raw materials for the phosphate industry, such as sulphur and potash. This cargo mix is basically unchanged since the 1920s. Recently, other forms of general cargo such as steel, citrus, lumber, meat, and automobiles have increased markedly. In addition, containerized cargoes are clearly in Tampa's future.

The size of motor vessels calling on the port of Tampa have increased from Henry Plant's 200-ft Mascotte which first called in 1886 (and which is depicted in the City of Tampa seal) to present-day bulk carriers over 900 ft long, 105 ft wide, in the range of 55-70,000 dead weight tons. Many of these vessels have potential drafts of up to 47 ft. The size of vessels has been a key issue since the very beginning. The fact that the Mascotte had to anchor off Gadsden Point and be unloaded by lighter is what caused Henry Plant to extend his railroad to Port Tampa and to seek changes in the very first harbor project.

The number of vessels calling on the port has also changed over the years. In 1891, Port Tampa handled 205 vessels loading 500 tons per day by hand. In 1910, over 1,000 vessels called on the port and by 1927 almost 2,900 sailings are reported. Today, the port averages around 2,000 ships and 1,100 barges calling per year.

CHRONOLOGY OF PORT DREDGING AND FILLING PROJECTS

A review of the original 1879 navigation chart of Tampa Bay reveals a natural central channel running from Egmont Key to the area south of Gadsden Point. Natural depths range from 21 to 37 ft in this area. From the westerly end of the basin south of Gadsden Point, there is a smaller natural channel which runs past the present site of Port Tampa up into Old Tampa Bay. With the exception of two small shoal areas, the depths in this channel range from 20 to 35 ft.

In Hillsborough Bay, 20 ft depths did not extend beyond a line running from Gadsden Point to what is now Apollo Beach. Natural depths of 13 ft extended north in the center of the bay to the latitude of Ballast Point. However, the limiting depth to Ballast Point itself, where many early sailing ships were anchored, was less than 11 ft. From this point northward to the mouth of the Hillsborough River, the limiting depth was approximately 5 ft.

Even by 1879, the end of the pristine nature of Hillsborough Bay was already in progress. At the request of local interests, the Corps of Engineers had conducted a survey of the bay in 1871. As a result of this survey, the Corps recommended that a 12-ft channel be constructed connecting the mouth of the Hillsborough River with deeper water offshore from Ballast Point. This channel could be constructed either straight up the center of the bay or along the course of the existing natural channel offshore of what is now Bayshore Boulevard.

If one inspects an 1899 navigation chart of the bay, the results of these recommendations, along with political action by local interests, can be observed. Figure 2 illustrates port improvements which took place between 1879 and 1899. An 8-ft channel had been dug from the vicinity of Ballast Point to the Hillsborough River, involving the excavation of approximately 150,000

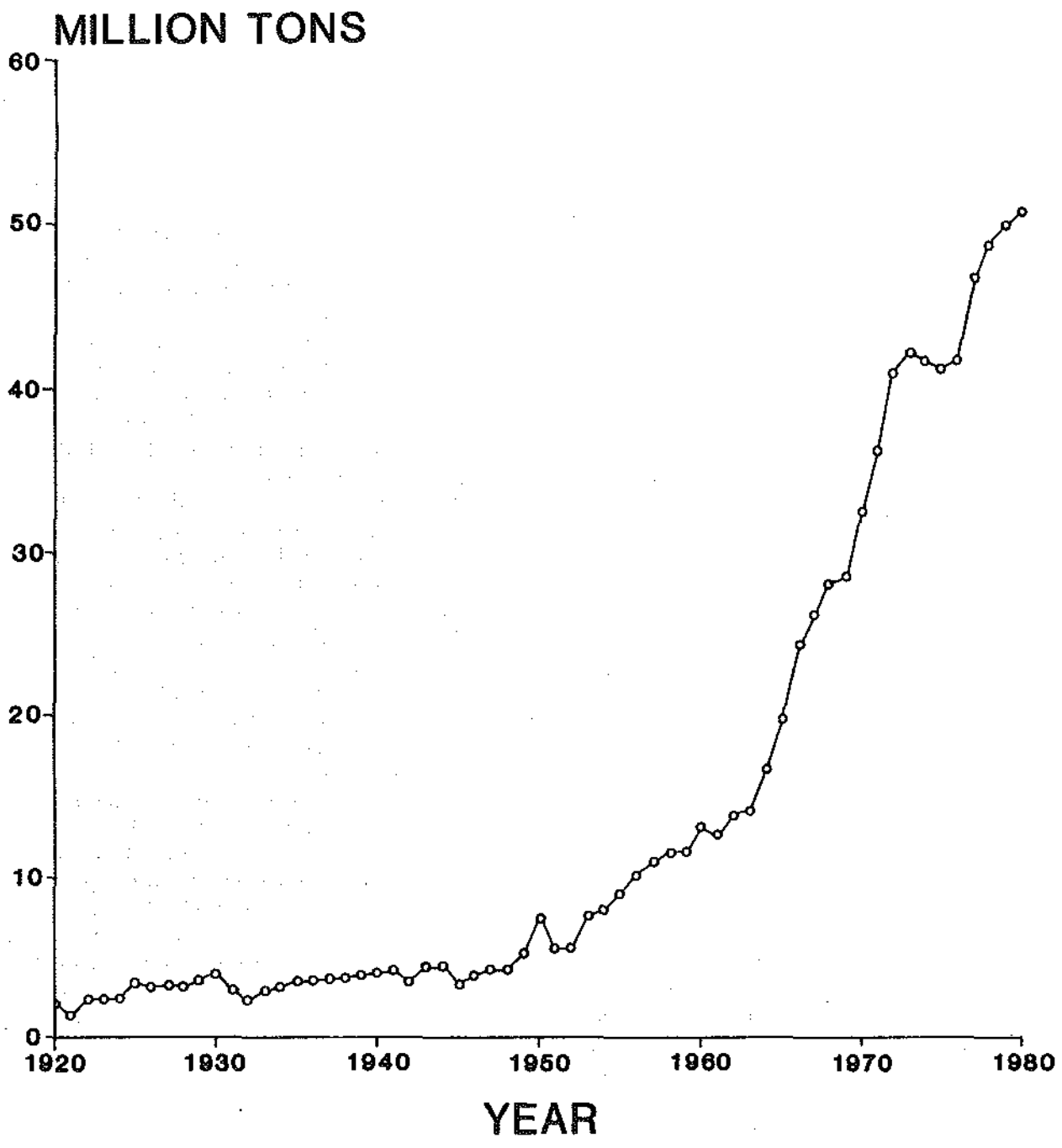

Figure 1. Tonnage, Port of Tampa, 1920-1980.

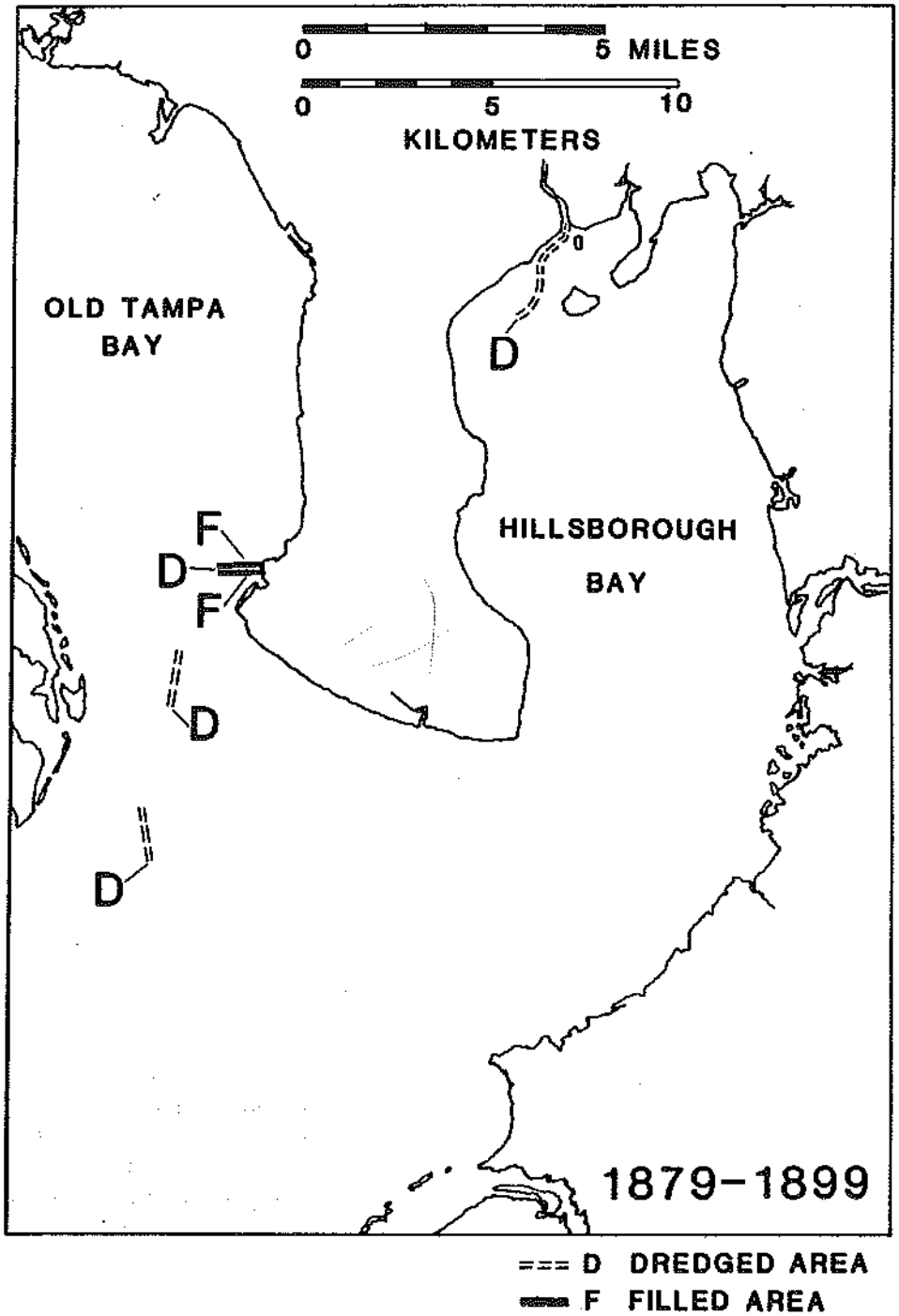

Figure 2. Improvements, Port of Tampa, 1879-1899.

cubic yds of material. This initial project was authorized in 1880 and originally called for the 12-ft channel cited above. However, the project scope was reduced as a result of the efforts of Henry Plant to divert the Corps' efforts elsewhere.

Over at Port Tampa, Mr. Plant had recently completed dredging up a new port facility at the termination of his South Florida Railroad. Through political efforts, Mr. Plant arranged for the Corps to construct two shortcuts through the natural shoals cited above, thus providing a 20-ft channel to the new terminal. This action, combined with the reduction in the Hillsborough Bay project, forced Tampa merchants to use his railroad, his port, and his ships. The economic "war" was on.

Figure 3 depicts port-related projects which occurred between 1900 and 1912. This was basically an era in which port interests in the City of Tampa played "catch-up" with Henry Plant's Port Tampa facilities. In 1899, Congress had approved a 27-ft channel to Port Tampa. This required not only additional dredging in the previous sites, but also some new dredging further down the bay between St. Petersburg and Cockroach Bay.

The 1899 Act called for a straight 12-ft channel through Hillsborough Bay to the mouth of the Hillsborough River. However, Tampa interests convinced Congress to approve a 20-ft channel in 1905. This channel was completed in 1907 and is often cited as the real beginning of the modern Port of Tampa.

At the northern end of the new Hillsborough Bay channel, the Seaboard Airline Railroad constructed a new terminal for phosphate shipments by dredging up what became Seddon Island. In addition, the Tampa Northern Railroad dredged a short spur channel to its new terminal on Hookers Point. From Figure 3, it can be seen that these improvements became what are now known as Seddon Channel and Sparkman Channel.

To provide more public wharves for wagon-borne cargo, other local interests dredged a channel eastward from the mouth of the river toward Hookers Point in 1908. Since this construction did not entirely alleviate the need for additional wharves, a channel northward through an existing estuary toward Ybor City was proposed. This channel was approved by Congress in 1910. These channels became what are today known as Garrison Channel and Ybor Channel.

The 1910 Act also called for the construction of Sparkman Channel between Hookers Point and the new Seaboard Airline terminal. This act also called for deepening of the entire Hillsborough Bay project to 24 ft, bringing it into closer competition with the Port Tampa facilities.

Figure 3 also indicates the creation of long shoals paralleling the channel through the deposition along the channels of dredged material. This is the earliest indication of the creation of spoil banks which remain today. It should be noted that by 1910 the die had been cast as to the basic configuration of the port. Decisions made in the first decade of this century just about insured many of the water quality problems which we face today.

We move now to the era of 1912 through 1932. Port improvements which occurred during this period are illustrated in Figure 4. In 1922, a 27-ft depth was approved for the entire Tampa Bay project and this work was completed in 1928.

As part of the 27-ft project, dredging was done in all of the previously constructed channels. Spoil was again placed on berms adjacent to each channel. In Hillsborough Bay, this resulted in the formation of a series of small spoil islands stretching from offshore of Gadsden Point all the way up to the vicinity of Davis Islands. Additional spoil was placed on these islands during later projects at the same time that natural forces were working to erode them away. However, a number of these small islands remain today.

During this period, additional spoil was placed along the eastern shore of Seddon Island and along the western

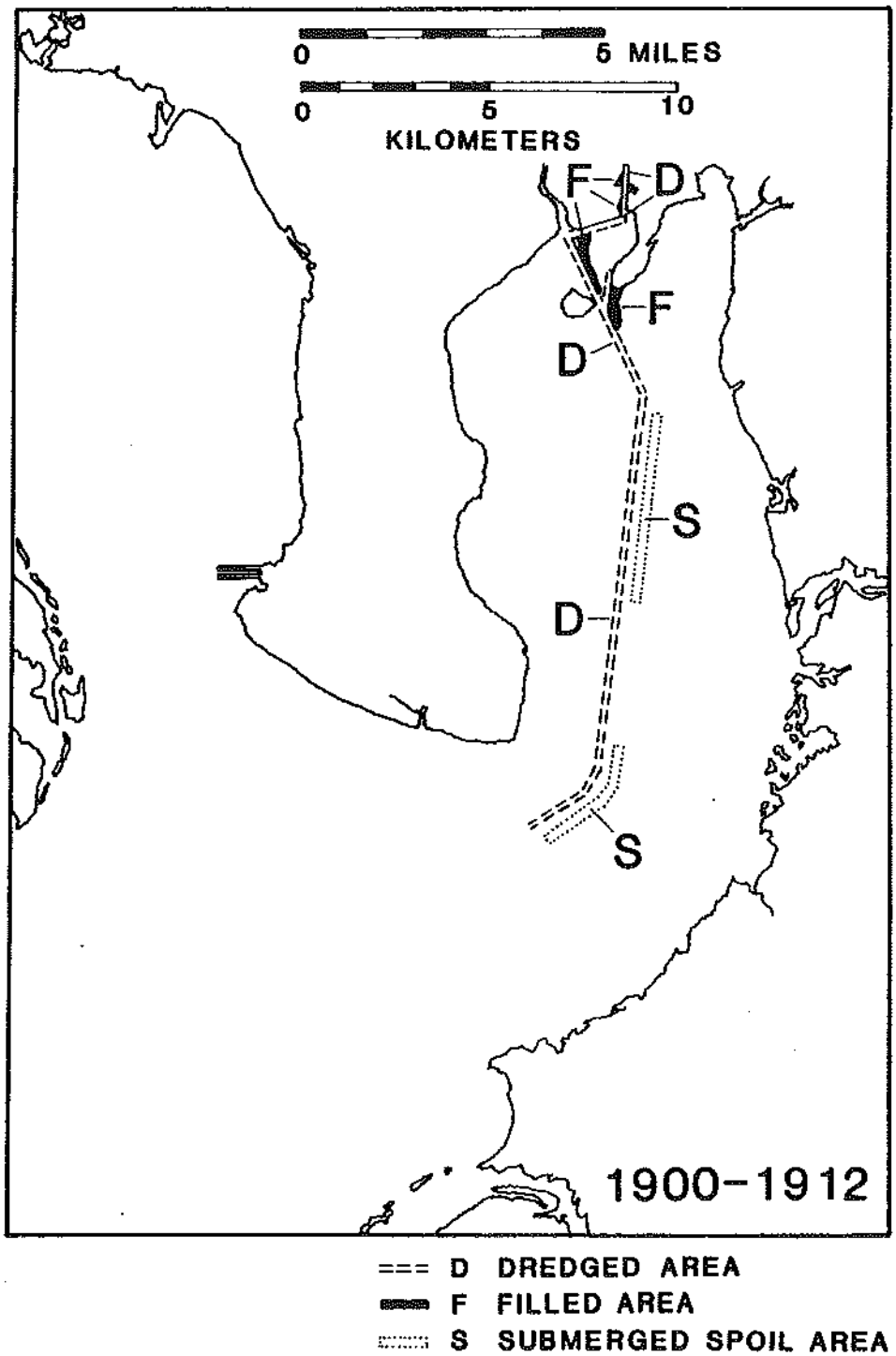

Figure 3. Port-related projects, 1900-1912.

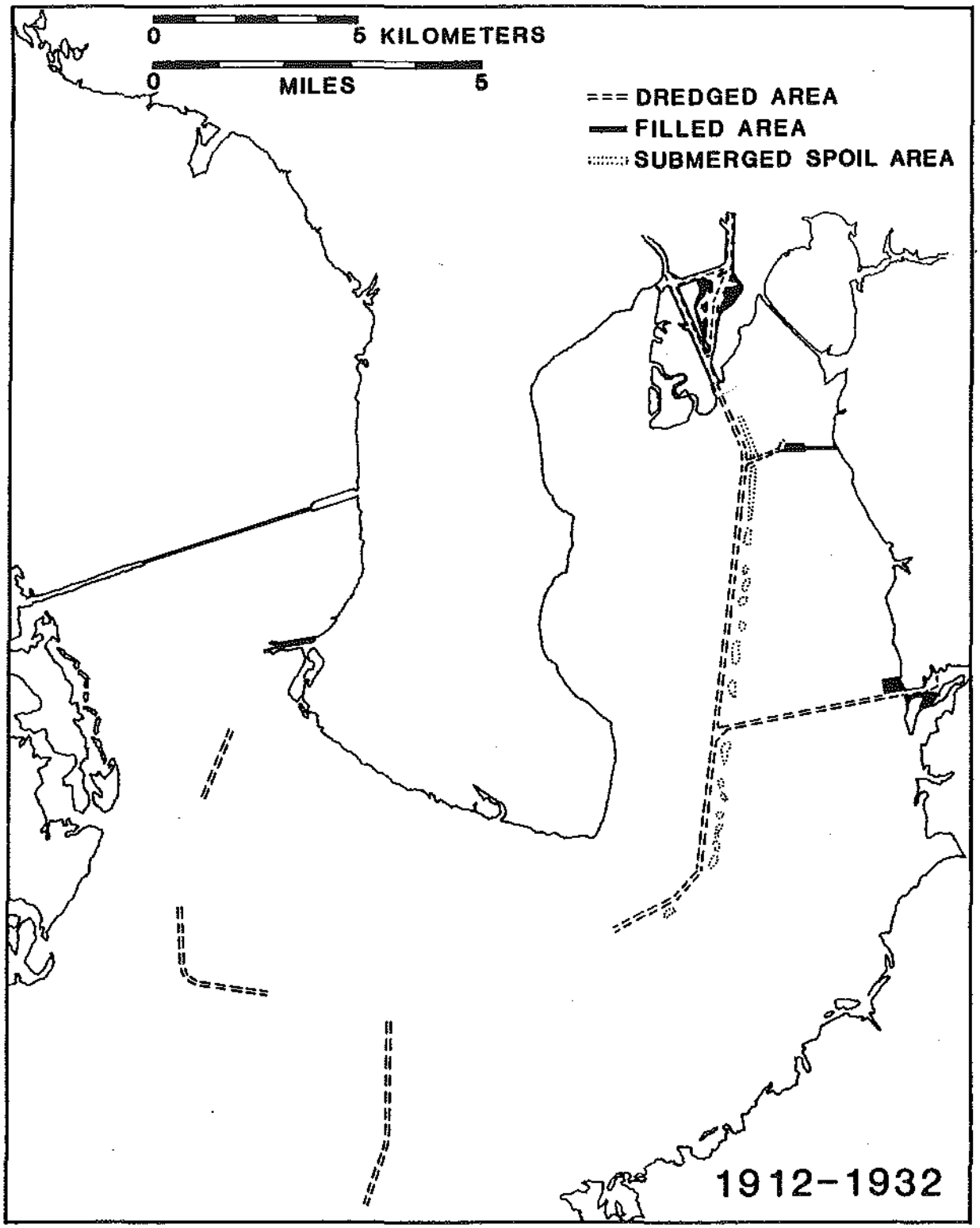

Figure 4. Port improvements, 1912-1932.

shore of Hookers Point, adjacent to Sparkman Channel.

In 1930, the American Cyanamid Phosphate Company dredged a 27-ft channel to Black Point on the eastern shore of Hillsborough Bay to create their own phosphate terminal on filled land. This project was abandoned soon thereafter and the property was sold to a Mr. Wayne Thomas whose family still owns much of Port Sutton, which is presently located at this site. The construction of this side channel strongly influenced the future shape of port channels in this area. It established a limit for the southerly expansion of Hookers Point and determined the location of the entrance to what is now East Bay.

By 1930, a 23-ft channel had been constructed from the main ship channel to the mouth of the Alafia River to service new phosphate terminals at East Tampa. The course of the Alafia River was dramatically changed by excavating through the north end of Pepper Key and placing dredged material in the old river course and north of the mouth of the river. Additional dredged material was placed in berms along the south side of the new channel, creating the initial stage of Bird Island, which is presently part of an Audubon sanctuary.

We move now to changes which occurred between 1932 and 1958 and which are illustrated in Figure 5. In 1935, Congress approved a 30-ft depth for the Tampa Bay project. This work was completed prior to World War II. During this same period, additional work was done to expand the channel to Black Point and enlarge the area of filled land at that site.

In 1950, Congress approved a 34-ft depth for the entire project. Work on this project was not fully completed until after 1960. This project required re-dredging of all the main channels from Tampa and Port Tampa all the way out to Egmont Key. Again, spoil material was placed on submerged and emergent disposal areas adjacent to the channels.

It should be noted that even with the 34-ft project there was a substantial part of the channel south of Gadsden Point which was still undredged. This area of the bay is only being dredged for the first time as part of the current 43-ft project.

Other changes which occcurred during this period included the completion of the present shape of Seddon Island, placement of fill in McKay Bay along the eastern shore of Hookers Point, and the construction of shallow-draft channels and terminals in the Rattlesnake area along the west shore of the Interbay Peninsula. In addition, a 34-ft channel was dredged from the Port Tampa channel to Weedon Island in Pinellas County as part of the construction of a new power plant. Material from the dredging was used to fill the site for the new plant.

The most dramatic changes in bay configuration resulting from development of port facilities occurred between 1958 and 1971. These changes are illustrated in Figure 6. During this period, the 34-ft project was completed with additional excavation of the Port Tampa Channel and Ybor Channel. This work resulted in the filling of what is now known as Picnic Island and the construction of a filled area in northern McKay Bay now occupied by the City of Tampa incinerator.

The major work during this period involved excavation and filling for the creation of new deep-water port terminals at the northern and southern ends of Hillsborough Bay. Private interests, including Tampa Electric Company, constructed a 34-ft channel from the main ship channel east of Gadsden Point to the Big Bend area south of the Alafia River. Material from this excavation was used to create four large filled fingers which are currently the site of the Big Bend power plant and phosphate-related terminals. During the same period, other private interests constructed the present Port Sutton Channel, using the excavated material to create what is now known as Pendola Point.

During the late 1960s, the Tampa Port Authority undertook a massive

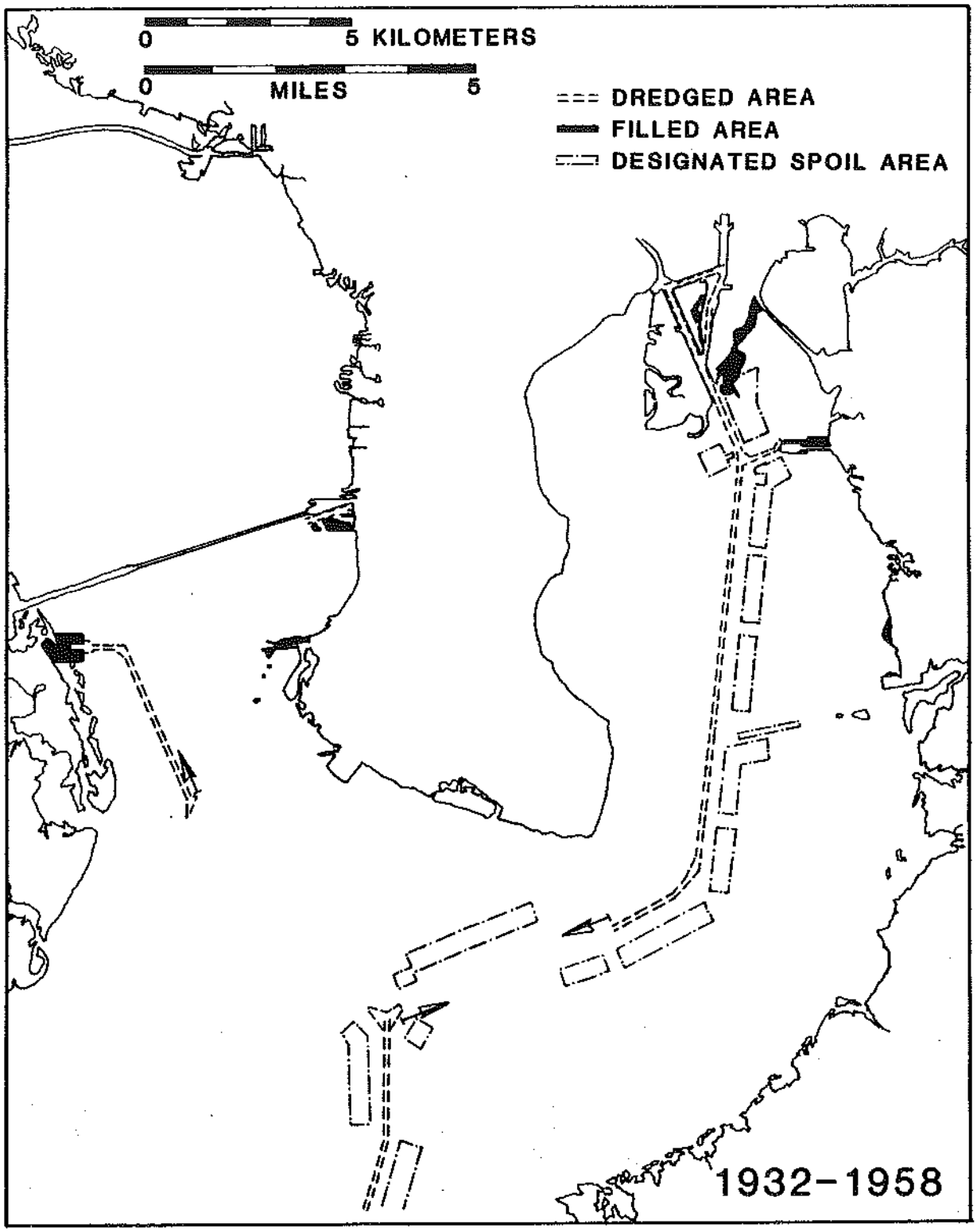

Figure 5. Port-related projects, 1932-1958.

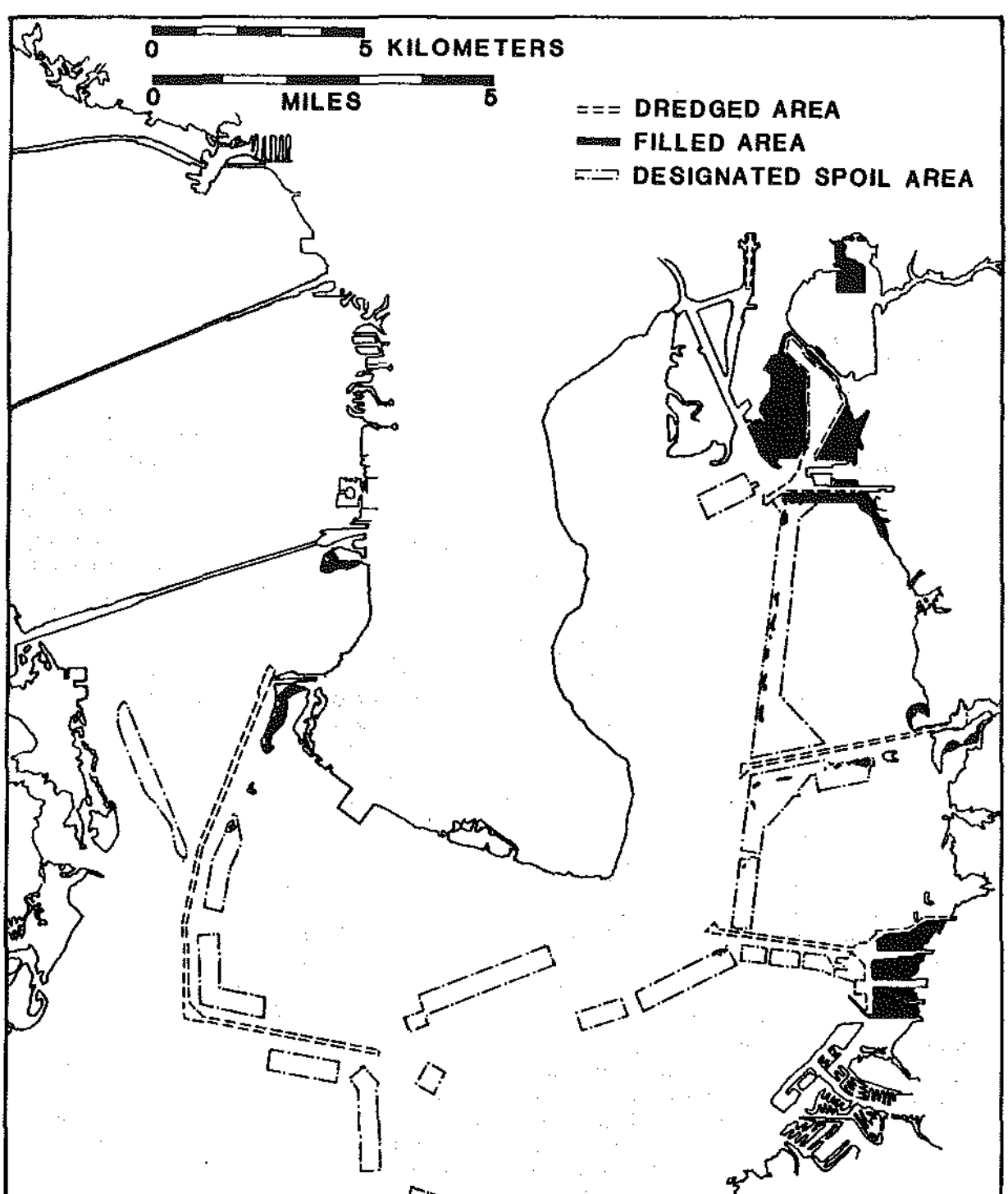

Figure 6. Port-related projects, 1958-1971.

project in what was then known as McKay Bay. This project resulted in the excavation of what is today known as East Bay. Material from this excavation was used to add several hundred acres of filled land to Hookers Point and to fill the eastern portion of McKay Bay for the development of new phosphate terminals. These areas today contain many of the port's most important facilities.

Additional work which occurred during this period included deepening of the Alafia River Channel to 30 ft, additional filling in the Rattlesnake area, and the construction of a 40-ft channel and filled port terminals at Port Manatee in southern Tampa Bay.

The passage of numerous pieces of environmental legislation in 1972 resulted in a dramatic decrease in the number of dredging projects associated with port development. Subsequent to that time, no additional shoreline areas have been filled for port-related facilities. However, the total volume of dredging has not decreased substantially.

In 1970, Congress authorized a 43-ft project for the main ship channels extending from East Bay to well west of Egmont Key. This project involves the excavation of almost 75 million cubic yds of material. As a result of this project, two large diked spoil islands have been created in the center of Hillsborough Bay, totalling over 1,100 acres in size. These hollow islands will be used to contain material excavated during future maintenance dredging operations. Other dredged material has been placed in submerged berms adjacent to the channels from the area south of Gadsden Point all the way down the channel to the area west of Egmont Key. In addition, some of the material excavated during this project has been hauled into the Gulf for disposal. This is a procedure which was also utilized for a portion of the 34-ft project during the 1950s.

Figure 7 highlights all of the areas which have been dredged or filled for port development in the past 100 years. It can readily be seen that the initial location of Fort Brooke at the mouth of the Hillsborough River and the desire of early business interests to remain competitive with Port Tampa have resulted in the extensive deep-water channels whose expansion and maintenance create major problems and challenges today.

FUTURE WORK

It would be unwise to conclude this survey without mentioning additional port-related work which can be expected to occur in the next few years. Most immediate among this future work is the completion of the current 43-ft project. This is expected to occur in late 1984.

With the completion of the deepening of the main ship channel, it can be expected that there will be strenuous efforts to obtain authorization and financing for the deepening of numerous berths and side channels in order to take advantage of transportation savings associated with the possible use of larger vessels. It should be noted that the deepening of Port Sutton, Cut D, Sparkman, Ybor, and Port Tampa channels was studied and approved as a part of the original authorization of the 43-ft project. That same authorization also requires local port interests to deepen berths which lie immediately adjacent to the newly-deepened channels. In addition, there are currently underway federal studies of the feasibility of deepening both the Alafia and Big Bend side channels.

A major challenge for both the Corps of Engineers and local interests is locating appropriate sites for the disposal of material which will be excavated as part of these future projects. Current environmental considerations will prevent use of most historical disposal strategies. The need to maintain adequate capacity for disposal of material from maintenance dredging operations precludes other alternatives, such as filling the newly-constructed diked islands. The cost of acquiring urban land, combined with problems associated with pumping salt water inland over fresh water aquifers, raises serious questions about the use of

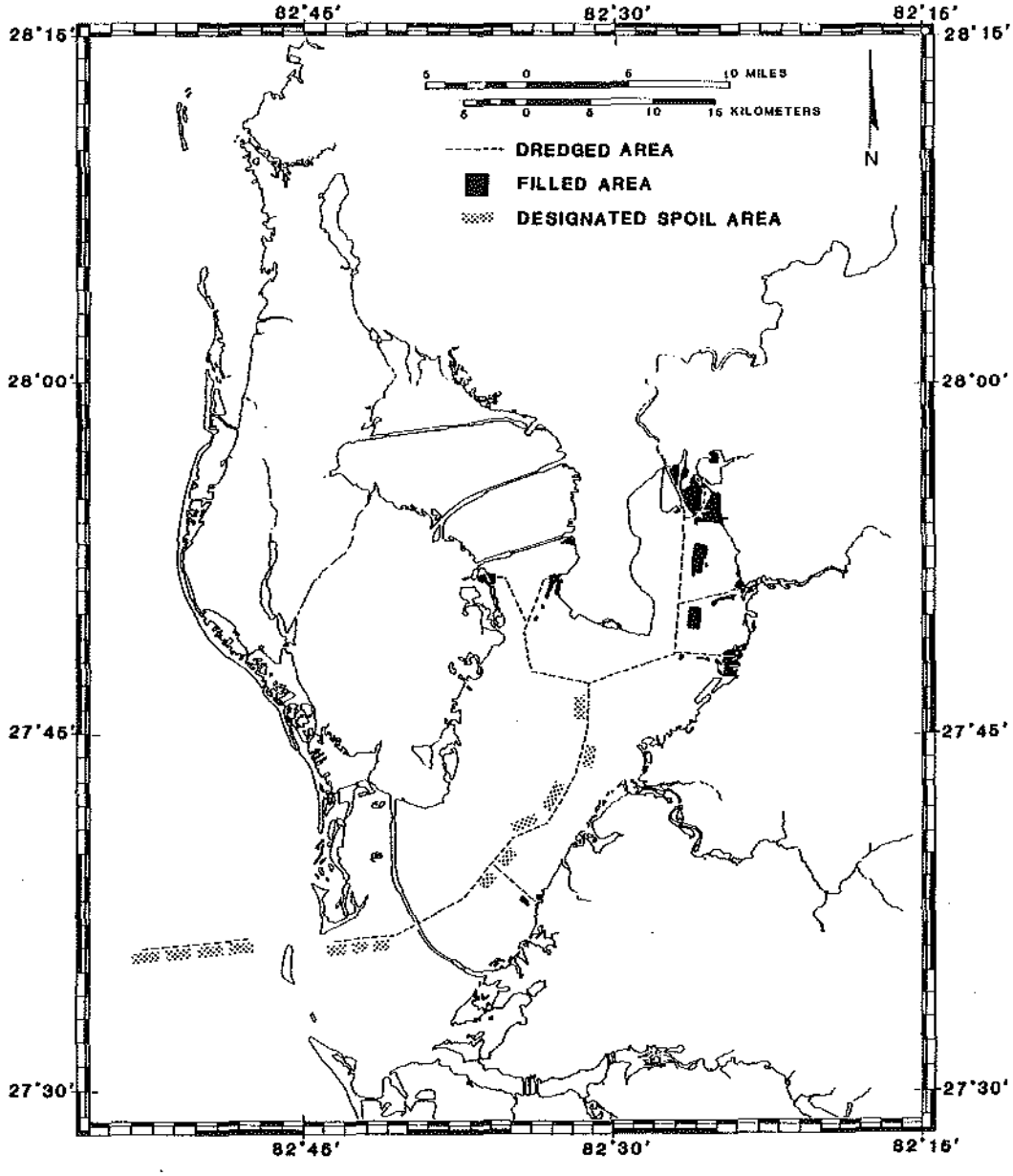

Figure 7. Areas of Tampa Bay dredged or filled for port development, past 100 years.

upland disposal sites. Finally, the great distance from most port areas to offshore disposal sites makes that option have limited financial feasibility. A successful solution to these problems which will protect the economic viability of the port and the environmental quality of the bay will require both innovation and close cooperation between port and environmental interests.

POWER PLANTS: THEIR PRESENT AND FUTURE IMPACT ON THE AQUATIC RESOURCES OF TAMPA BAY

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ABSTRACT

Impetus for the study of environmental impacts associated with power plants evolved with Congress's amended Federal Water Pollution Control Act, 1972. The Act provided the utility industry the opportunity to demonstrate through study that effluent limits based on best practical technology are more stringent than necessary to meet to goals of the Act. Presently, 5 steam electric plants are using Tampa Bay as a source of condensor cooling water and as a site for disposal of waste heat. The subject of this presentation is the environmental data and assessment strategies used to evaluate impacts of these facilities on the aquatic resources of Tampa Bay. The entrainment of meroplankton emerges as the most difficult impact to measure and assess because of uncertainties of determining the dimension of the animal population subject to intake effects. Measured changes in community structure and abundance of the benthic biota serves as an effective parameter to define boundaries of thermal impact. The areal extent of thermal impacts can be estimated and regional consequences assessed. Impingement of fish and shellfish appears as an impact of least adverse consequences to the aquatic resources of the Bay. Siting criteria are discussed as the most effective means of minimizing future environmental impacts. Existing technologies are reviewed as "fixes" for currently operating facilities.

A REVIEW OF ENVIRONMENTAL IMPACTS OF MUNICIPAL SERVICES IN TAMPA, FLORIDA

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INTRODUCTION

A city is a form of community organization, a cooperative structure originally made possible by the development of centralized agricultural practices. With centralization came an increase in population density, which resulted in the need for municipal utility services. The complexity of these services has changed drastically over the last several decades, especially as the need to live in harmony with the natural environment has become more evident to community leaders.

A city can be likened to a large industry or even to a living organism: each need continuous supplies of raw resources, pathways to distribute these resources, and methods to dispose of waste products. Distribution pathways in a city are numerous and include roadways, drainageways, sewer lines, and water lines. Waste products to be disposed of include stormwater runoff, sewage, and solid waste. Each one of these supply, distribution, and disposal systems has the potential for deleterious environmental effects.

In the following pages, the development of selected municipal services (potable water, sanitary sewers, drainage, and sanitation) in Tampa, Florida will be traced. Past and present technologies and environmental impacts associated with these technologies will be discussed.

POPULATION GROWTH IN THE TAMPA BAY AREA

Tampa, founded in 1887, is located along the northeastern shore of Tampa Bay, specifically at the head of Hillsborough Bay (Fig. 1). The 1980 population census for the two most populous counties bordering Tampa Bay are shown below.

Population figures for Tampa Bay area, 1980 census.

Pinellas County		Hillsborough County	
St. Petersburg	283,647	Tampa	271,523
Clearwater	85,528		
Other Municipalities/ Unincorporated	404,356	Other Municipalities/ Unincorporated	375,437
Total	728,531		646,960

Although the population of the City of Tampa has not increased significantly over the past 20 years, the total population of Hillsborough County has increased substantially and the urban core of Tampa proper is expanding into unincorporated areas. Hillsborough County's population has doubled in the last 26 years.

POTABLE WATER SERVICES

Centralized water supply services were initiated in Tampa in 1887, with the founding of the Tampa Water Works

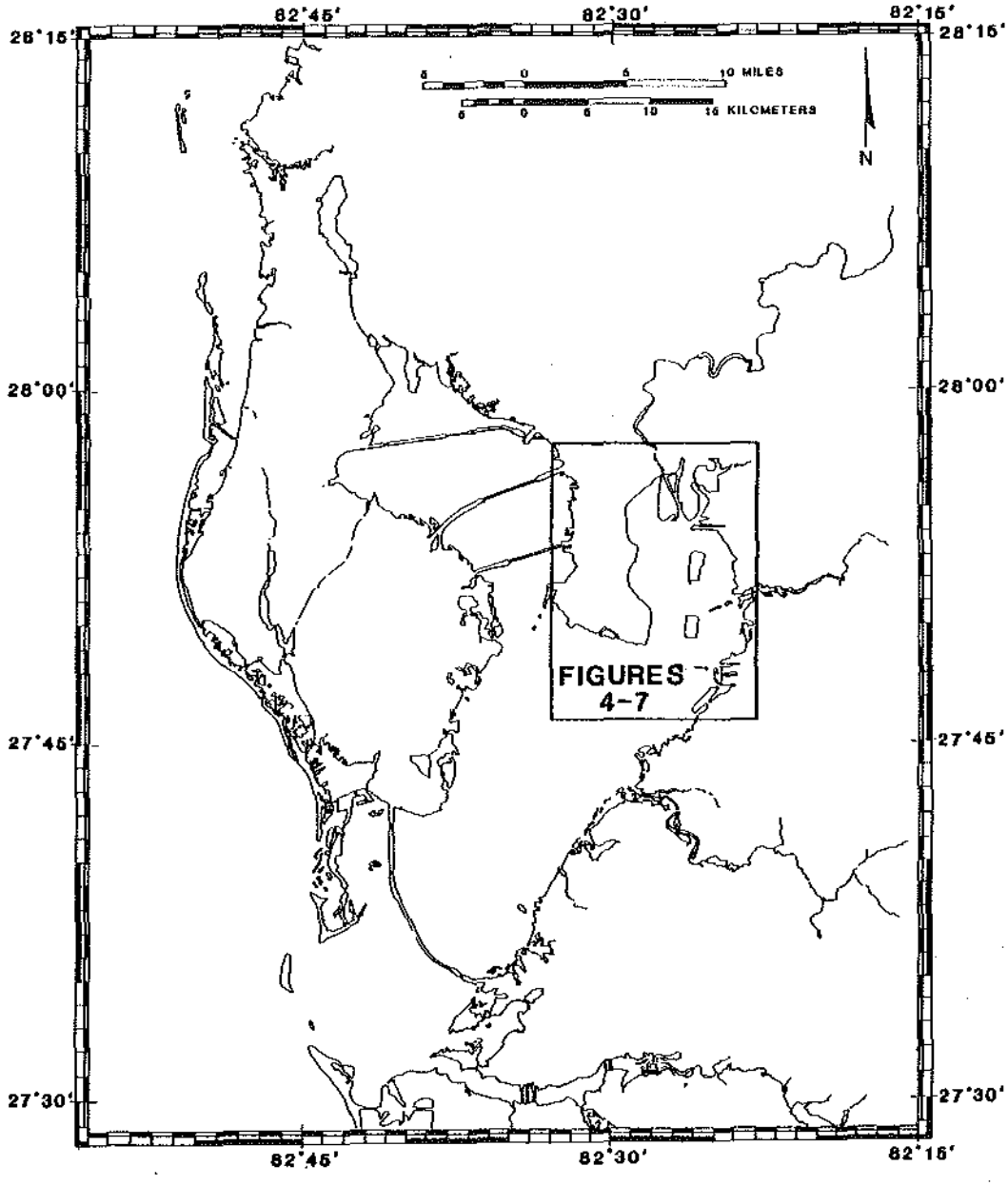

Figure 1. Tampa Bay area. Inset shows location of areas depicted in Figures 4-7.

Company. This company was given a 35 year lease and served the populace with approximately 45 wells located north and west of downtown Tampa. Residents at the time complained of poor water quality, apparently due to a combination of excess hardness and high salinity concentrations. In 1923, the City of Tampa purchased the water system for $1,400,000 and assumed responsibility for water service for approximately 73,500 residents. In 1930, the City built the 30th Street Water Treatment Plant which treated and distributed water from the Hillsborough River Reservoir, a water body created by the construction of a dam and hydroelectric station about 10 miles upstream from Hillsborough Bay.

The Tampa Water Department presently serves about 500,000 people and maintains 1,800 miles (2,897 km) of water mains. The three major sources of City water are listed in Table 1; the Hillsborough River Reservoir is, by far, the largest potable water source. In fact, the 30th Street Water Treatment Plant is the largest surface water treatment plant in Florida and treats one of the most highly colored surface waters in the country. The plant has a capacity of 72 to 96 million gallons per day, depending on the degree of color.

The method of treating highly colored water includes the use of aluminum sulfate (alum) as a coagulant to rid the water of organic tannic acids (Fig. 2). A by-product of this treatment is a gelatinous sludge, primarily composed of aluminum hydroxide. Until 1969, this sludge was discharged directly to the Hillsborough River downstream of the dam and accumulated in layers several feet thick along the river banks. Settling basins to separate sludge from water were first built in 1969, significantly reducing the discharge of solids to the river. However, it was not until the mid-1970s, when additional settling basins were built and the supernatant from these basins was used to irrigate an adjacent golf course, that discharges were practically eliminated. Figure 3 compares solids produced through the alum sludge treatment process with solids discharged to the river. Dried sludge is now stockpiled and landspread on property adjacent to the drying beds.

The City has initiated a pilot program to recover and reuse alum. If the process is successful, the need for land disposal of dried sludge will be greatly reduced and many dollars will be saved in the purchase of alum.

SANITARY SEWER SERVICES

Municipal utility services often originated only after increased growth and population density caused unbearable and unsanitary conditions. The following excerpt from the March 10, 1887 edition of the Tampa Journal illustrates this point:

> The Board of Health cannot be too vigilant in having the city put in proper sanitary condition. The weather is already quite warm and is likely to get much warmer. Houses are going up on almost every block in the city, and the population is becoming more dense. It has only required a casual investigation to warrant the statement that the town at present is not in proper condition. Many privies and backyards are disgraceful to say the least. Why is it? Simply because those whose duty it is to look after this matter have neglected their work and no official has had the nerve to compel the work to be done. The scavenger is not diligent and is unreliable.

The first centralized sewage collection system in Tampa was constructed in the 1890s. Privies and septic tanks were, however, the primary method of sewage disposal through 1949. The limited central collection service that did exist discharged directly to the nearby water bodies, the Hillsborough River and Hillsborough Bay. In 1950, the Hookers Point Primary Wastewater Treatment Plant was completed (Hookers Point was named after Brigadier General Joseph Hooker).

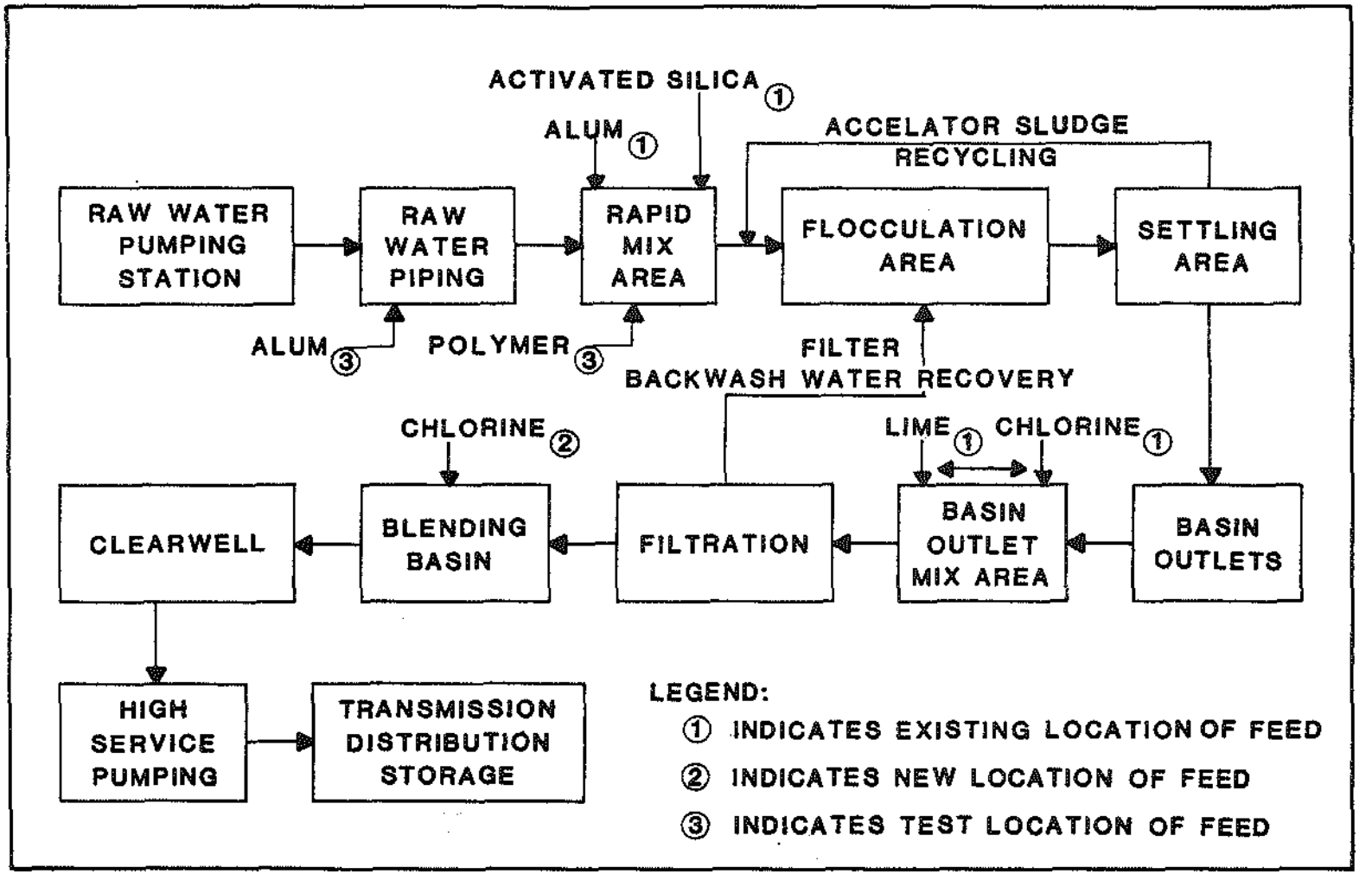

Figure 2. Process schematic, Hillsborough River Water Treatment Plant. From City of Tampa, 1981.

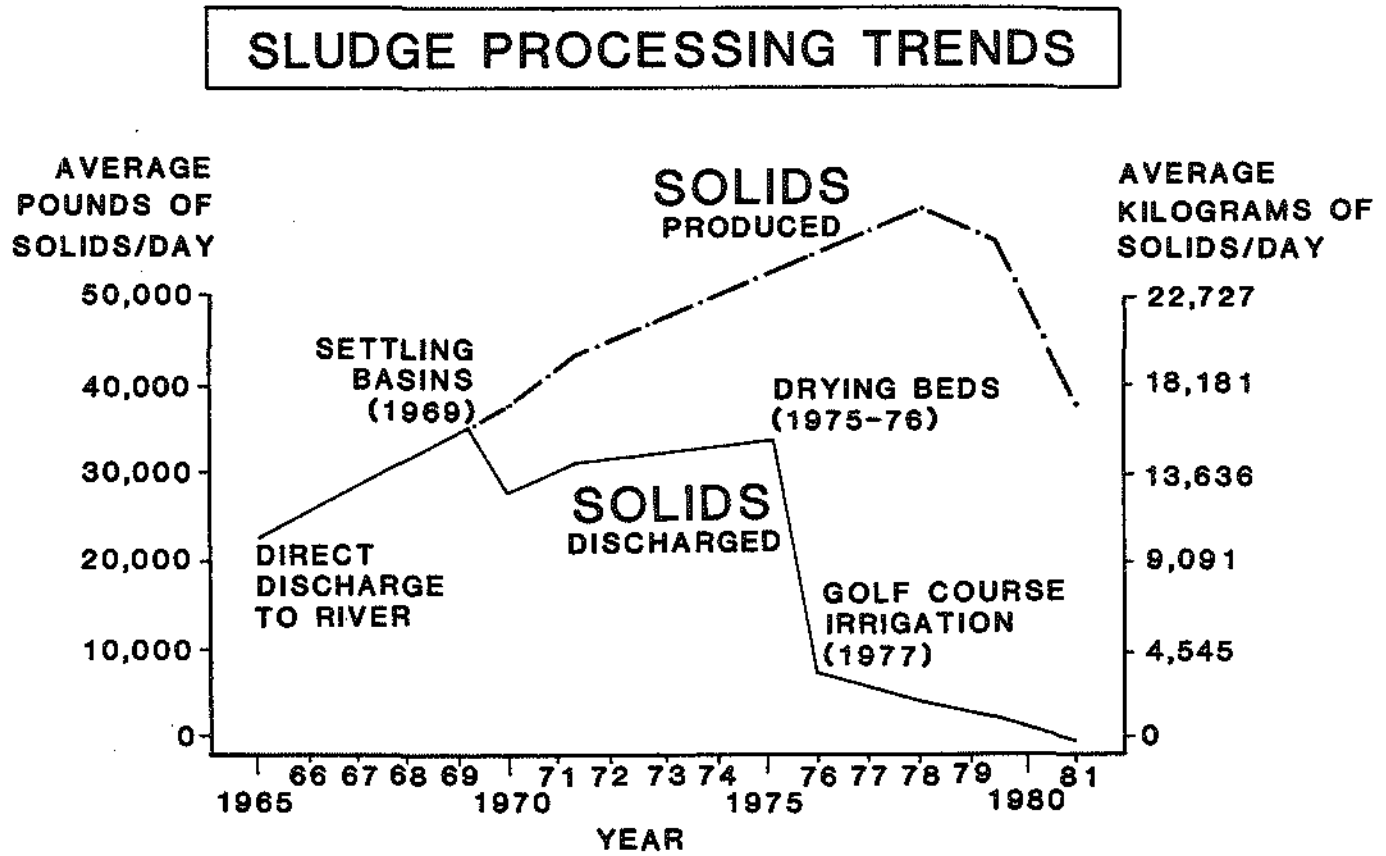

Figure 3. Sludge processing trends at Hillsborough River 30th Street Water Treatment Plant.

Table 1. Tampa potable water sources; and existing and projected water demands.

Potable water sources:

Hillsborough River Reservoir	72%
Morris Bridge Wellfield	17%
Sulphur Springs	11%

Existing and projected water demands (MGD):

	1978	1980	1990	2000
Average	53	64	73	85
Peak	75	92	100	115

This plant had a capacity of 13 mgd and cost approximately $4,000,000, including a main trunk line and interceptor piping. Further expansions and improvements were made to the system in the 1950s and 1960s, but the next major improvement came with the construction of an Advanced Wastewater Treatment (AWT) Plant at Hookers Point. This plant's design was initiated in 1972, but due to the complexity of funding and the difficulties associated with construction on a fill area, operation did not begin until 1978 for secondary treatment, and 1979 for advanced treatment. The plant's cost was approximately $90,000,000, 75% of which was provided by the U.S. Environmental Protection Agency (EPA) and the remainder by the City of Tampa. Initial permits called for a treatment level of 90 percent removal of biochemical oxygen demand (BOD), suspended solids, nitrogen and phosphorus, but because of the excellent design of the plant and thorough employee training programs, a level of pollutant reduction in excess of 90% has been achieved.

Permitted and achieved levels of pollutant reduction at the Hookers Point advanced wastewater treatment plant.

	BOD	Suspended Solids	Total Nitrogen	Phosphorus
Original permitted level of treatment, mg/l	27	27	3	7.5
Actual levels of treatment, mg/l	3.1	2.6	2.9	6.2

The Department of Sanitary Sewers now serves about 410,000 residents in Tampa and the surrounding area. Plant flow currently averages 50 mgd and is projected to reach an average demand of 116 mgd by the year 2020. The Department maintains approximately 1,000 miles of sewer pipeline, some of which is in need of immediate replacement. Wastewater transported to the plant is estimated to be 71% residential, 8% commercial/industrial and 20% seepage (inflow) into pipes. This seepage is caused by a combination of high groundwater levels and deteriorated pipes. Efforts are underway to reduce the amount of seepage by a replacement and repair program.

In the 1950s and 1960s, environmental problems in Hillsborough Bay, which were thought to be related to sewage discharges, were noted by complaints and documentation of odors, high turbidity, high fecal coliform concentrations, low dissolved oxygen, and high levels of algae growth. We now know that many of these problems are closely related, as nutrients can cause imbalances in algal growth, decreases in water clarity, and subsequent loss of seagrasses. Further problems arise when macroalgae die and their decomposition causes odor problems and lower concentrations of dissolved oxygen (DO) in the water column. Extensive dredging in Hillsborough Bay is also thought to be an important cause in the reduction of marshland and seagrass beds. A study sponsored by the U.S. Federal Water Pollution Control Administration (FWPCA) in 1969 noted many of these factors and was a great motivation in the decision to build the AWT plant in Tampa.

The FWPCA study, summarized by Rhodes (1980), illustrated percent contributions of several pollutants from major discharges to Hillsborough Bay prior to initiation of advanced wastewater treatment (Figures 4-7). These data indicate that, of pollutant sources compared, the Hookers Point Primary Wastewater Treatment Plant was responsible for the majority of the ammonia, Kjeldahl nitrogen, BOD, and fecal coliform loads to Hillsborough Bay. Total phosphate contributions from the Hookers Point Treatment Plant were minor, however, when compared to inputs from the Alafia River.

Initiation of secondary and advanced treatment at the Hookers Point Treatment Plant was accompanied by diminished pollutant concentrations at the discharge point, as depicted in Figures 8-12. These data indicate that the treatment plant is functioning in excess of "90% removal" permit requirements. Total phosphorus discharge concentrations were reduced to the tertiary treatment levels at the start of advanced treatment but have since been raised to secondary level concentrations due to a variance granted to the City by the Florida Department of Environmental Regulation (FDER). This variance was granted for the following reasons: 1) the relatively small input of phosphorus to Hillsborough Bay from the plant; 2) the substantial existing phosphorus concentrations in the Bay; and 3) the evidence indicating that phosphorus is not a limiting Bay nutrient and that its removal at the AWT plant would not significantly affect algal growth patterns.

Studies continue at the Hookers Point AWT Plant to document concentrations of nutrients in the effluent and in the surrounding Bay waters. In addition, algal assay studies have been initiated to attempt to document in vitro growth trends of Bay phytoplankton when exposed to varying nutrient concentrations. Data from all of these studies will be supplied to the FDER or used in future regulatory decisions concerning the Bay.

Several other studies have also addressed the impact of the Hookers Point AWT plant on the water quality of the Bay. Recent data from the City of Tampa Nationwide Urban Runoff Program (NURP) indicated that post-AWT percent pollutant loadings to Hillsborough Bay from the Hookers Point AWT plant have been significantly reduced from pre-AWT figures (Table 2).

A recent EPA-sponsored 201 study summarized information concerning future discharge limitations at Hookers Point. Several of the most pertinent studies were by Bernard Ross (see Ross and Jenkins 1977, 1978) in which future Bay nutrient concentrations and BOD/DO concentrations were modeled given several alternative sets of discharge variables. Ross and Jenkins (1977) concluded that when alternatives of no AWT discharge to Hillsborough Bay are compared with 100 mgd discharge (and both alternatives are combined with the projected 2000 year wet season), no measurable effect on the dissolved oxygen of Hillsborough Bay could be attributed to the discharge. The authors

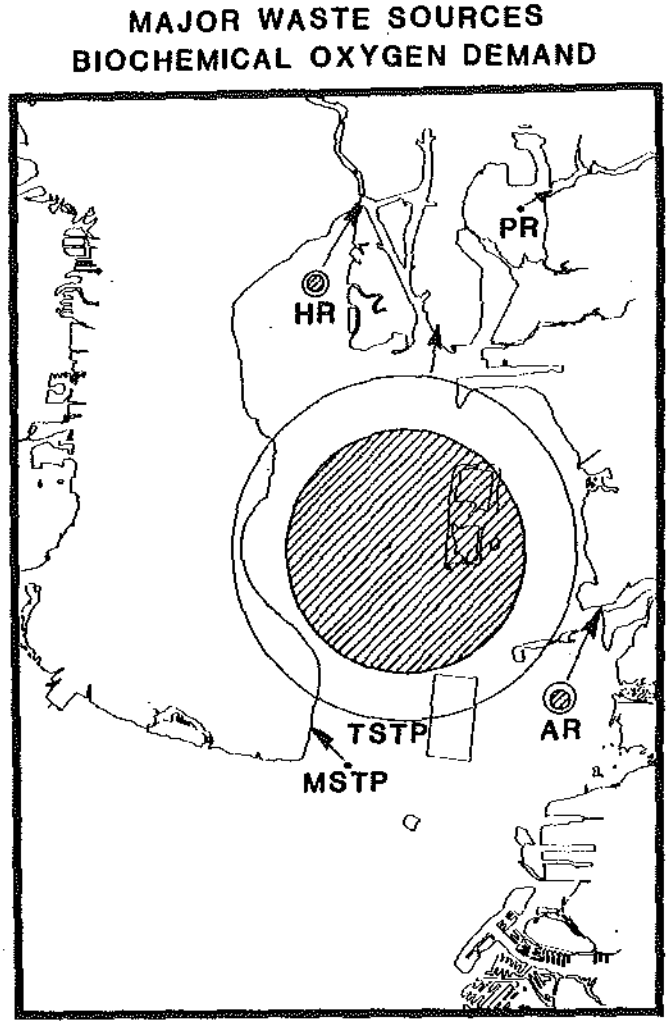

Figure 4. Pre-AWT major waste sources - Biochemical Oxygen Demand. From Rhodes (1980).

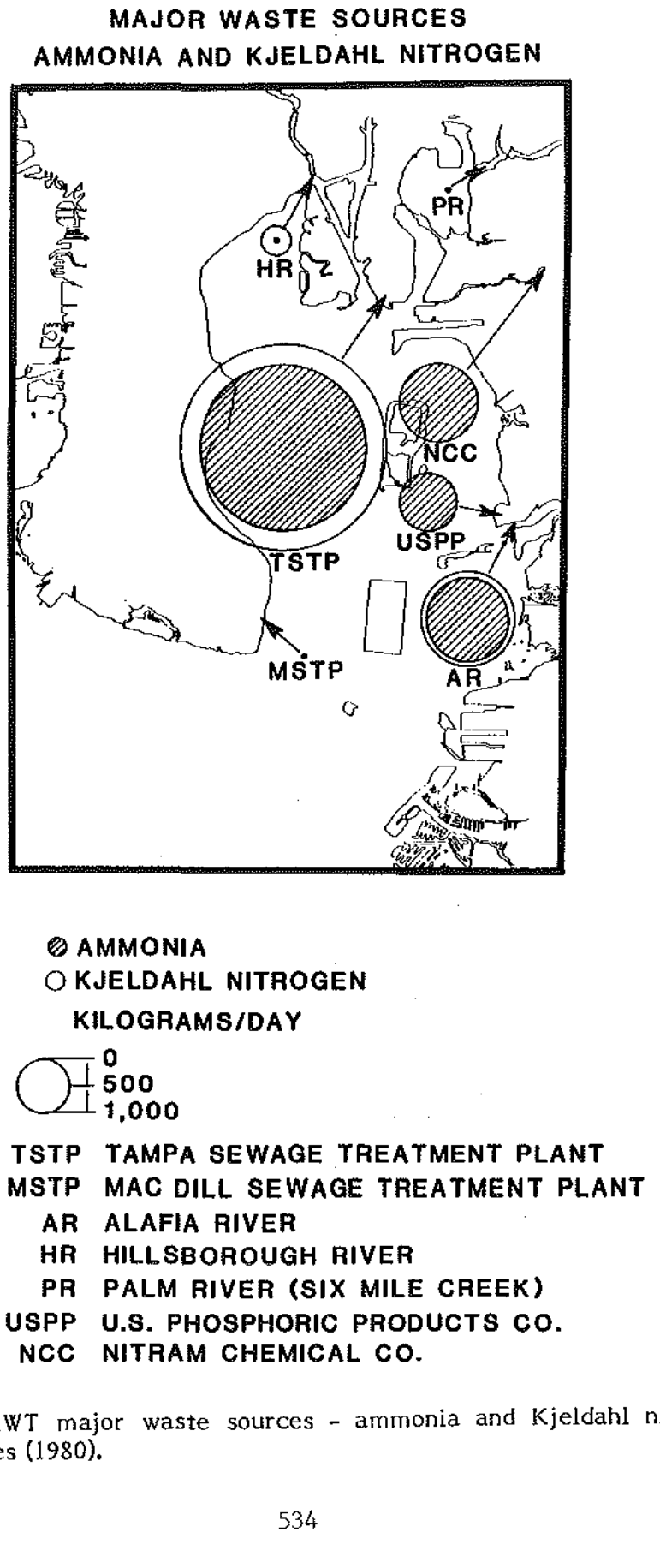

Figure 5. Pre-AWT major waste sources - ammonia and Kjeldahl nitrogen. From Rhodes (1980).

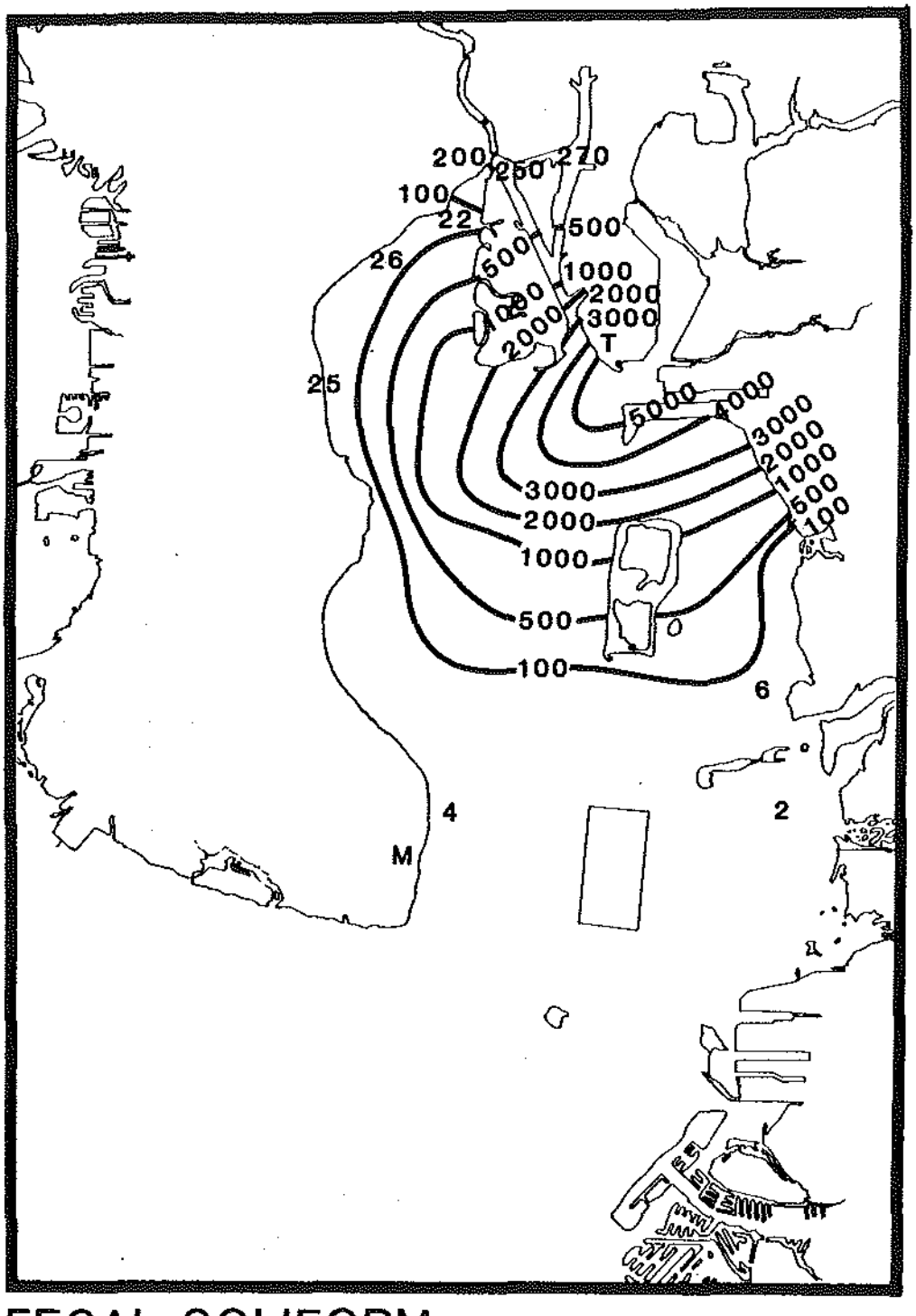

Figure 6. Pre-AWT fecal coliform - Hillsborough Bay, 1969. From Rhodes (1980).

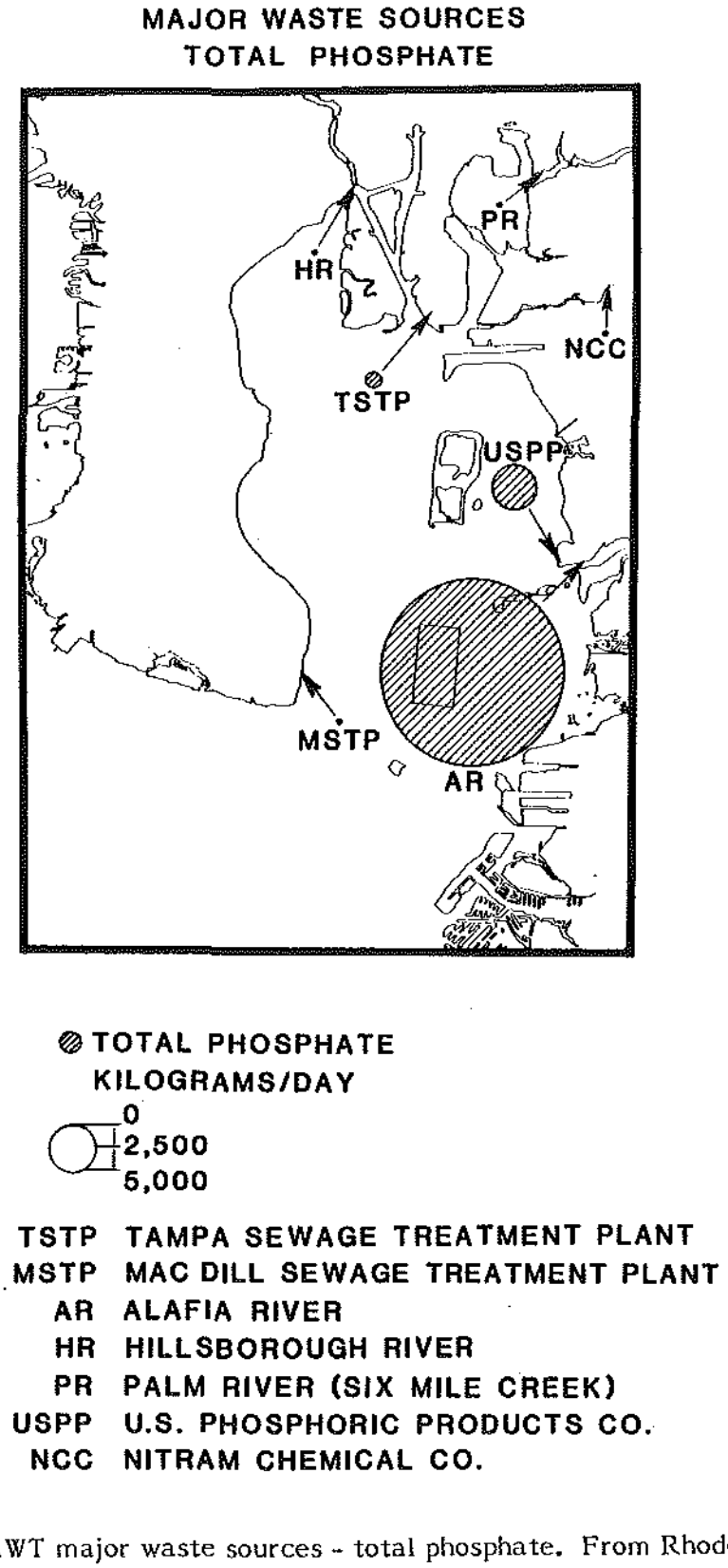

Figure 7. Pre-AWT major waste sources - total phosphate. From Rhodes (1980).

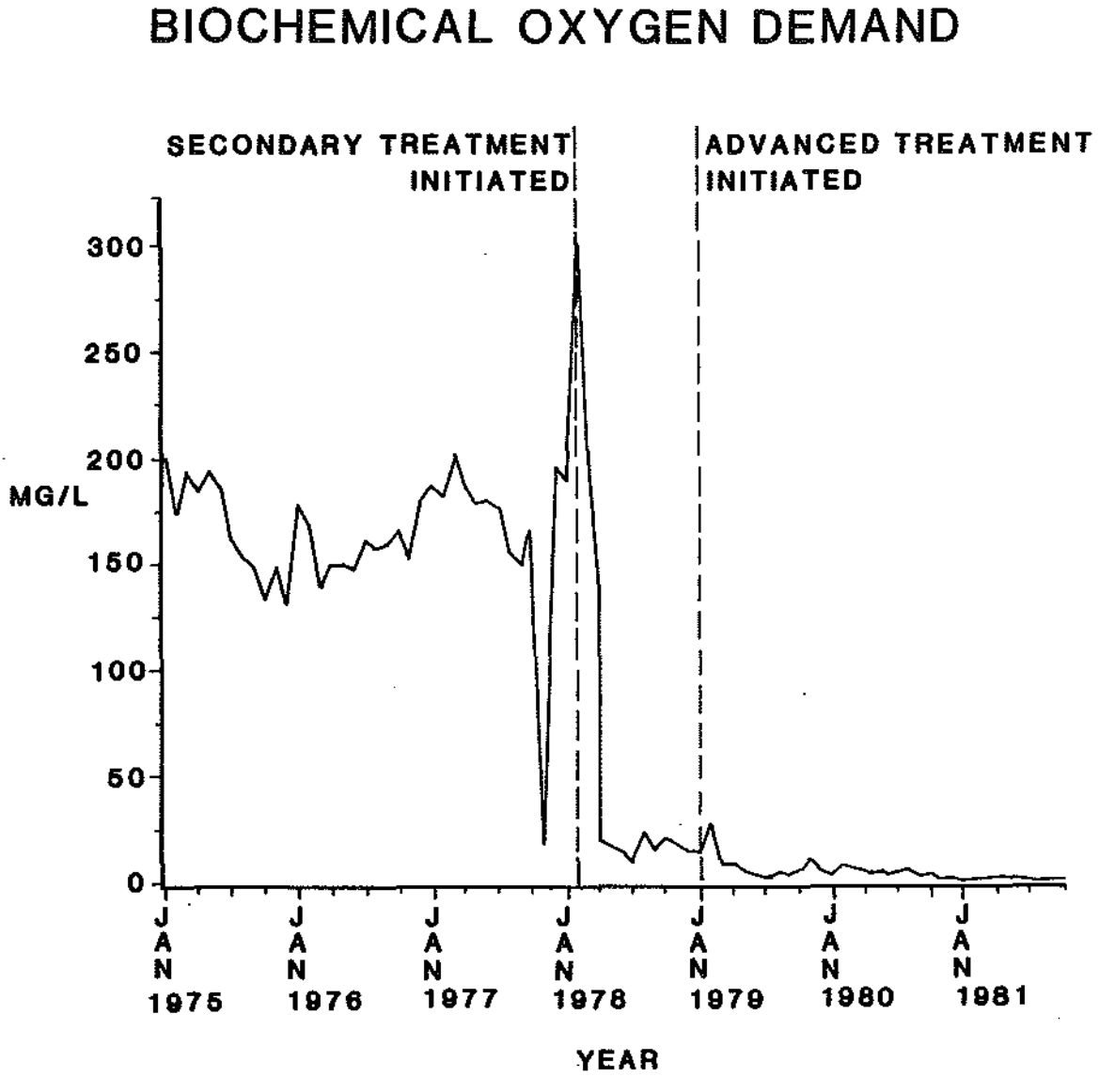

Figure 8. Biochemical Oxygen Demand - City of Tampa AWT effluent.

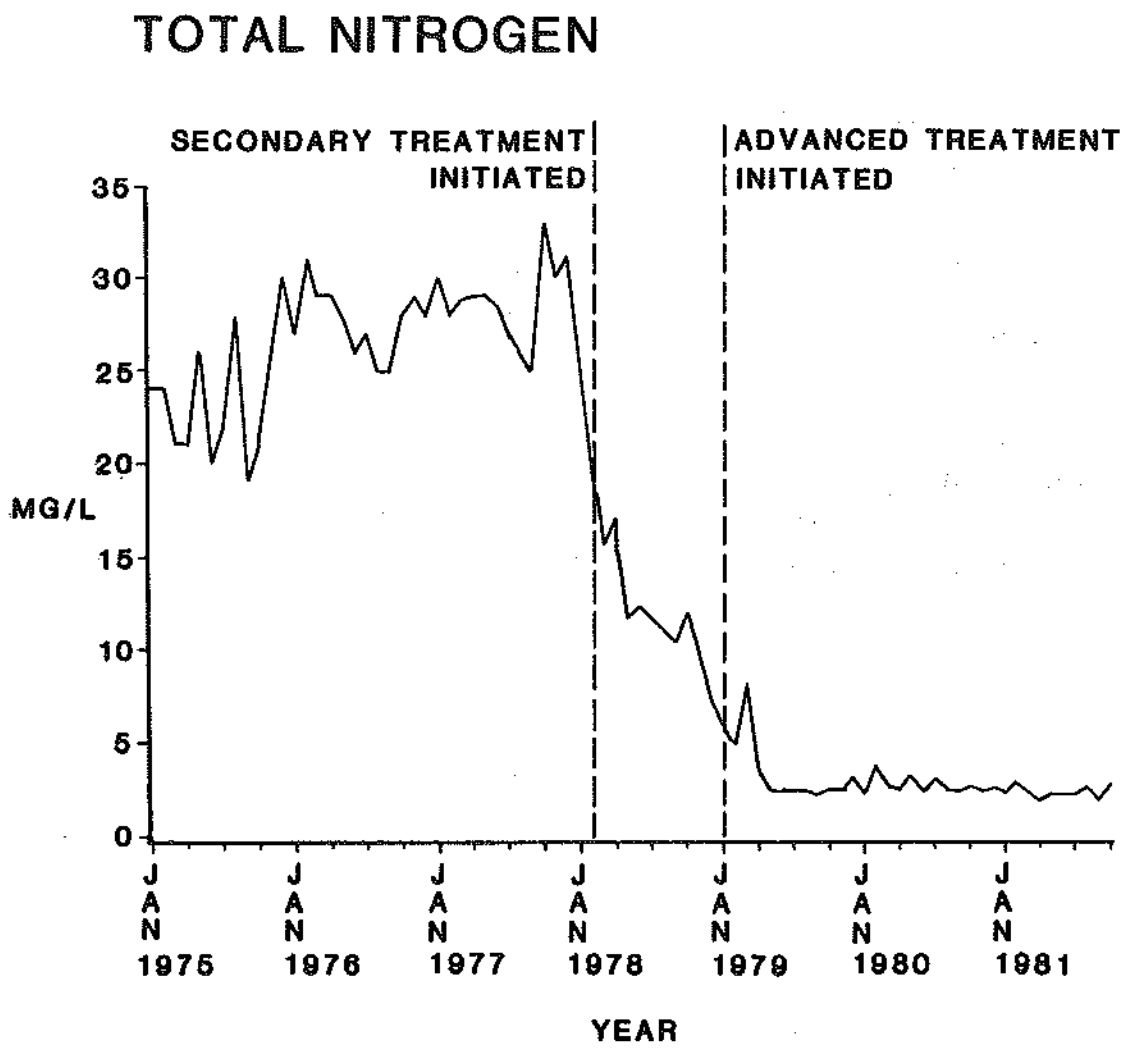

Figure 9. Total nitrogen - City of Tampa AWT effluent.

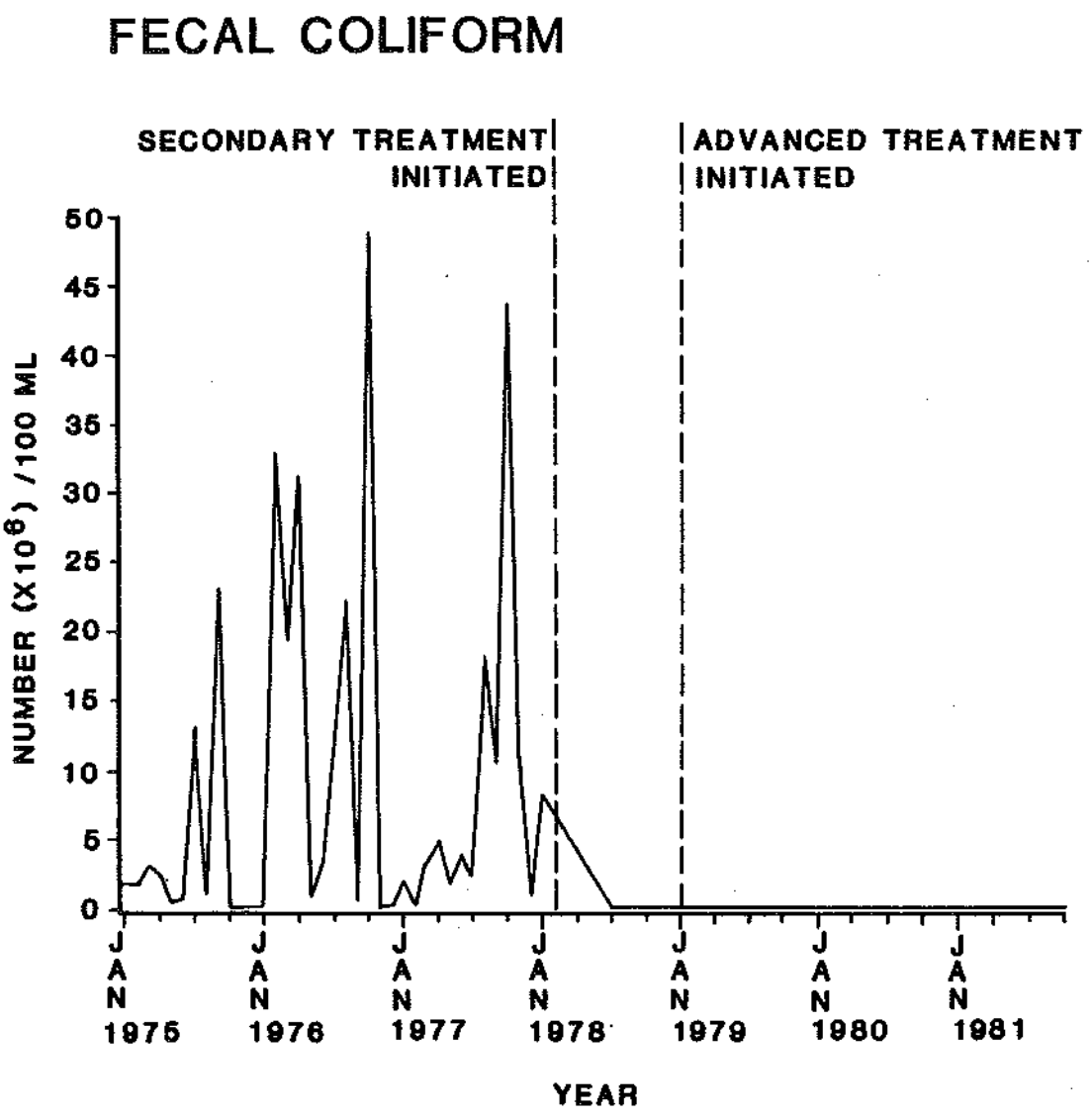

Figure 10. Fecal coliform - City of Tampa AWT effluent.

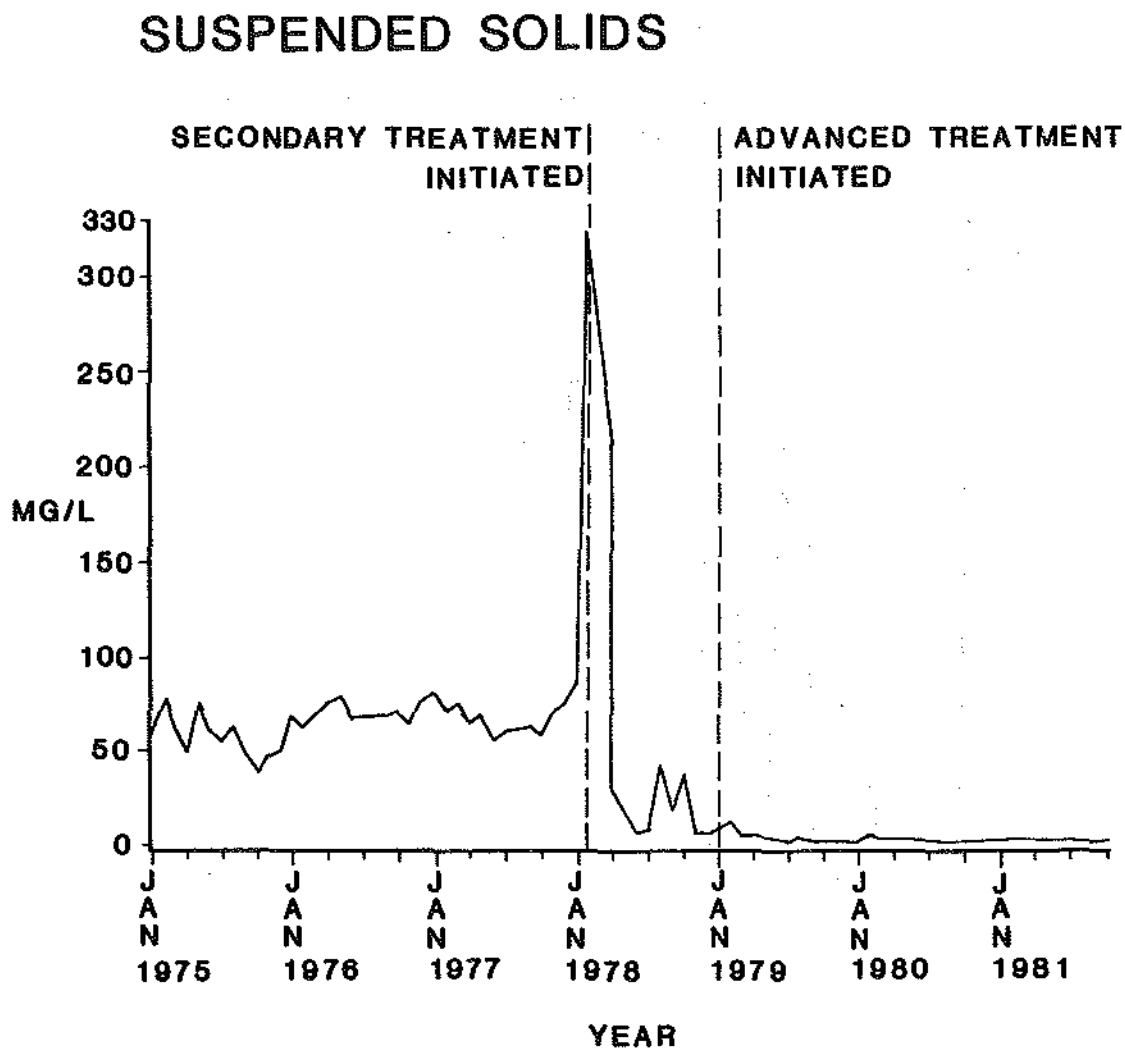

Figure 11. Suspended solids - City of Tampa AWT effluent.

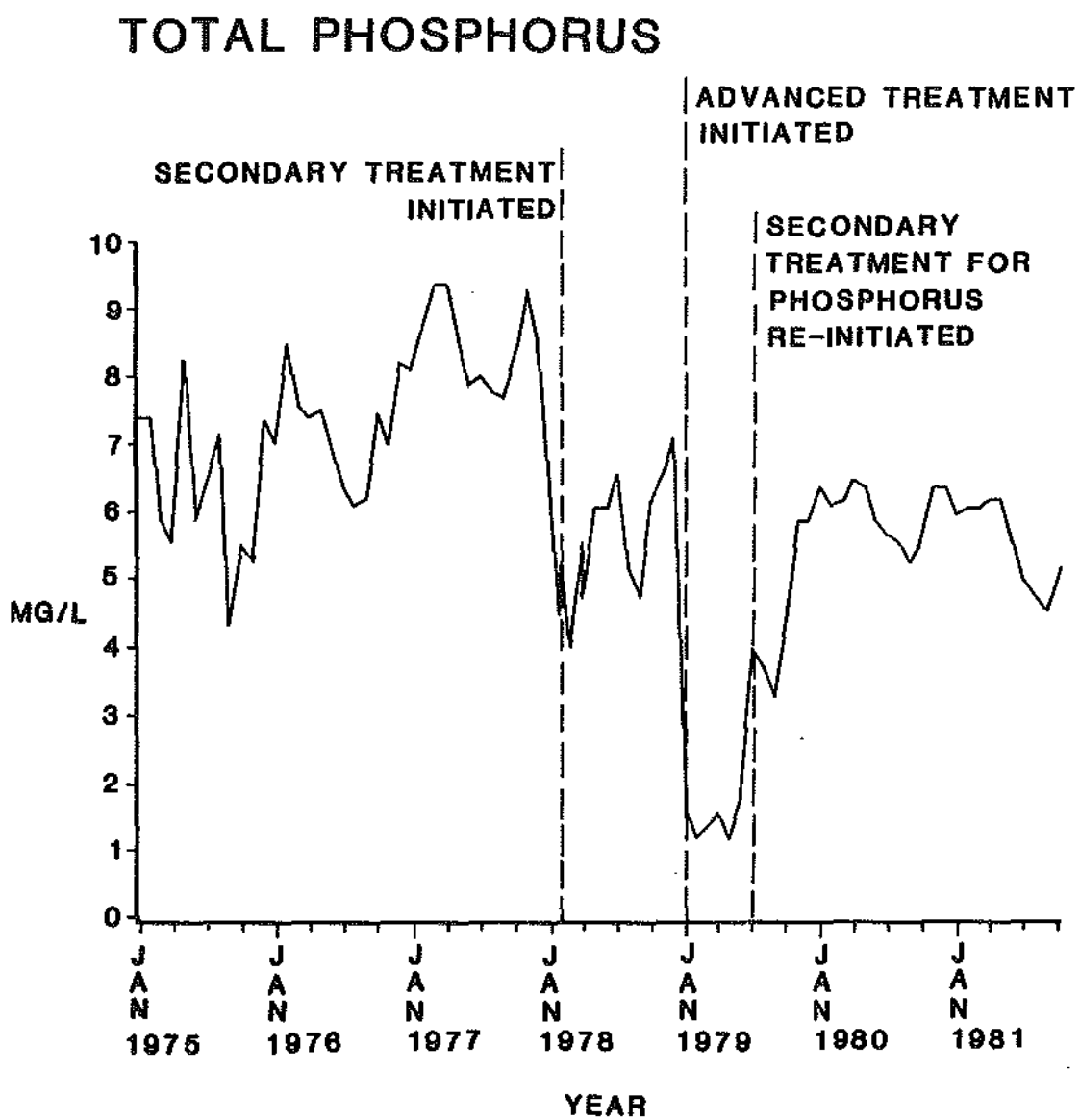

Figure 12. Total phosphorus - City of Tampa AWT effluent.

Table 2. Percent loading of pollutants to Hillsborough Bay, 1979 values. From City of Tampa, 1981.

	INDIVIDUAL COMPONENTS				
				Direct Bay Discharges	
	AWT Plant	Hillsborough River	Alafia River	Point Sources	Non-point Sources
Wet Month:					
Average flow rate	6	50	39	3	3
BOD	15	45	28	3	9
S.S.	2	57	25	8	8
Total N	3	30	64	1	1
Total P	10	12	66	10	1
Dry Month:					
Average flow rate	11	35	43	6	5
BOD	29	26	29	6	10
S.S.	4	25	44	18	9
Total N	10	32	53	12	2
Total P	16	5	61	17	1

also concluded that: "The year 2000 wet season runs do dramatically point out the need for a 20 to 30 percent reduction in non-point discharges, as will hopefully be obtained through the 201 planning process ... If the non-point source loading for Hillsborough Bay could be reduced by management practices by 30% to 18,789 lbs. per day (of carbonaceous BOD), the dissolved levels would rise 5 mg/l nearly everywhere in the Bay."

Future Concerns

Much has been accomplished in the Tampa Bay area in the last decade to reduce pollutant loading from municipal wastewater treatment plants, including the City of Tampa's initiation of advanced treatment and the City of St. Petersburg's construction of a $25,000,000 irrigation system utilizing secondary effluent which has undergone multi-media filtration. Nationally, during the period 1972-1980, $26 billion has been expended on sewer improvements with a subsequent increase in flow to public treatment plants of 36 percent (Chamblee 1982). This has been accomplished by an increase in sludge removal of 58 percent and an increase of 21 percent in the number of people served by at least secondary treatment.

Much remains to be understood concerning appropriate wasteloads for receiving water bodies. In Hillsborough Bay, algal blooms with accompanying odors are still a problem. The answers to questions on future sewage treatment requirements are not easy to obtain and will be arrived at only through accurate determinations of point and non-point source inputs to the Bay, natural atmospheric inputs, and through careful evaluation of nutrient cycling in the Bay, including biological and sediment/water column cycling. An EPA and City of Tampa sponsored Wasteload Allocation Study on Hillsborough Bay is now attempting to answer some of these important questions.

Other important environmental issues facing Tampa's Sanitary Sewers Department in the years ahead are future uses of effluent and sludge, and continued maintenance of collection systems. Nationwide, almost two-thirds of funds spent on sewer improvements go towards collection systems (Chamblee 1982). These underground improvements, though not visible to the public, are necessities for improving receiving water quality.

STORMWATER MANAGEMENT

Following the implementation of point source controls in the 1970s, regulatory officials turned their attention to the even more difficult to assess problem of non-point source pollutants, including urban stormwater runoff. The local Areawide Water Quality Management Plan (208 Study) (TBRPC 1978) identified the following as having the potential to contribute pollutants to urban runoff:

- Pollutants deposited on streets and parking lots; i.e., oil, grease, metals, sediment, etc.
- Construction activities creating sedimentation problems.
- Erosion from exposed ground surfaces; i.e., unpaved streets, unvegetated lots, etc.
- Lawn and landscape maintenance activities; i.e., fertilizers, pesticides, lawn and tree clippings, etc.
- Domestic pet litter, particularly dog.
- General trash, litter and organic debris.
- Atmospheric pollutant contributions.

Various 208 studies across the nation have now investigated the relationship of various pollutants to urban runoff and have generally concluded that:

- Stormwater runoff is a pollution problem (as stated earlier in this paper, Ross and Jenkins (1977) indicated that substantial improvements in Hillsborough Bay dissolved oxygen concentrations could come about through reductions in organic loadings from stormwater runoff.);
- Development of non-structural strategies and "Best Management Practices" are preferable to costly structural controls; and,
- There are many remaining questions concerning how serious a problem pollution from urban runoff is and what the best long range cost effective solutions are.

The results of the above mentioned studies, and the requirement that the City provide information to regulatory agencies on the impact of each new stormwater discharge point, led to the City of Tampa joining a nationwide effort to answer some basic questions about the significance of pollution from urban runoff. The Nationwide Urban Runoff Program (NURP), administered by EPA, was intiated to provide Congress with recommendations by 1983 on whether federal money should be used to control non-point source pollution. Twenty-eight cities joined the nationwide effort to determine the extent to which urban runoff causes water quality problems, the severity of these problems, and the cost effectiveness of control options. The Tampa NURP study is described elsewhere in this volume, but major study phases and goals are outlined below:

Phase 1

a. Survey existing data to determine various point and non-point sources of pollution to Hillsborough Bay and the Hillsborough River.
b. Determine, using existing loading and receiving water data, whether urban runoff is a significant problem, i.e. identify any major problems such as beach closings, fish kills, and failure to meet water quality standards, that could be easily attributed to runoff.
c. Determine best study location if stormwater runoff is a problem.

Phase 2

a. Characterize the quality of runoff in selected basins.
b. Test effectiveness of various control practices currently in use.
c. Test methods for predicting basin loadings.
d. Measure cause and effect relationship of runoff to receiving water impacts, if possible.

Phase 3

Develop a stormwater management plan.

Phase 1 has been completed with major determinations as follows:

Existing data indicate urban runoff is a significant contributor of pollutants to local receiving waters. Table 3 summarizes the worst case conditions (i.e., rainfall during dry season) for percent of pollution contributed by runoff during individual storm events and over a monthly average. The data show that during an individual storm event, significant percentages of pollutant loading from urban runoff (as much as 70% for biochemical oxygen demand) can enter the Hillsborough River. The percentage contribution of pollutants from urban runoff to Hillsborough Bay appears to be smaller.

Existing data indicate some wet season water quality problems. However, these data were not sufficient to isolate the impact of urban runoff. Table 4 summarizes wet weather trends primarily using existing data for 1978-1980. This period was selected because it provided the most recent data; is the only period when data for all three water bodies are available; is least affected by Hookers Point Wastewater Treatment Plant discharges; and contains a period (1979) with above average rainfall. Data from the year 1979 did include some sewage overflows which may have contributed to the trends which are evident in Table 4.

Phase 2 of the NURP study is underway, with continuous and synoptic receiving water data collection, automatic sampling of runoff in test basins, and bioassays on indicator organisms. The City of Tampa's Stormwater Management Division plans to integrate the results of the NURP study with other in-house efforts to improve drainage services and provide innovative alternatives for financing drainage improvements (Figure 13). The goal of all these studies is a stormwater management plan leading to implementation of environmentally compatible and effective drainage controls.

SOLID WASTE DISPOSAL SERVICES

The disposal of refuse has always been a part of man's history. Indians in the Tampa Bay area created shell mounds or refuse middens, which have provided archaeologists with much information about their lifestyle and diet (Willey 1949; Burger, this volume). Early settlers discarded their non-useable wastes in pits near their dwellings. In Tampa, news articles from as far back as the late 1800s recorded citizens' complaints about garbage disposal. In one case, complaints concerned odors caused by people throwing garbage out the windows of their homes. Since that time, open burning and incinerators have been used for solid waste disposal; however, land disposal has remained the primary method for disposing of garbage.

From 1947 to present, there have been approximately 30 land disposal sites in Hillsborough County. These sites were often located in isolated, unused areas, and therefore inadvertently in areas close to rivers or bay waters or in areas with high groundwater tables and, consequently, were a possible source of pollution. When refuse is buried at or near groundwater levels without leachate controls, contaminants from the buried refuse can be carried to groundwater aquifers. The contaminants would vary depending on the type of refuse buried and soil conditions. Hydrologic conditions and rainfall amounts both affect speed and movement of leachate. Typical concentration ranges of domestic refuse leachate from landfills without leachate control are listed in Table 5.

Atmospheric emissions of hydrogen sulfide and methane have also been recorded from landfills. The potential for any of these compounds causing hazardous conditions is very site dependent, and the fact that they are present does not necessarily mean they are present in hazardous concentrations. Consequently, these data only show the necessity for site specific information.

Table 3. Pollutant loadings to receiving water bodies by source. From City of Tampa, 1981.

Receiving Water Segment	Pollutant	Percent of Pollution Load by Source*		
		Urban Runoff	River Flows	Point Sources
Hillsborough Bay	Biochemical Oxygen Demand	10-25	65-45	30-30
	Suspended Solids	5-35	75-50	15-15
	Total Nitrogen	5-15	70-50	15-35
	Total Phosphorus	1-5	75-65	25-30
Lower Hillsborough River	Biochemical Oxygen Demand	35-70	65-30	0
	Suspended Solids	40-65	60-35	0
	Total Nitrogen	35-55	65-45	0
	Total Phosphorus	10-25	90-75	0
Hillsborough Reservoir	Biochemical Oxygen Demand	20-55	80-45	0
	Suspended Solids	15-50	85-50	0
	Total Nitrogen	15-25	85-75	0
	Total Phosphorus	5-15	95-85	0

*The first number represents the average for an average month and the second number represents the percentage for an individual storm event.

Table 4. Summary of adverse wet weather effects in receiving water bodies in the study area. From City of Tampa, 1981.

Receiving Water Body	Parameters Showing Adverse Trends During Wet Weather	Water Quality Issues
Hillsborough Bay	Dissolved Oxygen	- State standards, aquatic life
	Nutrients	- Eutrophication, odor problems, aesthetics
	Coliform Bacteria	- State standards, public health, restriction in use
Lower Hillsborough River	Suspended Solids	- Bottom deposits, benthic life, aesthetics
	Coliform Bacteria	- State standards, public health, restriction in use
Hillsborough Reservoir	Dissolved Oxygen	- State standards, aquatic life
	Nutrients	- Eutrophication, odor problems, aesthetics, water supply
	Metals	- Aquatic life, water supply

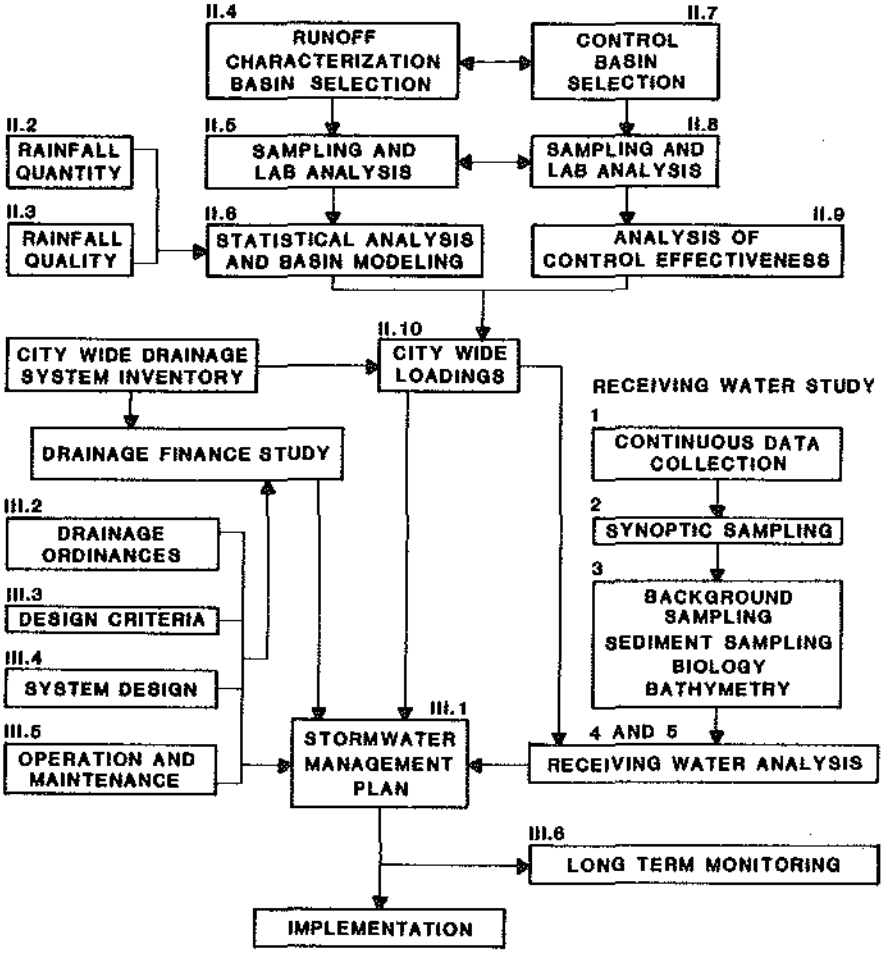

Figure 13. City of Tampa stormwater management planning, NURP.

Table 5. Range of typical domestic refuse leachate constituent concentrations (ASCE 1976)

Constituent	Concentration Range in milligrams per liter
Iron	200-1,700
Zinc	1-135
Phosphate	5-130
Sulfate	25-500
Chloride	100-2,400
Sodium	100-3,800
Nitrogen (Kjeldahl)	20-500
Hardness (as $CaCO_3$)	200-5,250
Chemical Oxygen Demand	100-51,000
Total Residue	1,000-45,000
Nickel	0.01-0.8
Copper	0.10-9.0
pH	4.00-8.5

State regulations adopted by the Florida Department of Environmental Regulation now strictly govern the location and other environmental aspects of land disposal to ensure that such sites are operated as sanitary landfills. A sanitary landfill differs from previous land disposal methods in the degree to which the area is protected from odor, fire, groundwater pollution, vermin, and aethetic problems. The state's regulations on sanitary landfills include standards on:

- Leachate control mechanisms such as clay or synthetic liners and treatment facilities;
- Proximity to waterways, potable water resources, and airports;
- Daily cover of 6" of earth and final cover of 2' of earth;
- Monitoring of groundwater movement (Hillsborough County's landfill has a full time geologist on staff);
- Litter and fire control;
- Drainage control;
- Methane gas monitoring.

Present Disposal Methods

Several communities in the Tampa Bay area are attempting to phase out land disposal of garbage, even in sanitary landfills, and are planning to incinerate it with electricity generation as a by-product. Incineration is not a new means of garbage disposal. In fact, the first garbage incinerator in the United States was built in Allegheny, Pennsylvania, in 1885, and before long there were many other "crematories" in the United States (APWA 1976). Incineration, however, was gradually phased out because of associated air pollution problems. The City of Tampa's Municipal Incinerator operated from 1967 to 1979, closing in 1979 because of a combination of air and water pollution problems stemming from its wet scrubber air pollution control system. Local governments are now in the planning or construction stages for three new energy recovery incinerators with state-of-the-art air pollution controls.

Location	Tonnage (tpd)	Status
Pinellas County	2000	Construction Phase
City of Tampa	1000	Contracts signed; financing in progress
Hillsborough County	1400	Planning Stage

These plants utilize the heat produced from burning garbage to produce steam which is used to drive a turbine generator. On the average, a community's garbage can provide 1-2 percent of its electrical needs. In producing steam, heat is transferred from the exhaust gases to water in the tube-lined furnace. The exhaust gases are cooled in this process sufficiently so the electrostatic precipitators can be used for particulate emissions control. Additionally, the City of Tampa plant (McKay Bay Refuse-to-Energy Facility) will not cause water pollution because the plant will not discharge any water to adjacent McKay Bay. All wastewater and cooling water blowdown will be tranferred to the Hookers Point Advanced Wastewater Treatment Plant for treatment prior to discharge.

The construction of refuse-to-energy facilities is fortunately an example of how an environmental problem can be solved in a way which protects our natural resources, conserves energy, and in the long term is less costly.

CONCLUSIONS

A review of environmental impacts of municipal services enables one to easily identify areas for continuing concern and study. This paper has identified some problems which have been substantially solved or have a definitive solution proposed: alum discharges from the water treatment plant, leachate production from solid waste disposal, and reduction of loadings from municipal wastewater treatment facilities. There are, however, questions which remain:

- The driving forces behind water quality in Hillsborough Bay are still not thoroughly understood. Better information on nutrient cycling in the Bay should help address continuing problems with algal blooms and subsequent odors, and should provide an effective management tool for industry, municipalities, and regulatory agencies as they deliberate appropriate wasteload allocations.
- Reuse of effluent from Hookers Point Advanced Wastewater Treatment Plant has been considered for several years. Studies are needed to determine the best use of this important resource.
- Use of surplus water from the Tampa By-Pass Canal has also been under study. The potential exists for this water to be an important agricultural or potable water supply.
- There are many questions to be answered concerning the feasibility of cleaning an urban river such as the Hillsborough River. The NURP study should go far toward determining the impact of urban runoff on the river's water quality. The City's Sanitary Sewers Department is presently attempting to improve collection systems and thereby lessen chances of wet season overflows into the river caused by groundwater infiltration. However, economic and social questions will also have to be addressed as cost effective alternatives to cleaning the river are evaluated.
- Of extreme importance is the continued protection of potable water sources. The City of Tampa has been fortunate in having an administrative structure that is equally responsible for protection of the reservoir and for drainage improvements. This structure will help ensure protection of reservoir waters as we plan environmentally sensitive drainage control.

As we progress into the 1980s we need to remain aware of the necessity for a coalition of local efforts on the part of government, the scientific community, and the interested citizenry. Only long-term, organized, and well thought out plans can ensure our steady progress toward an improved urban environment.

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POINT SOURCE DISCHARGE IN THE TAMPA BAY AREA

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ABSTRACT

A point source inventory describing municipalities, industries and commercial businesses which discharge effluent into surface waters of the State and the Tampa Bay areas was performed. Data for the inventory was retrieved from 1980 monthly operating reports required by the State and Federal National Pollutant Discharge System (NPDES) permits. The reports revealed 59 sources along rivers and sites which discharge into Tampa Bay. In 1980, these sources contributed 190 billion gallons of water carrying 2.35 and 3.58 million pounds of phosphorus and nitrogen respectively to Tampa Bay. Among the six rivers contributing to Tampa Bay, the Alafia River contributed 75% of all the water discharged from permitted point sources. This volume of water is attributed to the extensive phosphate mining operations in Polk County. Although this is a high volume, the greatest nutrient load was discharged by municipal sources which spill directly into Tampa Bay (78% and 84% annual load of phosphorus and nitrogen respectively). Events required to correct these discharge levels will evolve from alternative sewage disposal methods including spray irrigation, water reuse, land reclamation projects and limited Federal funds. Since 1980, significant reductions in nutrient discharge to the bay have resulted from these efforts.

INTRODUCTION

In the year 1980, the immediate Tampa Bay area (Fig. 1) received surface water discharges from 59 reported sources including both domestic and industrial sources (Table 1). Although a variety of effluent disposal alternatives are used in the Tampa Bay area, i.e. spray irrigation, percolation ponds, and deep well injection, many municipal and industrial facilities are permitted to discharge directly into State waters as an available, efficient and in most cases an historical method of disposal. Both technical based standards and water quality standards provide the interpretive methods to assess effluent limitations. Three procedures using water quality standards are utilized by regulatory agencies to provide the tools necessary to evaluate surface water dischargers (point sources).

The wasteload allocation represents the first step for an applicant to receive a discharge permit following extensive water quality analysis. In this procedure, the assimilative capacity of a lake, river or stream is determined by analyzing the chemical and biological characteristics (ammonia, TKN, BOD, nitrite, etc.) of the receiving body and the point source prior to and after discharge. Depending on the size, type and flow of the receiving water body, additional discharges may be added until the maximum assimilative capacity of the receiving water body is achieved without causing a water quality violation.

Site Specific Alternative Criteria are utilized when an applicant can demonstrate that man-induced or natural causes contributing to reduced water quality cannot be controlled or abated by technology. These criteria can be imposed when an applicant requests a permit to discharge into water below standards due to man-induced or natural causes. When water quality conditions cannot be abated by technological or

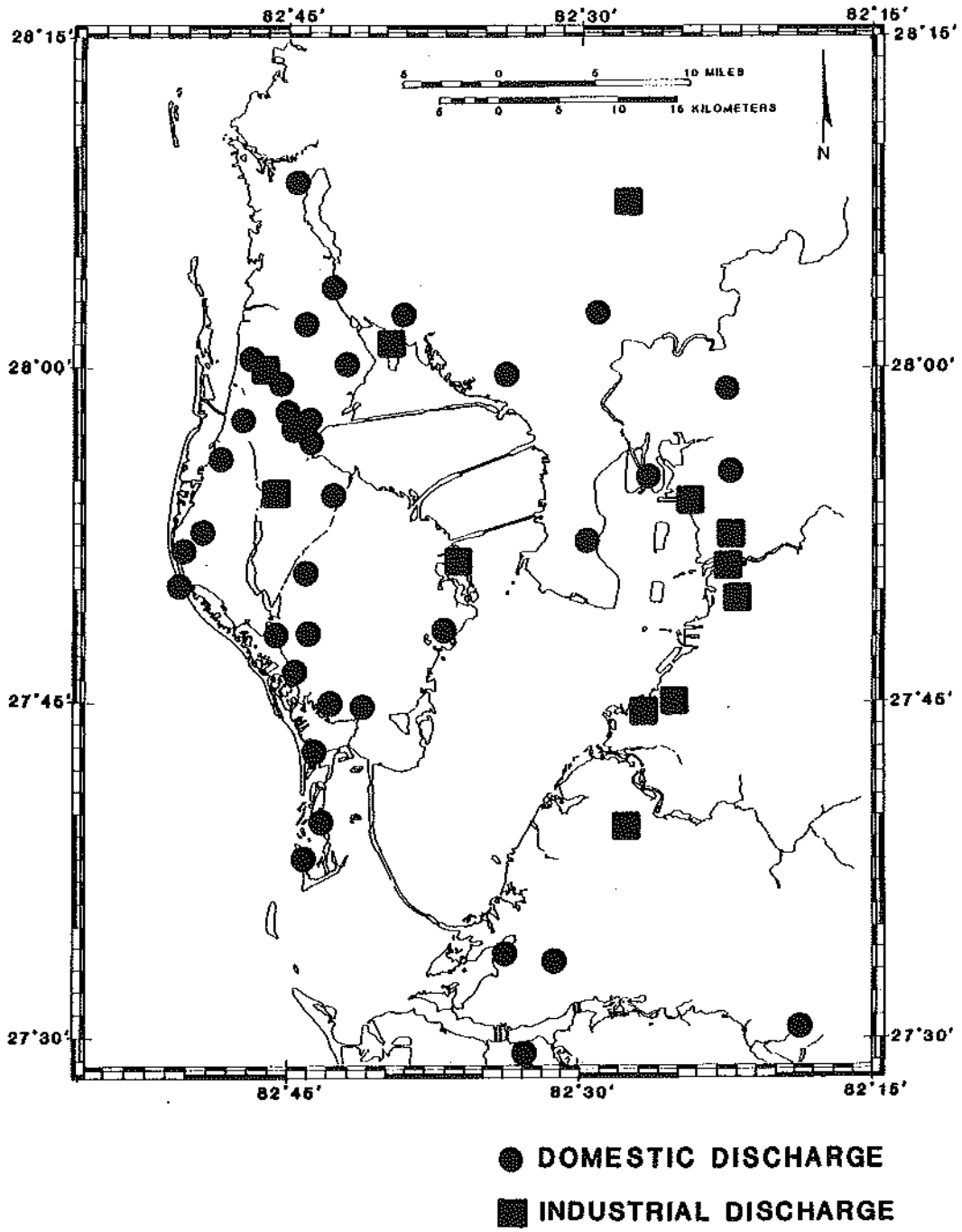

Figure 1. Reported discharge sources, Tampa Bay area, 1980.

Table 1. Point source dischargers. Number within parentheses indicates location of discharge according to BASIS Tampa Bay subdivisions.

Tampa Bay

Florida Power, Higgins (1)
Florida Power, Bartow (1)
Aerosonic Corporation (1)
Boulevard Park (1)
Southgate Mobile Home Park (1)
City of Oldsmar (1)
Carrollwood S/D (1)
City of Largo (1)
East Plant, Clearwater (1)
Northeast, Clearwater (1)
River Oaks (1)
Hookers Point (2)
Gardinier Inc. (2)
Alafia Motor Home Park (2)
IMC Port Sutton (2)
Gibsonton Speed Wash (2)
Eastside Water Company (2)
Bayshore Palms Apts (2)
Northeast St. Pete STP (3)
Albert Whitted STP (3)
Bahia Beach Restaurant (3)
Amax, Piney Point (4)
South Cross Bayou (5)
Northwest, St. Pete (5)
Ft. DeSoto Park #1 (5)
Ft. DeSoto Park #2 (5)
Ft. DeSoto Park #3 (5)
Ft. DeSoto Park #5 (5)
Holiday Harbor Trailer Park (5)
McKay Creek (5)
Clearwater, Marshall Plant (5)
Southwest St. Pete STP (5)
City of Palmetto (6)

Anclote River

City of Tarpon Springs

Alafia River*

City of Mulberry (2)
Farmland Industries (2)
W. R. Grace, Bartow (2)
Mobil Chemical Corp. (2)
Conservation Spillways (2)
IMC Kingsford (2)
Brewster Phosphates (2)
Agrico (2)
Amax (2)
Brewster Spillways (2)

Manatee River

City of Bradenton (7)
Tidevue Estates (7)
Tillman Elementary Schools (7)
Ruskin Laundromat (7)

Palm River

Adamo Acres Facility (2)

Hillsborough River

City of Plant City (2)
Meadowbrook Motor Park (2)
Foxwood S/D (2)
Kraft Foods (2)
Seaboard Coastline (2)

Little Manatee River

Ruskin Laundromat (3)

*Some industrial discharges have more than one outfall.

management processes, the applicant may be eligible for a discharge permit if evidence has been submitted to support other criteria more relevant to a particular site.

Finally, a Temporary Operation Permit can be issued when a source does not qualify for an operating permit. Following satisfaction of all technical requirements and a public notice, the Department may issue a Temporary Operation Permit which places restrictions and limitations on increasing sewage for a particular facility until it can comply with discharge limitations.

MATERIALS AND METHODS

All records for this point source survey were compiled from 1980 records held in State archives and offices of the Southwest District, Department of Environmental Regulation. These records came from two sources: monthly operating reports (domestic sewage treatment plants), and NPDES reports (industrial discharge) which were produced and submitted to our Department by the permittee. Total phosphorus, nitrogen and flow values were extracted from reports to compare common features among both domestic and industrial discharge permits.

The domestic waste portion of this survey is susceptible to variability among both secondary and tertiary treatment plants. This is attributed to plant design, special modifications, loading rates, operating philosophies and operator expertise.

RESULTS

There are 6 rivers in the immediate Tampa Bay area which serve as major surface water receiving bodies for domestic and industrial effluent. All except the Anclote River flow directly into the Bay. Tampa Bay serves as an initial receiving body for many discharge sites (Table 1). Total flow from discharge points along these rivers and the Bay amount to an annual volume of approximately 190 billion gallons (Table 2). Sources along the Alafia River and Tampa Bay (Fig. 2) contribute 75% and 23% respectively of this annual volume, with the remaining rivers contributing together less than 2% of the total flow.

The total annual reported discharge of phosphorus into Tampa Bay and the six area rivers exceeds 2.3 million pounds (Table 2 and Fig. 3). The annual total phosphorus load shows sources along

Table 2. 1980 Stream segment and waterbody analysis.

Waterbody	Total Annual Flow (MG)	Total Annual Phosphorus (lb.)	Total Annual Nitrogen (lb.)
Alafia River	142,485 (75%)	430,693 (18%)	124,967 (3%)
Tampa Bay	42,968 (23%)	1,846,628 (78%)	3,039,152 (85%)
Hillsborough River	1,638 (<1%)	4,460 (<1%)	39,054 (1%)
Manatee River	1,590 (<1%)	25,259 (1%)	198,711 (5%)
Anclote River	1,161 (<1%)	49,515 (2%)	178,419 (5%)
Palm River	27 (<1%)	1,788 (<1%)	5,350 (<1%)
Little Manatee River	2 (<1%)	-	-

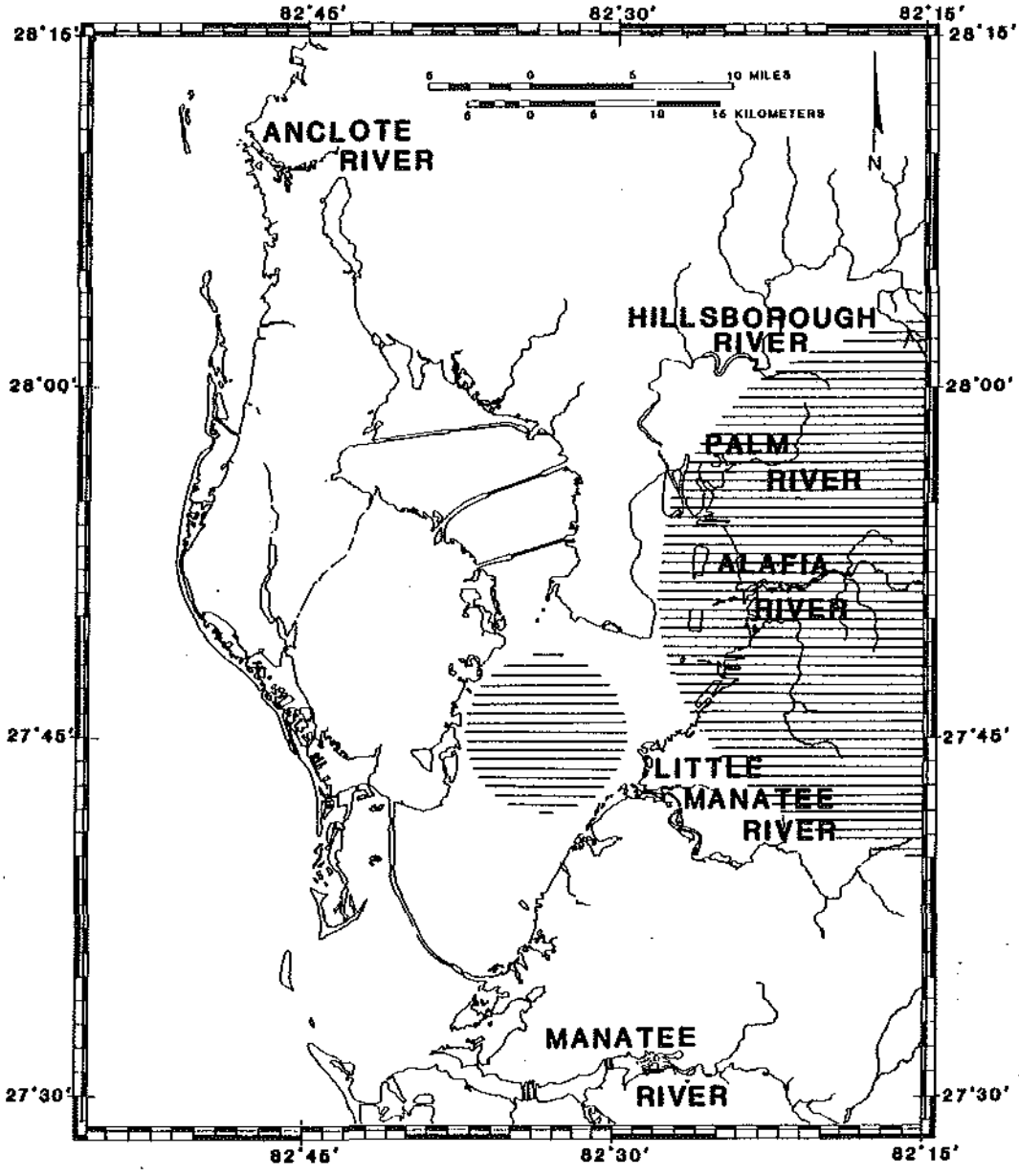

Figure 2. Total annual flow.

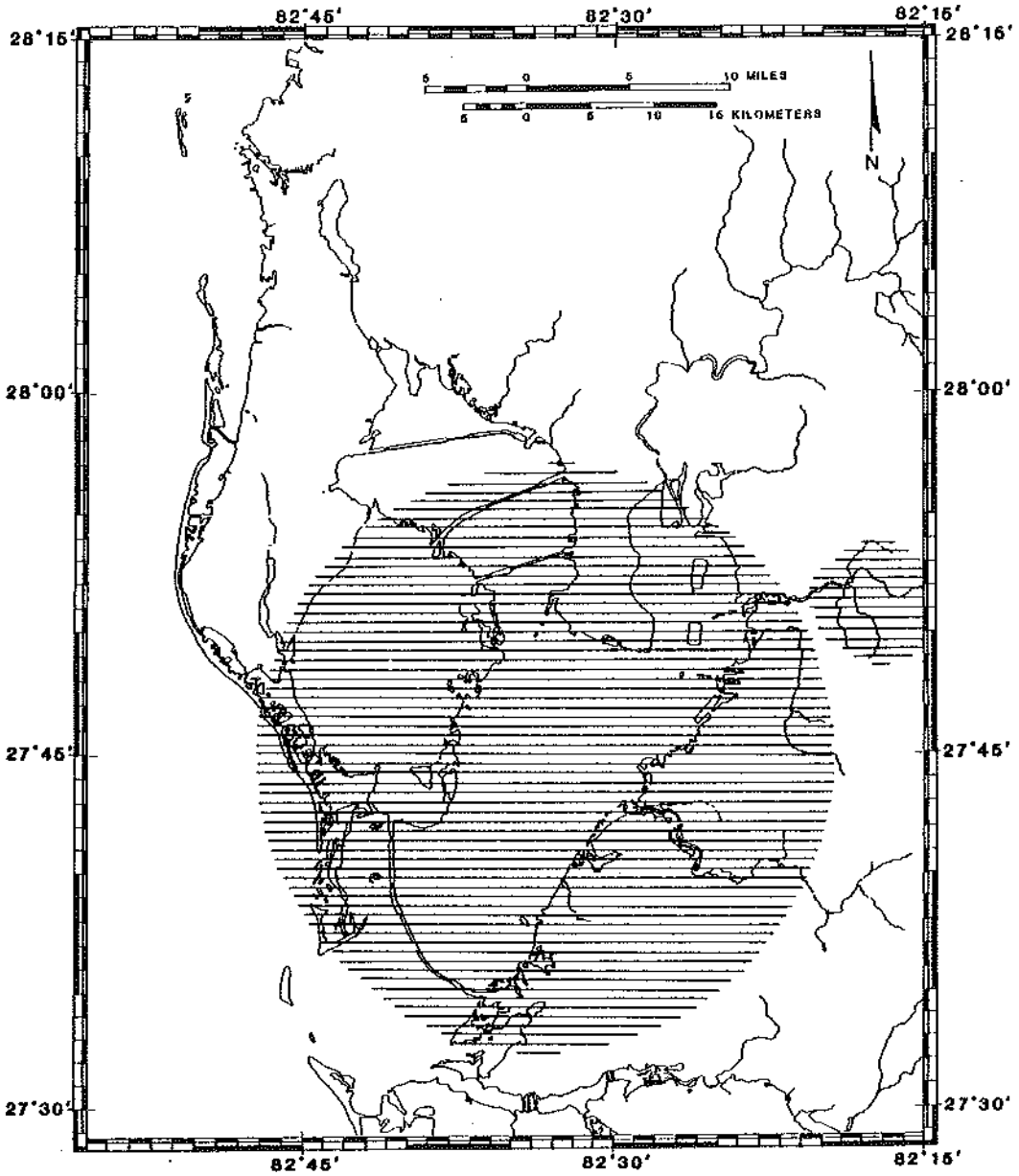

Figure 3. Total annual phosphorus.

Tampa Bay and the Alafia River contribute 96% of the annual total reported phosphorus load.

The total annual reported discharge of nitrogen into Tampa Bay and six area rivers from point sources exceeds 3.5 million pounds (Table 2; Fig. 4). Values for annual total nitrogen load show that sources along Tampa Bay dominate with 85% of the total annual reported load and remaining sources somewhat evenly distributed between 1% and 5%.

A comparison between industrial and domestic discharge sources (Table 3) shows that within the Tampa Bay area, 97% and 81% of the annual load of nitrogen and phosphorus is discharged from domestic sources. In contrast, the Bay area receives 3% and 19% of the annual load of nitrogen and phosphorus respectively from industrial sources. Among domestic sources, Tampa Bay receives 87% and 96% of the total annual nitrogen and phosphorus load from discharge sources along its shores.

DISCUSSION

A point source report survey has limitations and variations which are due in part to the nature of the permitting system and the method of data gathering. The provisions of industrial (and some domestic) discharge permits may not require comprehensive analysis of the effluent for both nitrogen and phosphorus. Phosphate mining discharge, for example, will probably not be analyzed for nitrogen since their processes do not normally allow for the introduction of nitrogen either before or after use. In a similar way, small domestic plants may not have the economic strength to provide comprehensive analysis of their effluent as is commonly required by large municipal facilities.

Power generating facilities use tremendous quantitities of cooling water from Tampa Bay. Although considered a point source, these have not been included in this survey because of the singular thermal modification of the effluent.

All discharge reports are written and submitted by operators, owners or personnel contracted with each point source facility. The Department assumes integrity among those submitting reports, although inadequate analytical procedures, weekend discharges and occasional loss or lack of technical data are rarely reported.

Precipitation significantly affects discharge flow rates of both domestic and industrial sources. Among municipal sewage treatment facilities, stormwater and old collection systems with high infiltration rates may boost flow rates high above the community they serve. In the phosphate industry, heavy summer precipitation may result in high volume discharges in order to lessen the threat of dam failure. Finally, depressed economic conditions affect mining operations and is eventually reflected as decreased flow values to surficial waters.

An analysis of total nitrogen, phosphorus and flow rates from 59 reported domestic and industrial point sources shows that the Alafia River (with associated mining activities) contributes 75% of the annual volume from point sources to Tampa Bay. The nutrients (phosphorus and nitrogen), however, are contributed primarily by domestic sources along the Bay rather than by industrial facilities. A graphic evaluation of nutrient discharge from domestic sources along Tampa Bay shows that the Pinellas County area provides more phosphorus than all other contributing areas (Fig. 5). In addition, Pinellas County contributes over 90% of all the nitrogen discharged to the Bay area from domestic sources (Fig. 6).

These findings are not surprising when population density and public service demands are considered. Evaluation of sewage treatment plants in the Pinellas County area show that they are efficient even though some operate very near or above design capacity. The unusually low values for nitrogen in the Hillsborough County area (Fig. 6) is attributed to the efficient operation of Hookers Point Advanced Wastewater Treatment Plant.

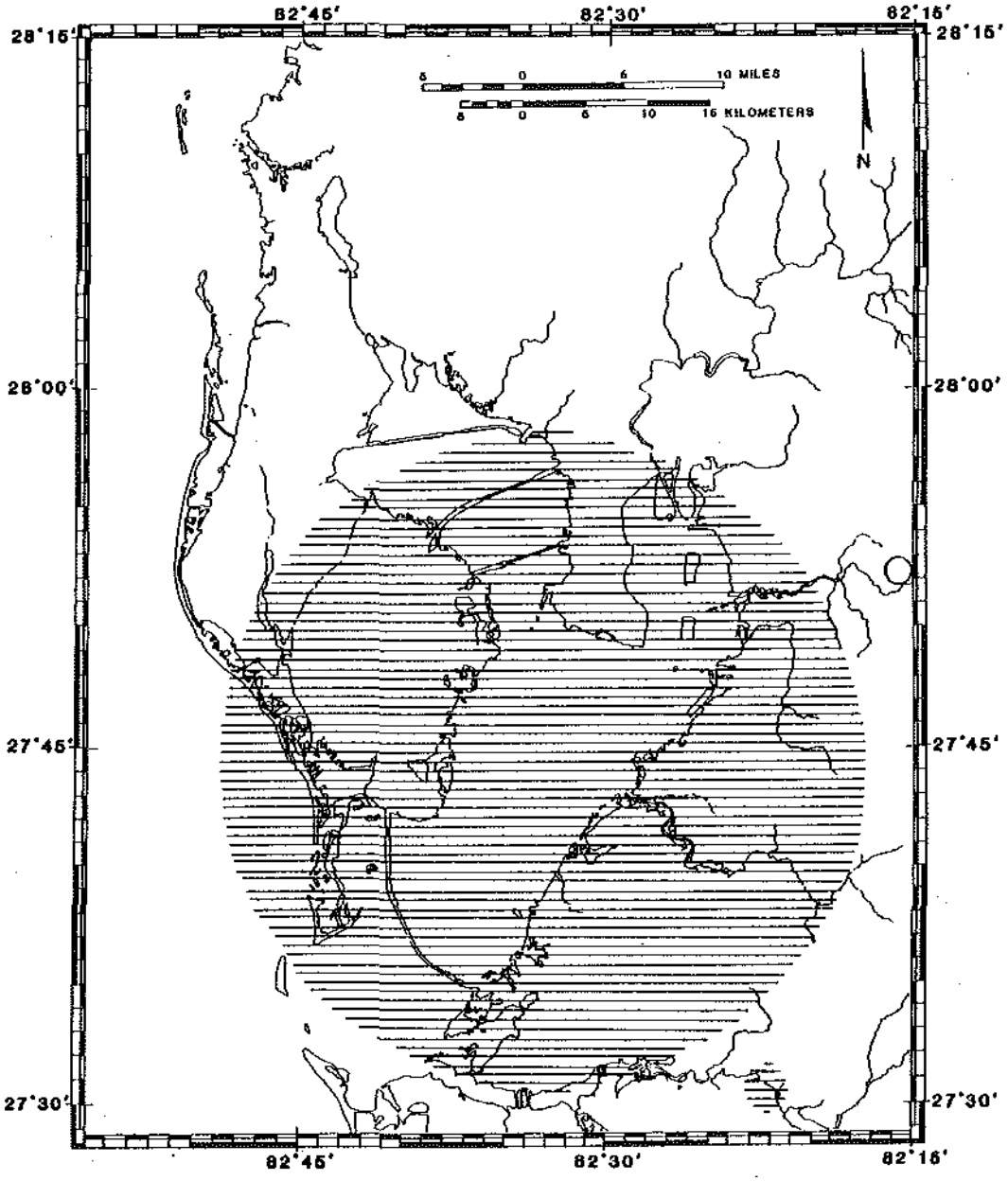

Figure 4. Total annual nitrogen.

Table 3. Industrial and domestic discharge comparison.

Waterbody	Nitrogen (annual total, lbs.) Domestic		Nitrogen (annual total, lbs.) Industrial		Phosphorus (annual total, lbs.) Domestic		Phosphorus (annual total, lbs.) Industrial	
Tampa Bay	3,037,865	(87%)	1,287	(1%)	1,833,344	(96%)	13,284	(3%)
Manatee River	198,711	(6%)[1]	-		25,259	(1%)	-	
Anclote River	178,419	(5%)	-		49,515	(2%)	-	
Hillsborough River	38,839	(1%)	215	(<1%)	4,260	(<1%)	200	(<1%)
Alafia River	14,534	(<1%)	110,433[3]	(99%)	4,157	(<1%)	426,536	(97%)
Palm River	5,350	(<1%)	-		1,788	(<1%)	-	
Little Manatee River	-		-		-		-	
	3,473,718	(97%)[2]	111,935	(3%)	1,918,323	(81%)	440,020	(19%)

[1] percentage contribution of individual waterbodies
[2] percentage of either domestic/industrial contribution
[3] TN is not usually reported by phosphate industries.

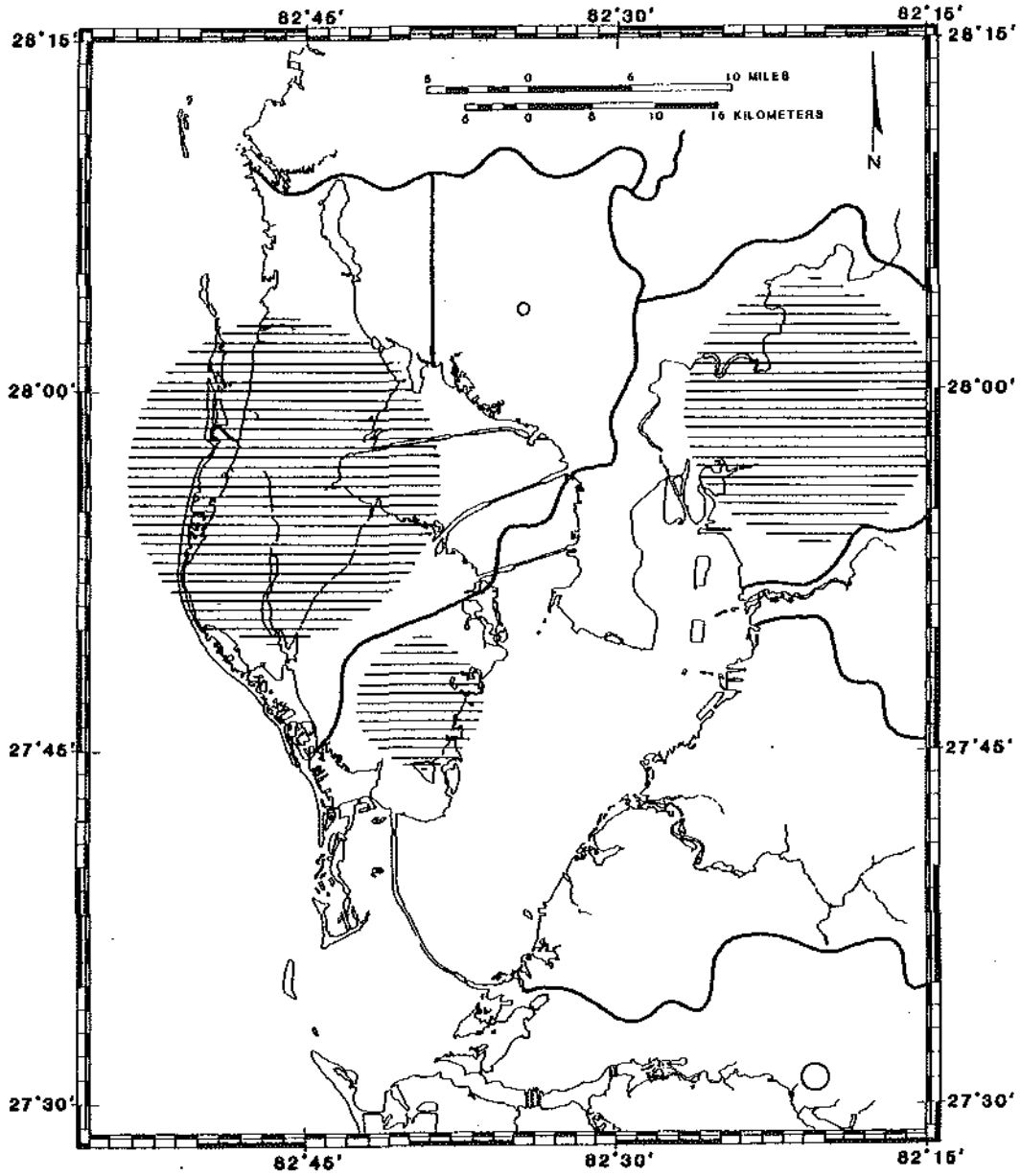

Figure 5. Total annual phosphorus (domestic).

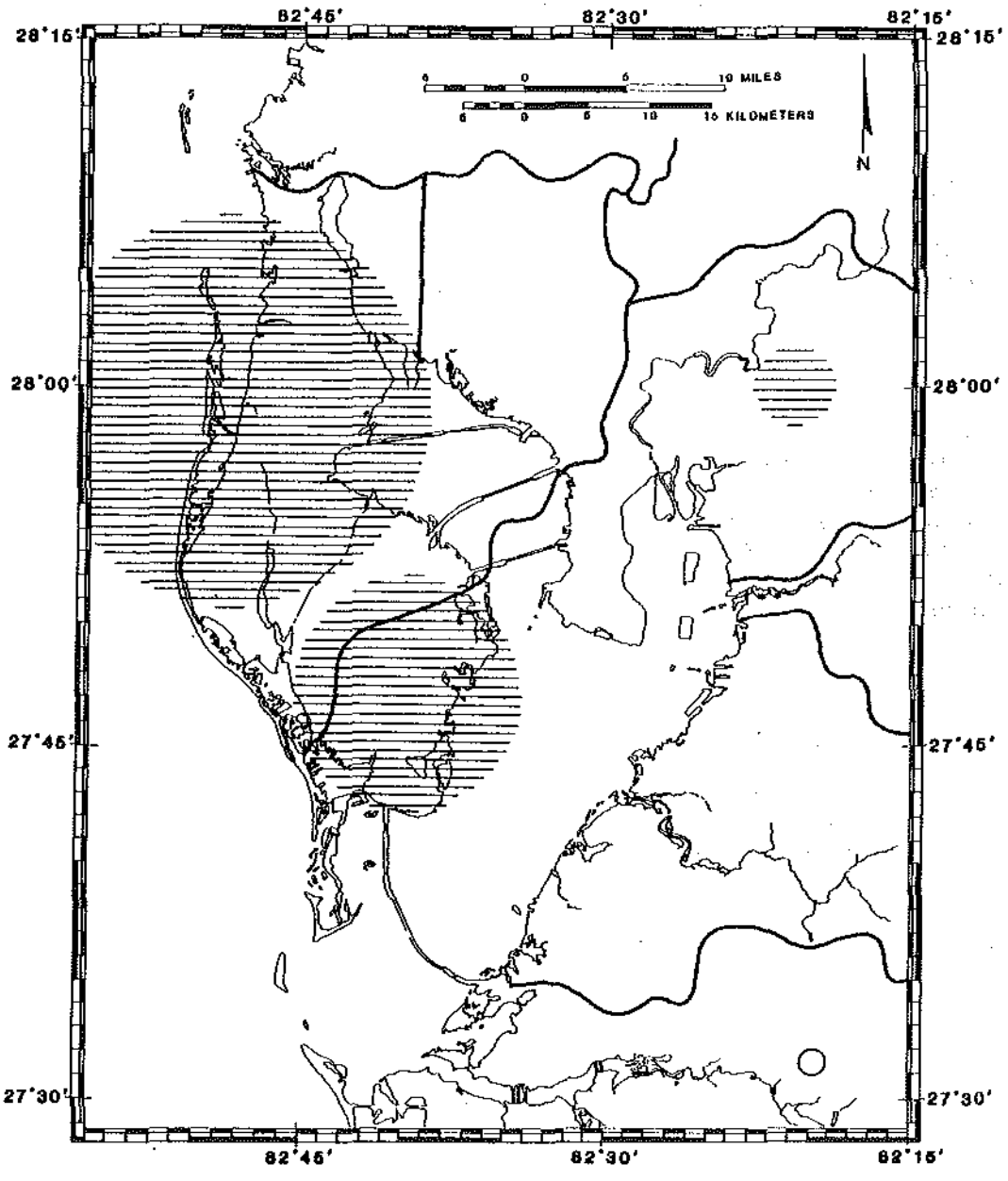

Figure 6. Total annual nitrogen (domestic).

Since 1980, reported domestic effluent discharge to Tampa Bay has improved and will continue to decrease in nutrient content as alternative methods of disposal are implemented. Among domestic sources significant improvements in wastewater treatment in the Tampa Bay area have resulted in a calculated decrease of 35% in total annual nitrogen and 18% in total annual phosphorus loads to the Bay. In the last two years, five facilities have been taken off line and tied into more efficient sewage treatment plants. Three sources no longer discharge; two have been converted to deep well injection and reuse; and two facilities have been improved in treatment method. These improvements have been accomplished through limited Federal and local funds which provide construction grants to improve various aspects of wastewater treatment. During fiscal years 1982 and 1983, additional improvements are expected in both Pinellas and Hillsborough Counties.

SUMMATION

A point source analysis of permitted domestic and industrial discharges has shown that the Bay receives large volumes of water from mining activities along the Alafia River and predominant nutrient loads (nitrogen, phosphorus) from municipal sewage treatment plants. Regulatory agencies and individual city governments are seeking alternative ways to decrease the discharge of nutrient-rich effluent into the Bay. Point source regulation is by itself not enough, however, to improve water quality. Non-point contributions (stormwater, urban runoff and agricultural runoff) contribute significant nutrient loads to the Tampa Bay system. These contributions are more difficult to regulate since the effluent is rarely characterized for each and many sources are pre-existing and not regulated. As we continue a successful campaign to limit point source pollution, non-point sources are emerging as new challenges to the Tampa Bay ecosystem.

ACKNOWLEDGEMENTS

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THE EFFECTS OF ADVANCED WASTEWATER TREATMENT ON THE COLIFORM CONCENTRATION IN HILLSBOROUGH BAY

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In the years before 1978, the City of Tampa sewerage system discharged its primary-treated sewage into Hillsborough Bay rendering it unsuitable for recreational use for most months of the year. This discharge also had the effect of rendering all of Hillsborough Bay unsafe for shellfish harvesting (Hillsborough County Environmental Protection Commission 1972).

In anticipation of the installation of the City of Tampa's advanced wastewater treatment (AWT) system in late 1977 a survey of coliform concentrations at selected sites was initiated. The complete change to secondary treatment was not made, however, until September 1978, and to tertiary treatment in January 1979. This study consists of total coliform concentrations for a period of two years before the AWT system was operational and two years afterward.

Four sites were selected representing a range of coliform concentrations from none to very heavy as indicated in the Hillsborough County Environmental Protection Commission (EPC) report for 1972. The sites are described in increasing order of bacterial concentration. The first site (Fig. 1) was south of the marker buoy at Gadsden Point (EPC #11). The second was just outside the channel to the Alafia River (#55); the third, between the Ballast Point Pier and the Tampa Yacht Club (#6); and the fourth, southeast of the seaplane basin on Davis Island and within 200 yds of the sewage outfall (#52).

The EPC changed methods in 1974 to one which did not match the technique used in our study so data was used only for those years in which the methods were identical. The American Public Health Association recognizes two methods for the examination of water and wastewater, the Most Probable Number (MPN) technique and the Membrane Filter (MF) technique. Although the two methods are considered equivalent, significant differences exist which would influence the choice of one over the other; turbidity of the water, treatment of sewage with chlorine, and natural water composition (Evans et al. 1981; McFeters et al. 1982). The EPC used the MPN technique until 1974 at which time it switched to the MF method (HCEPC 1973-1974).

Water samples were collected from three feet below the surface with a Wheaton Grab sampler and were processed immediately on board by the Most Probable Number technique (Am. Public Health Assoc. 1976).

In the U.S., the level of total coliforms in water considered safe for recreational use is 1,000 per 100 ml of water. Health officials have observed that, in general, with these levels, very few pathogens exist. It should be noted, however, that there is little world-wide agreement as to what constitutes a safe level. English and Welsh standards allow 10,000/100 ml; Japan allows 50,000/100 ml, whereas Australia and South Africa have no standards at all (Brenneman et al. 1981).

Coliform concentrations were generally well above the 1,000/100 ml limit at Davis islands and Ballast Point in the years of primary sewage treatment (Table 1). In this same period, levels at the Alafia River and Gadsden Point sites also occasionally exceeded this limit. After September 1978, however, the levels of coliforms were consistently low with only one of 36 samples (3%) exceeding the 1,000/100 ml limit (Fig. 2). Seven of 17 (41%) exceeded that

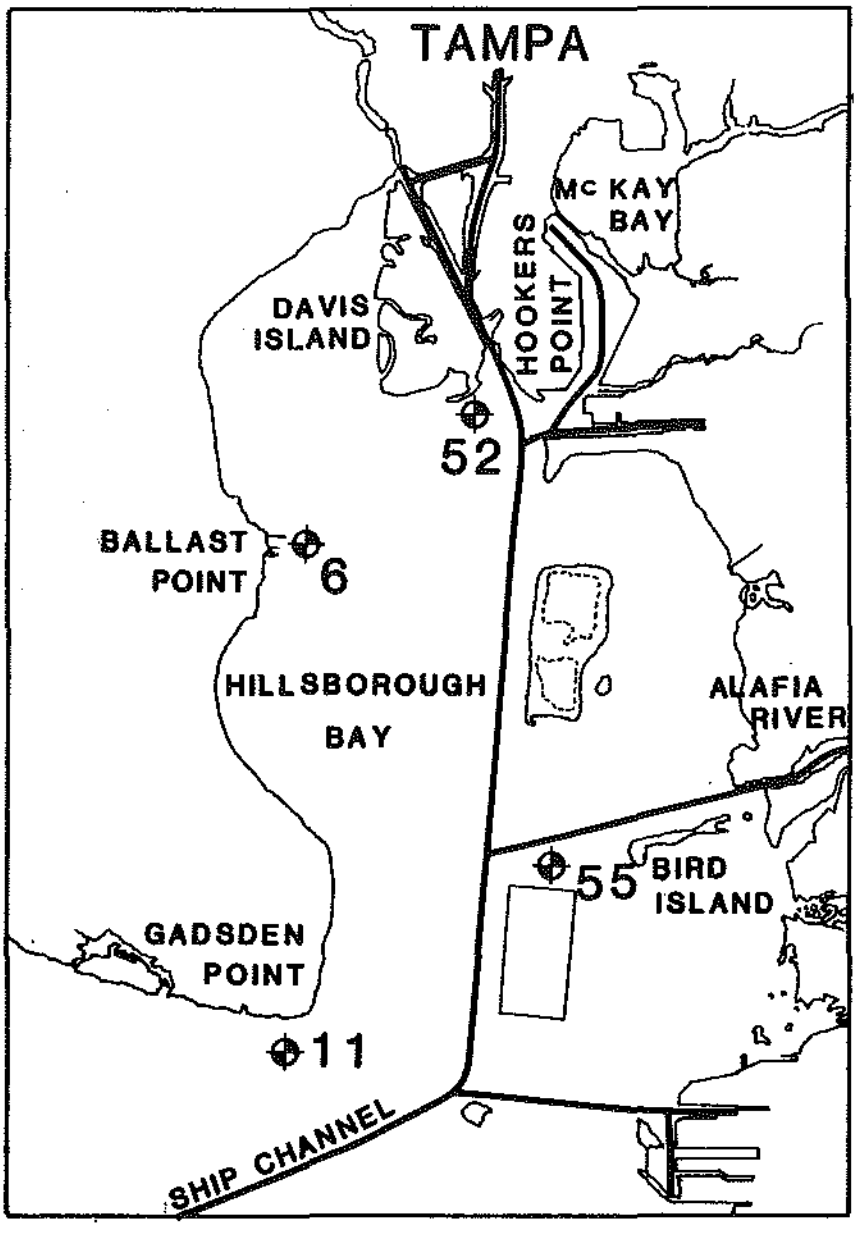

Figure 1. Sampling stations in Hillsborough Bay. 11 - Gadsden Point; 55 - Alafia River Channel; 6 - Ballast Point; 52 - Davis Islands.

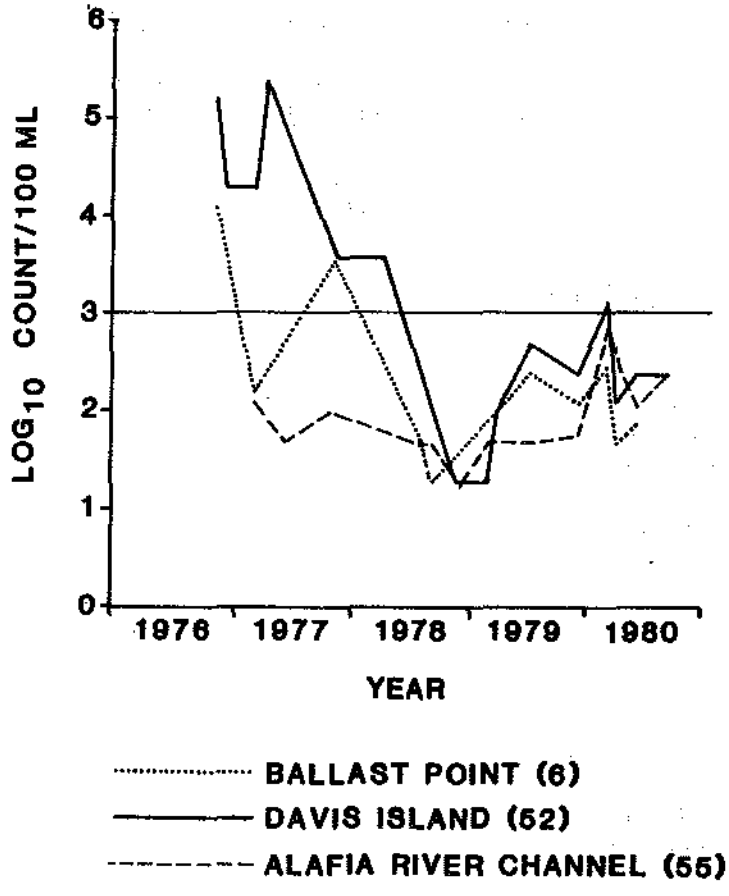

Figure 2. Total coliform concentration (log_{10}) at three sites in Hillsborough Bay.

Table 1. Comparison of total coliform concentrations (MPN presumptive test) at four sites in Hillsborough Bay.

Site (EPC#)	Total coliform count per 100 ml Primary treatment Yearly range (Average)			AWT Study range (Average)
	1972[a]	1973[a]	1976-6[b]	1978-80
Davis Islands (52)	490-79,000 (21,683)	2,200-24,000 (12,333)	4,000-230,000 (86,800)	20-1,300 (598)
Ballast Point (6)	0-24,000 (2,440)	2-7,900 (1,300)	170-13,000 (5,550)	20-790 (180)
Alafia River (55)	0-2,220 (190)	2-4,900 (1,356)	50-130 (97)	20-330 (88)
Gadsden Point (11)	0-2,400 (274)	2-1,100 (152)	20 (20)	20-130 (29)

[a]EPC data
[b]Present study, 16 October 1976 - 23 October 1977.

level before September 1978. The samples taken during the four years of this study which indicated excessive coliforms actually were from the Davis Islands and Ballast Point sites only. At no time did either the Alafia River or Gadsden Point sites have excessive levels.

Excluded from the data is a sampling taken in August of 1979 during a period when extremely heavy rains caused seepage of groundwater into the eroded main sewer line (Tampa Tribune 1979). The overloaded pumping stations subsequently dumped raw sewage into the Hillsborough River causing extremely high bacterial counts to be recorded. The level at Davis Islands was 918,000/100 ml; 2,400 at Ballast Point, 790 at the Alafia River, and 20 at Gadsden Point.

It is apparent that the AWT system was effective in reducing coliform levels in Hillsborough Bay. The City of Tampa's antiquated sewage lines, however, will continue to cause periodic problems until they are replaced. It has also been suggested that viruses can survive on particulate matter and be present in a water that has been declared safe because of a low coliform count. Little, indeed, is known about viral levels in the Tampa Bay area or about the relationship between viruses and coliforms in these waters.

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URBAN STORMWATER RUNOFF IN THE TAMPA BAY AREA

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DESCRIPTION OF THE AREA

The urban study area referred to as the Tampa Bay area in this paper includes the counties of Hillsborough and Pinellas and the cities of Clearwater, St. Petersburg, and Tampa, in west-central Florida. The land area and population of each county and city are listed below (Thompson 1977; Florida Dept. of Commerce 1980):

	Area (mi^2)	Population (1979)
Hillsborough County	1,038	634,469
Pinellas County	265	725,457
City of Clearwater	22.4	82,905
City of St. Petersburg	55.4	240,427
City of Tampa	84.5	275,686

The City of Tampa is the largest city in Hillsborough County and contains nearly 45% of its population while occupying less than 10% of the land area. The cities of Clearwater and St. Petersburg are the two largest cities in Pinellas County and contain approximately 45% of its population. Pinellas County is the second smallest county in Florida, but it has the highest population density.

Parts of Pinellas and Hillsborough Counties, particularly in the Clearwater - St. Petersburg - Tampa area, are heavily urbanized. Many areas in both counties are experiencing or are planning for additional urban development. Land use in Pinellas County and the cities of Clearwater, St. Petersburg, and Tampa is primarily for residential and commercial purposes. The major land uses in unincorporated Hillsborough County are residential, agricultural, and strip mining. The region's major heavy industry activity is centered around the Port of Tampa in Hillsborough Bay. Light industry is scattered throughout both counties. For the most part, large chemical plants, breweries, packing houses, and other industries are confined to zoned industrial areas. The present land-use pattern is primarily coastal oriented with most urban development adjacent to shoreline regions.

The natural shoreline consists of many small bays, inlets, and marshlands adjacent to tributary streams. The bay system is comprised principally of shallow estuarine areas. The shoreline system of interest in this paper includes Tampa Bay, Old Tampa Bay, and Hillsborough Bay. The Hillsborough River is the largest river draining the region and discharges into Hillsborough Bay. There are many smaller streams that drain Hillsborough and Pinellas Counties and discharge into the bay. The general urban area tributary to Tampa Bay is shown in Figure 1.

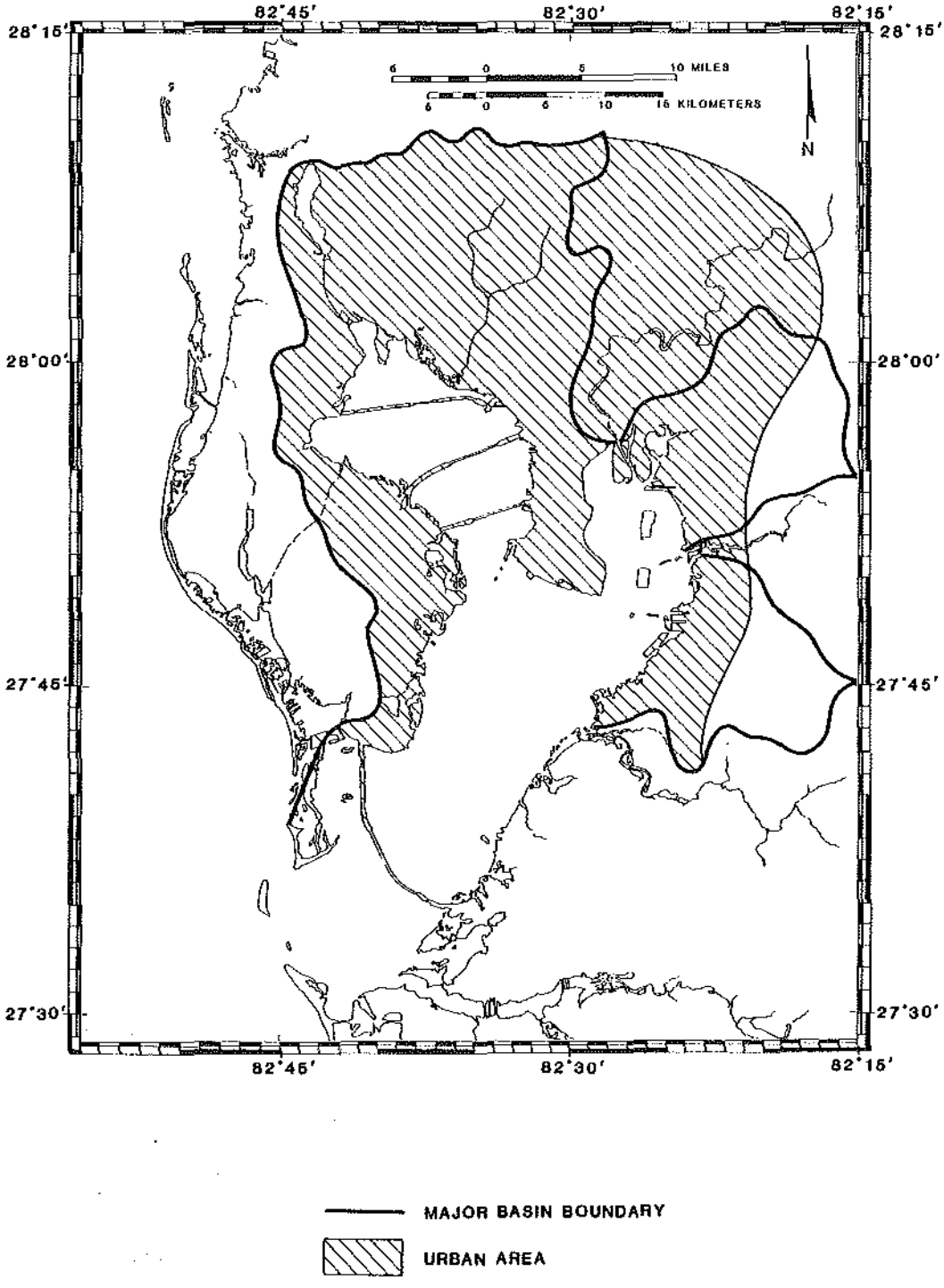

Figure 1. General urban area tributary to Tampa Bay.

DEFINITION OF THE SUBJECT

Urban stormwater runoff is the water which flows off rooftops, lawns, paved areas and streets during and after a rainstorm. All stormwater runoff originates as a rainfall and is usually discharged within several hours after a rainfall event. The amount of runoff varies with the rainfall intensity, duration, antecedent conditions and level of development.

In an urbanized area, runoff characteristics are significantly different than those of a similar undeveloped basin. Development in an urban watershed may be characterized by residential areas that have paved streets drained by large paved parking lots. Because urbanization increases the amount of impervious area, the peak and volume of storm runoff is increased. Generally, residential roof areas are not directly tributary to storm sewer systems and do not contribute directly to runoff. Runoff from these impervious areas not directly connected to a storm sewer or drainage channel will flow over land and be detained as depression storage or infiltrate through previous surfaces. Roofs of commercial or industrial buildings that drain onto paved parking lots that have storm sewer inlets and streets with curbs and gutters that drain directly to a storm sewer are considered to be hydraulically connected impervious areas. These types of hydraulic characteristics in urban areas also shorten the time in which runoff occurs (decreases the time of concentration).

Watershed and drainage system hydraulic characteristics also contribute to quality characteristics of runoff. Pollutants associated with paved areas that are directly connected to storm-drainage systems will wash off easily during the initial phases of a rainfall event. This results in high concentrations at the beginning of the storm, decreasing as the event progresses. This type of first-flush effect is also characteristic of basins that have a high percentage of hydraulically connected impervious area. Pollutants that are evenly spread throughout the basin or basins that have small percentages of hydraulically connected impervious areas tend to have wash-off characteristics closely related to the storm-runoff hydrograph. That is, pollutants are washed off and transported through the basin at a uniform rate. Highest pollution concentrations occur simultaneously with peak discharge, whereas initial and final concentrations are small.

Sources of urban stormwater pollution have been identified as trash and litter deposited on streets and parking lots, erosion of exposed ground due to construction, lawn and landscape maintenance, domestic pet litter, automobile emission, and atmospheric pollution. These non-point sources of pollution are concentrated by stormwater collection systems and transported to a point of discharge. As a result of this pollution, over-enrichment of streams, lakes, and bays may occur. The enrichment will produce accelerated growth of nuisance plants, such as water hyacinths and algae, and depletion of dissolved oxygen in surface water.

HISTORY OF THE DISCIPLINE IN THE TAMPA BAY AREA

Urban stormwater runoff as associated with growth in the Tampa Bay area may be characterized by development that occurs in flood prone areas, development that creates additional stormwater runoff. Flood plain development has occurred along shorelines, on lake fronts, along rivers, and in wetlands. Development of this type is eventually subjected to flood damage. Property owners that sustain flood damage related loss usually turn to local government for relief in the form of reimbursement for private property loss, low interest loans, and public works projects such as dams, bypass canals, and storm sewer systems. In addition, because of the inconvenience, health hazard, and property damage, citizens expect stormwater to be removed soon after its occurrence.

Historically, stormwater was

handled with the shortest distance between two points approach. Drainage system design included: identification of flood prone areas, determinaton of design flows, sizing of pipes, and discharge of runoff to the nearest receiving body of water. This type of drainage system collects, transports and disposes of pollutants contained in urban stormwater in such a manner that little attenuation of pollutant loads occurs during the actual transmission of the runoff. The bulk of pollutants are concentrated or assimilated in the receiving bodies of water. Environmental assessment studies of the Tampa Bay area (Tampa Bay Regional Planning Council 1978) have identified urban runoff as a major contributor of non-point source pollution.

Due to an environmental awakening during the late 60s through early 70s and the advent of federal, state and local restrictions on the pollution of state waters, the methods and approaches to drainage system design and stormwater pollution have changed dramatically. In March 1982, the Florida Department of Environmental Regulation (FDER) adopted a comprehensive set of regulations dealing with stormwater (Chapter 17-25, Florida Administrative Code). While it was common practice to discharge stormwater into the nearest receiving body, this legislation will significantly change this practice. FDER will now review most stormwater discharges to waters of the state and issue permits if acceptable levels of water quality treatment are provided. Treatment of stormwater is primarily through nonstructural means, that is, elimination or reduction of pollutants by the use of detention/retention basins or underground exfiltration systems. Most of these approaches to stormwater quality are relatively new and will require extensive data collection and analysis of information on land use, rainfall, runoff and water quality.

Over the past 20 years there has been a wide variety of studies conducted in the Tampa Bay area on urban stormwater quantity and quality. These studies have been produced by organizations ranging from local governments to universities for purposes ranging from identification of flood prone areas to characterizing pollutants in stormwater. The majority of these reports were produced during the past ten years.

CIRCUMSTANCES RESPONSIBLE FOR FEW STUDIES

The primary emphasis on water quality in Tampa Bay has, until recently, been associated with types of pollution sources other than urban stormwater runoff or non-point source pollution. These other sources of water quality problems range from sewage discharges (point source) to environmental effects of dredging. Point sources such as sewage discharge have received greater emphasis and wider attention than urban runoff, due to a variety of reasons. There has been greater availability of federal funds, including the EPA Construction Grants Program for upgrading facilities treatment process, and also supporting legislation dealing with available funds. Other sources of pollution such as dredging activities and harbor construction have also had the support of federal funds. One may conclude that both of these water quality problems have had greater emphasis than non-point source pollution due to their greater visibility, suspected environmental impact, and economic impact.

In addition, there are problems associated with the monitoring of stormwater runoff which have resulted in less data being available. While point sources can be collected and treated with known technology and can be dealt with through structural process treatment, this is not the case for urban runoff. There are also a greater number of variables that must be dealt with, such as geographic location of outfalls, chemical variation of pollutants, and seasonal variations with respect to quantity of flow. With point sources being more easily handled with respect to measurability and treatability and also more visible to the public, they have

received wider attention and thus, more emphasis in past studies.

Positive steps have been taken to reduce pollution loads in an effort to reverse the deterioration of water quality in Tampa Bay. In the early 1970s, phosphorus coming from industrial plants was reduced, and the City of Tampa upgraded its wastewater treatment plant at Hookers Point from primary to advanced treatment in 1979. Other local governments have also improved point source discharges in the Bay area. With these significant improvements in the quality of point source discharges, it has become important to focus attention on other sources of pollution such as urban runoff.

REVIEW/COMMENTARY

Local references are discussed in a chronological fashion and include reports dealing with stormwater quantity and quality. These references include research on floods in Tampa and work conducted at the University of South Florida (including several masters' theses and stormwater runoff modelling reports). Also included are the outputs from the Tampa Nationwide Urban Runoff Program (NURP), U.S. Geological Survey reports, and reports by state and local agencies and private individuals. All of these are references dealing with urban stormwater runoff quantity and/or quality in the local Tampa Bay region.

LOCAL RESEARCH

During the early '70s, there were a number of papers or reports produced by the University of South Florida on stormwater runoff. These included an examination of pollutant loading and flow variation from an existing developed urban basin (Shearer 1973), and an examination of quantity and quality changes in runoff from a developing basin (Anderson 1975). In addition to these site-specific reports, there was graduate work done on predicting the quantity and quality of stormwater runoff for the Tampa Bay region (Copeland 1973). For the most part, these were the most detailed works completed on stormwater during this period.

In 1974, the U.S. Geological Survey (USGS) in cooperation with the Southwest Florida Water Management District, Hillsborough County, Pinellas County, and the cities of St. Petersburg, Tampa and Clearwater, initiated a study to determine the effect of urban development on the quality and quantity of storm runoff in the Tampa Bay area. The objectives of the study, which ran from 1974 to 1979, were to: 1) assess the quantity and quality of stormwater; 2) relate stormwater runoff and water quality to land use and intensity of development; and 3) develop planning and management information needed for design and management of storm drainage systems to meet peak flow and water quality criteria.

To accomplish objectives of the study, a broad urban runoff data collection program was established. Stream flow, climatic, physiographic, and water quality data were collected at nine urbanized watersheds (Fig. 2). Watersheds were selected to provide information ranging from moderate to advanced stages of urban development. Watershed drainage areas ranged from 0.34 mi^2 to 3.45 m^2. Land use was mixed and development ranged from a sparsely populated watershed with 19% impervious area to a commercial-residential watershed with 61% impervious area (Table 1).

Gaging stations were established to continuously record (5-minute intervals) runoff from each watershed. In addition, a network of recording rain gages was established to obtain magnitude, intensity, and areal variations of rainfall. Physiographic parameters of each watershed were compiled from aerial photographs, U.S. Geological Survey topographic maps, planning agency data, and field observations. This data consisted of size, shape, and slope of the watershed, type of land use, degree of land use, amount of impervious area, type of storm drainage, soil types, and amount of storage in lakes or detention ponds.

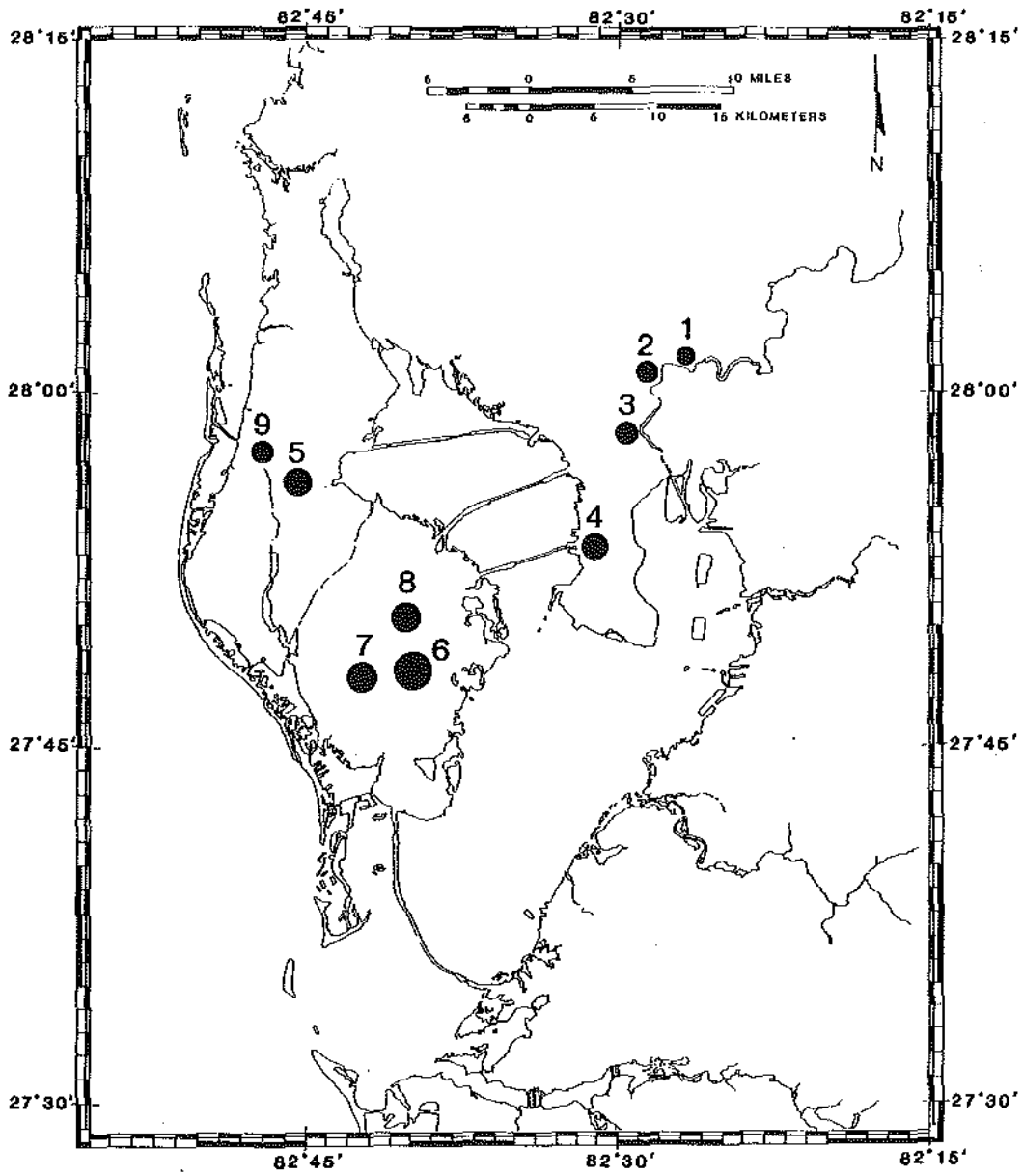

Figure 2. Location of USGS urban watersheds.

1 Arctic St. storm drain, Tampa
2 Kirby St. drainage ditch, Tampa
3 St. Louis St. drainage ditch, Tampa
4 Gandy Blvd. drainage ditch, Tampa
5 Allen Creek, near Largo
6 Booker Creek, St. Petersburg
7 Bear Creek, St. Petersburg
8 St. Joe's Creek, St. Petersburg
9 Turner St. storm drain, Clearwater

Table 1. Land use characteristics for USGS urban watersheds. Site number designations as shown in Figure 2.

Site	1	2	3	4	5	6	7	8	9
Drainage area (mi^2)	0.34	1.40	0.51	1.29	1.79	3.45	1.89	1.72	0.45
Percentage of watershed area in various land uses:									
Roads	14.7	4.4	11.8	8.5	10.3	12.3	12.8	12.0	12.7
Single-family residential	46.2	69.0	68.1	31.6	59.0	48.8	66.1	47.7	37.4
Multifamily residential	0	3.3	0	5.1	3.9	1.7	4.3	0.1	1.4
Commercial	36.5	4.5	3.3	21.0	7.0	18.1	5.8	16.2	28.0
Industrial	0	0	0	0	0	4.4	0	7.7	20.0
Institutional	1.5	2.2	6.5	3.9	7.9	3.0	5.5	1.8	0.4
Recreational	0	1.0	2.3	5.6	0.5	2.7	1.0	1.9	0
Open space	1.1	15.6	8.0	24.3	11.4	9.0	4.5	12.6	0.1
Percentage total impervious area	61	19	27	38	36	41	32	38	48
Percentage hydraulically connected impervious area	53	5.5	9.0	28	26	26	25	26	33

Water quality data was collected during storm periods to determine the variation of water quality within storm events and among individual storms. Most storms sampled occurred during the wet season months of July through September when the frequency of rainfall events was highest. Samples were also collected during base-flow periods to provide data for comparing water quality during such periods with storm quality and for use in determining total annual loads. This data was also used to evaluate the effects of antecedent rainfall conditions, land use, and runoff volume on water quality from urban watersheds.

A more detailed description of the study area, procedures for the selection of watersheds, data collection sites, data collection techniques, and a tabulation of data processed through September 30, 1976, are included in a report by Lopez and Michaelis (1979). Two other reports are in the process of being published at this time. One evaluates the chemical-quality characteristics of urban storm runoff in the Tampa Bay area and develops a method of estimating pollutant loads for gaged and ungaged watersheds under existing or future developed conditions (Giovanelli and Lopez, in preparation). The other covers the urban runoff quantity portion of the study, including development of flood frequency relations for urban basins in the area (Lopez and Woodham, in preparation).

This study by the USGS is by far the most extensive work on urban stormwater done in the Tampa Bay area to date. This being the case, some of the results from this study are presented here. In addition, since the primary focus of these proceedings is the water quality in Tampa Bay, these discussions focus on that aspect of the study.

The first phase of water quality analysis consisted of studying the range and average concentrations for major constituents sampled. The range in concentrations for selected constituents sampled is shown in Table 2 for all watersheds. In most cases, the data reflects variations in constituent levels from base-flow to peak-flow conditions. Turbidity and specific conductance are indicators of suspended and dissolved solids concentrations, respectively. High turbidity values indicate a greater amount of suspended material in the runoff than when the values are low. The BOD, COD, and TOC constituents are indicators of the amount of organic and oxygen demanding materials in the stormwater runoff. Total phosphorus and total nitrogen are indicators of the amount of nutrients in storm runoff. Residential land uses are generally sources of nutrients in urban storm runoff. Each watershed had about 40% or more of the basin in residential land uses, possibly explaining the similarity of nutrient concentrations. On occasion, higher than normal concentrations were measured, such as the 12 mg/l maximum for nitrogen; this was considered to be atypical.

Coliform concentrations are a measure of the sanitary quality of water and its suitability for general use. Presence of fecal coliform in storm runoff indicates contamination with human or animal feces. Total coliform indicates general bacteriological contamination and includes the fecal coliform and bacteria that may have originated from other sources. There are two types of analysis performed to determine coliform concentrations, the multiple-tube fermentation test and the membrane filter technique. Results of the multiple-tube fermentation tests are expressed as "most probable number" (MPN), an index of the number of coliform bacteria that more probably than any other number would give results shown by the laboratory examination. This test does not give an actual enumeration of the bacteria. The membrane filter technique provides a measure of coliform densities in a given volume of water (colonies per 100 milliliters). In most cases, results of these two tests are comparable.

Bacteriological data obtained in the study is highly variable and cannot be regarded as providing complete or final

Table 2. Range in streamflow, average baseflow, and average storm runoff concentrations for selected constituents at all USGS watersheds.

Constituent (units)	RANGE IN STREAMFLOW min.	RANGE IN STREAMFLOW max.	AVERAGE BASEFLOW number of samples	AVERAGE BASEFLOW average	AVERAGE STORM RUNOFF number of samples	AVERAGE STORM RUNOFF average
Streamflow (ft^3/s)	0.01	344.00	50	3.60	189	54.00
Turbidity (NTU)	1.00	270.00	20	18.00	97	46.00
Specific Conductance (micromhos)	63.00	585.00	20	37.00	40	216.00
5-day Biochemical Oxygen Demand (mg/l)	0.30	41.00	35	5.50	169	5.30
Chemical Oxygen Demand (mg/l)	5.00	210.00	24	58.00	173	54.00
Total Organic Carbon as C (mg/l)	0.00	88.00	14	19.00	153	14.00
Total Phosphorus as P (mg/l)	0.02	1.70	33	0.25	182	0.33
Total Ortho Phosphorus as P (mg/l)	0.02	0.35	31	0.10	125	0.15
Total Nitrogen as N (mg/l)	0.20	12.00	24	1.70	121	2.90
Total Organic Nitrogen as N (mg/l)	0.00	12.00	34	1.00	181	1.20
Total Ammonia Nitrogen as N (mg/l)	0.03	2.10	31	0.28	147	0.29
Total Nitrite Nitrogen as N (mg/l)	0.00	0.13	30	0.10	147	0.04
Total Nitrate Nitrogen as N (mg/l)	0.00	1.70	31	0.35	147	0.31

Table 2 continued.

Constituent (units)	RANGE IN STREAMFLOW min.	RANGE IN STREAMFLOW max.	AVERAGE BASEFLOW number of samples	AVERAGE BASEFLOW average	AVERAGE STORM RUNOFF number of samples	AVERAGE STORM RUNOFF average
Confirmed, Coliform (MPN) x 10^3 (colonies/100 ml)	4.60	11,000	...	...	69	810.00
Fecal Coliform, EC Broth (MPN) (colonies/100 ml)	0.93	11,000	...	...	69	343.00
Total Immed. Coliform x 10^3 (colonies/100 ml)	2.00	82,000	5	263.00	42	2,060.00
Fecal Coliform, 0.7 UF-MF x 10^3 (colonies/100 ml)	0.31	170.00	5	18.00	37	49.00
Total Arsenic as As (ug/l)	0.00	8.00	16	1.80	125	1.70
Total Recoverable Copper as Cu (ug/l)	0.00	100.00	15	8.00	125	14.00
Total Recoverable Lead as Pb (ug/l)	5.00	1,600.00	19	104.00	170	187.00
Total Recoverable Zinc as Zn (ug/l)	7.00	400.00	15	120.00	116	108.00
Total Recoverable Mercury as Hg (ug/l)	0.00	6.00	16	2.80	125	0.77

information concerning the quality of urban storm runoff. Patterns and reliable ranges are not available for the bacteriological data. Results must be considered on an individual basis considering the sanitary conditions surrounding the source.

Trace metals are present in storm runoff in much smaller concentrations than organic and nutrient constituents. Concentrations of copper and zinc were considerably higher than arsenic and mercury, and lead had the highest concentrations of all trace metals. A source of copper could be sprays used to control biological growth in ditches, whereas zinc may be present because of deterioration of galvanized iron. Concentrations of lead appeared to be highly related to commercial development, and streets and highways are an important link in collection and transport of lead to storm-drainage systems.

Average concentrations of selected constituents for base-flow and storm-runoff conditions are also listed in Table 2. Average concentrations were determined by taking the arithmetic mean of sample concentrations for each given flow condition. Base flow is defined as sustained fair-weather runoff and is composed primarily of ground-water discharge. Base-flow samples were collected for discharge ranging from about 0.1 to 8.0 ft^3/s. Storm-runoff samples were collected for mean discharges ranging from about 6 to 130 ft^3/s. Average storm runoff concentrations were computed from samples collected during one or more storm events.

Average levels of turbidity for storm samples were more than two times higher than those for base-flow conditions. In many cases, the average turbidity for base-flow samples was within the recommended maximum criteria for drinking water of 5 turbidity units. In every case, average turbidities of storm runoff exceeded this limit. This indicates that suspended material is picked up and transported by high velocities associated with storm discharges. Addition of suspended material to receiving waters may have the effect of blanketing the bottom and damaging invertebrate populations, blocking gravel beds where fish spawn, and, if the material is organic, causing the depletion of dissolved oxygen.

Average concentrations of organic constituents generally did not vary significantly between base-flow and storm conditions. Addition of organic and oxygen demanding material to receiving water bodies results in biological degradation and depletion of oxygen.

Average concentrations of nutrients did not vary much between base-flow and storm conditions. Addition of nutrients to receiving water may result in enrichment that can produce excessive growth of algae and aquatic plants. Average concentrations of organic and nutrient constituents shown in Table 2 may be compared with concentrations of treated and untreated domestic sewage recorded at the Tampa Sanitary Sewage Treatment Plant:

	Concentration (mg/l)		
Constituent	Typical domestic sewage influent for Tampa	1981 average Tampa sewage AWT effluent	USGS Average Stormwater samples (from Table 2)
BOD	225	2.2	5.3
COD	500	-	54.0
Total nitrogen as N	32	2.5	2.9
Total phosphorus as P	10	5.8	0.33

In every case, average concentrations of BOD, COD, nitrogen and phosphorus listed in Table 2 are less than those of typical untreated domestic sewage. The average stormwater runoff concentrations of BOD were higher than AWT treated sewage effluent, and total nitrogen also exceeded AWT treated sewage effluent. Average concentrations of phosphorus from the urban data were below that of the treated sewage effluent (note: AWT plant operating with phosphorus variance).

The range in average coliform concentrations was highly variable. This data should be evaluated on an individual basis for each site considering existing hydrologic and land-use conditions. The presence of coliform bacteria in receiving waters may have detrimental effects to human and aquatic life forms.

Average concentrations of lead were highly variable, depending on commercial land use in the basin and sampling conditions. Average base-flow concentrations of lead ranged from 17 to 323 ug/l, whereas average storm concentrations ranged from 47 to 782 ug/l. High concentrations of toxic materials, such as the trace metals, can cause fish kills or render receiving water unfit for human activities or shellfish harvesting.

The Florida Department of Environmental Regulation (1979) has outlined criteria for maximum concentrations of various parameters in receiving waters by class and intended use. Class IA waters are potable surface-water supplies, Class II are shellfish propagation and harvesting, and Class III are for recreation or propagation and management of fish and wildlife. The Florida Department of Environmental Regulation has set limits for trace metal concentrations for Class III waters as follows:

Constituent	Class III Waters Maximum Concentration (ug/l)	Average Concentrations of Stormwater (from Table 2; ug/l)
Mercury	0.1	0.77
Copper	15	14
Zinc	30	187
Lead	30	108

Average concentrations of mercury were above the maximum allowable limit and copper was slightly below the maximum limit. Average concentrations of lead and zinc in stormwater runoff were considerably higher than the Class III standards. This was especially true for urban basins with large commercial development, such as Arctic Street and Turner Street that also had base-flow average concentrations higher than Class III standards.

Variations of constituent concentration with time is also an important factor in characterizing pollution from urban storm runoff. Pollutants may be flushed by initial runoff from a storm or may be washed from the basin at a rate related to the intensity of rainfall and discharge. Hydrographs showing variations of concentrations from major constituents with discharge and rainfall distribution for selected storm events are shown in Figures 3-6. These figures illustrate various types of flushing characteristics, variations in constituent concentrations, and components of total concentrations for nutrients and trace metals in runoff.

Variations in rainfall, discharge, turbidity, and concentrations of BOD, COD, TOC, total nitrogen and total phosphorus during selected storm events for two types of basins are shown in Figures 3 and 4. This data is based on samples collected during the initial phase

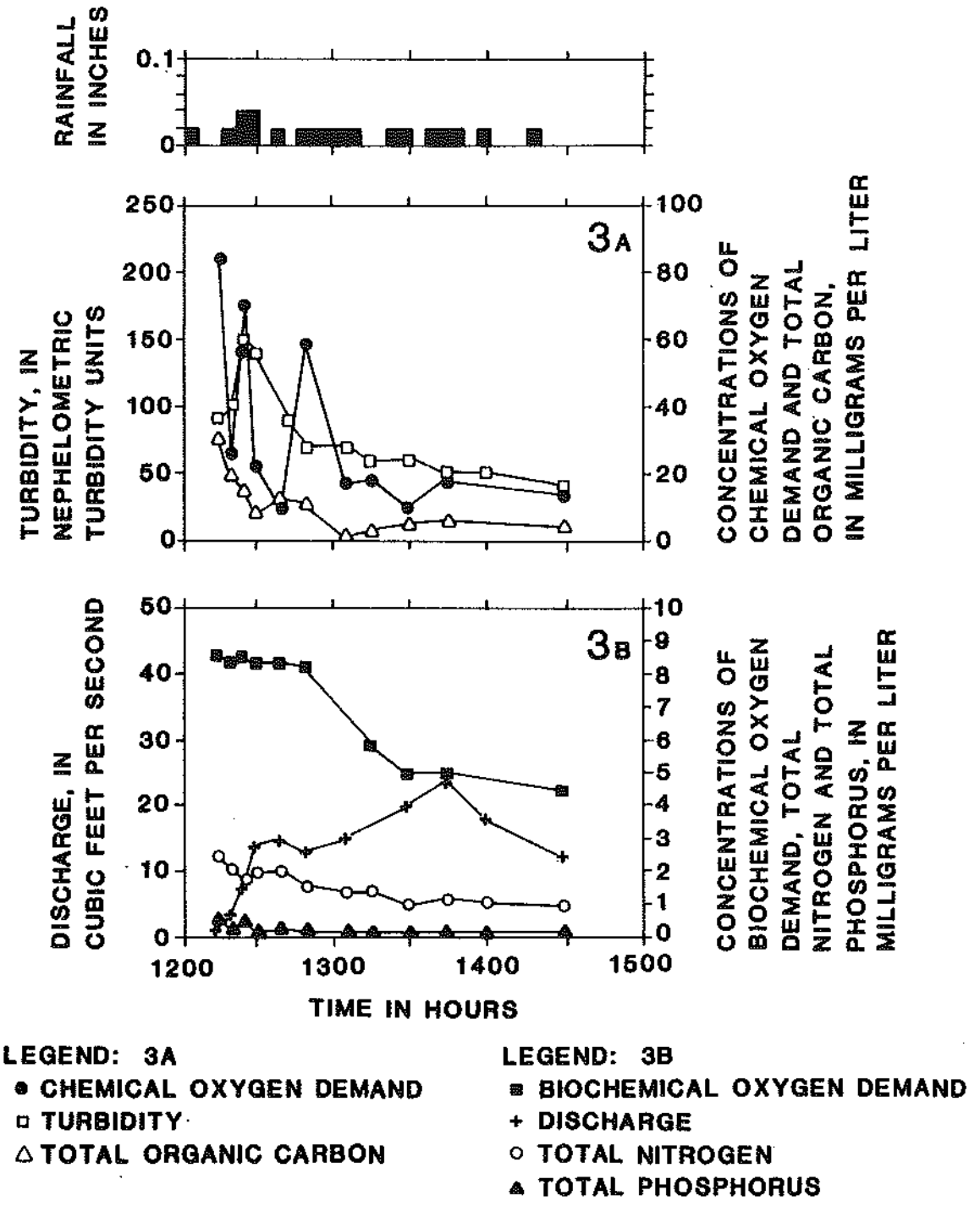

Figure 3. Variation of rainfall, discharge, and concentrations of biochemical oxygen demand, total nitrogen, total phosphorus, turbidity, chemical oxygen demand, and total organic carbon at Arctic Street on August 1, 1978.

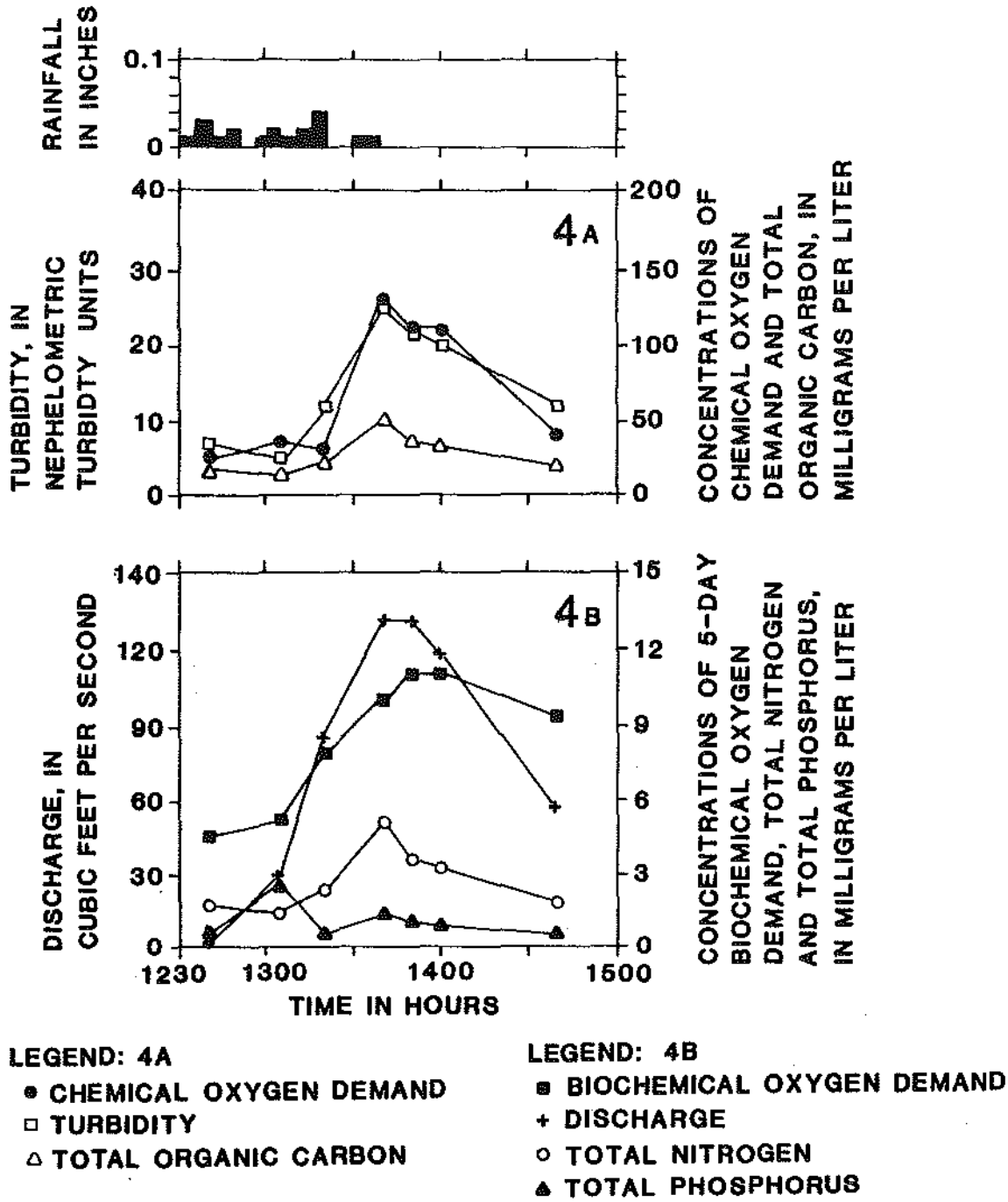

Figure 4. Variation of rainfall, discharge, and concentrations of biochemical oxygen demand, total nitrogen, total phosphorus, turbidity, chemical oxygen demand, and total organic carbon at Allen Creek on March 13, 1980.

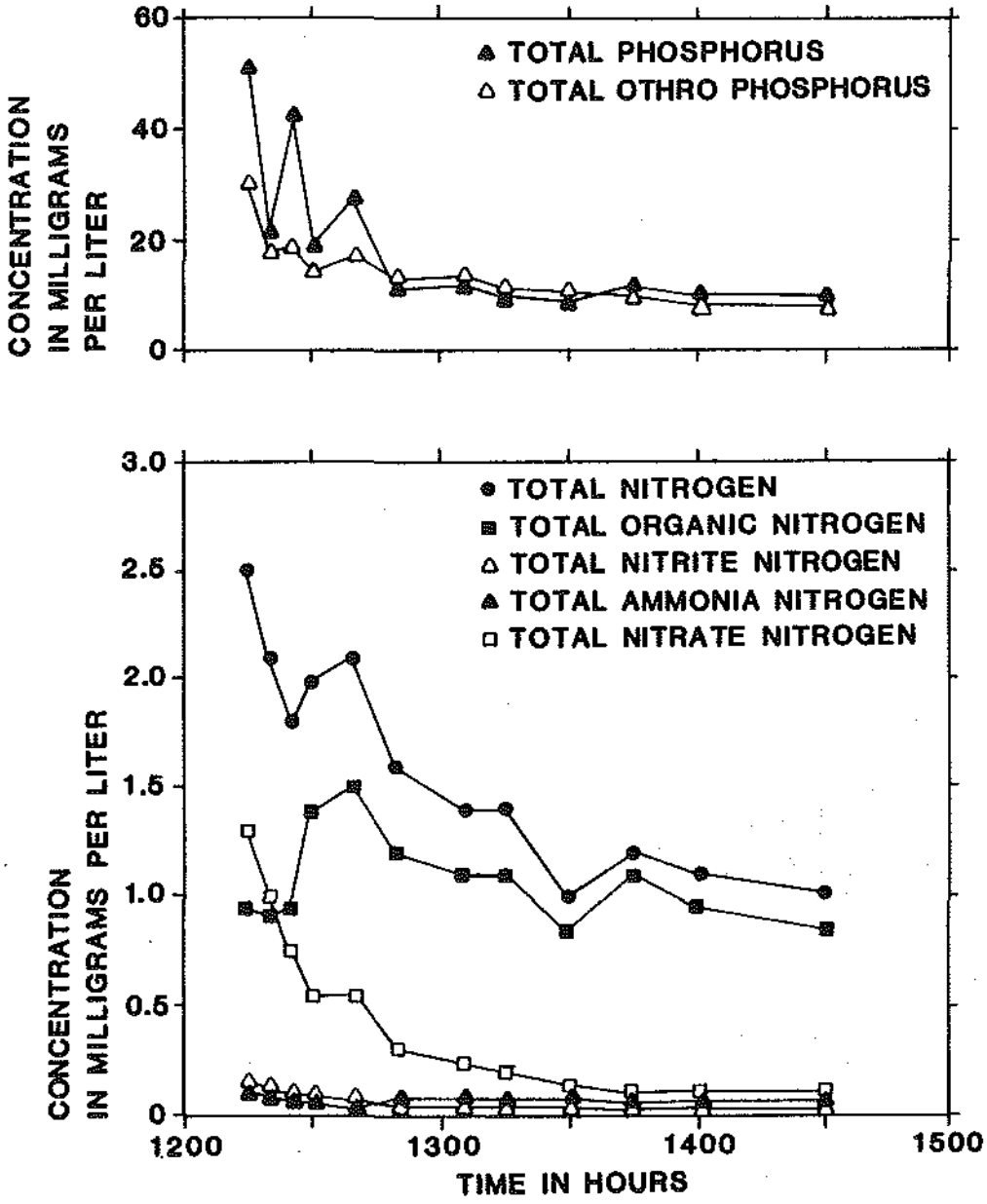

Figure 5. Variation in concentrations of nitrogen and phosphorous species at Arctic Street on August 1, 1978.

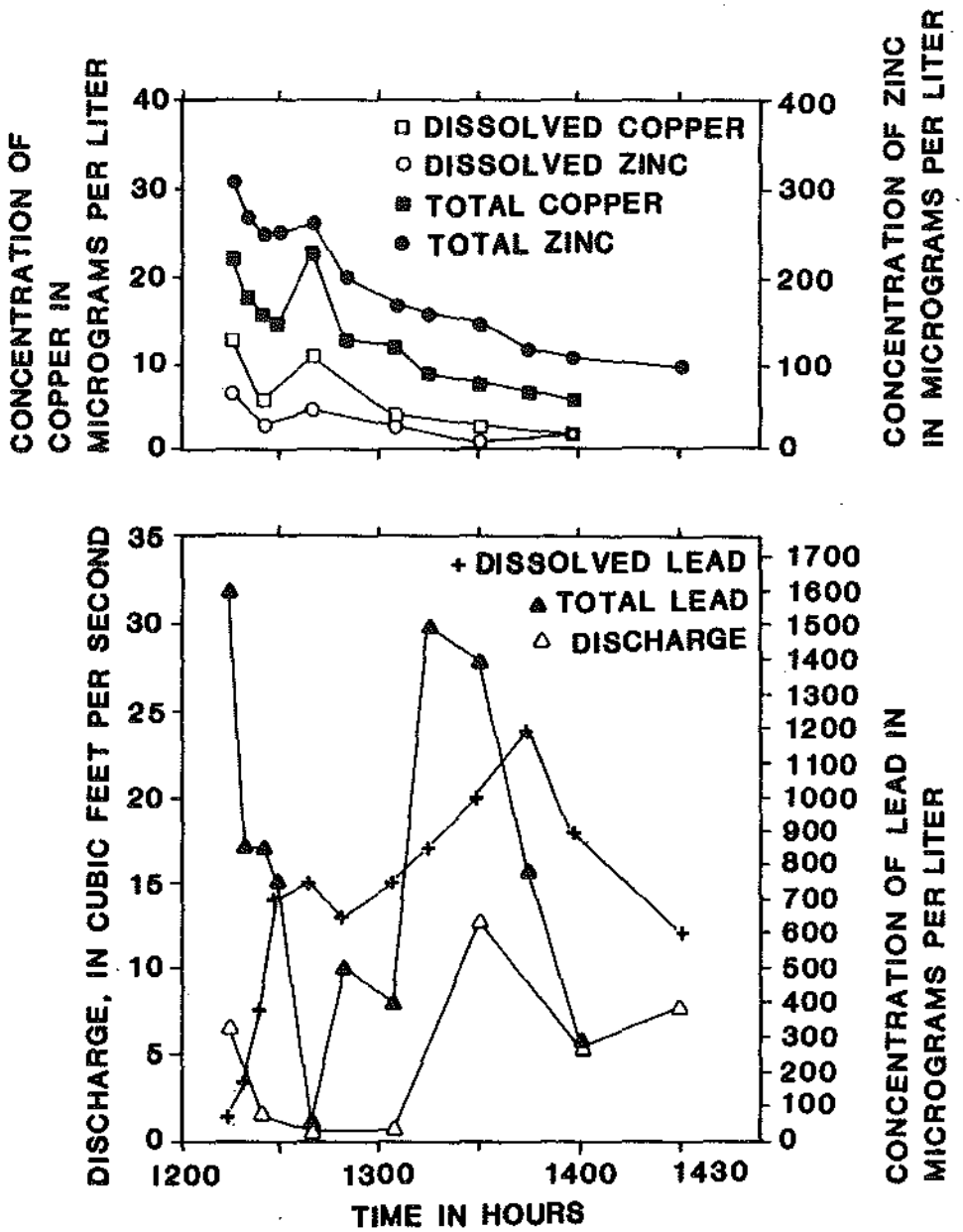

Figure 6. Variation in concentrations of total and dissolved lead, zinc, and copper at Arctic Street on August 1, 1978.

of the storms and at periodic intervals throughout the storm events. Arctic Street basin (Fig. 3) exhibited a first-flush type characteristic with high concentrations at the beginning of the storm and decreasing concentrations as the storm progressed. Initial concentrations were generally twice as large as concentrations on the recession portion of the runoff hydrograph. Concentrations at the Allen Creek basin were directly related to discharge, Figure 4. For this station, peak concentration corresponded to peak discharge and was generally twice the initial concentrations.

Concentrations of nitrogen and phosphorus for a storm event at the Arctic Street basin are shown in Figure 5. Nitrogen may be present in urban storm runoff in the following forms: organic, ammonia, nitrate, and nitrite nitrogen. Organic nitrogen accounts for nearly all of the nitrogen present in runoff, whereas concentrations of ammonia and nitrite nitrogen were negligible. Phosphorus is presented by total and orthophosphorus. Concentrations of orthophosphorus comprise nearly all of the total phosphorus at the Arctic Street basin.

Variations in concentrations of total and dissolved lead, zinc, and copper for a storm at the Arctic Street basin are shown in Figure 6. Trace metals selected in order of decreasing concentration were lead, zinc, and copper. Concentrations of arsenic and mercury were negligible for most storms sampled; therefore, these metals were not presented. Flushing characteristics for trace metals were very similar to those of organics and nutrients; Arctic Street experienced first-flush effects with most concentrations being higher at the beginning of the storm than at the end. Lead concentrations in the Arctic Street basin were generally 8 to 10 times greater than those found in the other basins. A large four-lane road that runs the length of the basin and two shopping-mall parking lots are the main sources of lead in the Arctic Street basin. In most cases, dissolved concentrations were about 50% or less of the total concentrations of trace metals.

The second phase of the water quality analysis consisted of developing equations for estimating storm loads discharged from urban watersheds. A multiple linear-regression analysis was used to relate measured storm loads for selected constituents to runoff volume, watershed and precipitation characteristics. In addition, equations were developed to predict storm-runoff volumes and base-flow from urban areas as a function of rainfall and watershed characteristics. These equations and the storm-load equations were then used to estimate pollutant loads from gaged and ungaged watersheds in the Tampa Bay area. More detailed discussions on data and methods of analysis are available in the final reports.

This information produced by the USGS enables estimates to be made on the quantity and quality of stormwater being generated from urban areas. In order to assess the water quality impact of stormwater runoff on receiving waters, it is essential to identify other main sources of pollution and estimate their magnitude in relation to stormwater. This type of analysis was performed for a small segment of the Tampa Bay system as part of a study being conducted by the City of Tampa.

The City of Tampa is participating in the Nationwide Urban Runoff Program (NURP), a program established by the U.S. Environmental Protection Agency for the purpose of developing the knowledge needed to control water pollution from stormwater runoff. Tampa is one of 28 prototype projects around the country which will attempt to identify stormwater-related pollution problems and evaluate performance, efficiency and cost effectiveness of known control methods for pollutant reduction. In addition, the City is trying to determine the types and levels of effects that stormwater runoff has on receiving waters. The goal of Phase I was to compile existing data and identify the relative magnitude and impact of non-point source pollution in three

receiving bodies of water adjacent to the City of Tampa.

The urbanized portions of Tampa, Temple Terrace, and unincorporated Hillsborough County which drain to the Hillsborough River below the Fowler Avenue bridge, or drain directly to Hillsborough Bay, comprise the study area for the purpose of urban runoff characterization. This area has been divided into three drainage areas for purposes of analyzing runoff flows and loads (Fig. 7). The individual flows and loads of the three major drainage areas can be combined to estimate the characteristics of the runoff generated by the entire Tampa urban area.

In order to perform an evaluation of the water quality impacts related to different sources, each individual source must be quantified in terms of flow (rate and volume) and load (pounds/time). The principal sources contributing inputs to the Tampa study area receiving waters are: rivers (Hillsborough River and Alafia River); point source discharges (municipal and private); and non-point sources (urban runoff). Each of these sources was individually evaluated in terms of wet weather inputs to various river segments and to the Hillsborough Bay system. The method used to quantify flows and pollution loads from each source is described as follows:

1. Urban stormwater runoff was quantified using regression equations developed on a preliminary basis by the USGS based on data collected between 1975 and 1979 in the nine urban basins in the Tampa - St. Petersburg area.

2. Point sources were quantified based on compliance monitoring data, when available, and state and federal discharge permit information.

3. River flows were quantified by using flow and water quality data from USGS and county gaging and sampling stations and adjusted to different locations, when needed, based on a ratio of drainage areas.

These methods were used to estimate flows and pollution loads for two different time periods. The selection of a given time period is important because stormwater runoff occurs intermittently and other sources normally occur continuously so that changing the time period can change the relative importance of each source. A longer term period of one month was selected to cover several storms and reflect the accumulative impact of runoff with respect to other continuous sources. A second time period of several days was selected to cover a single storm and reflect the impact of short term loadings. Each of these two time periods was quantified during the wet season (July - October) and during the dry season (November - June). A typical month during each season was selected based on a review of 40 years of rainfall records. The individual storm selected to compare short term impact consisted of approximately 2.0 inches of rain which would occur about once per year in one hour.

The loading distribution by source is summarized in Table 3 for the one month period, and in Table 4 for the single storm period. As expected, the shorter time frame shows the largest impact. Stormwater runoff can contribute as much as 65-70% of the BOD_5 and suspended solids in the lower River during the dry season. A somewhat lesser impact is shown for the Hillsborough Reservoir and Bay. For the longer time period of one month, the same trends occur with urban runoff contributing as much as 40% of the BOD_5 and suspended solids in the lower River. The loading distribution shown in Tables 3 and 4 indicate that urban runoff can contribute a significant portion of selected pollutants to the receiving waters of the area.

The research type works discussed in the paper represent, in the authors' opinion, the most significant investigations on stormwater runoff in the Tampa Bay area to date. However, other information is available both as

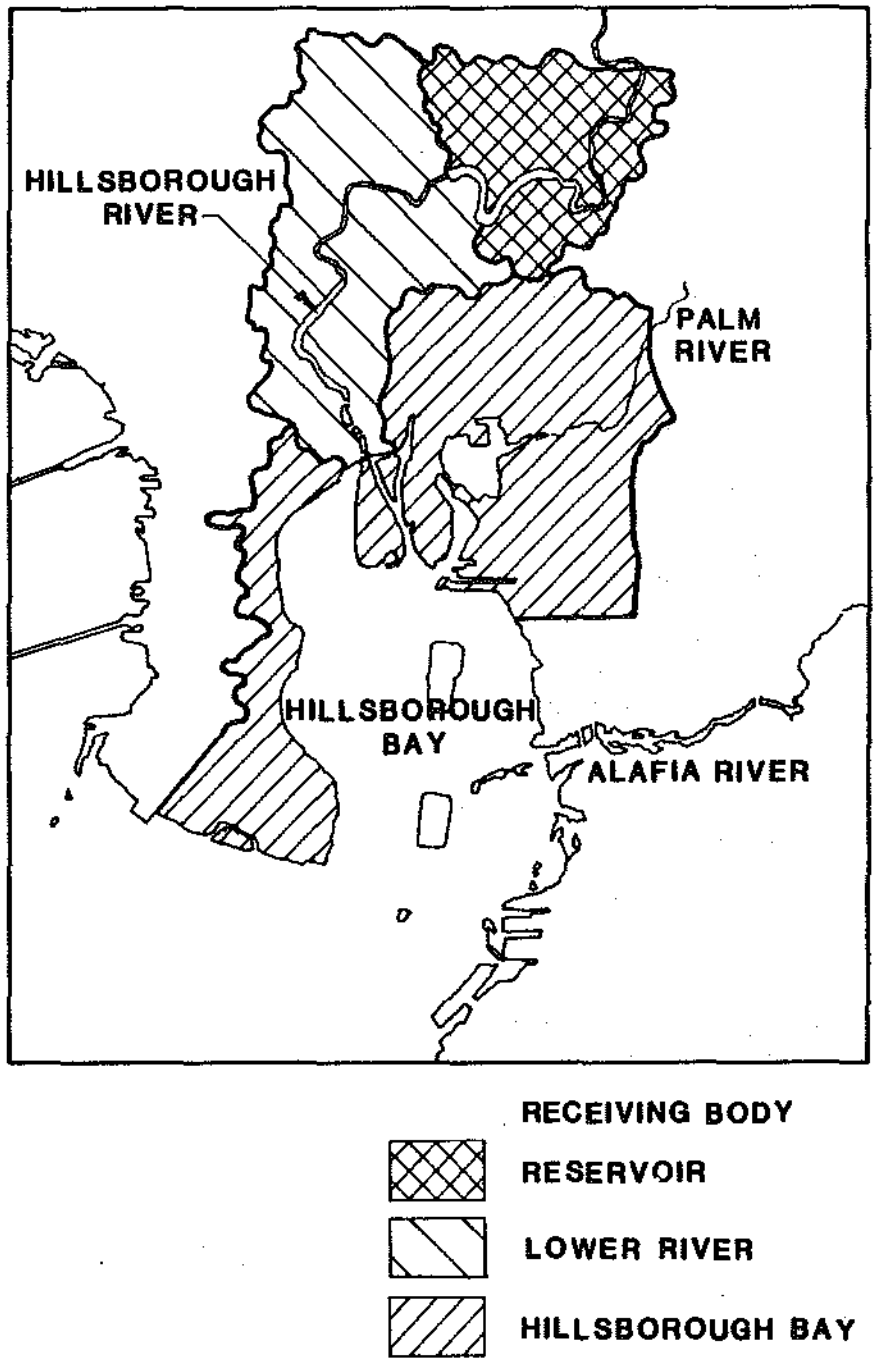

Figure 7. Urban areas tributary to three receiving bodies of water used in Tampa NURP study.

Table 3. Estimated monthly pollutant loadings to each receiving water body by source.

Receiving water segment	Pollutant	Percent of total monthly pollution load by source: URBAN RUNOFF[1] dry month	URBAN RUNOFF[1] wet month	RIVER FLOWS[2] dry month	RIVER FLOWS[2] wet month	POINT SOURCES[3] dry month	POINT SOURCES[3] wet month
Hillsborough Bay	Biochemical Oxygen Demand	10	5	65	80	25	15
	Suspended Solids	5	5	75	90	20	5
	Total Nitrogen	5	5	70	90	25	5
	Total Phosphorus	1	1	75	90	25	10
Lower Hillsborough River	Biochemical Oxygen Demand	35	25	65	75	0	
	Suspended Solids	40	20	60	80	0	
	Total Nitrogen	35	25	65	75	0	
	Total Phosphorus	10	5	90	95	0	
Hillsborough Reservoir	Biochemical Oxygen Demand	20	15	80	85	0	
	Suspended Solids	15	15	85	85	0	
	Total Nitrogen	15	15	85	85	0	
	Total Phosphorus	5	5	95	95	0	

[1]Urban runoff represents pollution loads from the urban areas adjacent to the water bodies.
[2]River flows represent pollution loads from the Hillsborough, Alafia and Palm Rivers.
[3]Point sources represent those discharging directly to the water bodies.

Table 4. Estimated short term pollutant loadings to each receiving water body by source.

Receiving water segment	Pollutant	Percent of short term pollution load by source: URBAN RUNOFF[1] dry season	URBAN RUNOFF[1] wet season	RIVER FLOWS[2] dry season	RIVER FLOWS[2] wet season	POINT SOURCES[3] dry season	POINT SOURCES[3] wet season
Hillsborough Bay	Biochemical Oxygen Demand	25	15	45	70	30	15
	Suspended Solids	35	20	50	70	15	10
	Total Nitrogen	15	10	50	75	35	15
	Total Phosphorus	5	1	65	80	30	20
Lower Hillsborough River	Biochemical Oxygen Demand	70	40	30	60	0	
	Suspended Solids	65	20	35	80	0	
	Total Nitrogen	55	25	45	75	0	
	Total Phosphorus	25	10	75	90	0	
Hillsborough Reservoir	Biochemical Oxygen Demand	55	30	45	70	0	
	Suspended Solids	50	30	50	70	0	
	Total Nitrogen	25	15	75	85	0	
	Total Phosphorus	15	5	85	95	0	

[1]Urban runoff represents pollution loads from the urban areas adjacent to the water bodies.
[2]River flows represent pollution loads from the Hillsborough, Alafia and Palm Rivers.
[3]Point sources represent those discharging directly to the water bodies.

research and in other forms which cannot be addressed in this type of proceedings.

FUTURE PROJECTIONS

Due to the changing attitudes by regulatory agencies on arbitrarily setting effluent standards or water quality criteria, there appears to be a move toward waste load allocations for receiving bodies of water. This is illustrated by the repeal of the 1972 Wilson Grizzle Bill (Section 403.086(1)b, Florida Statutes), which originally required advanced wastewater treatment for all discharges into surface waters of the west-central portion of Florida. Since this bill's repeal in 1981, requirements are that waste load allocations be specified on a case-by-case basis for point source discharges. At the time of its repeal, a survey was also required by the legislature on the impact of existing non-point sources discharging into the waters of the original Wilson Grizzle area (FDER 1982). This being the case, there will be needs and opportunities to collect and analyze new and existing data on the magnitudes and interrelations of point and non-point source pollution in the Tampa Bay area.

In addition, with the advent of the new stormwater rule (Chapter 17-25, FAC), each new stormwater discharge will require some type treatment system to be included. Although there is some information available as to the extent of pollution and efficiencies of control practices, there is a need to develop more detailed data on existing controls and develop new methods for efficiently controlling stormwater pollution.

The City of Tampa is currently conducting studies which will develop some of the types of information previously described. The objectives of the three studies are as follows:

1. Runoff Characterization (NURP):
   a. determine the types and levels of pollutants associated with stormwater runoff; and
   b. investigate the effectiveness of selected control measures in reducing pollutant loads.

2. Receiving Water Study (Lower Hillsborough River):
   a. determine the existing receiving body water quality;
   b. determine the effects of stormwater runoff on water quality; and
   c. predict receiving water reaction to reduced pollutant loads.

3. Biological Study (Lower Hillsborough River):
   a. assess the impact of stormwater runoff on the biological community of the lower river; and
   b. identify areas that can be used to minimize the effect of stormwater runoff.

SUMMARY AND CONCLUSIONS

All of the previous studies and assessments have identified urban runoff as a source of pollution in the Tampa Bay area. There is a recognized need to develop better understanding of the problems and possible solutions associated with urban stormwater runoff. There have been studies done ranging from delineation of flood prone areas to the quantification of the types and levels of pollution in storm water.

The existing data base used to identify water quality problems was not collected specifically to define the role of urban stormwater runoff and is not adequate to establish a cause and effect relationship between urban runoff and water quality. The receiving water data consists primarily of single samples taken throughout the receiving water system on an irregular basis. It is not clear from this data to what extent urban runoff contributes to water quality problems when compared to other sources of pollution such as river flows and point sources. Existing data needs to be supplemented by programs which are designed to specifically relate stormwater and receiving water quality.

Environmental protection and the solving of urban drainage problems are two issues which must be dealt with concurrently, since water quality and

quantity cannot be separated. Although urban stormwater runoff is thought of as the largest contributor to non-point source water pollution, it has not been quantified. Shock loading (the introduction of mass quantities of oxygen demanding, heavy metals, and other deleterious substances following heavy rainfall) is a known problem, but the actual extent of the damage is unclear. Also, there are no specific limits which define acceptable short term water quality conditions which could result from urban runoff loading. State standards generally address steady state long term conditions. Therefore, it is important to consider the amount of stress a water body can tolerate for short time periods while still maintaining acceptable conditions. It may be acceptable to violate state standards for short periods due to urban runoff and not impair intended water uses. One approach to this issue is to describe the type of biological community which would be expected in a natural unpolluted environment and to tailor pollution reductions to achieve a water quality environment which can support such a community.

Another problem is that of overlapping stormwater management responsibilities, that is, when various agencies have control over, and place emphasis upon a different aspect of water quantity and quality. Many times the goal of one agency (or interpretation of community goals) may be in direct conflict with the policies of another agency. For example, while a city may be primarily concerned with the rapid disposal of water from city streets and public and private property, and the quantity and quality of water entering the city, the Hillsborough County Environmental Protection Commission and the Florida Department of Environmental Regulation are primarily concerned that water quality of the receiving body of water will not be adversely impacted. While the Southwest Florida Water Management District is concerned with flood control, it is also concerned with water quality and the use or reuse of flood waters. The real issue arises when these competing needs and interests initiate projects which are not coordinated, and in some cases, are in conflict with the programs of other agencies.

Finally, there is a need in the Tampa Bay area to develop a comprehensive management plan to deal with both the quantity and quality aspects of stormwater runoff. Such a plan would address existing water quality problems, support the local governments' efforts to deal with flooding problems in an environmentally sound manner, and satisfy state requirements for stormwater permits and water quality criteria.

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IMPACT OF THE PHOSPHATE INDUSTRY ON TAMPA BAY, FLORIDA

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ABSTRACT

The phosphate industry has had numerous impacts on Tampa Bay, including direct perturbations caused by accidental losses of wastes from mining areas inland, and disposal of wastes from mines and chemical plants inland and on the bay shore. Past direct perturbations of the bay by the phosphate industry include: spills of clay wastes from phosphate ore beneficiation systems into the Alafia River; release of effluents enriched in fluorides, acid, and heat from chemical plants near the mouth of the Alafia River and at Port Manatee; loss of habitat in nearshore and intertidal areas to industrial uses; and disposal of gypsum wastes in the bay. Indirect effects of the industry on the bay include incentives for development of coastal areas from product transshipment and energy production, and expansion of port facilities. Barring unforeseen accidents, the industry's direct impact on the bay is minimal compared to ten years ago. Regulation of the industry and increased technological capabilities have minimized these perturbations of the bay system. The effects of earlier industrial activities and of indirect impacts may be significant in some areas. Where mitigation attempts have been made and the results studied, recovery of bay environments after perturbation ceases seems to be relatively rapid.

NATURAL RADIONUCLIDES IN TAMPA BAY, FLORIDA

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ABSTRACT

Miocene strata that crop out throughout the drainage basin of Tampa Bay contain abundant phosphate. The phosphate mineral, carbonate fluorapatite, contains trace quantities of uranium. This uranium and its daughters are ubiquitous in the area and are redistributed and concentrated by natural and cultural means. Although there is ample reason to suspect that uranium and its daughters are present in Bay sediments, water, and biota, little work has been done to determine sources, pathways and sinks of these isotopes in the Bay. Natural sources of uranium and the principal daughter of concern, radium, include streams, ground water and Bay sediments. Phosphatic strata are eroded by streams and phosphatic minerals and soluble radionuclides are transported to the Bay. In addition, ground water transports soluble radionuclides into the Bay and uranium-bearing, detrital phosphate minerals in the Bay can release small quantities of radiation to the water column and biota. Cultural sources include release of uranium and radium to the Bay and its tributaries through phosphate mining and processing. Radium levels in ground water may also be elevated as salt water intrudes clay-rich portions of the coastal aquifer system.

Much emphasis has been placed on radium in ground and surface waters tributary to the Bay and at least two studies have addressed radium uptake in aquatic organisms in Bay tributaries. There are only three studies of note that deal with radiation in the Bay itself. Scientists at the University of South Florida Marine Science Department are studying radium in water and plankton in the Bay and adjacent Gulf. The late M. I. Kaufman, while at Florida State University, studied uranium flux to the Bay in the Alafia River. Our group is studying the impact of inputs from natural and industrial sources on Bay tributaries and adjacent portions of the Bay. Results of these studies indicate that radium is accumulating in bottom sediments and biota of the Bay. Radium activities in Bay water and biota are relatively high in comparison with other estuaries. Additional research is needed as to the fate of uranium and its daughters in the Bay and the long-term effects of chronic exposure of biota in the Bay to low levels of ionizing radiation.

INTRODUCTION

Radioactive isotopes are of general concern because they are known to cause a number of health-related problems in humans and may debilitate the ecosystem. Both natural and artificial radionuclides are of concern. Nationally, the artificial radionuclides produced by nuclear reactors and by weapons testing are of greatest interest. This is because they are widespread if introduced to atmospheric or hydrologic cycles and because disposal is difficult. There are relatively few areas in the country where naturally-occurring radionuclides are of prime concern. These areas include

regions where granitic rocks are exposed; where coal, petroleum, and other organic deposits are extracted; or where uranium is exposed, mined, or milled.

Florida falls into the latter category. Artificial radionuclides are widely dispersed throughout Florida and there are several reactors that deal with these materials. Major concern in the state, however, is with naturally-occurring radionuclides, such as uranium, radium, and radon. These radionuclides enter the food chain, are transported in ground and surface waters, and, as radon gas, enter enclosed structures as an atmospheric contaminant. The major concern with respect to Tampa Bay is that these natural radionuclides are present in sediments, the food chain, and water in the Bay. This paper summarizes present knowledge of naturally-occurring radiation in Tampa Bay, Florida.

SOURCE OF RADIATION

The ultimate source of the radioactive materials in Tampa Bay is sedimentation during the Neogene (Miocene, Pleocene, Pleistocene, and Holocene Epochs) in Florida. During this period, phosphate minerals were deposited throughout the state. Phosphatic sediments were originally deposited during the Miocene in marine and perimarine environments. Later leaching and reprecipitation, exposure by erosion, and reworking in coastal and fluvial environments have made phosphatic materials widespread in most environments around the Bay. Phosphatic sediments are exposed and some are mined in the drainage basins of the Hillsborough, Alafia, Little Manatee, and Manatee Rivers. More recent sediments in the Bay also contain reworked phosphate. See the papers by Doyle and Campbell in this volume for references and descriptions of these phosphatic materials.

The phosphatic minerals exposed in this area are complex in their mineralogy and origin. The primary mineral, and the ore mined in the central Florida phosphate district, is carbonate fluorapatite or francolite, $Ca_5(PO_4CO_3)_3F$. Other phosphate minerals that occur in the area include:

- vivianite, $Fe_3^{+2}(PO_4)_2 \cdot 8H_2O$
- wavellite, $Al_3(PO_4)_2(OH)_3 \cdot 5H_2O$
- crandallite, $CaAl_3(PO_4)_2(OH)_5 \cdot H_2O$
- millisite, $(NaK)CaAl_6(PO_4)_4(OH)_9 \cdot 3H_2O$

Wavellite, crandallite, and millisite are concentrated at the top of the phosphatic ore section and are a product of leaching of the francolite (Althschuler et al. 1956). Carbonate fluorapatite and its weathering products contain uranium and thorium in trace quantities. The actual mode of incorporation of these elements in the phosphatic minerals is not clearly known, but they may be substituted for calcium in the francolite (Altschuler et al. 1958).

Guimond and Windham (1975) have summarized the distributions of radioactive materials in phosphate ore and the partitioning of those radionuclides during mining, beneficiation, and chemical processing. It is interesting to note that they found that in 1973 the U.S. uranium mining industry processed 6.77×10^6 tons of ore with 3,550 Curies of radium-226, a major daughter of uranium-238. In the same period, the phosphate mining industry, which produced 91% of its ore from Florida, handled 139.7×10^6 tons of ore and 4,860 Curies of radium-226. Thus, uranium and its daughters are important components of the phosphatic sediments of the region and, regardless of source or means of mobilization, readily available to Tampa Bay through exposures in the Bay and on its shores, runoff, ground-water inflow, and industrial effluent.

Other sources of uranium and thorium are suspected, but have not been investigated. These include sorbed ions on clays and complexed ions on organics. We are beginning an investigation of these alternate sources at the present time.

Although uranium-235, uranium-238, and thorium-232 are all present in Florida rocks and water, only uranium-238 and its daughters are of immediate concern. Guimond and Windham (1975) investigated the abundances of the three

parent elements in phosphate rock and found that average phosphate ore contains 1.9 pCi/g (picoCuries/gram) uranium-235, 41 pCi/g uranium-238, and 0.44 pCi/g thorium-232. Thus, approximately 95 percent of the radioactive parent material in phosphate is uranium-238.

Table 1 shows the decay series of these three parent isotopes. It is clear from these decay series and the relative abundances of the parent isotopes that only a few daughter isotopes are of prime importance. Radium-226, which has a moderate half life and is chemically similar to calcium, is the major isotope of concern. This is because it can substitute for calcium in calcified tissues (bones, shells, carapaces, etc.) and cause various carcinomas. Radon-222 is a gas and, although present in most environments, it is only of concern in enclosed environments where the gas cannot escape. Thus, it is important to human health if encountered in enclosed structures and may be of importance to infaunal elements of terrestrial and aquatic ecosystems. Other radioisotopes in the three decay series rarely show up in analytical procedures because they have short half lives or are present in quantities below detectable limits.

NATURAL RADIOISOTOPES IN TAMPA BAY

There has been very little work on radiation in Tampa Bay. This has been in part due to a failure to perceive any problems in the Bay and in part failure of funding institutions to support studies in this politically and economically sensitive area.

Water. Most of the studies that are applicable to the Bay involve radiation in water bodies adjacent to the Bay. This is because primary concern has been exposure of humans to potable water. Most of these analyses are of ground water, since ground water is a major water source in the area and has been shown to contain locally elevated radium-226 activities. Relatively little work has been done on surface water outside of the immediate area of phosphate mining, where radium activities are closely monitored.

There are two ground-water problem areas that have been identified: 1) phosphate mining areas where disruption of rock bodies, ore beneficiation, and chemical processing may cause radium-226 activities to be elevated in surface and ground waters; and 2) coastal aquifer systems, where radium-226 activities appear to be elevated because of mixing with salt water.

All companies in the mining district monitor radium-226 and gross alpha activities in surface and groundwater systems. These data are submitted to the Southwest Florida Water Management District on a regular basis and are available for inspection there. The numerous industry Development of Regional Impact applications contain additional data on radium in the mining district. Upchurch et al. (1979) and Upchurch and Kaufman (1979) conducted a study of the radium-226 content and general water quality in surface and ground waters in one mine in the Alafia River watershed. They concluded that, although local problems exist, there was no impact on ground water outside of the mine site. This conclusion is in general agreement with the conclusions of other, less comprehensive studies and with the E.P.A.'s Areawide Impact Study (Texas Instruments, Inc. 1978). Thus, we do not feel that radioactivity in ground-water in Bay headwaters needs additional comment.

Because there is a commonly-held, popular perception that the phosphate industry is responsible for all radioactivity in ground water, Kaufman and Bliss (1977, 1978) compared the levels of radium-226 in coastal waters with those in the phosphate mining district. Although radium-226 activities are elevated in both situations, they concluded that there is no relationship between mining and enrichment of coastal waters in radium. They concluded that the elevated radium-226

Table 1. Simplified decay series for uranium-235, uranium-238, and thorium-232.

Isotope	Radiation of Decay	Half Life
Uranium-235 (Actinium) Decay Series		
Uranium-235	alpha, gamma	7.07×10^{8} yrs
Thorium-231	beta, gamma	25.6 hrs
Protactinium-231	alpha	3.25×10^{4} yrs
Actinium-227	beta, gamma (98.8% to thorium-227); alpha, gamma (1.2% to francium-223)	21.7 yrs
Thorium-227	alpha, gamma	18.2 days
or		
Francium-223	beta, gamma	21 min
Radium-223	alpha, gamma	11.7 days
Radon-219	alpha, gamma	3.92 sec
Polonium-215	alpha	1.83×10^{-3} sec
Lead-211	beta, gamma	36.1 min
Bismuth-211	alpha, gamma	2.16 min
Thallium-207	beta, gamma	4.76 min
Lead-207	none	stable
Uranium-238 Decay Series		
Uranium-238	alpha	4.51×10^{9} yrs
Thorium-234	beta, gamma	24.1 days
Protactinium-234	beta, gamma	1.17 min
Uranium-234	alpha, gamma	2.48×10^{5} yrs
Thorium-230	alpha, gamma	7.5×10^{4} yrs
Radium-226	alpha, gamma	1.62×10^{3} yrs
Radon-222	alpha, gamma	3.82 days
Polonium-218	alpha	3.05 min
Lead-214	beta, gamma	26.8 min
Bismuth-214	beta, gamma	19.7 min
Polonium-214	alpha, gamma	1.5×10^{-4} sec
Lead-210	beta, gamma	19.4 yrs
Bismuth-210	beta	5.0 days
Polonium-210	alpha, gamma	138.4 days
Lead-206	none	stable
Thorium-232 Decay Series		
Thorium-232	alpha	1.39×10^{10} yrs
Radium-228	beta	6.7 yrs
Actinium-228	beta, gamma	6.13 hrs
Thorium-228	alpha, gamma	1.90 yrs
Radium-224	alpha, gamma	3.64 days
Radon-220	alpha, gamma	54.5 sec
Polonium-216	alpha	0.16 sec
Lead-212	beta, gamma	10.6 hrs

Table 1. continued

Isotope	Radiation of Decay	Half Life
(Thorium-232 Decay Series)		
↓ Bismuth-212	alpha, gamma (33.7% to thallium-208); beta, gamma (66.3% to polonium-212)	60.5 min
Polonium-212	alpha	3×10^{-7} sec
or Thallium-208	beta, gamma	3.1 min
Lead-208	none	stable

activities in coastal ground waters may be a result of 1) maturation of ground waters after movement along long flow paths and interaction with aquifer rocks, 2) partial dissolution of phosphatic sediments where sea water and ground water are mixed, or 3) displacement of sorbed radium from clay-rich sediments in the aquifer system.

There are no known published radionuclide analyses in ground waters discharging directly to Tampa Bay. The data of Kaufman and Bliss (1977, 1978) and Sutcliffe and Miller (1981) for coastal waters of Sarasota and Manatee Counties are the best available to show the potential radionuclide content of coastal ground waters near Tampa Bay. Kaufman and Bliss (1977) found an average of 20.8 pCi/l radium-226 in the water table aquifer near the coast. The geometric mean of Floridan aquifer samples from Sarasota County, including coastal environments, was 7.5 pCi/l. All coastal, water-table aquifer samples exceeded E.P.A. recommended maximum criteria of 5 pCi/l radium-226 and 70% of Floridan aquifer samples exceeded this value. Similar results were found by Sutcliffe and Miller (1981). Thus, there is good reason to expect, but little evidence to substantiate, that ground water flowing into the Bay may be enriched in radium-226.

Surface water is generally lower in radium-226 activity than ground water. This is a result of 1) dilution and 2) sorption of radionuclides on clays and organics suspended in the water column and on the bottom of area streams and lakes. Table 2 gives the results of radium-226 analyses of surface waters that are tributary to Tampa Bay. Clearly, radium activities in surface water are significantly lower than ground water. None of the samples reported exceed the E.P.A. criteria for drinking water.

These radium activities for surface water should not be interpreted to indicate that there in no problem in surface waters tributary to the Bay. These samples are insufficient for categorical conclusions. Radium activities vary with stream discharge, turbidity, biological activity, tidal stage, and other factors.

Table 2 indicates that an average of about 30 percent of the total radium-226 in tributary streams is bound in some form on particulates. In other estuaries it has been shown that sorbed radium is released to the water column from particulates upon entering the mixing zone. For example, Elsinger and Moore (1980) found that, in the Pee Dee River - Winyah Bay estuary system, desorption of radium effectively increased the dissolved radium load in the mixing zone of the estuary. The zone of desorption is broad and dependent on discharge. During average discharge conditions, the

2. Radium-226 contents of streams tributary to Tampa Bay, Florida.

Location of sample (References)	Filtered (pCi/l)	Unfiltered (pCi/l)
Hillsborough River		
Cypress Creek at SR 52, Pasco County (Upchurch et al. 1981; in press.)	0.57 ±0.05[1]	0.47 ±0.05[3]
Alafia River		
Lithia Springs near Lithia (Irwin and Hutchinson 1976; Kaufman and Bliss 1977)	0.68 ±0.07[1]	0.80 ±0.08[2]
Alafia River at Lithia (Irwin and Hutchinson 1976; Kaufman and Bliss 1977)	0.06 ±0.01[1]	0.53 ±0.05[2]
Alafia River at Lithia (Upchurch et al. 1981; in press)	1.44 ±0.10[1]	1.63 ±0.11[3]
Little Manatee River		
Tributary streams in Four Corners Mine tract, average of 18 samples (Morton 1977)	0.18[4]	---
10 km upstream from mouth (Fanning et al. 1982)	---	0.83[3]
Manatee River		
Sullivan's Bridge, Lake Manatee surface water (Johnson 1975)	0.32 ±0.02[4]	0.34 ±0.05[5]
Manatee County Utility System raw water from Lake Manatee (Johnson 1975)	0.04 ±0.00[4]	0.05 ±0.01[5]
Head, Lake Manatee (Upchurch et al. 1981; in press)	0.40 ±0.04[1]	1.07 ±0.08[3]

[1]Filtered, raw water
[2]Acidified and then filtered water
[3]Unfiltered, raw water
[4]Method of preparation unknown
[5]Obtained by adding activity of filtered water and activity of solids removed by filtration.

dissoved radium activity reaches a maximum at 15 to 25°/oo salinity, while during high discharge events the maximum is not reached until normal marine salinites are reached. Thus, it can be expected that, as tributary water enters Tampa Bay, sorbed radium is released to the water column, where it is either dispersed, metabolized, or resorbed.

Kaufman (unpublished data presented in Osmond and Cowart 1976) studied uranium as a function of salinity in the Alafia River. Osmond and Cowart (1976) interpret Kaufman's data to indicate that uranium is conservative, or soluble, in the river from salinities of 0 to approximately 14°/oo. Uranium concentrations increase linearly seaward from about 0.4 ppb to 1.5 ppb. At the mouth of the river, uranium peaks at about 5.5 ppb and 21°/oo salinity. This peak is attributed by Osmond and Cowart to uranium releases by the Gardinier Inc. phosphate chemical plant at the mouth of the river. In the Bay, uranium concentrations decline in a non-linear fashion to normal salinities where uranium concentrations are about 2.4-2.5 ppb. This non-linear decline is interpreted by Osmond and Cowart (1976) to reflect accumulation of uranium in sediments of the Bay. The shape of Kaufman's salinity vs. uranium concentration curve is much more peaked than the desorption curves shown by Elsinger and Moore (1980), but desorption of uranium may also be taking place at the mouth of the river.

Water in Tampa Bay also varies in radium activity with tide state, tributary discharge, turbidity, and biological activity. There are relatively few analyses of radium in Bay water and these are insufficient for adequate characterization of the Bay. Table 3 lists radium-226 and radon-222 analyses available for the Bay and nearby Gulf of Mexico waters. There are several clear trends in these data that point to significant contributions of radium from tributary waters. Water in Hillsborough Bay, which receives most of the tributary runoff to the Bay, averages 1.71 pCi/l radium-226 ($n=8, \sigma=0.42$). This average is high compared to the remainder of the Bay and the Gulf of Mexico (Table 3), and is equal to the highest activities recorded in the Alafia River (Table 2). There are several possible explanations for these high radium values in Hillsborough Bay. First, the data are compatable with the conclusions of Osmond and Cowart's (1976) observations on Kaufman's uranium data and may reflect releases from the Gardinier, Inc. chemical plant at the mouth of the Alafia River. Second, the elevated radium-226 activities in Hillsborough Bay were determined from water samples filtered at 0.45u. This indicates that the radium is soluble in these estuarine waters, in which case the Bay radium activities are much higher than those observed in any tributary. Desorption from clays (Elsinger and Moore 1980) at the salt water mixing zone may account for these high activities. Finally, the values in Hillsborough Bay are roughly comparable with those observed in coastal ground waters of Manatee and Sarasota Counties (Kaufmann and Bliss 1977, 1978; Sutcliffe and Miller 1981) and may represent localized discharge of ground water into the Bay. There is a clear need for resolution of these sources in order to manage Bay water quality.

The remainder of Tampa Bay (Table 3) averages 0.78 pCi/l radium-226 ($n=7, \sigma=0.45$) and the Gulf of Mexico near Tampa Bay averages 0.13 pCi/l radium-226 ($n=10, \sigma=0.10$). This trend is consistent with mixing of the Bay and Gulf water and does not indicate any other significant sources of radium in the system.

Fanning et al. (1982) described the relationship of radon-222 gas to radium-226 in Tampa Bay (Table 3). They found that radon gas contained in Bay waters is in excess of that expected from normal radioactive decay processes. Tampa Bay had an average excess of radon of 1.62 pCi/l ($n=7, \sigma=0.64$), while the Gulf of Mexico had an average excess of 0.01 pCi/l ($n=8, \sigma=0.08$; sample near Anna Maria Island deleted). Thus, excess

Table 3. Radium-226 and radon-222 activities in water of Tampa Bay and adjacent Gulf of Mexico.

Locality	Salinity	Radium-226 Activity (pCi/l)	Radon-222* Activity (pCi/l)	Source
Hillsborough Bay				
Range marker off	---	(T)**1.38 ± 0.07	---	1
Davis Island	---	(B)**1.94 ± 0.07	---	1
0.25 mi NW Gardinier	---	1.38 ± 0.07	---	1
Alafia Channel, 0.25 mi	---	(T) 1.25 ± 0.07	---	1
SW Gardinier	---	(B) 1.71 ± 0.07	---	1
	---	2.5	---	2
Range marker near	---	(T) 1.54 ± 0.07	---	1
Bullfrog Creek	---	(B) 2.00 ± 0.07	---	1
Tampa Bay				
Bayboro Harbor	26.26	0.96	1.79	3
Near Sunshine Skyway	31.94	0.47	1.57	3
Locality not specified	24.72	1.45	1.73	3
	27.51	1.12	0.89	3
	27.56	0.89	0.68	3
	32.94	0.29	2.41	3
	33.35	0.27	2.26	3
Gulf of Mexico				
Near Anna Maria Island	33.91	0.31	---	3
	34.00	0.30	1.65	3
Mid-shelf off Anna	36.21	(T) 0.10	-0.04	3
Maria Island	36.08	(B) 0.12	0.20	3
	36.28	(T) 0.09	-0.04	3
	36.25	(B) 0.12	-0.01	3
Outer continental shelf	36.21	(B) 0.05	-0.02	3
off Anna Maria Island	36.29	(B) 0.07	-0.02	3
	36.20	(T) 0.05	-0.01	3
	36.25	(B) 0.05	0.02	3

*Radon-222 gas present in excess (or deficit) over equilibrium with radium-226.
**(T) and (B) indicate samples taken from near the top or bottom of the water column, respectively.

Sources: 1 - Wahl 1980a, filtered samples; 2 - This study; previously unpublished, filtered samples; 3 - Fanning et al. 1982, unfiltered samples.

radon gas is being added to Bay water as compared to the Gulf of Mexico shelf waters, which are in approximate equilibrium with radium-226. They speculated that this excess radon gas was being derived from 1) phosphatic bottom sediments in the Bay, 2) tributaries, or 3) ground water.

Bottom Sediments. The only data on radioactivity in bottom sediments in the Bay are from Upchurch et al. (1976), Upchurch et al. (1982), and related, previously unpublished data. All of these samples (Table 4) are from the mouth of the Alafia River and immediately offshore from the outfalls of Gardinier, Inc. Therefore, these data are likely to be high in comparison with similar sediments elsewhere in the Bay.

During the 1960s and early 1970s Gardinier, Inc. discharged fluoride-rich waste waters to the Bay (Taft and Martin 1974; Martin and Taft 1975; Upchurch et al. 1976; Upchurch et al. 1982). This effluent built up small deltas immediately to the north and to the south of the gypsum waste disposal areas on the shore. In 1976 the southern delta had an area of 4 ha of solid crust and a total area of approximately 13 ha. The northern delta has a total area of approximately 7 ha, with a solid crust of 1 ha. Both deltas are composed of crusts and disseminated flakes of fluorite (CaF_2) and pachnolite ($NaCaAlF_6 \cdot H_2O$) in a matrix of quartz sand. Also disseminated throughout the deltas and adjacent sediments are flakes of gypsum ($CaSO_4 \cdot 2H_2O$) derived from wave erosion of sediments from an earlier delta that extended into the bay prior to storage of the gypsum wastes in the large area on shore. The fluorite and pachnolite deltas are being eroded by waves and portions are being buried under bay sands, so they are no longer well preserved.

The fluorite/pachnolite deltas contain as much as 809 pCi/g radium-226 and 128 pCi/g uranium-238 (Table 4). For comparison, marketable phosphate rock averages 42 pCi/g radium-226 and 41 pCi/g uranium-238 (Guimond and Windham 1975). Thus, the crusts at Gardinier, Inc. represent significant concentrations of radium and uranium. Gypsum and gypsiferous sands from the Bay near the plant contain minor radium-226 owing to co-precipitation with calcium. Sands (Table 4) are predominantly composed of quartz with minor admixed fluorite, pachnolite, and francolite. Radium contents of sands near the Gardinier plant are probably similar to those elsewhere in the Bay where natural francolite accumulations exist.

Biota. Considering the obvious presence of radium and other natural radionuclides in the Bay area, it is surprising that so few analyses of these isotopes have been made on tributary or bay organisms. At the present time, there are two on-going studies that relate to this problem. Fanning's group at the Department of Marine Science, University of South Florida, is in the early stages of investigating radium in plankton and certain macroinvertebrates in the Bay. Our group is involved in a continuing program to evaluate radium and other radionuclides in tributary organisms and in the zones of mixing in estuaries marginal to the Bay.

At the present time, the only available data are from our studies of the radium-226 from waters tributary to the Bay and at the mouth of the Alafia River. Upchurch et al. (1981; in press) studied the radium-226 content of portions of the food chain in the phosphate mining district. Our sampling plan was designed to test the hypothesis that mining activities are related to radium in the biota. Three different major environments were sampled. Control areas were chosen in Pasco County, where there is minimal exposure of phosphatic rock and no mining. Areas characterized by exposures of phosphatic rock but no mining were chosen in Manatee and Sarasota Counties to determine the natural radium contents of biota in phosphatic terranes. Unreclaimed and reclaimed phosphate mining areas were chosen to evaluate the impact of mining on radium in aquatic biota. One of the Pasco County sites is on Cypress Creek, a tributary of the

Table 4. Radium-226 and other radionuclides in sediments of Hillsborough Bay.

Locality	Radium-226 Activity (pCi/g)	Other nuclide activity (pCi/g)	Nuclide	Source
Fluorite/pachnolite crust, Gardinier north discharge point	156. 809.	--- 5.62 127.6	--- U-235 U-238	1 2,3
Fluorite/pachnolite crust, Gardinier south discharge point	20 24.0	--- 1.54 1.01 1.69	--- U-235 Th-232 K-40	1 2,3
Gypsum, Gardinier north discharge point	6.4*	---	---	1
Gypsum, Gardinier south discharge point	2.1*	---	---	1
Sand, offshore of Gardinier north discharge point	1.5 0.17	--- ---	--- ---	1 1
Sand, offshore of Gardinier south discharge point	2.9 1.8	--- ---	--- ---	1 1
Gypsiferous sand, near Gardinier gypsum disposal area	0.39*	---	---	1

*Radium activities may be low owing to analytical procedures used.
Sources: 1 - Upchurch et al. 1976; 2 - Upchurch et al. 1982; 3 - unpub. data.

Hillsborough River. The Manatee County sites include one in Lake Manatee, on the Manatee River. The phosphate mining areas included a site on the Alafia River at Lithia Springs, and several small streams and lakes on mined land that drain to the Alafia and/or Peace Rivers.

We (Upchurch et al. 1981; in press) found that radium-226 is concentrated in aquatic biota. Greatest radium activities were found in plants (Table 5) and radium content per unit mass declined up the food chain. Thus, there is no evidence of biomagnification in the food chain. We also found that the radium content of fish is at least partly a function of size of the individual. In Lepomis macrochirus (bluegill), radium content per unit weight increases linearly with weight in control area samples. A linear regression of the control samples predicted the radium content of bluegills from the phosphatic, but unmined terranes. The linear regression underestimated the radium content of bluegills in mined areas by an average of 479 pCi/kg. Thus, bluegills in mined areas concentrate radium-226 well in excess of expected levels based on size and contact with radium-bearing rocks.

Table 5 summarizes the radium content of elements of the aquatic food chain by land use. Clearly, radium can be incorporated into the food chain. Disruption of phosphatic terranes seems

Table 5. Summary of radium-226 activities by land use and position in food chain in aquatic biota. From Upchurch et al. (1981, in press). Numbers in parentheses are numbers of samples.

	Control areas		Unmined phosphatic terrane		Mined lands		Alafia River at Lithia Springs	
Water (pCi/l)								
Filtered	0.65	(2)	0.40	(1)	0.71	(4)	1.44	(1)
Unfiltered	0.61	(2)	1.07	(1)	1.03	(4)	1.63	(1)
Plants (pCi/kg)	---		92,954	(1)	10,781	(5)	---	
Herbivores (pCi/kg)								
Invertebrates	252.8	(2)	---		---		---	
Fish	707.2	(1)	---		118	(1)	504	(1)
Carnivores (pCi/kg)								
Fish	210.2	(10)	200.0	(10)	482	(16)	250	(3)

to increase the ability of the biota to secure and concentrate radium. Since the radium is incorporated by substitution for calcium in the hard parts (bone, shell, carapace, etc.) of the animals in these systems, there is no indication of direct hazard to man from consumption of small quantities of flesh from fish in these aquatic systems.

Data from Tampa Bay are less extensive. The results of analyses of organisms from Hillsborough Bay are given in Table 6. The data are insufficient to show any relationship with the structure of the food chain, but our data from freshwater biota suggest that no biomagnification of radium-226 exists. Several trends are evident in the data, however. First, it is obvious that most of the radium-226 is incorporated in the hard parts of the taxa studied. This minimizes the impact on humans of radium in ingestion of soft tissues. Second, Hillsborough Bay contains numerous species that have concentrated radium-226 from the water. Average concentration factors for crustaceans are 50X in hard parts and 2X in soft tissues, and for fish they are 118X in whole animal and 3X in soft tissues. These concentration factors suggest that soft tissues are minimal in their ability to accumulate radium-226. Hard parts vary in their ability to concentrate radium, with the chitinous carapaces of crustaceans being less capable of concentrating radium than are the bones of vertebrates. Finally, sufficient data exist to suggest that the highest radium activities are from individuals nearest the mouth of the Alafia River and Gardinier, Inc.'s nearby chemical plant.

Comparison with the data for freshwater taxa (Table 5) indicates that estuarine taxa accumulate radium-226 at about the same levels as do freshwater organisms from areas that have not been subjected to phosphate mining. Radium-226 levels in taxa from Tampa Bay, therefore, do not appear to be subjected to stresses resulting from exposure to radium that are any different from those in other systems in Florida. Comparison with systems outside of Florida is difficult owing to lack of equivalent data. Table 7 indicates that Tampa Bay biota are elevated in radium-226 content with respect to systems outside of

Table 6. Radium-226 in fauna from Hillsborough Bay.

Organism	Locality	Conditions	Radium-226 Activity (pCi/kg)	Source
Penaeus sp. (shrimp)	Mouth, Alafia R.	Whole animal, dry wt.	367	1
	0.25 mi NW Gardinier, Inc.	Head and shell, wet wt.	160	2
	0.25 mi SW Gardinier, Inc.	Head and shell, wet wt.	62.1	2
		Soft tissue, wet wt.	5.09	2
	Range marker off Bullfrog Creek	Head and shell, wet wt.	56.0	2
	Range marker off Davis Island	Head and shell, wet wt.	60.7	2
		Soft tissue, wet wt.	1.84	2
Callinectes sp. (blue crab)	Mouth, Alafia R.	Whole animal, dry wt.	621	1
Merluccius sp. (whiting)	Mouth, Alafia R.	Whole animal, dry wt.	880	1
		Whole animal, dry wt.	353	1
	0.25 mi NW Gardinier, Inc.	Fillet, wet wt.	3.84	2
		Whole animal, wet wt.	40.3	2
	Range marker off Davis Island	Fillet, wet wt.	5.20	2
Symphurus sp. (tongue sole)	Mouth, Alafia R.	Whole animal, dry wt.	364	1
	0.25 mi SW Gardinier, Inc.	Fillet, wet wt.	6.70	2
	Range marker off Bullfrog Creek	Fillet, wet wt.	6.65	2
Galeichthys sp. (catfish)	Range marker off Davis Island	Fillet, wet wt.	2.07	2
Melongena sp. (conch)	Mouth, Alafia R.	Whole animal, dry wt.	184	1
Misc. mollusca	Mouth, Alafia R.	Whole animals, dry wt., composite sample	260	1

Sources: 1 - unpublished data; 2 - Wahl 1980a.

Table 7. Comparison of radium-226 activities in selected components of the Tampa Bay system with similar systems elsewhere. (Source references in parentheses).

Component	Average radium-226 in Tampa Bay system		Radium-226 in comparable systems	
Sea water	0.13 pCi/l	(1)	0.04 pCi/l	(2)
Estuary water	1.71 pCi/l (Hillsborough Bay)	(1)	0.16 pCi/l	(3)
	0.78 pCi/l (Tampa Bay, excl. Hillsborough Bay)	(1)		
Mollusca (dry wt. basis)	222. pCi/kg	(4)	not available	
Crustacea (dry wt. basis)	84.7 pCi/kg hard parts	(4)	not available	
	3.5 pCi/kg soft tissue	(4)		
Fish (wet wt. basis)	202. pCi/kg whole animal	(4)	not available	
	4.89 pCi/kg soft tissues	(4)	0.2-5.1 pCi/kg soft tissues	(2)
			50 pCi/kg bone	(5)

Sources: 1 - Table 3; 2 - Woodhead 1973; 3 - Elsinger 1979; 4 - Table 5; 5 - Holtzman 1969.

Florida. This is also true for freshwater taxa (Upchurch et al. 1981; in press), which suggests that exposure to low levels of ionizing radiation is ubiquitous in central Florida.

The reasons for high radium contents in the biota of Hillsborough Bay seem obvious. First, soluble radium has been introduced to the Bay from natural causes (e.g., groundwater inflow and tributary discharge) throughout the history of the Bay. Second, desorption of radium and uranium from suspended particulates in estuarine mixing zones contributes radium to the Bay. Increased inflow of particulates owing to: 1) harbor maintenance; 2) mining, agriculture, and other extractive land uses; and 3) modification of the discharge characteristics of area streams has certainly increased the importance of this source of radium in recent years. Finally, Gardinier, Inc. has discharged uranium- and radium-rich effluents to the Bay in the past. The sediments deposited at the outfalls from the chemical plant clearly indicate this source, and reworking of those sediments by waves and currents redistributes these materials throughout the Bay. We sampled effluent from the plant at the time of our study (Upchurch et al. 1976) and could not detect any radium, so radium discharges at that time were

negligible. Clearly, more work should be done on the levels of radium, and other radioactive isotopes, in the food chain of the Bay. It is of special importance to evaluate 1) effects of chronic exposure to radium on the viability of the food chain; 2) impact of dredging and sediment resuspension on radionuclide release; and, 3) potential sources of radionuclides in human diet from Bay fisheries.

OTHER RADIONUCLIDES IN TAMPA BAY

There are few analyses of radionuclides in Tampa Bay other than radium-226 and radon-222. We have analyzed several freshwater organisms by gamma spectrometry (Table 8) and found, in addition to radium-226, that radium-228, thorium-228, potassium-40, niobium-95, zirconium-95, and ruthenium-103 are present in some taxa. Benthic plants (i.e., Naja) seem most active in concentrating these isotopes. Table 8 also indicates those isotopes which were expected, but could not be detected.

NEEDED WORK

As indicated, data available is not sufficient for detailed analysis of the impact of radioactive materials in the Bay. We need to understand the sources and sinks of these radionuclides in the Bay and the impacts of storm, major discharge events, dredging, and chronic and accidental releases of phosphate mine and chemical plant effluent on water quality and biota. We need data as to the flushing time of radionuclides from the Bay and modes of transport of radionuclides in the Bay. We need data on the effects of tidal cycles and organic pollutants on these transport modes. Distribution of radiation in the food chain and location of radionuclides in each taxon should be determined. Finally, it is most necessary to determine if there is long-term impairment of the viability of the biotic community by concentration of radionuclides. It is clear that both fresh- and saltwater systems in central Florida are subjected to similar stresses, so any problems that may exist (none have been demonstrated) are not restricted to the Bay. They exist throughout the region.

CONCLUSIONS

Uranium and its daughter, radium, are widespread in the drainage basins of Tampa Bay as well as in the Bay itself. The major source of these radionuclides

Table 8. Analyses of selected aquatic organisms in waters tributary to Tampa Bay for radionuclides other than radium-226. (--- = below detection limits).

Radionuclides (pCi/kg)	Naja guadalupensis	Micropterus salmoides	Lepisosteus spatula
Ra-226	10,396	164	74
U-235	---	---	---
U-238	---	---	---
Ra-228	401	72	---
Th-228	0.25	---	---
K-40	1,183	7,262	2,884
Nb-95	316	---	---
Zr-95	233	---	---
Ce-141	---	---	---
Ce-144	---	---	---
Ru-103	199.6	---	---
Cs-137	---	---	---
Be-7	---	---	---

is uranium incorporated in the phosphate mineral, francolite. Natural weathering of francolite-bearing rocks in the drainage basins and of sediments in the Bay contribute uranium and radium to the Bay waters. In addition, ion exchange with clays in the groundwater system causes radium influx to the Bay. Mining and ore processing have increased the rate at which radium and uranium are being added to the Bay. Although no short term problems in water quality or biota viability have been demonstrated as a result of these natural and cultural releases of radioactivity to the Bay, there is strong evidence that waters, sediments, and all elements of the biota are accumulating these radionuclides, especially radium-226. Caution should be exercised as to perception of the extent of any problems that may result in the long term. Data are insufficient at this time to evaluate long-term impacts of radionuclide enrichment in water, sediment, or biota. Much additional, systematic work is needed to evaluate potential hazards from these releases of radionuclides. A special need is for work on the distribution of radionuclides through the food chain.

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A REVIEW OF COMMERCIAL FISHERIES DATA: TAMPA BAY, FLORIDA

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INTRODUCTION

Historically, Tampa Bay thrived as a commercial fishing center. During the 19th century the bay served as seasonal commercial fishing grounds for large fishing companies whose home fishing areas were out of season. It has been reported (Pizzo 1968) that schooners from as far away as New England frequently fished in the bay waters. Catching Spanish mackerel, grouper and snapper, these ships would carry off more than 500,000 fish per day (Pizzo 1968).

Documentation of commercial fisheries data for the Tampa area did not begin until well into the 20th century. The Florida Department of Natural Resources (formerly the Florida Board of Conservation), U.S. National Marine Fisheries Service, and the Marine Advisory Program (Sea Grant) have published some fisheries data for Tampa Bay and the surrounding area: Hillsborough, Pinellas and Manatee counties. The purpose of this report is to present and summarize as much of the agency data as is available. We have also investigated the methods used in collecting the landings data and the overall reliability of those data.

DATA ACCUMULATION

As stated, the data used here were obtained primarily from reports published by the Florida Department of Natural Resources, U.S. National Marine Fisheries Service (NMFS), and the Marine Advisory Program (MAP). Based on the available information it appears that two methods of data accumulation are employed by these agencies. Dockside surveys are accountings done by government surveyors at the time and place of catch transfer from boat to dealer. Data has also been gathered from voluntary reports of fish purchases made by retailers. Both methods have problems associated with accuracy and require cooperation among fishermen, wholesalers, retailers and government agencies. Considering the number of times that each catch changes hands and the incentives for not reporting inventories, it is reasonable to assume that the available information is not entirely reliable.

Some of the problems in accumulating data can be traced to the NMFS monthly report form reproduced in Figure 1. This form is to be completed by all seafood retailers in the region, regardless of the size of the operation. On the form the dealer is asked to indicate the county where the catch is landed (item 3). Landing here implies the location where the catch was brought to port for sale, not the area where the catch was made. Nowhere on the form or in the available records is it indicated where many of the commercially valuable species are actually caught. Consequently, obtaining reliable information on some species (abundance and distribution) in inland waterway and estuarine systems such as Tampa Bay is difficult, particularly when seafood is being landed from catches made in other parts of Florida or South and Central America.

When the data has been accumulated it is then compiled and reported by the various agencies. The comparisons shown in Table 1 illustrate an example of the inconsistencies found among reports by different agencies. Table 1 outlines spotted seatrout landings in the Tampa Bay area as

MAIL IMMEDIATELY
AT END OF EACH MONTH

MAIL THIS FORM TO: Department of Natural Resources
National Marine Fisheries Service
75 Virginia Beach Drive
Miami, Florida 33149

DATE ....

1 DEALER ....

ADDRESS .....

.....

2 THIS REPORT IS FOR THE MONTH OF: .....

3 COUNTY WHERE FISH LANDED: .....

4 NUMBER OF POUNDS OF FISH AND SHELLFISH PURCHASED FROM FISHERMAN OR PRODUCED:

	SPECIES – SHELLFISH	AVERAGE PRICE	POUNDS
300	Clams (sunray venus)		
301	Oysters (Bushels)		
301	Oysters (Gallons)		
301	Oysters (Barrels)		
302	Clams (hard) (Gallons)		
303	Scallops Bay (Gals.)		
304	Scallops Calico (Gals.)		
305	Conchs (Meats)		
403	Crawfish (Spiny Lobster)		
405	Spanish Lobster		
401	Blue Crabs (hardshell)		
402	Blue Crabs (softshell)		
404	Stone Crabs (Whole)		
404	Stone Crabs (Claws)		
	Shrimp Heads-off Heads-on		
501	Squid		
502	Turtle Green		
503	Turtle: Loggerh. ad		

	SPECIES – FINFISH	AVERAGE PRICE	POUNDS
201	Alewives (Herring)		
101	Amberjack		
100	Angelfish		
202	Ballyhoo		
102	Barracuda		
103	Bluefish		
104	Bluerunner		
105	Bonito		
106	Bottom Fish		
108	Cobia		
109	Catfish (fresh water)		
110	Catfish (salt water)		
203	Cigarfish		
112	Croaker		
113	Dolphin		
114	Drum (black)		
115	Eels		
116	Flounders		
129	Goatfish		
118	Groupers & Scamp		
119	Grunts		

	SPECIES	AVERAGE PRICE	POUNDS
208	Herring, Thread		
120	Hog Snapper (hogfish)		
121	Jack (crevalle)		
122	Jewfish		
123	Kingfish (mackerel)		
206	Ladyfish (skipjack)		
204	Menhaden (pogies)		
124	Mullet, black (Lisa)		
125	Mullet, silver		
126	Mutton Snapper (muttonfish)		
131	Nile Perch		
127	Permit		
128	Pigfish		
130	Pompano		
132	Red Fish (channel bass)		
117	Sand Perch (mojarra)		
134	Sea Bass (common)		
133	Sea Trout (gray) (E. coast)		
134	Sea Trout (spotted)		
135	Sea Trout (White) (W. coast)		
136	Shad (common)		
205	Sharks		
138	Sheepshead		
139	Snapper, lane		
140	Snapper, mangrove		
141	Snapper, red		
142	Snapper, vermilion		
143	Spanish Mackerel		
156	Spanish Sardines		
144	Spot		
145	Sturgeon		
153	Swordfish		
157	Tile Fish		
146	Trigger Fish		
147	Triple Tail		
207	Trash Fish		
155	Wahoo		
148	Warsaw		
149	White Snapper (porgy)		
150	Whiting, boat		
150	Whiting, beach		
151	Yellowtail		
106	Miscellaneous Food Fish		

Please add species not listed such as: various sponges, leather jacket, tuna, Sailors Choice, Etc.

Figure 1. National Marine Fisheries Service monthly dealer's report form.

Table 1. Spotted seatrout landings as reported by the National Marine Fisheries Service (NMFS) and Florida Sea Grant Marine Advisory Program (MAP) during the periods 1963-1969 and 1970-1976.

	REPORTED BY:	
	NMFS	MAP
1963-1969:		
Total pounds	1,535,500	3,039,951
Annual average	219,357	434,278
1970-1976:		
Total pounds	855,100	2,197,261
Annual average	122,157	313,894
NET CHANGE		
Total pounds	-680,400	-842,680
Annual average	-97,300	-120,384

reported by NMFS and MAP during two seven-year periods. The area designated as Tampa Bay by NMFS does not include Boca Ciega and Terra Ceia Bays. The MAP sea trout landings data were compiled by summing values reported for landings in the three counties surrounding the bay (Hillsborough, Pinellas and Manatee counties). The two agencies' values show differences of 214,921 pounds in the annual averages for 1963-1969 and 191,737 pounds in the annual averages for 1970-1976. Inconsistencies such as these have led to much misunderstanding as to which species are caught and marketed in significant amounts from Tampa Bay waters.

The data presented here include bay-wide landings for all species of finfish and shellfish reportedly landed in Hillsborough, Pinellas and Manatee counties. In discussing the Tampa Bay area as a whole we have combined the values for the three counties during the period when the data was most available, 1952-1978. The most important (i.e. representing a high percentage of total landings) commercially-caught species data have been reviewed and presented separately in addition to presenting total values.

BAY-WIDE TOTAL FINFISH LANDINGS

As shown in Figure 2, the data available for finfish landings in the three counties have been combined to represent the Tampa Bay area. In 1978, this tri-county area's landings comprised approximately 12.8% of the total finfish landings in the state of Florida. Manatee County contributed 44.8% to the reported total Bay area landings, Pinellas County 44.6%, and Hillsborough County 10.5%.

During the 1952-1978 period, the largest annual amount of finfish reportedly landed in the bay area occurred in 1964 when a total of more than 18,000,000 pounds were landed. A sharp decline in fish catches occurred in 1970-1971. During that year, less than 8,500,000 pounds of fish were traded. Throughout the 26 years reviewed here, many fluctuations in reported fish landing poundages are observed. It is not uncommon to find a biennial difference of 5 million pounds of landed finfish.

The National Marine Fisheries office publishes landings data for 47

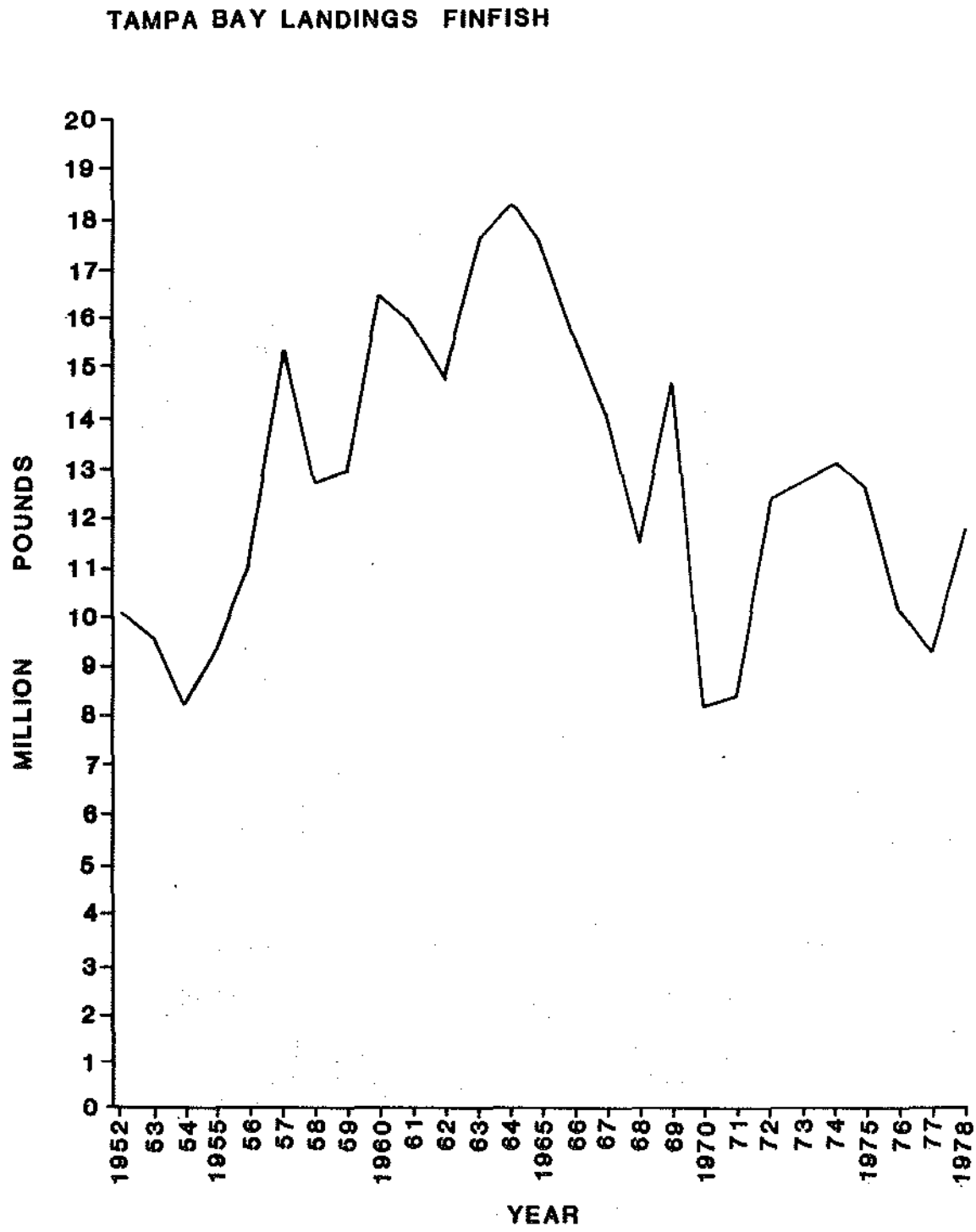

Figure 2. Tampa Bay area finfish landings, 1952-1978.

species of finfish. Of those species, only eleven are commonly caught in Tampa Bay waters and are listed in Table 2. Figure 3 illustrates a comparison of annual landings between these 11 commonly caught bay species and total finfish market of the bay area. Both trends appear similar with the common bay species representing approximately 50-60% of the total catch in most years.

BAY-WIDE TOTAL SHELLFISH LANDINGS

As shown in Figure 4, the data available for shellfish landings has been compiled for the entire Tampa Bay tri-county area. In 1978, landings from the tri-county area contributed approximately 7.3% to the total shellfish landings for the state of Florida. Of the reported total bay area landings, Pinellas County represented 59.9%, Hillsborough County 37.7%, and Manatee County 2.8%.

During the 1952-1978 period a decline in shellfish landings occurred from a 1956 maximum of almost 20,000,000 pounds to a 1971 low of approximately 2,000,000 pounds landed. A 1971-1978 recovery was evident but the poundage of shellfish landed did not reach the peaks found in the 1950s and 1960s. It is not known whether the recovery trend continued past 1978.

COMPARISONS BY COUNTY

Hillsborough County. The 1952-1978 fisheries data available for Hillsborough County (Fig. 5) shows trends consistent with the combined Tampa Bay tri-county data. Both the finfish and shellfish data available indicate a general decline in poundages landed from the early 1960s high to the low reported in the 1970s.

The shellfish trade was important to Hillsborough County. Shellfish landings reached nearly 20,000,000 pounds in the late 1950s and early 1960s and account for almost all of the shellfish landings of the Bay area during that time. In 1957 Hillsborough County contributed 70% to the total Bay area shellfish landings. Most of this can be attributed to the once-flourishing shrimp industry of Hillsborough Bay.

Pinellas County. In contrast to the Hillsborough County data, finfish landings in Pinellas County exceeded shellfish landings for the entire 1952-1978 period (Fig. 6). The declining trend of the early 1960s to early 1970s is again evidenced by Pinellas County finfish landings. Concurrent with the 1970-1971 finfish decline is a decline in shellfish landings. However, unlike the finfish, shellfish data shows a recovery from less than 200,000 pounds to almost 3,800,000 pounds during the two-year period from

Table 2. Commercial fish species commonly caught in Tampa Bay waters.

COMMON NAME	SCIENTIFIC NAME
Sea Catfish	Arius felis
Crevalle	Caranx hippos
Red Drum	Sciaenops ocellata
Black Drum	Pogonias cromis
Flounder	Paralichthys albigutta
Black Mullet	Mugil trichodon
Silver Mullet	Mugil cephalus
Spotted Sea Trout	Cynoscion nebulosus
Sand Sea Trout	Cynoscion arenarius
Sheepshead	Archosargus probatocephalus
Scaled Sardine	Harengula jaguana

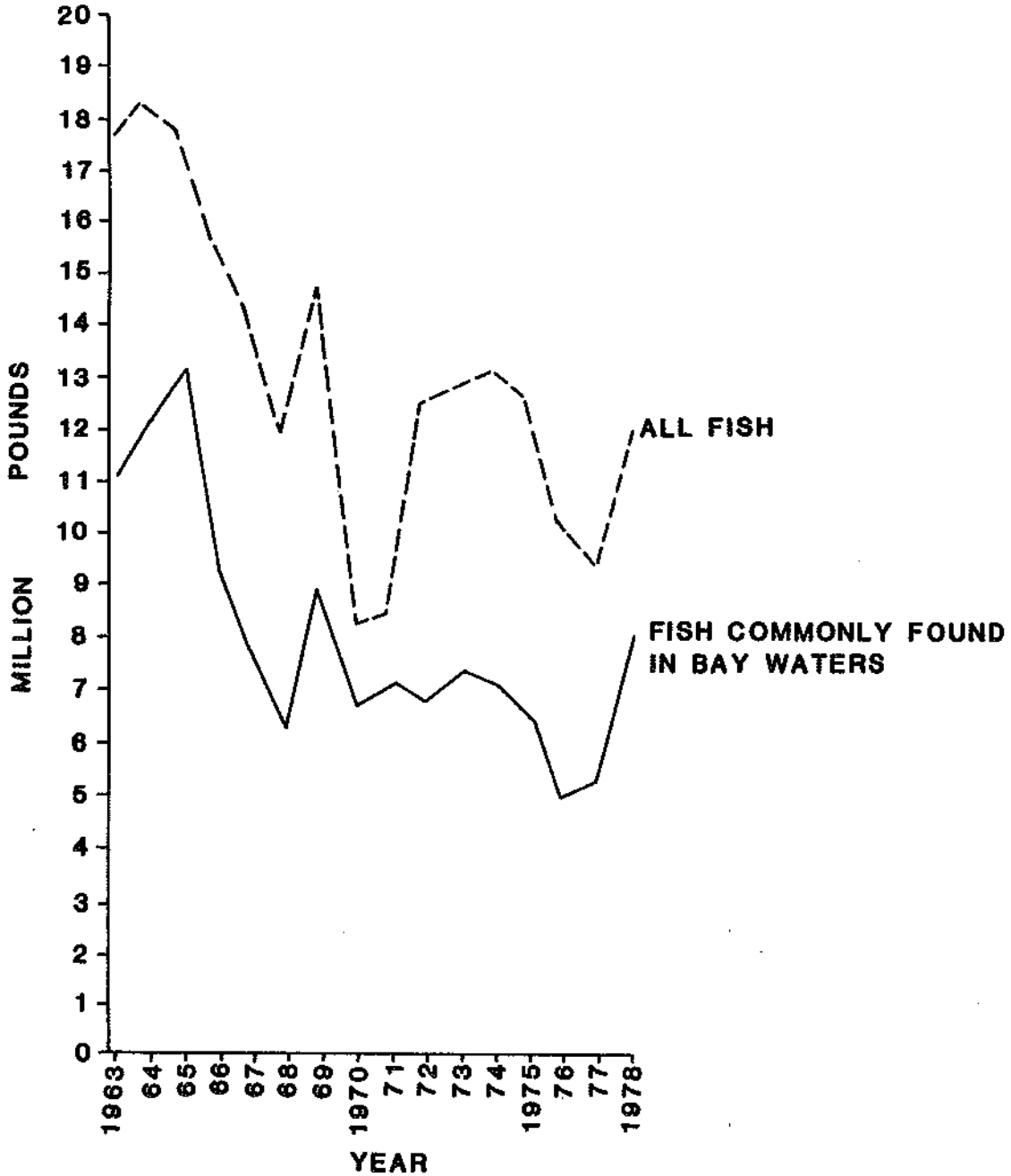

Figure 3. Comparison of species commonly caught in Tampa Bay waters vs. total landings for area.

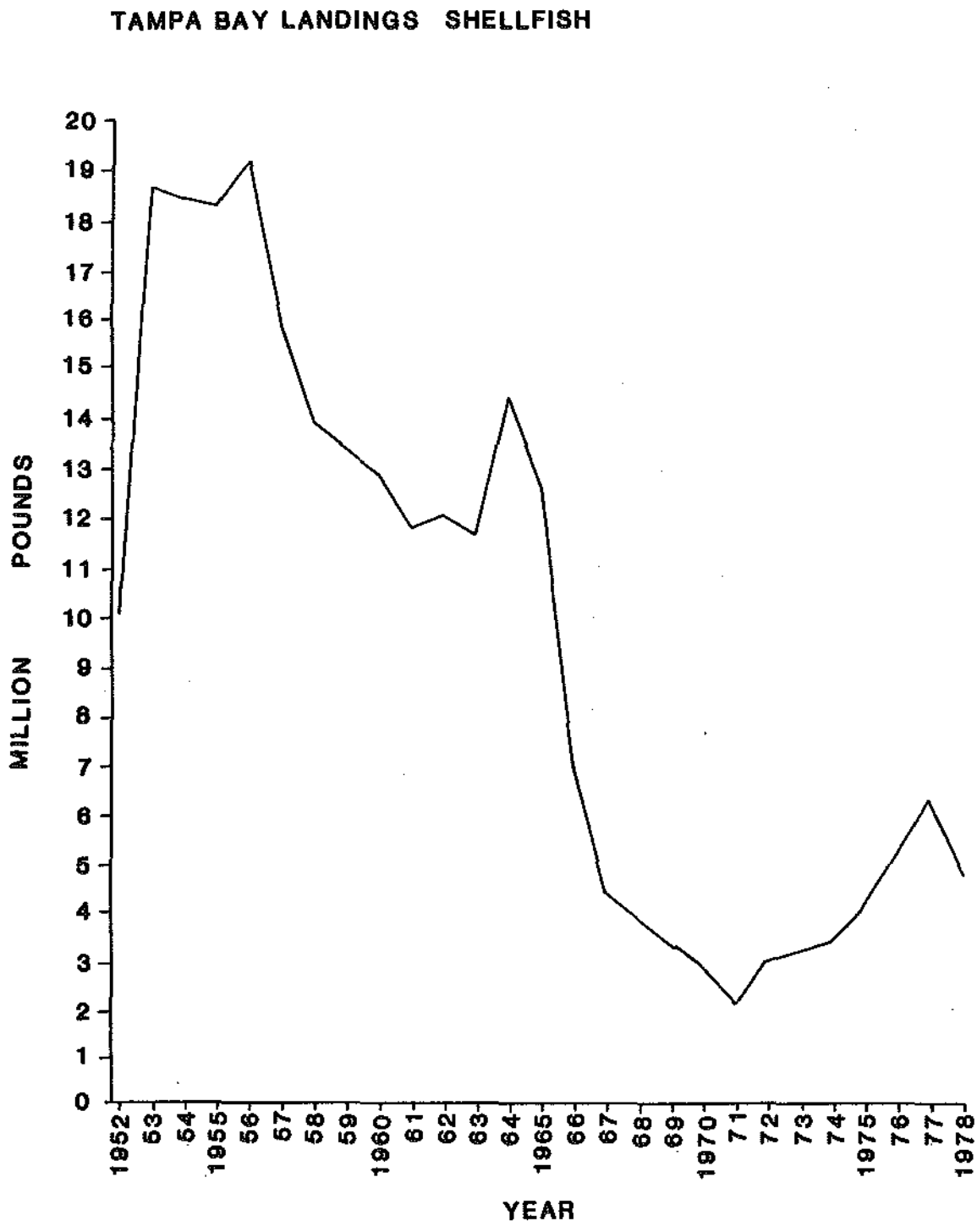

Figure 4. Tampa Bay area shellfish landings, 1952-1978.

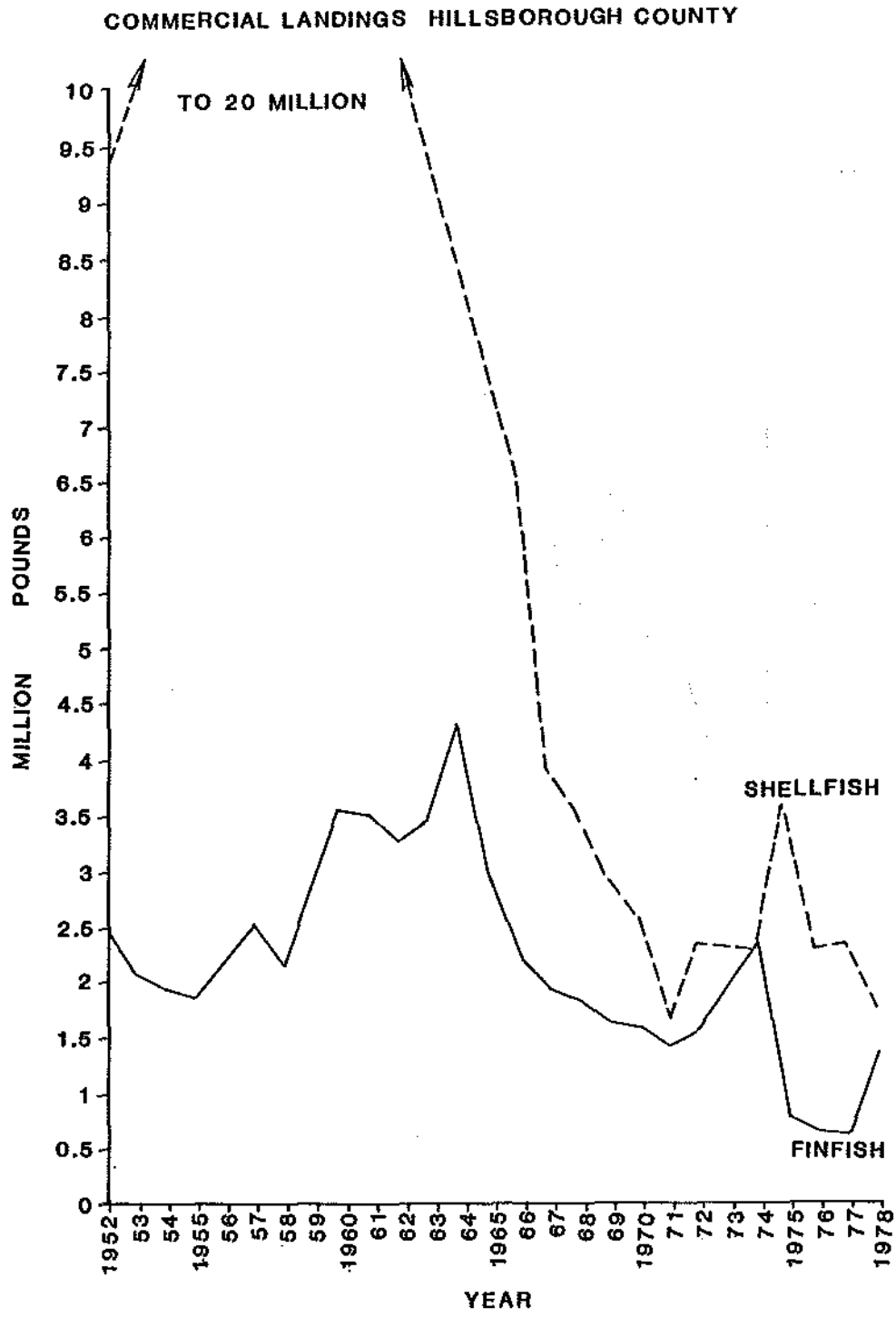

Figure 5. Hillsborough County commercial shellfish and finfish landings, 1952-1978.

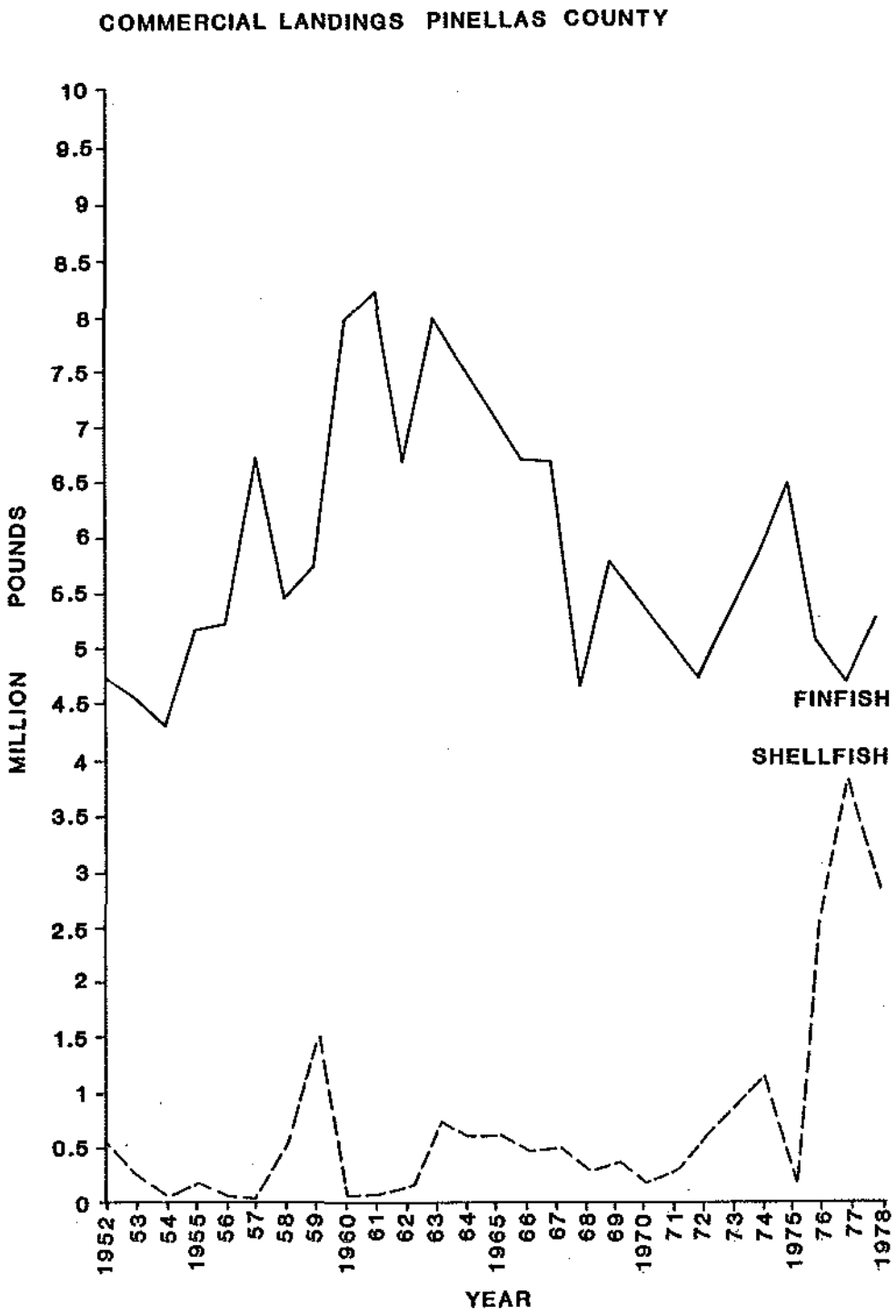

Figure 6. Pinellas County commercial shellfish and finfish landings, 1952-1978.

1975 to 1977. Pinellas County finfish landing poundages show a completely opposite trend for the same period.

Manatee County. Manatee County has had consistently low values for shellfish landings throughout the entire 26 year period (Fig. 7). The contribution of Manatee County to the total Bay area shellfish landings is approximately 2.8%.

The mid-1960s to early 1970s decline shown for the combined tri-county landings is also seen in the isolated Manatee County data. Numerous and rapid fluctuations are evident in Manatee County fin/shellfish landings as they are in the combined tri-county data.

IMPORTANT FINFISH SPECIES

Because of the location of Tampa Bay, ease in catching, and market value, a few finfish species dominate the pounds-landed data for the Bay area. Importance is determined by the percentage of total landed pounds represented by each species. Three of the four species discussed here: silver mullet (Mugil cephalus), spotted seatrout (Cynoscion nebulosus), and red drum (Sciaenops ocellata) are commonly caught within the boundaries described for Tampa Bay by Lewis and Whitman (this volume). The fourth species, red snapper (Lutjanus campechanus), is commonly harvested from deep Gulf waters but represents a relatively high percentage of the total landings data.

Silver Mullet. Silver mullet represents 55% of all fish landed in the tri-county area in 1978. In the mid-1960s, landings of mullet increased to almost 8,000,000 pounds followed by a rapid decrease in the late 1960s (Fig. 8). Unlike most other species reported, the least productive years for harvesting mullet were 1975-1977 rather than 1970-1971. From 1977 to 1978 an increase in mullet landings of approximately 2.5 million pounds was reported.

Spotted Seatrout. The trends shown in Figure 9 for landings of spotted seatrout are similar to those found for the total tri-county area finfish data. Marked peaks in trout landings are shown for the mid-1960s after a rapid increase from the late 1950s. As in the case of many other local species, landings for trout plummeted in the early 1970s. Although spotted seatrout landings represent only 2.4% of the total tri-county landings for 1978, it is one of the most commonly caught commercial fish in the Bay waters.

Red Drum. Listings of red drum catches by the National Marine Fisheries Service only began in 1965. The available data from 1965-1978 is illustrated in Figure 10. The trends in the data of red drum differ from those shown by the total finfish landings and from the species previously discussed. The highest values reported occurred in the early 1970s, to a high of approximately 250,000 pounds in 1974. The increase seen from the mid-1960s to the early 1970s is unique among the finfish species discussed here.

Red Snapper. Red snapper is commonly caught in the deep water middle grounds of the Gulf of Mexico. Since the available data indicates that large quantities of red snapper are landed (brought to market) in the tri-county area it has been included in this report. Red snapper represents almost 5% of all finsfish landed in the area. In the 1952-1978 period three peaks in pounds landed can be noted (Fig. 11). The high values reported in 1957-1958, 1965 and 1975 are each preceded by a rapid increase and succeeded by a rapid decrease. For example, in 1973 480,000 pounds were landed, followed by an increase to 1,380,000 pounds one year later and decreasing to less than 540,000 pounds by 1977.

IMPORTANT SHELLFISH SPECIES

At present, shellfishing in the Tampa Bay area is limited to the harvest of small bait shrimp and blue crabs. Larger food shrimp and oysters have historically been harvested from the bay waters, but those industries have declined to the point where they are now virtually non-existent within the geographic boundaries of Tampa Bay.

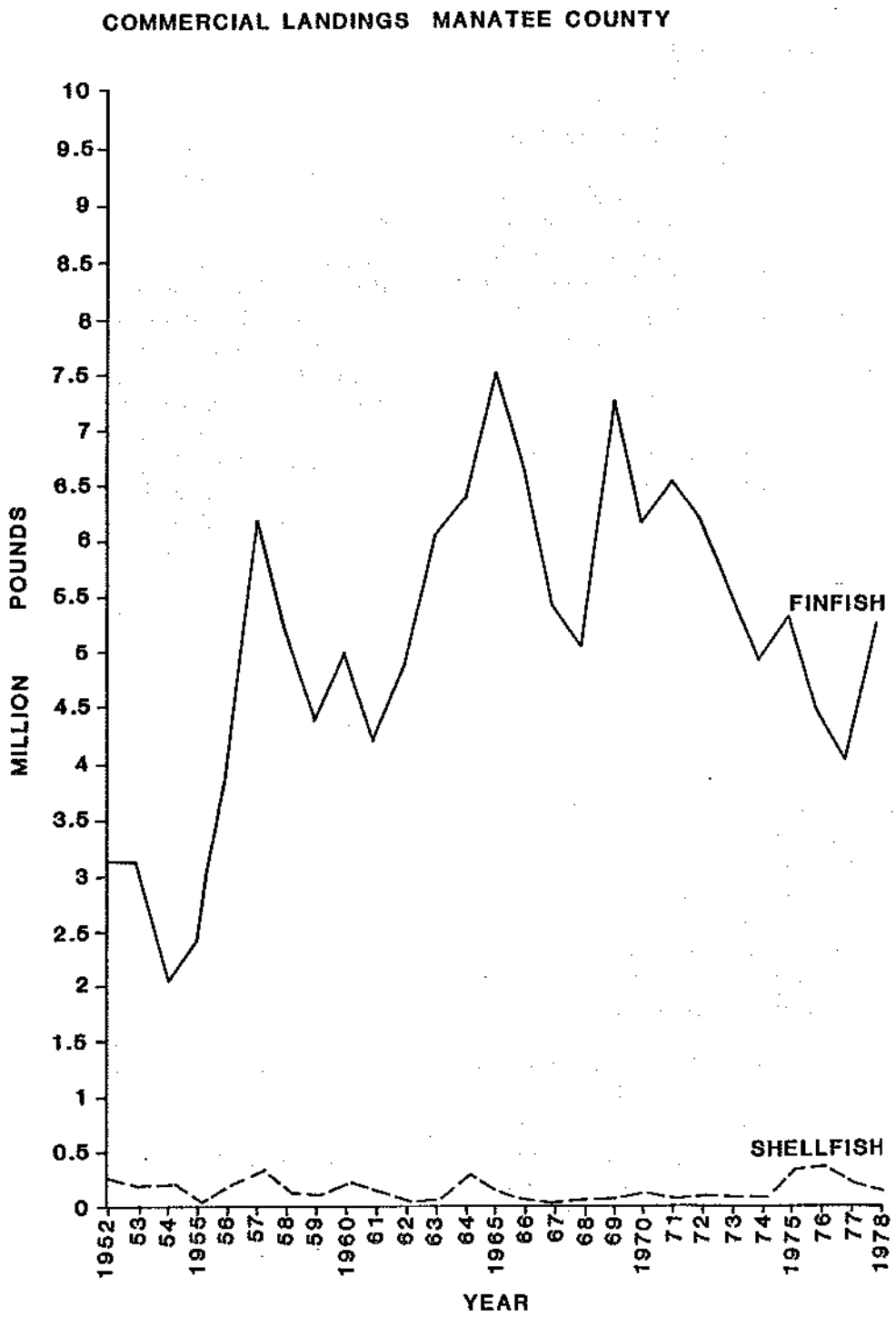

Figure 7. Manatee County commercial shellfish and finfish landings, 1952-1978.

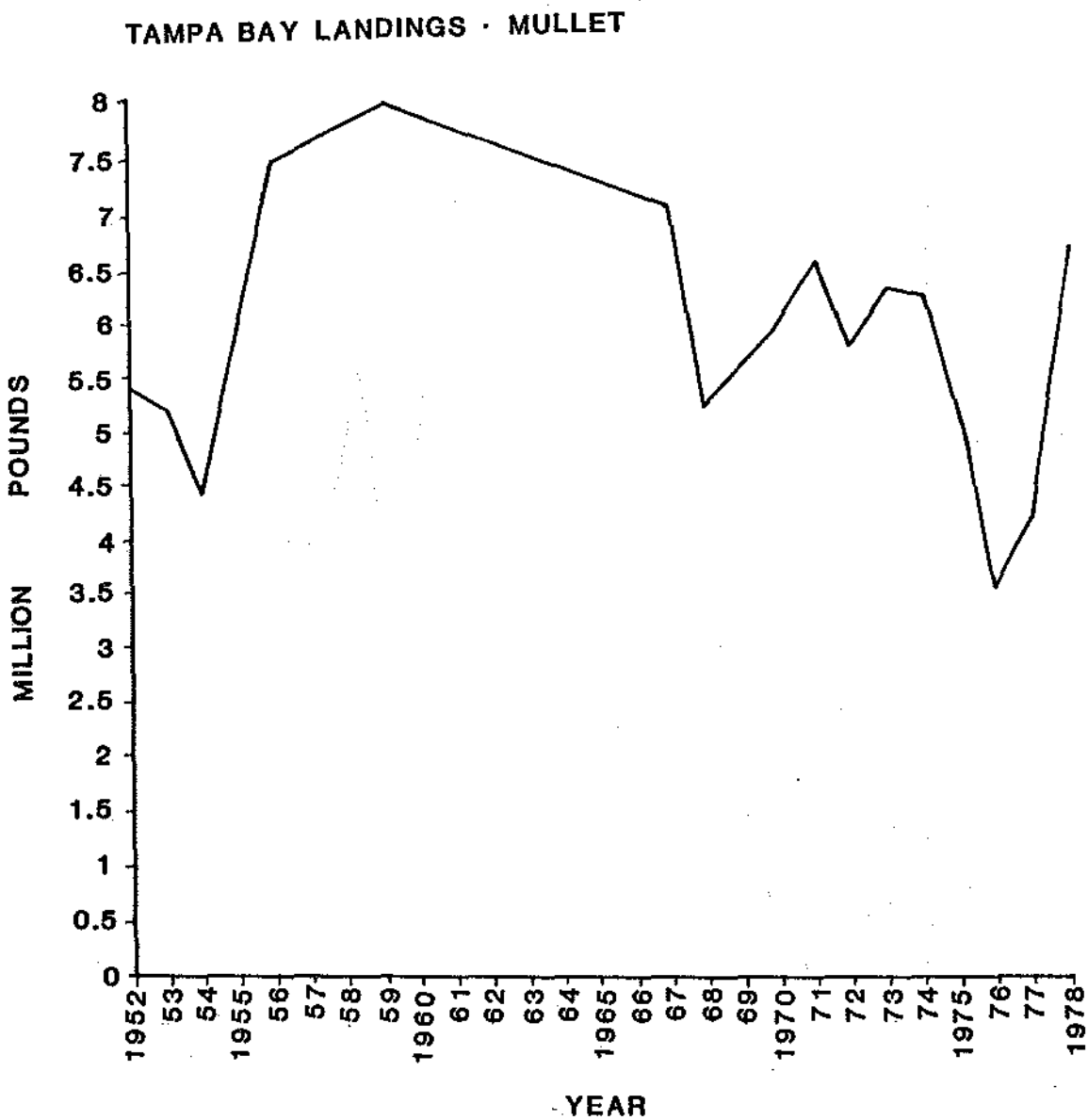

Figure 8. Tampa Bay area silver mullet landings, 1952-1978.

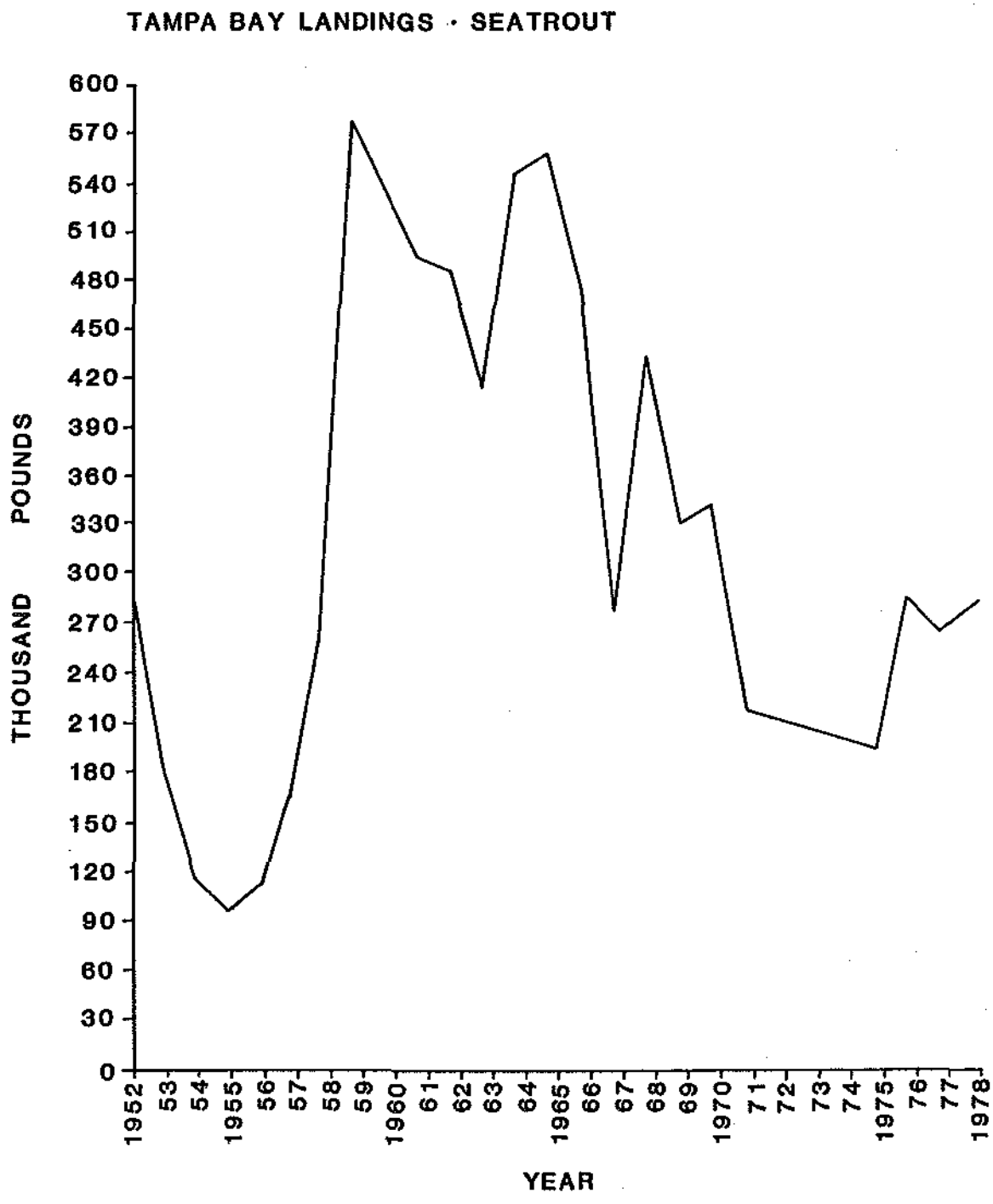

Figure 9. Tampa Bay area seatrout landings, 1952-1978.

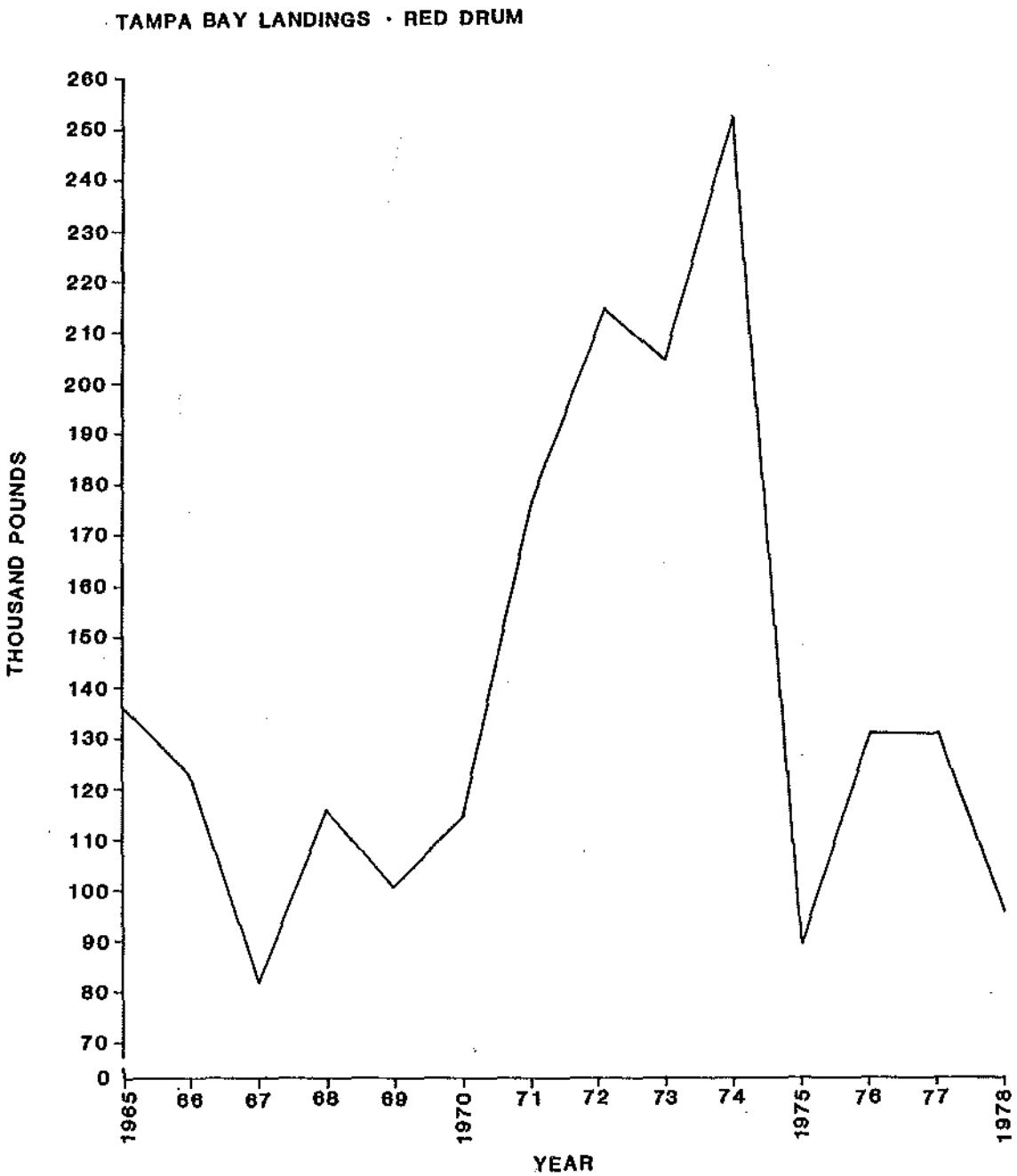

Figure 10. Tampa Bay area red drum landings, 1952-1978.

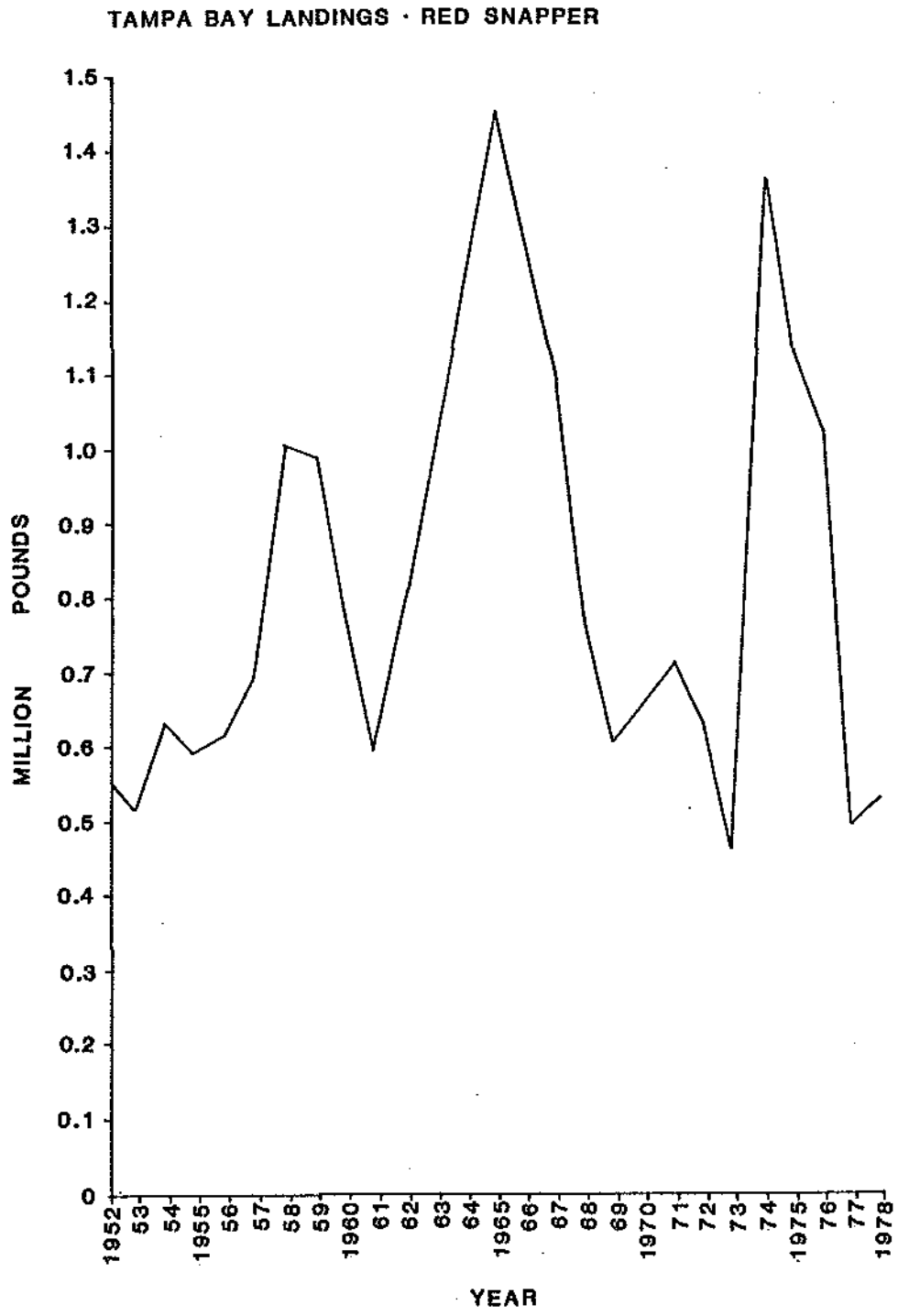

Figure 11. Tampa Bay area red snapper landings, 1952-1978.

Shrimp. Throughout the past 26 years the shrimping industry has suffered an extreme decline. In the mid 1950s nearly 15,000,000 pounds were harvested from Hillsborough Bay annually. These catches accounted for almost all of the Hillsborough County and total tri-county area shellfish landings (Fig. 4 and 5). Specific county data on annual shrimp landings has not been compiled for this report. Almost all of the shrimp types listed in the NMFS and MAP reports are not caught in the bay area. Any compilation of these data would give a false impression of the contribution of bay area shrimp to the shellfishing industry. The categories of shrimp listed in the available reports are confusing. Classification of shrimp has been by type; i.e. food shrimp or bait shrimp; by location, i.e. Campeche shrimp and Tortugas shrimp; and by processing type, i.e. heads-on or headless shrimp. In the past 26 years the shrimp landing categories have been re-classified no less than 7 times, making data organization nearly impossible.

Oysters. The commercial oyster industry in Tampa Bay is no longer active. Throughout the 19th century it was extremely active, with Hillsborough County (which then included Pinellas County) ranking second in oyster production in Florida (Dawson 1953). A rapid decline in oyster landings occurred in the 1940s. In 1942 over 16,600 gallons of oyster meat were landed in Pinellas County and by 1952 the landings had declined to 496 gallons[1]. By 1951 there were only 10 active oyster leases (67.18 acres) in Tampa Bay, eight of which were in Pinellas County. There are presently a few acres in the Bay being leased for oyster production but there is no ongoing commercial harvest of these beds.

Blue Crab. The available data for blue crab landings in the bay area are presented in Figure 12. In 1978 blue crab accounted for approximately 5% of the total bay area shellfish landings. The most productive years for the industry were 1965-1967. A decline from 1967 to the early 1970s low is evident and consistent with much of the other fisheries data. It is not indicated in the literature whether the data refer to live or processed crabs. Blue crabbing is still very active in south Tampa Bay during late spring and summer. Thousands of crab traps can be seen throughout the remaining grassbeds from Cockroach Bay to Egmont Key.

CATCH EFFORT

The quantity of fish harvested is related to numbers of fishermen and methods of collection. There is presently no readily available accumulated data base of this type of information. In an attempt to document catch effort expended, commercial boat registration data from Hillsborough, Pinellas and Manatee counties have been compiled. These data were obtained from the Marine Patrol of the Florida Department of Natural Resources and are presented in Figure 13. The number of commercial boats registered in the three counties declined to a 1972-1973 low from a mid-1960s high. The pre-1964 data were not available. There are currently (1981) more than 2,200 commercial boats operating out of the three Tampa Bay counties.

With the rapid growth and development of the bay area, the non-commercial sport fishing effort has increased. As indicated in Figure 14, the number of pleasure boats has increased at least three-fold in each of the counties during the past 15 years. Not all of the pleasure boats represent fishing interest, but it is assumed that the increase in sportfishing vessels is proportional to the increase in total pleasure boats over the 15 year period. Whether there is a direct effect of sport fishing on the bay's commercial fish populations is not known at this time.

[1] Data accumulated by Florida Board of Conservation, 1941-1952.

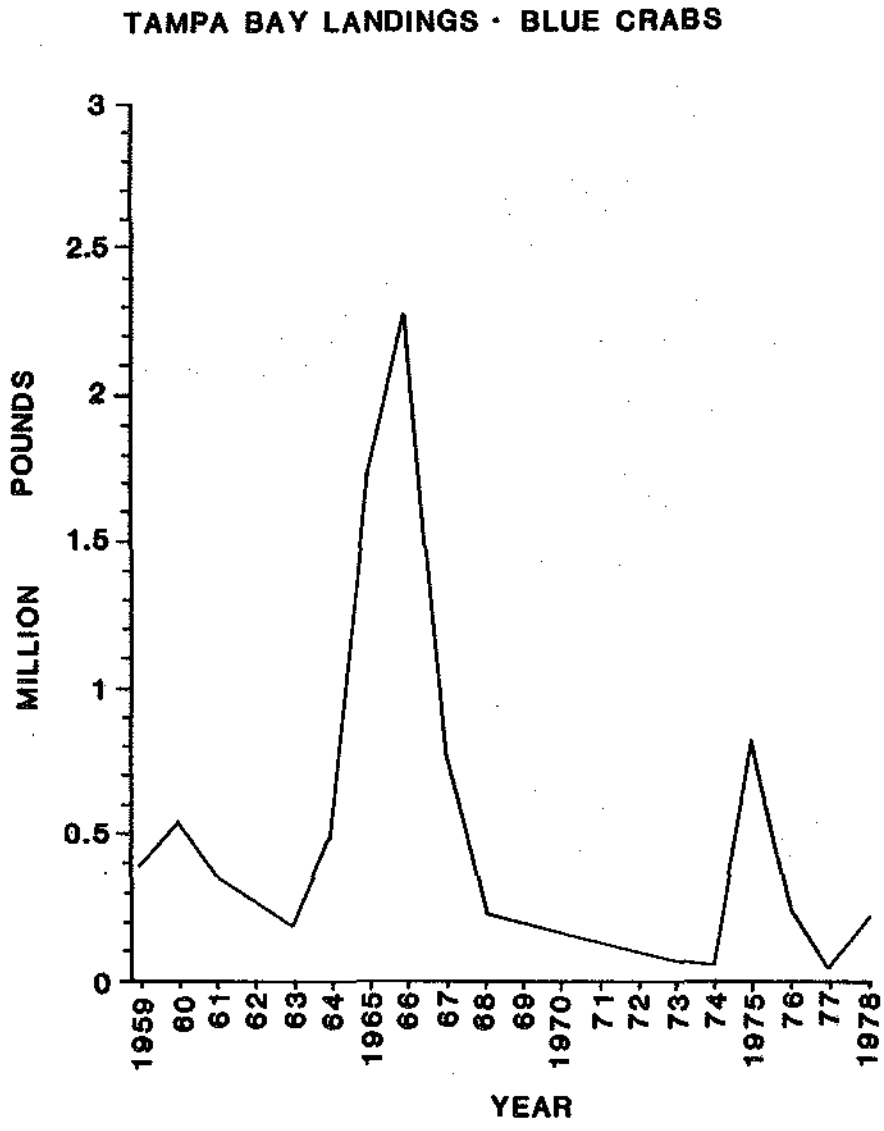

Figure 12. Tampa Bay area blue crab landings, 1959-1978.

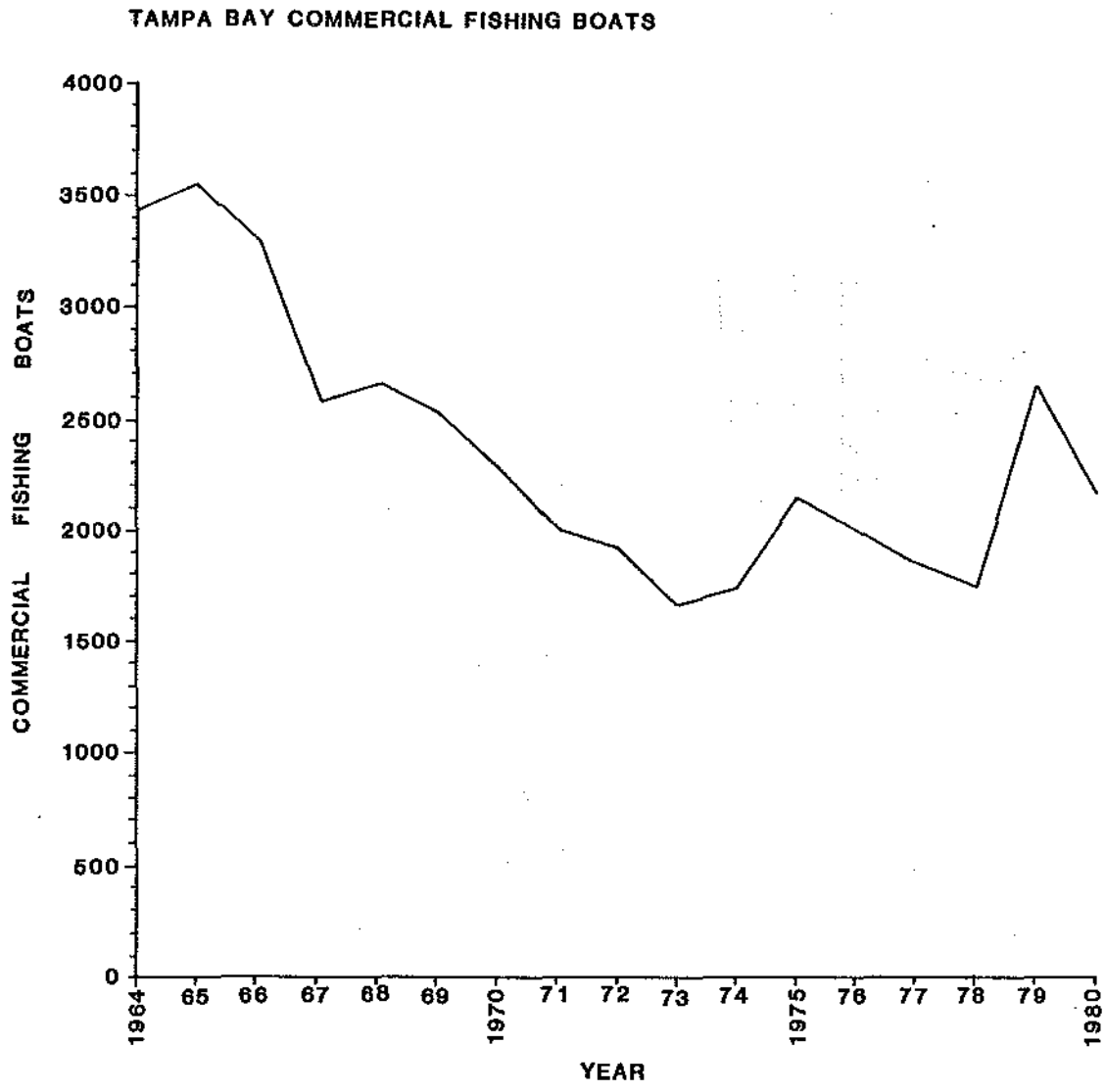

Figure 13. Tampa Bay area commercial fishing boats, 1964-1980.

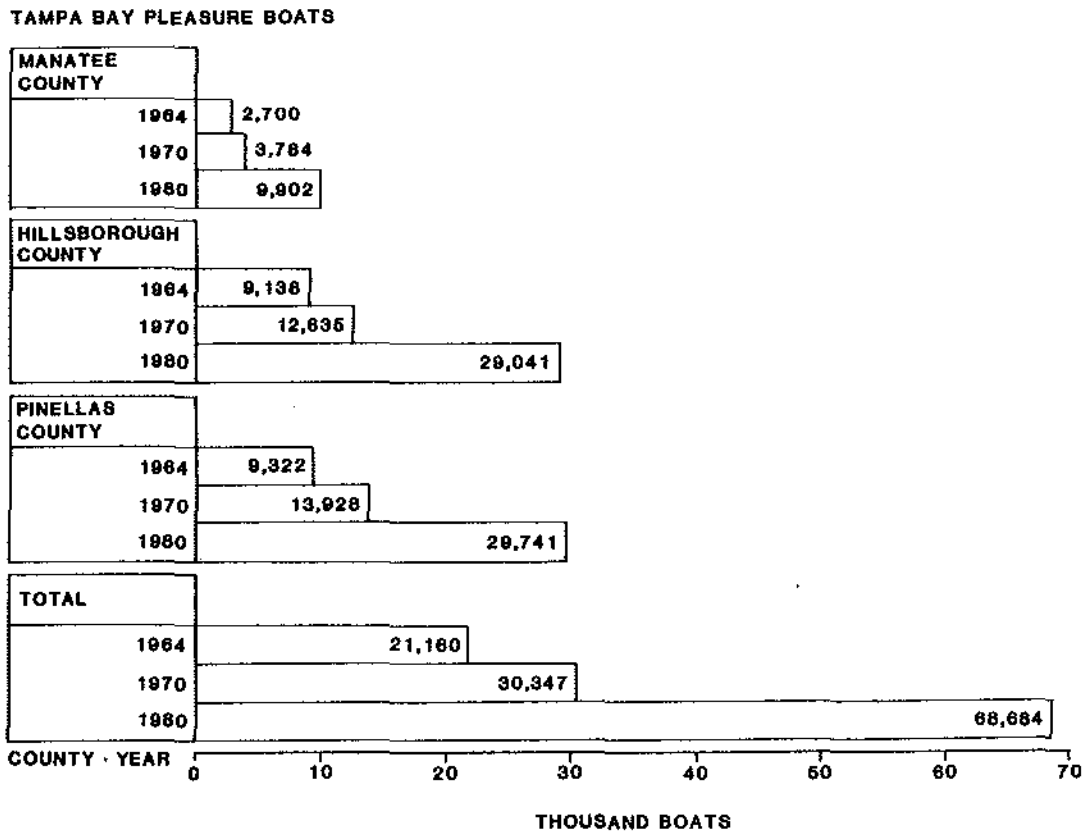

Figure 14. Tampa Bay area pleasure boats, 1964-1980.

SUMMARY CONCLUSION

As previously stated, the purpose of this report has been to summarize and present the available Tampa Bay fisheries data. In accumulating these data some long term trends and fluctuations have been noted. Many of the fluctuations may be only an artifact of combining data from the three counties in order to represent Tampa Bay as a whole. It is further suspected that natural fluctuations in population sizes may also be represented in the landings data as long term increasing or decreasing trends.

In July of 1971 an outbreak of Ptychodiscus breve (Florida red tide) occurred in the Tampa Bay area. The effect of this phenomenon was devastating to the area's fish populations and offshore reef communities. Steidinger and Joyce (1973) suggest a relatively long term effect as a result of this outbreak. In almost all of the data presented in this report a sharp decrease in landings consistently occurred in the early 1970s. The red tide undoubtedly affected the fishing industries at that time. Also noted in the early 1970s is a decrease in the number of commercial fishing boats registered in the area (Fig. 13). 1972-1973 was a period of low fuel availability making the operation of fishing vessels expensive and difficult. The decrease in number of vessels registered reflects a similar decrease in catch effort, resulting in the low values reported for the early 1970s.

Finally, the continuing loss of fish nursery habitats has also contributed to the overall decline in Tampa Bay fish populations. In the past 100 years Tampa Bay has suffered a loss of 80% of its original seagrass beds (Lewis et al. this volume) and 44% of the original mangrove areas (Lewis 1977). Both seagrass and mangrove habitats are used by many local fish species for foraging and nursery activities. Loss of these areas as a result of dredge and fill operations, development, and pollution discharge is occurring and continues to contribute to the overall decline in utilizing Tampa Bay fisheries as both a commercial and recreational resource.

ACKNOWLEDGEMENTS

We would like to thank Bill Lindall of the National Marine Fisheries Service and Allan Huff of the Florida Department of Natural Resources, Marine Research Laboratory, for their assistance in providing data and helpful comments.

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SPECIAL SPECIES AND THEIR ENDANGERED HABITAT

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ABSTRACT

Data collection for many taxa has been more complete for Hillsborough and Pinellas Counties than for Manatee. Although scientific interests (including this symposium) and regulatory responsibilities often encourage a dichotomy between uplands and estuarine/marine environments, environmental managers should take a more holistic approach to the Tampa Bay area. First, the ecological and hydrologic relationships of upstream freshwater wetlands (and their basins, which often include many other "upland" habitats) to receiving estuarine environments must be more completely recognized. Second, the status of special species (including, but not limited to, those officially classified as "endangered" or "threatened") is often only a reflection of habitat and environmental health. Third, since Florida provides a disproportionately richer fauna and flora than most of the United States, any decrease in species from this region could conceivably result in a larger percentage decrease in diversity at the national level of consideration. Causes for the rareness of plants and animals include natural causes and direct exploitation, but habitat and hydrologic alteration are, by far, the most severe and pervasive problems. Focus needs to be directed at the overall value of interacting communities, avoiding a tunnel visioned approach which relies on the presence of a single species to justify habitat protection. Intelligent environmental protection will only be possible when the environmental manager 1) is working from, and understands, a solid data base, and 2) has a clear understanding of how science and societal decision-making must be integrated.

HABITAT RESTORATION IN TAMPA BAY

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INTRODUCTION

Population increases and industrial development continue to severely stress Tampa Bay. Substantial losses of habitat, 4,423 ha or 44% of emergent vegetation and 25,220 ha or 81% of submergent vegetation (Lewis et al. 1979; Lewis et al., this volume), have been documented over the past 100 years. Although a number of factors have contributed to this decline, it is primarily due to dredge and fill operations associated with urban growth. Direct impacts include removal and burial of plant material during dredge and fill operations; an example is the dredging and filling of 1,400 ha in Boca Ciega Bay, which resulted in the immediate loss of 1,100 metric tons of seagrasses (Taylor and Saloman 1968). Increased turbidity due to dredging, industrial and sewage discharges, and general water quality degradation constitute indirect perturbations which can also result in loss of wetland plant material.

A direct result of habitat loss has been a decline in associated fauna (e.g., decrease in commercial fisheries catch; Lombardo and Lewis, this volume). Wetland vegetation communities are important biologically and physically in maintenance of a viable estuarine system. They are among the most productive ecosystems on earth (Wood et al. 1969; Gosselink et al. 1974; Thayer et al. 1978), and are important in stabilizing sediments and reducing erosion (Scoffin 1970; Zieman 1972). Hutton et al. (1956) recognized the importance of seagrass beds to commercial and recreational fisheries. They warned that destruction of seagrass areas along the west coast of Florida, including Tampa Bay, could seriously jeopardize the economy of the state. Past dredge and fill activities in Boca Ciega Bay resulted in an estimated annual loss of $1.4 million in fisheries (Taylor and Saloman 1968). In response to this loss of wetland habitat, numerous projects have been undertaken in Tampa Bay to restore habitat through the planting of wetland vegetation.

Planting of wetland vegetation was first documented in India in the late 1800s where mangroves were grown for silviculture (Walsh 1974). Experimental plantings of cordgrasses (another group of important intertidal vegetation) were begun in the 1960s in the United States (Woodhouse et al. 1974). The earliest mangrove work in Tampa Bay was done by Savage (1972) to test transplanting techniques while techniques for Spartina alterniflora (smooth cordgrass) were developed in 1976 by Lewis and Lewis (1977). Several studies have investigated techniques for transplanting seagrasses in Tampa Bay in the hope of restoring these important communities (Woodburn

1961; Kelly et al. 1971; Phillips 1974; Van Breedveld 1975; Durako and Moffler 1981). The projects to date have all been experimental and success rates have been extremely variable.

REVIEW

Methods. General methodologies for mangroves, cordgrass, rush, and seagrasses are discussed in the following sections. There are, however, considerations which apply for all these plants and methods. Perhaps the single most critical factor in successful habitat restoration is selection of a suitable planting site.

When selecting a planting site, tidal elevation must be taken into account for the intertidal species (the elevation consideration for subtidal species such as seagrasses is to insure sufficient light penetration). Intertidal plantings in Tampa Bay have been done at elevations ranging from +0.23 m MLW to +0.88 m MLW (Hoffman and Rodgers 1981). Tidal inundation, not just elevation, is the critical factor. In general, Rhizophora mangle (red mangrove) and Spartina alterniflora can withstand longer periods of inundation than can Avicennia germinans (black mangrove), Laguncularia racemosa (white mangrove), and Juncus roemerianus (black rush). However, there is a good deal of variability. Perhaps the best way to determine proper elevation is to survey the elevations of the source material and existing material adjacent to the proposed planting site. Plantings should then be done at elevations as close to these as possible. Pulver (1976) points out that when transplanting mangroves, each tree should be planted at an elevation similar to that at which it originally grew (regardless of species).

For a successful planting, the site must have low (or no) wave energy as well as proper tidal elevation. High wave energy plantings in Tampa Bay have been unsuccessful (Lewis 1982) and studies elsewhere have also indicated that they are not successful (Hannan 1975; Teas 1977). High wave energy physically undermines and removes plant material before it can become established. The same phenomenon can be seen where established vegetation is undermined by increasing wave energy, as from increased boat traffic.

1. Mangroves. When establishing mangrove species (R. mangle, A. germinans, and L. racemosa), there are three basic options which have been employed. Mangroves can be planted as seed (commonly referred to as a propagule in R. mangle), nursery grown seedlings, or transplant of field stock. Planting of red mangrove propagules (Figure 1A) is the quickest and easiest. Planting of black seeds by shallow (5-10 cm) burying of them has not been successful (Lewis, unpub.). Propagules are collected and then placed so the radicle is in the substrate and the apical meristem is left exposed for growth (Lewis and Dunstan 1976). Nursery seedlings (Figure 1B) are grown from seed usually 6-24 months before planting. In addition to the obvious advantage of planting an older plant, the rootball of a seedling serves as an anchoring device for the plant. Nursery stock is especially desirable when establishing young A. germinans and L. racemosa. These smaller seeds are not planted as easily as R. mangle propagules as they must be anchored or will be washed away.

The majority of mangrove work done in Tampa Bay has been with transplanting of field stock, while larger scale projects (3-5 ha) elsewhere have used propagules of red mangroves (Lewis 1982). The guidelines below for transplanting 0.5 to 1.5 m tall mangroves were developed by Pulver (1976):

1. Top and side branches should be pruned to about two-thirds of their original length.
2. When removing trees, retain a rootball diameter about half of the original tree height.
3. The rootball should be watered and stamped down when replacing soil to insure a seal between the rootball and the sides of the hole.

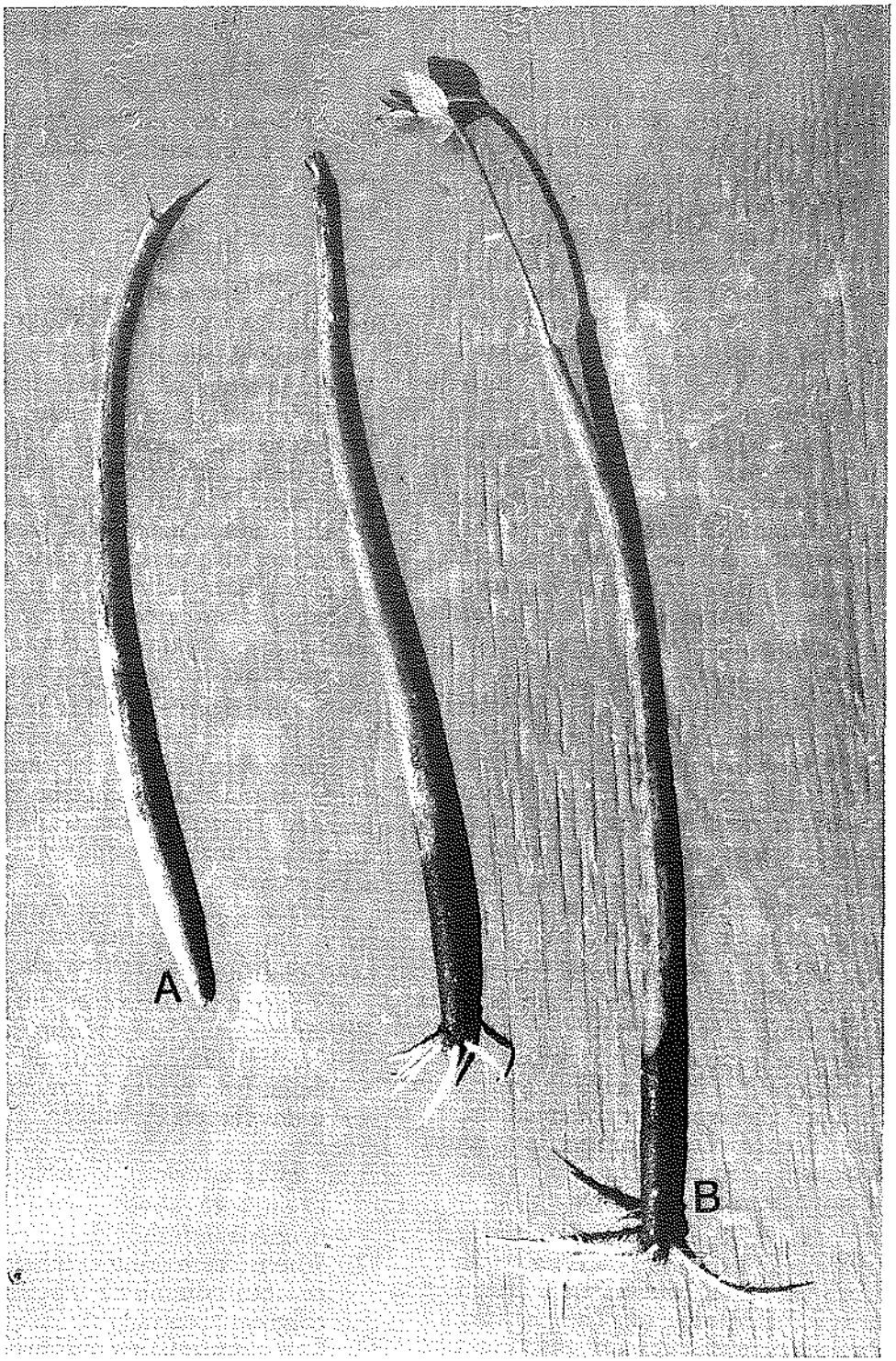

Figure 1. Rhizophora mangle (red mangrove) propagule (A) and seedling (B).

4. Trees should be planted at approximately the same level in the ground and at the same tidal elevation as the tree's source site.
5. Trees should not be planted in unstable substrates.

A variation on this method which has also met with success would be to not prune prior to transplanting (Hoffman and Rodgers 1981).

2. Cordgrass. The methods employed to establish Spartina alterniflora and S. patens are to transplant field stock or install nursery grown stock. Nursery stock is material which is collected in the field, separated, and "grown-out" in the nursery before installation. When transplanting field stock, plant material is collected by removing 15 cm "plugs" of cordgrass (Figure 2A) randomly from a mature marsh with a posthole digger. Each plug contains the intact substrate/rhizome complex as well as aerial portions of the plants. Plugs are removed randomly from established stands, usually at the rate of one plug per m^2, where regrowth eliminates traces of plug removal (Lewis and Lewis 1977; Hoffman and Rodgers 1981).

The plug transplant method involves planting whole plugs intact (Hoffman and Rodgers 1981), whereas the culm transplant method (Lewis and Lewis 1977) involves separation of the plugs into individual culms (Figure 2B) for planting. Many culms can be derived from a single plug, thus decreasing labor in collecting plugs.

3. Rush. Juncus roemerianus or black rush is planted much the same as S. alterniflora. Plugs are removed from mature marsh via posthole digger. Juncus, however, is easily crushed and destroyed by human traffic. Therefore plugs are not removed randomly, but from discrete areas where all traffic can be concentrated and plant material removed before it is damaged (Lewis 1983a). For ease of handling (since Juncus tips are very sharp) and to reduce aerial transpiration, the top one-third of the Juncus blade is usually removed. However, care must be taken to prevent high tide from covering the cut as this has been shown to reduce survival (Coultas 1980).

4. Seagrass. The majority of transplant work performed in Tampa Bay has involved sods, plugs or clumps of Thalassia testudinum (turtle grass). Transplanting stock was obtained from established beds using either shovels, some type of posthole digger, or coring devices. Phillips (1974) referred to work he performed in 1960-61 in which he transported wet burlap covered sods in a flat bottomed boat. Kelly et al. (1971) tested three methods of transporting and anchoring plugs: 1) placing the plugs in tin cans, 2) balling them in burlap, and 3) temporarily bagging the roots and rhizomes in polyethylene, which was removed just prior to planting. This last method was also used by Van Breedveld (1975). Plugs of Syringodium filiforme (manatee grass; Van Breedveld 1975) and sods of Halodule wrightii (shoal grass; Phillips 1974) have also been experimentally transplanted in Tampa Bay.

Initial work by Phillips (cited in Woodburn 1961) indicated that erosion damaged most of his plantings. He used concrete blocks with board or sheet metal barricades to protect the sods from prevailing southeasterly winds. Kelly et al. (1971) also utilized concrete block wave and current barriers around their transplanted plugs. In addition, these authors tested various anchoring devices to hold individual sprigs of T. testudinum in place (e.g. cast iron pipe, construction rod and brick). Some of the sprigs were also placed in a 10% NAPH (naphthalene acetic acid) solution for 1 h prior to transplanting. Van Breedveld (1975) tested 5% NAPH/seawater and 5% Root Dip/seawater solutions for growth promotion and tried polyethylene bags for single shoots and plugs as well as construction rod anchors. The bags were slit along the sides and planted with the plug or sprig.

Recent seagrass restoration work in Tampa Bay has involved the use of T. testudinum seedlings (Durako and

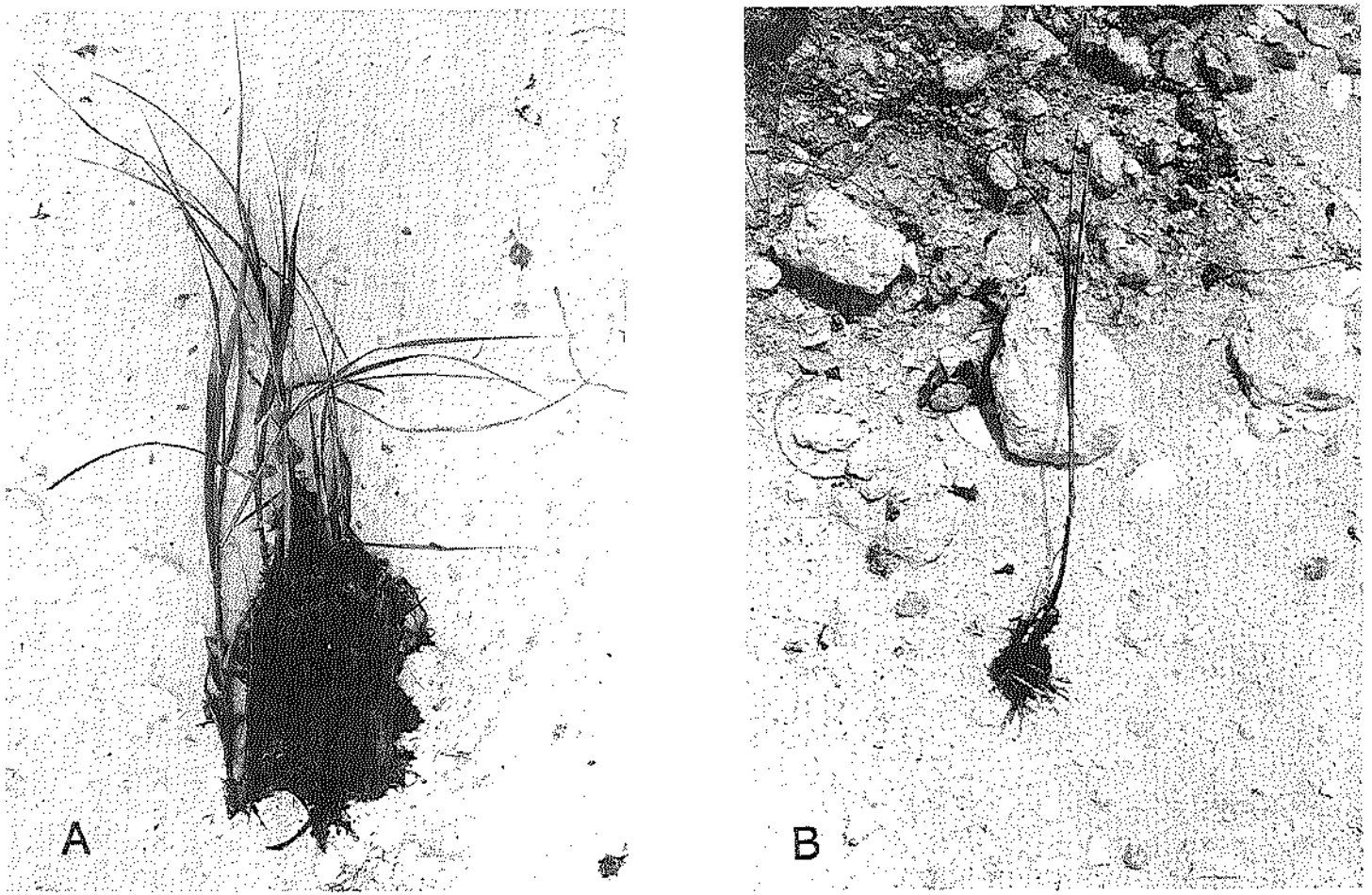

Figure 2. Spartina alterniflora plug (A) and sprig (B) used in habitat restoration projects.

Moffler 1981). The seedlings were cultured in either plastic pots filled with aragonite shell hash or in peat pellets until they had established well developed root systems. The peat pellets provide a suitable growth environment for the seedlings and aid in anchorage when transplanted. These were transplanted after 3 months in laboratory culture. Seedlings cultured for one year in the plastic pots have also been transplanted (Moffler and Durako, unpubl. data). A review of seagrass restoration methodology is provided by Phillips (1982).

RESULTS

Table 1 summarizes the habitat restoration projects in Tampa Bay. The sites can be located on Figure 3. Nineteen separate projects have been undertaken to re-establish the ten species which constitute the major intertidal and subtidal vegetation groups found in Tampa Bay. The success of early smaller test plantings (with as few as 35-45 plants) led to successful large plantings where 8,000-21,000 plants covered up to 3.04 ha for one project (Juncus roemerianus on the Manatee River, Lewis 1983a). The most common reason for restoration in recent years has been mitigation of habitat destruction. Sunken Island is the only site where the reason for planting was habitat restoration per se. Culm or plug transplant was the favored method for cordgrass establishment while most of the work on mangroves was transplanting of mature field stock.

The greatest growth rates are seen for plantings of Spartina alterniflora (up to 1100% for 14 months at Sunken Island). These growth rates over 100% reflect an increase in culm number from the original planting due to the rhizomatous growth typical of cordgrass. Figure 4 shows an example of S. alterniflora planting and 14- and 24-month growth. Within 2 years, the original rows (2 m apart) are obscured due to coalescence of individual plugs. Note the pioneer mangrove seedlings in Figure 4C, which have been trapped in the cordgrass, a process noted by Lewis and Dunstan (1976).

A number of factors affect success of an intertidal planting in addition to wave energy and tidal elevation. If local residents did not want the planting and had access to it, they destroyed the planting. This occurred at the Cockroach Bay site where mangrove transplants were uprooted. The survival at Simmons Park ranged from 0 to 250% over the first 6 months. The low figure reflects areas where fishermen trampled the plugs, while those areas remote to traffic were unaffected and grew normally. At Apollo Beach, the mangrove seedlings were planted while still in plastic containers. The plants died within 9 months due to an inability to produce a sufficient root mass. Neptune Lagoon is an example illustrating the importance of proper tidal elevation. Tidal elevations of the planting were lower than those specified (by approximately 5 cm). As a result, S. alterniflora in the upper portions of the planting survived and coalesced within the expected amount of time while that in the lower areas did not survive. Time of year may have been critical to the mangrove transplants on CDA-D. Of the first 100 trees which were planted in December, all experienced leaf drop during the period from December - February. Only 34 of these trees recovered, indicating that the stress of low temperatures had compounded the stress of transplanting.

The poorest survival rates were on CDA-2D for the original plantings of S. alterniflora nursery stock and Rhizophora mangle seedlings, probably due to poor substrate quality and improper plant installation. While Juncus roemerianus showed a 50% survival rate, it also exhibits a rhizomatous growth habit and has the potential for greater than 100% survival (i.e. spreading). However, spreading is slower than Spartina (Lewis 1983).

Table 2 summarizes the different techniques that have been utilized in transplanting seagrasses in Tampa Bay. The first attempt to transplant

Table 1. Intertidal habitat restoration projects in Tampa Bay to 1982. R = random planting; N/A = not available; + = survival is evident; however, no quantity available. PURPOSE: TP = test planting; M = mitigation; HR = habitat restoration; EC = erosion control. TECHNIQUE: P = propagule; CT = culm transplant; NS = nursery seedling; T = transplant; PT = plug transplant.

Project Site (Reference)	Date Planted	Plants Used	Purpose	Number Planted	Technique	Area Covered	% Survival /Time (mos.)
Howard Frankland (Savage 1972)	Sep 71	R. mangle	TP	61	NS	R	67.2/3
Terra Ceia (Savage 1972)	Apr 71	R. mangle	TP	5	T	R	60.0/6
	Apr 71	A. germinans	TP	5	T	R	80.0/6
	Apr 71	L. racemosa	TP	5	T	R	0/6
Mullet Key (Pulver 1976)	Mar 73	R. mangle	TP	40	T	R	100/12
	Mar 73	A. germinans	TP	40	T	R	95.0/12
	Mar 73	L. racemosa	TP	40	T	R	100/12
Fishhook Spoil (Lewis and Dunstan 1976)	Jul 74	R. mangle	TP	100	P	10 m^2	25/72
(Lewis and Dunstan 1977)	Sep 76	S. alterniflora	TP	36	CT	36.0 m^2	741/10
Archie Creek (Lewis et al. 1979)	May 78	S. alterniflora	M	2,127	CT	2127 m^2	75/12
Apollo Beach (Fehring et al. 1979)	Jun 78	R. mangle	M	275	NS	275 m^2	74.5/5
Cockroach Bay (Durako, unpub. data)	Sep 78	R. mangle	M/TP	45	T	400 m^2	88.9/6
	Sep 78	A. germinans	M/TP	45	T	400 m^2	51.1/6
	Sep 78	L. racemosa	M/TP	63	T	400 m^2	66.7/6
Neptune Lagoon (Fehring et al. 1979)	Dec 78	S. alterniflora	M	700	PT	700 m^2	64.0/5

Table 1 continued.

Project Site (Reference)	Date Planted	Plants Used	Purpose	Number Planted	Technique	Area Covered	% Survival /Time (mos.)
Sunken Island (Hoffman and Rodgers 1981)	Mar 79	S. alterniflora	HR	7,261	PT	1.64 ha	1100/14
(Hoffman, unpub. data)	Oct 79	S. patens	HR	300	CT	300 m^2	230/3
CDA-D	Jun 79	A. germinans	M	947	T	0.32 ha	63.0/13
(Hoffman and Rodgers 1981)	Jun 79	L. racemosa	M	566	T	0.19 ha	37.0/13
Palm River	Jun 79	S. alterniflora	EC	1,050	PT	326 m^2	20.0/6
(Courser and Lewis 1981)	Jun 79	P. vaginatum	EC	400	PT	368 m^2	100/6
CDA-2D	Dec 79	S. alterniflora	M	N/A	NS	N/A	0/2
	Dec 79	S. patens	M	N/A	NS	N/A	+/2
	Dec 79	R. mangle	M	N/A	NS	N/A	0/2
Manatee River (Lewis 1981)	Jun 80	J. roemerianus	M	21,000	PT	3.04 ha	50/22
Channel A (Hoffman, unpub. data)	Sep 80	S. alterniflora	EC	8,091	PT	0.81 ha	235/6
Simmons Park (Hoffman, unpub. data)	Sep 80	S. alterniflora	EC	7,999	PT	0.80 ha	97.0/6
CDA-2D (Philp, unpub. data)	Jun 81	S. alterniflora	M	N/A	PT	2.0 ha	+/12

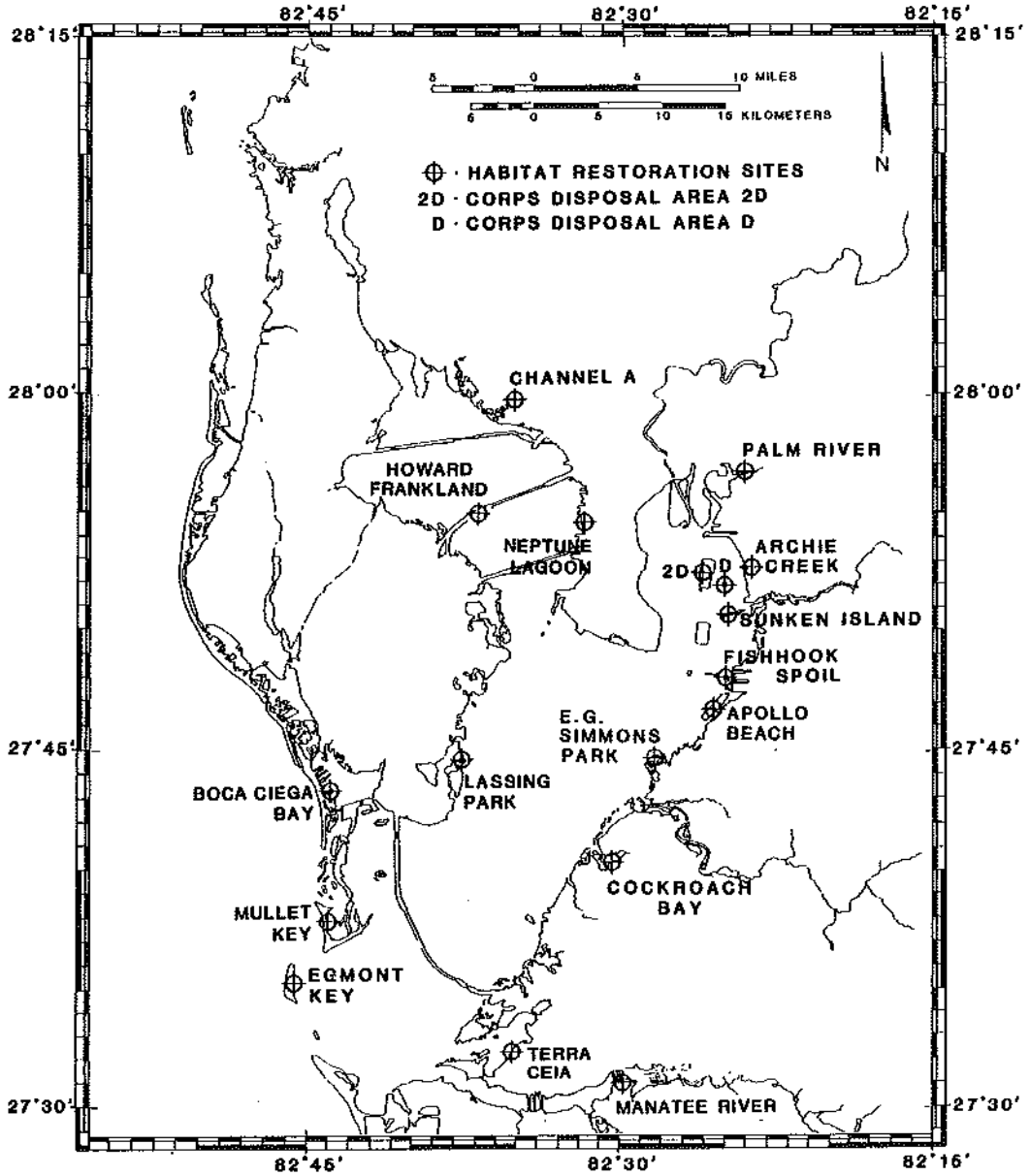

Figure 3. Habitat restoration project sites in Tampa Bay.

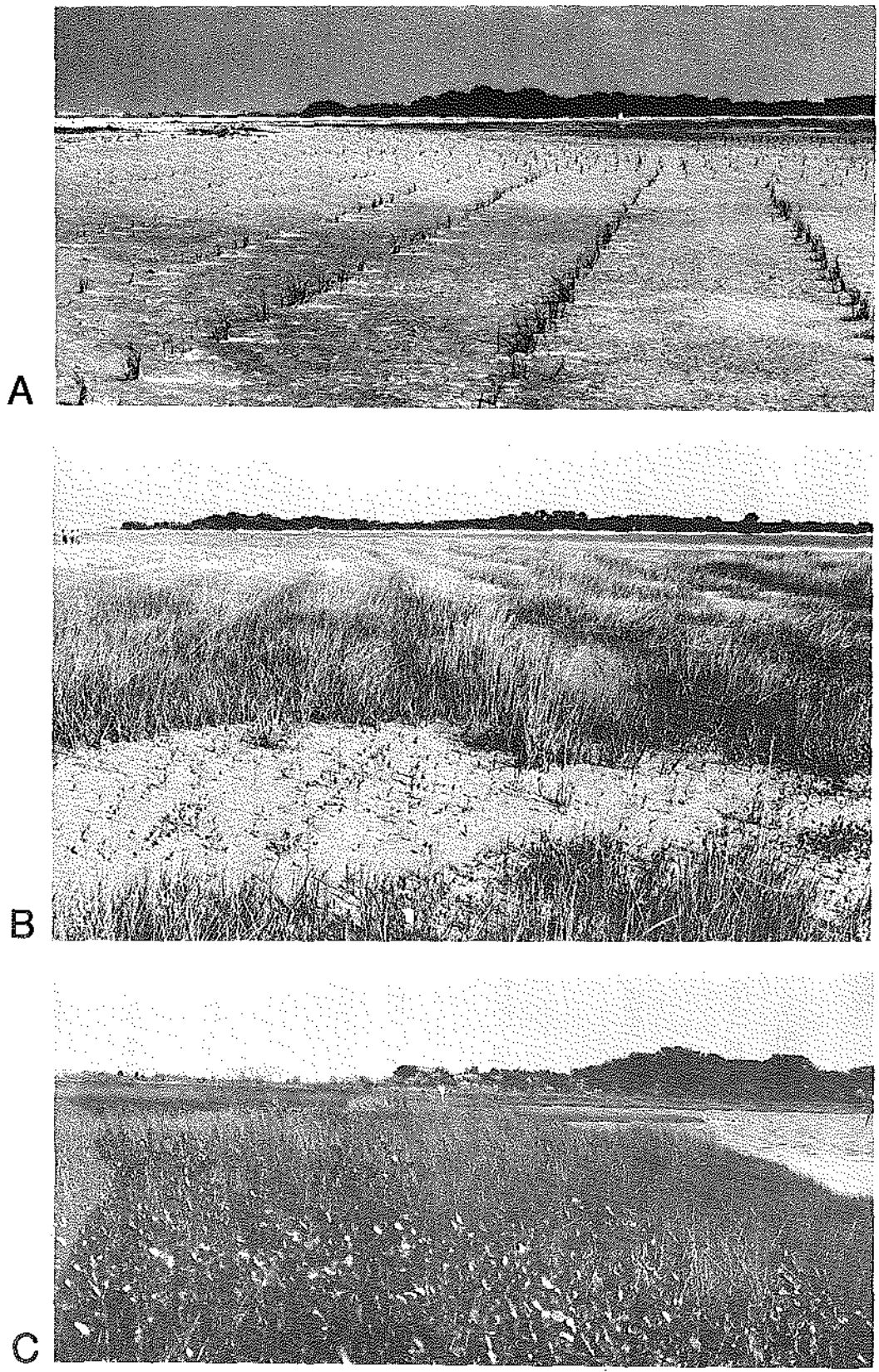

Figure 4. Spartina alterniflora at zero (A), 14 (B) and 24 (C) months after planting.

Table 2. Seagrass experimental plantings in Tampa Bay to 1982.

Project site (Reference)	Date	Species	Number Planted	Technique	% Survival	Comments
Tampa Bay (Phillips 1974)	Aug 1960	T. testudinum H. wrightii	52	sods (0.1 m^2)	0 moderate	erosion problems prompted use of wood or sheet metal barricades.
Boca Ciega Bay (Kelly et al. 1971)	Jul 1966	T. testudinum	120	plugs (400 cm^2)	0-70	plugs anchored in cans more successful when protected by concrete enclosures.
	Apr 1967	T. testudinum	60	sprigs	0-100	construction rod best anchor; NAPH induced heavy rooting.
Lassing Park (Van Breedveld 1975)	Feb 1972	T. testudinum	10	plugs (single row)	100	unanchored.
			60	shoots (6 rows)	0-100	construction rod better than polyethylene bags as anchors.
Cats Point (Van Breedveld 1975)	Mar 1972	T. testudinum	60	plugs (2 rows - 10; 8 rows - 5)	30-100	various anchors tested, high energy site.
Lassing Park (Van Breedveld 1975)	Mar 1972	T. testudinum	40	plugs (single row)	15-37	site exposed at spring low tides.
Point Brittany (Van Breedveld 1975)	Jul 1972	T. testudinum	20	plugs (4 rows)	20	unanchored; deep, high turbidity site.
North of Bayway (Van Breedveld 1975)	Aug 1972	T. testudinum	40	plugs (8 rows)	50-60	unanchored; aerobic sediments.

Table 2 continued.

Project site (Reference)	Date	Species	Number Planted	Technique	% Survival	Comments
Lassing Park (Van Breedveld 1975)	Aug 1972	T. testudinum	60	plugs (6 rows)	100	unanchored; spread and formed massive bed.
	Sep 1972	T. testudinum	11	plugs (circular)	27	unanchored; 2.5 m spacing too large; aerobic sediments.
	Oct 1972	T. testudinum	10	plugs (single row)	100	unanchored, 60 cm spacing, lower water temperatures.
	Nov 1972	S. filiforme	10	plugs	100	unanchored, rapid spread.
	Dec 1972	T. testudinum, S. filiforme	10	plugs (single row alternating)	100	unanchored.
Boca Ciega Bay (Durako and Moffler 1981)	Nov 1980	T. testudinum	42	seedlings	0	site was physically disrupted, water turbid.
Egmont Key (Moffler and Durako unpub.)	Jul 1981	T. testudinum	24	seedlings	4	Tampa Bay seedling only survivor, site disturbed.

seagrasses in the bay found that sods of H. wrightii were moderately successful, but sods of T. testudinum completely failed due to substrate erosion (Phillips 1974). The use of barricades for erosion control improved survival success in higher energy areas. Erosion of transplants has proved to be a major problem locally. The number of techniques that have been tested to overcome this problem reflects its complexity. Kelly et al. (1971) attained complete or partial success in 7 of 14 techniques they tested. All plugs that were balled in burlap failed, presumably due to toxic decomposition products of the decaying burlap. Plugs anchored in tin cans were 50% successful at their control site, but only 15% successful at a finger fill canal site, where concrete block barriers were required as erosion control. Plugs transported to the site in polyethylene bags and then directly transplanted were less successful (3:5) than the use of tin cans. Construction rods were found to be the most effective device for anchoring sprigs, and rods used in conjunction with the hormone treatment resulted in 100% success. Pipe and brick proved to be poor anchors as well as being more difficult to handle in the field. All new short shoots produced by the transplants arose from rhizome apices, which also occurred in earlier tank cultures (Fuss and Kelly 1969).

While early work concentrated on anchoring devices, Van Breedveld (1975) studied the importance of substrate in the success of Thalassia transplants. He found that transplanting clumps of 4 to 7 short shoots including sediments was the most successful method. In unfavorable sediments the clumps should be closely spaced; in favorable areas they can be planted up to 30 cm apart. He recommended transplanting when water temperatures are below 21°C and found no increase in survival or growth when plant hormones were used. Also, the S. filiforme transplants he performed survived and exhibited relatively rapid growth.

The lack of success in initial transplanting of laboratory cultured T. testudinum seedlings from the Florida Keys, Biscayne Bay and Tampa Bay to a site in Boca Ciega Bay was mainly due to physical disturbance of the site as well as to high water turbidity (Durako and Moffler 1981). Many of the peat pellets were knocked out of the sediments, which prevented an accurate assessment of the technique. One year old seedlings that were transplanted to Egmont Key exhibited rapid initial growth and appeared healthy (Moffler and Durako, unpubl. data). After approximately 50 days, leaf areas were drastically reduced due to grazing on the blades. The plot was then buried by what appeared to be propwash. Only one seedling from Tampa Bay survived the burial and this plant continued to grow, producing a second short shoot 8 months after being transplanted. However, seedlings from the Florida Keys had produced additional short shoots after only 21 days from transplanting, indicating variability between populations.

COMMENTARY

There has been a relatively large volume of experimental and mitigative habitat restoration work in Tampa Bay. No doubt, factors contributing to this include interest of local private companies, proximity of the Florida Department of Natural Resources (FDNR) Marine Research Lab, support of the Tampa Port Authority, and a labor force made available for a short time by the Young Adult Conservation Corps. But this is not to minimize the fact that there has been and continues to be a genuine need for restoration of habitat in Tampa Bay. The total restored area for all projects in Tampa is approximately 9.1 ha, just 0.03% of the habitat estimated to have been lost in the last 100 years (Lewis et al. 1979).

The primary reasons for the plantings undertaken in Tampa are varied; however, they all do provide habitat. The quality of the restored habitats varies substantially. All of the established plant material provides primary and secondary production to the

The apparent success of several large scale seagrass transplanting projects in Biscayne Bay, Florida, utilizing seeds and seedlings (Thorhaug 1974, 1979), indicates that this technique may be the most suitable for projects involving T. testudinum. Transplanting seed material over large distances is feasible and the use of seeds is apparently nondestructive to source beds, although the contribution of sexual reproduction in maintenance of established beds is unknown (Durako and Moffler 1981). Recent work in the Florida Keys has suggested the planting of T. testudinum seedlings in an earlier successional stage meadow containing H. wrightii plugs (Derrenbacker and Lewis 1983). This technique was found to be one of the least expensive ($5,700/acre) methods tested (Continental Shelf Associates, Inc. 1982).

The low success of the initial transplants using seed material of T. testudinum in Tampa Bay should not be discouraging as physical disturbances were implicated as the major causes of failure. More research on these techniques is presently being carried out at the FDNR Marine Research Lab. Ease of sowing, transport and handling of the seedlings and peat pellets suggests that they may offer a viable alternative to transplanting vegetative material. Future research should center on lowering costs while increasing the rate of coverage of transplants and determining the overlying water quality parameters necessary to support transplanted seagrass material. Open water cultivation of seedlings which would alleviate the need for laboratory culture facilities would substantially reduce costs. The use of nutrients and hormones to increase growth rates and possibly increase reproductive success may also have promise in reducing the number of transplant units required in mitigation projects. Despite the fact that over 20 years have passed since the first seagrass transplanting was attempted in Tampa Bay, seagrass restoration or mitigation can still be considered to be in its infancy.

SUMMARY

Stress on the Tampa Bay system has caused substantial loss of emergent and submergent wetland vegetation (total loss of 29,643 ha) with subsequent loss of habitat. Nineteen projects which involve re-establishment of one or more of the three mangrove species, cordgrass, black rush, and seagrass species are discussed. The primary reason for these plantings has been mitigation of some habitat destruction, while much of the earlier work was to test techniques. Historically, the most successful plantings have been those involving Spartina alterniflora.

The created habitats range from minimal value (for small, discrete plantings in areas of frequent human traffic) to habitat used extensively by larger fauna such as colonial waterbirds (at large continuous plantings in remote areas). A cost analysis indicates that Spartina alterniflora is the least expensive means of habitat restoration at $4,971/ha while mangrove transplants are the most expensive, $12,479-62,943/ha.

It is recommended that further research be done in the areas of nursery and propagation techniques, especially air-layering and seed storage and use. Cost information should be included when reporting on projects to enable a full evaluation of the feasibility of the project. Areas for future habitat restoration projects need to be chosen carefully. Efforts should be put forth to create large, continuous plantings which can be fully utilized by fauna as this would maximize benefits while being less expensive on a per plant and unit area basis.

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ARTIFICIAL REEFS IN TAMPA BAY

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Artificial reefs have long been known to be effective at concentrating benthic fish species into an area easily accessible to fishermen. These reefs have also been shown to increase the actual primary production of the water column when built in the photic zone (Mathews 1966). Recent studies have also shown that an artificial reef can actually support a larger total fish biomass than a natural reef, even a coral reef (Smith 1979). Most artificial reefs in this country have been built in coastal waters out on the continental shelf at depths from 10 to 50 meters. Artificial reefs in estuarine waters have been built in Florida and Texas in the past, but the results have generally fallen short of the great increases in fish populations occurring with offshore reefs. Tampa Bay was the site of some of these early inshore reefs, and has also been the site of a more recent larger scale reef building project. This paper will examine these early reefs as a comparison of how recent increases in our understanding of reef dynamics has improved the effectiveness of artificial reefs in shallow waters.

HISTORY

The first reef built in Tampa Bay was a car body reef built in 1959 by a local fishing club. This reef was built prior to the State's permit regulation, so no record of its exact location could be found; however, its construction was reported in the St. Petersburg Times (Marston 1959). This reef apparently was effective for several years, but the effective life span of car body reefs is rather short, so no traces of this reef remain today. No records can be found to indicate that any site studies were conducted prior to the construction, nor any evaluation of its effectiveness other than to say fish were caught in the area afterwards for several years.

In the early 1960s, the City of St. Petersburg began attempts to permit a reef in Tampa Bay. They had to obtain an exemption from a Florida statute that controlled dumping into estuarine waters, but this was finally accomplished in April of 1965 by the legislature, and permits were obtained in November of 1965. There were two sites permitted, one off Pinellas Point in Lower Tampa Bay and another farther up the Bay off the Vinoy Hotel in Old Tampa Bay (Schug 1978). The first site used was the one off Pinellas Point, and was a joint project with the City of St. Petersburg and Pinellas County providing the funding. A local marine contractor was paid to construct 4,425 3-tire units, held together with reinforcing rods and filled with concrete ballast in the bottom. These 3-tire units were dropped from a barge into some 3 to 5 meters of water, but again there is no indication that any type of site study was conducted either prior to the drop or after its construction. The site off the Vinoy Hotel was completed in 1968 with a total of 4,400 of the same 3-tire units.

In 1973 the author began work on a county-wide artificial reef program. The project was to include artificial reefs adjacent to the principal municipalities of Pinellas County in a joint City-County program. All 10 sites were carefully selected after underwater surveys by the author and Greg Smith, a diver/biologist from the Department of Natural Resources Laboratory in St. Petersburg. The Tampa Bay site was the most difficult to locate because of the general occurrence of soft substrate in the deeper waters of that section of the Bay. Most areas surveyed have 0.5 to 1.5 m of soft silt-clay bottoms that were unsuitable for reef construction. The site finally selected was northeast of the

St. Petersburg Municipal Marina and east of Coffeepot Bayou. The depth was 10 to 12 m with less than 0.25 m of soft material over a sand/shell substrate. The original 1968 drop site was surveyed, but no trace of the 4,000+ tire units could be found. The first material placed on this new reef was a 35' steel hull abandoned in the City Marina, and then full scale development began in 1977 and continues to the present.

In 1980 the Hillsborough County Solid Waste Department became interested in the possibility of using artificial reefs in Tampa Bay as a means of disposal for scrap auto tires. These tires are a problem in any landfill operation, and the county contacted the author for assistance in site selection and the necessary biological reports for permitting (the author directs the Florida Sea Grant Artificial Reef Resource Team that has provided such help to local groups since 1977). Three sites were selected: one off Courtney Campbell Causeway; another south of MacDill Air Force Base; and a third up in Hillsborough Bay. This plan, however, was placed on hold after the county realized that using these tires for a reef was not cheaper than the landfill method of disposal. This was firmly established by Eila Hanni in a Florida Sea Grant Technical Paper published in 1977 (Hanni and Mathews 1977).

Elsewhere in the state, Wakulla County in 1963 built a small tire reef in the waters of Apalachee Bay in the panhandle. The author did some pre-drop surveys while in graduate school at Florida State University and made several post-drop dives to evaluate the reef's effectiveness. The water was just under 8 m deep, but very large populations of black sea bass (Centropristes striata) were attracted to the tire units. This reef was "lost" to local fishermen for some 15 years but was relocated by divers from the Florida State University Marine Lab in 1981 and is still providing very effective fish habitat.

Dade County has recently built an inshore artificial reef in upper Biscayne Bay along a causeway with Florida Department of Environmental Regulation funds to try to improve the poor quality of the estuary after many years of dredge and fill activity have damaged the bay greatly. So far the project has had only limited success, probably in part because the site chosen has very poor tidal circulation, and most of the funds were spent on the construction of the fishing pier rather than on the actual reef materials around the pier.

In Washington State, the building of artificial reefs has been funded by the state (over $3,000,000 in 1982) and large scale reefs have been built in the inshore waters; however, the conditions there are in no way similar to what occurs in Florida on Tampa Bay. Texas also has had some limited success with inshore reefs.

COMPARISONS: PINELLAS POINT VS ST. PETERSBURG REEF

A comparison of these two reefs will provide much insight into the problems in building artificial reefs in estuaries and inshore waters. The Pinellas Point reef was constructed by well-meaning citizens and fishermen, but no studies were made of the bottoms available prior to the start of contruction. A location was selected that was easily accessible to fishermen, one that was apparently already in use by fishermen on a regular basis. The site was adjacent to marine grass beds, and exposed to some wave action from the open parts of Tampa Bay. The 3-tire units had insufficient concrete ballast for the shallow (3 to 5 m) depth and the tire units soon began to shift off the site. The reef buoys were soon lost, so local shrimp boats were unable to determine exactly where the reef site was, and many of the tire units were pulled off station by their trawls. Shrimp boat captains tell of these tire units being caught in their trawls some distances from where the original site was permitted. Needless to say, this experience did not make local commercial fishermen very supportive of future artificial reef construction. While

the reef was on station however, fishermen did report increased catches of sea bass, trout and grouper. A few local fishermen today still fish the old site waters and still report catches of these species; several underwater surveys by the author could not locate any of the original tire units, but the large area of the original permit site prevented a complete meter-by-meter bottom survey. While some of these tire units are probably still on site, embedded into the bottom, the general effect of the artificial reef has long since been lost.

However, the reef off the Bayfront was carefully surveyed by scientists prior to the start of construction. The bottom substrate was a thin silt overlay on a firm sand/shell bottom. Since the start of construction in 1976 this reef has received: 498 concrete pilings, many coming from the removal of the old Gandy Bridge span; 3 steel barges donated by local marine contractors; 2 steel lifeboats; and 162 sections of concrete culvert. Several thousand split tires were placed on this reef from a single barge load dropped during a demonstration of reef building during an artificial reef conference held at Bayboro in 1977. To date, a total of 3,226 tons of reef materials have been placed on this reef, most by local marine contractors during seawall removal or bridge construction projects. As far as the number of fish attracted/taxpayers' money spent, this is probably one of the most effective reefs in the state because very little county money has gone into its construction.

The turbid nature of the waters of this part of Tampa Bay has prevented making the transect surveys that we use on the other reefs off Pinellas County so our evaluation of the reef's effectiveness has come from questionnaires distributed to the fishermen by the Pinellas County Artificial Reef Program staff. Those responding report good catches of trout (Cynoscion nebulosus), whiting (Menticirrhus littoralis), catfish (Bagre marinus), sheepshead (Archosargus probatocephalus), black grouper (Mycteroperca bonaci), and even a few medium-sized jewfish (Epinephelus itajara), and several species of small sharks. A single fisherman reported a total of 161 trout in 8 trips to this reef.

Comparing these two reefs indicates that much care must be placed in the original site selection. With inshore artificial reefs the bottom selected must be free of existing benthic communities that would be damaged by the addition of reef materials. Grass bottoms are already very productive, and nothing can be gained by destroying one productive marine community to replace it with another. The Keys Rotary Reef is a good example. Instead, these reefs can be more effectively used to improve otherwise barren bottoms which are common in most estuaries. Soft bottoms are usually unsuitable due to the loss resulting from sinking into the bottom. Once a suitable site has been selected, the reef materials must be chosen with care to insure their stability on the bottom from wave action and currents. If reefs are built in an area with strong tidal currents, some scouring can occur which could undermine the reef materials and result in some loss of effectiveness. On the other hand, reefs should not be built in areas with poor tidal circulation, i.e. Miami, because much of the fouling communities so important to the reef food chains are filter feeders requiring a steady stream of plankton-filled water for survival. The concrete and steel materials used on the St. Petersburg reef are of large diameter and high density, so there is no chance of their shifting off site from wave action. Low density materials like tire units are probably best utilized only on deeper water reefs where the wave energy is low to prevent their shifting off this site and becoming a problem elsewhere.

CONCLUSION

This brings us to the question, do artificial reefs have a positive impact on estuarine waters like Tampa Bay? The results of this study and many others over the last few years would indicate

that these reefs do increase habitat for benthic invertebrates and fish, and when built in the photic zone they also provide substrate for benthic algae growth that increases the food available up the food chains leading to the higher trophic levels. The limited observations of these inshore reefs also indicate that they have a very heavy juvenile population of many important food and game fish species, so there can be no doubt that they are serving as more than just a concentrator of existing species as was originally thought.

With the removal of much of the old Skyway Bridge in the next few years, there will be additional reef materials available, and already the plans are being made to build additional reefs in Tampa Bay using this material. Hopefully, the State will take the time to make adequate pre-construction studies to insure that these reefs do in fact improve the ecology of the Tampa Bay estuary.

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BASIS
(Bay Area Status in Summary)

Once Tampa Bay had five subdivisions,
Till Robin decided to make some incisions;
And change it to eight, so all could agree
On the name of each station, from McKay to the Key.

We're told that it's drier than it used to be,
And the last major storm came in 1903;
So the people got bold and built on the shores,
But the sea level's rising, and when it rains here it pours.

The Bay it is shallow, mostly quartz, sand and shell,
So the Port and the Corps are out dredging like hell;
To ship out the phosphate, and when that is gone,
They'll ship it back in, 'cause there will be none.

Fresh water is moving under the Bay,
Salt water intrudes from March until May;
Where the two meet, we are not sure,
There's plenty of it, but it is not pure.

Nitrates and phosphates in Hillsborough abound,
But under the seagrass no fish can be found.
The plankton seem healthy, just doing their thing,
Till eutrophication starts in late spring.

Red tide takes it toll,
It zaps all biota;
But according to Joe,
They return to their quota.

From Ernie we learned the importance of leaves,
That fall from the mangroves each time there's a freeze;
But where do they go? And who benefits?
Out to the Gulf? Do they break in small bits?

There's fungus among us,
And microbes galore.
If we eat oysters,
We might drop to the floor.

Jeff caught some plankton, in nets from a boat,
But only the ones that manage to float.
He gave a fine talk, we all would agree,
But to take on Joel Hedgpeth's like swatting a bee.

Jim found some live bottoms,
But not in the Bay;
They were down at a bar
Near Terra Ceia.

There are more gulls and terns than steaks down at Berns,
And the Spoonbill and Ibis look fine.
There's more habitat than fleas on a mat,
Let's hope that the eagle returns.

Don't be too hard on TECO and "Gard,"
For causing the high delta "tees."
The temperature's fine, in mid-winter time,
For warming the Bay's manatees.

Here's thanks to Kumar for the rides in his car,
And to Ane for our great morning run.
And to your fine Bay, may it flourish each May,
And soak up the rays of the sun.

My last word to you, is to hang on like glue,
Your Bay is a rare precious gem.
With BASIS the cure, you've cleaned up your sewer,
Sincerely, your tired rapporteur.

James W. Rote
May 6, 1982