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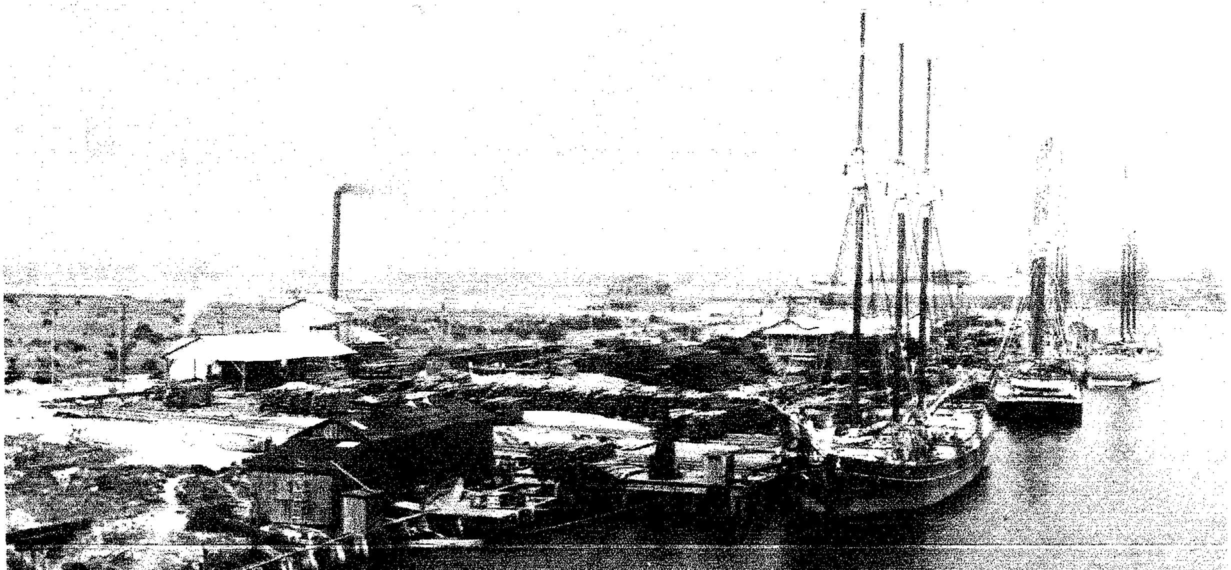
THE ECOLOGY OF TAMPA BAY, FLORIDA:
AN ESTUARINE PROFILE



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Cover photographs:
Upper left: Brown pelican (*Pelecanus occidentalis*) on a nest in mangroves in Terra Ceia Bay.
Upper right: Tampa baseball player Dazzy Vance (left) and local guide Ed Alexander (right) with redfish (*Sciaenops ocellatus*), December 1931.
Lower: View of ships at the docks of the old Lee Terminal on Tampa Bay, October 13, 1919.

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THE ECOLOGY OF TAMPA BAY, FLORIDA: AN ESTUARINE PROFILE

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PREFACE

The width, depth, and perimeter of Tampa Bay have changed over the past century due to natural and human causes, and so have the numbers, kinds, and distributions of plants and animals in the bay. Society's uses of the bay and attitudes toward it also have been changing, and these changes can be read in the bay's past and present condition.

We are entering a new era in a series of bay-management eras. At first, the bay was a completely natural ecosystem, affected little by the small, prehistoric human populations that lived along the shore. In the second era--beginning with Spanish fishing camps and ending with the demise of sturgeon late in the 19th century--the bay's natural fertility was exploited without harm to the underlying ecosystem. The bay enabled and richly subsidized the region's settlement and made fortunes for many poor settlers. Exploitation of the bay's resources continued into the third era, which was a period when projects for public and private gain began to affect the system. Local areas or resources of the bay were declining in area of productivity, but the losses were imperceptible against the relatively limitless expanse of adjacent bay and coastal reaches.

The third era began a period of resource erosion that continues to the present, but was different from modern times because there was no basis in science or law for understanding or controlling impacts. The science of ecology would not develop for decades and there was no bay attitude comparable to a farm land ethic which could foresee the long-term, cumulative consequences of superficially beneficial projects.

The fourth era arose about 25 years ago when the overall condition of the bay was considered to be failing or in very poor condition. This era was significant for signalling the treatment of the bay as a conceptual unit and ecological entity: a single, albeit immense, landscape element. This era was also marked by scientific studies of things and events in the bay, and by the advent of rudimentary health and environmental regulations. Unfortunately, the fourth era has been a period of extensive resource decline, and recent events seem even less acceptable given heightened awareness of the bay's working and importance and the numerous laws and regulations which are popularly believed to prevent such damage.

The new era in bay management is perhaps the most critical in the history of human settlement in the region because events of the new era may be irreversible, at least compared with those of the past. On the one hand, assaults to the bay from physical changes, chemical wastes, or stock depletion may occur with heretofore unheard-of magnitudes. On the other hand, there is widespread support for preserving the bay and for restoring parts of it to cause a net improvement in its existing condition. Within liberal limits it is entirely within our ability to make Tampa Bay whatever we choose. Hopefully the information in this Estuarine Profile will help as society makes that choice. We concur fully with a conclusion of the Tampa Bay Area Scientific Information Symposium (BASIS) that "with proper management and restoration, the Bay would become perceptibly more productive and valuable to its users."

We are grateful to the resource managers, environmental specialists, regulatory agency staff, scientists, and students who have helped to generate information about Tampa Bay during the past 30 years. The job of writing this profile was simplified greatly by the authors of BASIS reports, and by subsequent information produced by the Tampa Bay Regional Planning Council, Agency on Bay Management, and other offices of government. For their roles in fostering the wise stewardship of Tampa Bay we also wish to dedicate this volume to Melvin Anderson, John V. Betz, Sally Casper, Betty Castor, Don Castor, William D. Courser Lamar Cox, Mary Grizzle, Robert King, Plant Norton, Jan Platt, Bernard E. Ross, Joseph L. Simon, Roger Stewart, Sally Thompson, and William H. Taft.

In the time that has passed between the preparation and publication of this estuarine profile, progress has been made on several fronts in Tampa Bay. Although bay management has improved, our original conclusions regarding the shortfalls of existing programs are still basically correct. Progress has also been made in some areas of bay science. For example, new and useful studies of sediments have recently ended (and others have begun) in Hillsborough Bay, and a major basin-wide study of the Little Manatee River is underway. In addition, a major new program to assist Tampa Bay and other Florida surface-water management (the Surface Water Improvement and Management or SWIM Bill) passed and received funding during the 1987 legislative session. A NOAA "Estuary of the Month Seminar" was held in Washington, D.C., in December 1987 on Tampa and Sarasota Bays, and many recent bay projects will be summarized in the proceedings of the seminar, scheduled for release in 1988.

Lastly, this profile was one of several products produced as a result of a 3-year cooperative study by the U.S. Fish and Wildlife Service and the Tampa Port Authority. Other products include:

Auble, G.T., A.K. Andrews, D.B. Hamilton, and J.E. Roelle. 1985. Fish and wildlife mitigation options for port development in Tampa Bay: results of a workshop. U.S. Fish Wildl. Serv. NCET Open File Rep. 85-2. 36 pp.

Dial, R.S., and D.R. Deis. 1986. Mitigation options for fish and wildlife resources affected by port and other water-dependent developments in Tampa Bay, Florida. U.S. Fish Wildl. Serv. Biol. Rep. 86(6). 150 pp.

Fehring, W.K. 1986. Data bases for use in fish and wildlife mitigation planning in Tampa Bay Florida: project summary. U.S. Fish Wildl. Serv. NWRC Open File Rep. 86-6. 38 pp.

Kunneke, J.T., and T.F. Palik. 1984. Tampa Bay environmental atlas. U.S. Fish Wildl. Serv. Biol. Rep. 85(15). 78 pp + 38 maps (A1 through B21).

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CONVERSION TABLE

Metric to U.S. Customary

Multiply	By	To Obtain
millimeters (mm)	0.03937	inches
centimeters (cm)	0.3937	inches
meters (m)	3.281	feet
meters (m)	0.5468	fathoms
kilometers (km)	0.6214	statute miles
kilometers (km)	0.5396	nautical miles
square meters (m^2)	10.76	square feet
square kilometers (km^2)	0.3861	square miles
hectares (ha)	2.471	acres
liters (l)	0.2642	gallons
cubic meters (m^3)	35.31	cubic feet
cubic meters (m^3)	0.0008110	acre-feet
milligrams (mg)	0.00003527	ounces
grams (g)	0.03527	ounces
kilograms (kg)	2.205	pounds
metric tons (t)	2205.0	pounds
metric tons (t)	1.102	short tons
kilocalories (kcal)	3.968	British thermal units
Celsius degrees (°C)	1.8(°C) + 32	Fahrenheit degrees

U.S. Customary to Metric

inches	25.40	millimeters
inches	2.54	centimeters
feet (ft)	0.3048	meters
fathoms	1.829	meters
statute miles (mi)	1.609	kilometers
nautical miles (nmi)	1.852	kilometers
square feet (ft^2)	0.0929	square meters
square miles (mi^2)	2.590	square kilometers
acres	0.4047	hectares
gallons (gal)	3.785	liters
cubic feet (ft^3)	0.02831	cubic meters
acre-feet	1233.0	cubic meters
ounces (oz)	28350.0	milligrams
ounces (oz)	28.35	grams
pounds (lb)	0.4536	kilograms
pounds (lb)	0.00045	metric tons
short tons (ton)	0.9072	metric tons
British thermal units (Btu)	0.2520	kilocalories
Fahrenheit degrees (°F)	0.5556 (°F - 32)	Celsius degrees

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Mary Parks and Anne Twitchell provided valuable library assistance at Mote Marine Laboratory. Laurie Fraser processed several drafts of text, and Denise Latulippe, Bob Whitman and Robert Dixon produced the figures. Data and reports were provided by Carl Goodwin, U.S. Geological Survey, Tampa; Rick Wilkins, Hillsborough County Environmental Protection Commission, Tampa; and the Southwest Florida Water Management District. Authors of review papers presented at the 1982 Tampa Bay Area Scientific Information Symposium deserve special thanks for distilling the enormous body of original literature upon which this profile is based. William Fehring, Benjamin McPherson, Joseph L. Simon, Michael Heyl, Joseph Carroll, Jr., Lorna Sicarello, Millicent Quammen, and Edward Pendleton provided constructive criticism of early drafts. Kate Lyster and Beth Vairin edited the draft. Sue Lauritzen was responsible for layout design and graphics assistance.

CHAPTER 1. INTRODUCTION

1.1 TAMPA BAY AS A NATURAL UNIT

Tampa Bay, Florida's largest (1,030.8 km^2) open-water estuary, is a y-shaped embayment located on the west coast of the peninsula between latitude 27°30' and 28°00'N (Figure 1). The bay receives drainage from nine named rivers or streams (Table 1) in a watershed that covers approximately 5,700 km (Figure 2).

Tampa Bay is subdivided into seven named subunits: Old Tampa Bay, Hillsborough Bay, Middle Tampa Bay, Lower Tampa Bay, Boca Ciega Bay, Terra Ceia Bay, and the Manatee River (Figure 3, Table 2; Lewis and Whitman 1985). Other common place names used in this report are indicated in Figure 3.

The origins of the bay, structural or erosional, have not been clearly defined. White (1958) hypothesized that Hillsborough Bay and Lower Tampa Bay may have been formed by erosion in the valley of the Hillsborough River at a lower stand of sea level. Old Tampa Bay has no apparent relationship to any large stream and may have been connected to the Gulf of Mexico by the Lake Tarpon Trough (Hutchinson 1983).

1.2 POLITICAL SUBUNITS OF THE BAY

The political subdivisions bordering the bay are shown in Figures 2 and 3; included are three major counties (Hillsborough, Pinellas, Manatee), three additional counties (Pasco, Polk, and Sarasota) that lie partly in the watershed, and three major cities (St. Petersburg, Tampa, and Bradenton). Total population in the watershed is approximately 1.7 million, located in the three major cities and more than 45 smaller cities and towns.

The portion of the bay lying within Hillsborough County is owned by the Tampa Port Authority, the remainder by the State of Florida. Various private landowners have titles to submerged lands scattered along the edges of the bay.

1.3 BIOLOGICAL SUBUNITS OF THE BAY

Tampa Bay is classified as a subtropical estuary, although the northern half, in particular, experiences low temperatures sufficient to kill mangroves every 10 to 20 years (Wooten 1985). McCoy and Bell (1985) discussed this controversy further but drew no definite conclusions.

Each of seven named subunits of the bay consists of open water and vegetated intertidal zones, as listed in Table 2. Ninety-three percent of the bay is open water (967.2 km^2), and 7% is vegetated intertidal area with mixtures of mangrove and tidal marsh vegetation.

Around the periphery of the bay there is a shallow shelf varying in width from 500 to 1,200 m (Figure 4), with a maximum depth of approximately 1.5 m at its outer edge. Upon this submerged estuarine shelf grow the majority of the algae and seagrasses in the bay. Outside of the shelf, the bay drops off to natural depths of 7 m, with dredged channels as deep as 13 m. Olson (1953) determined that the modal depth (the depth at 50% of the total bay area on a hypsographic curve) of the bay was 3 m and the mean depth 3.5 m. At the time of his measurements, the estuarine shelf made up 33% of the open-water area of the bay. This has since been reduced substantially by dredging and filling of the bay's shallows and shorelines (Lewis 1977).

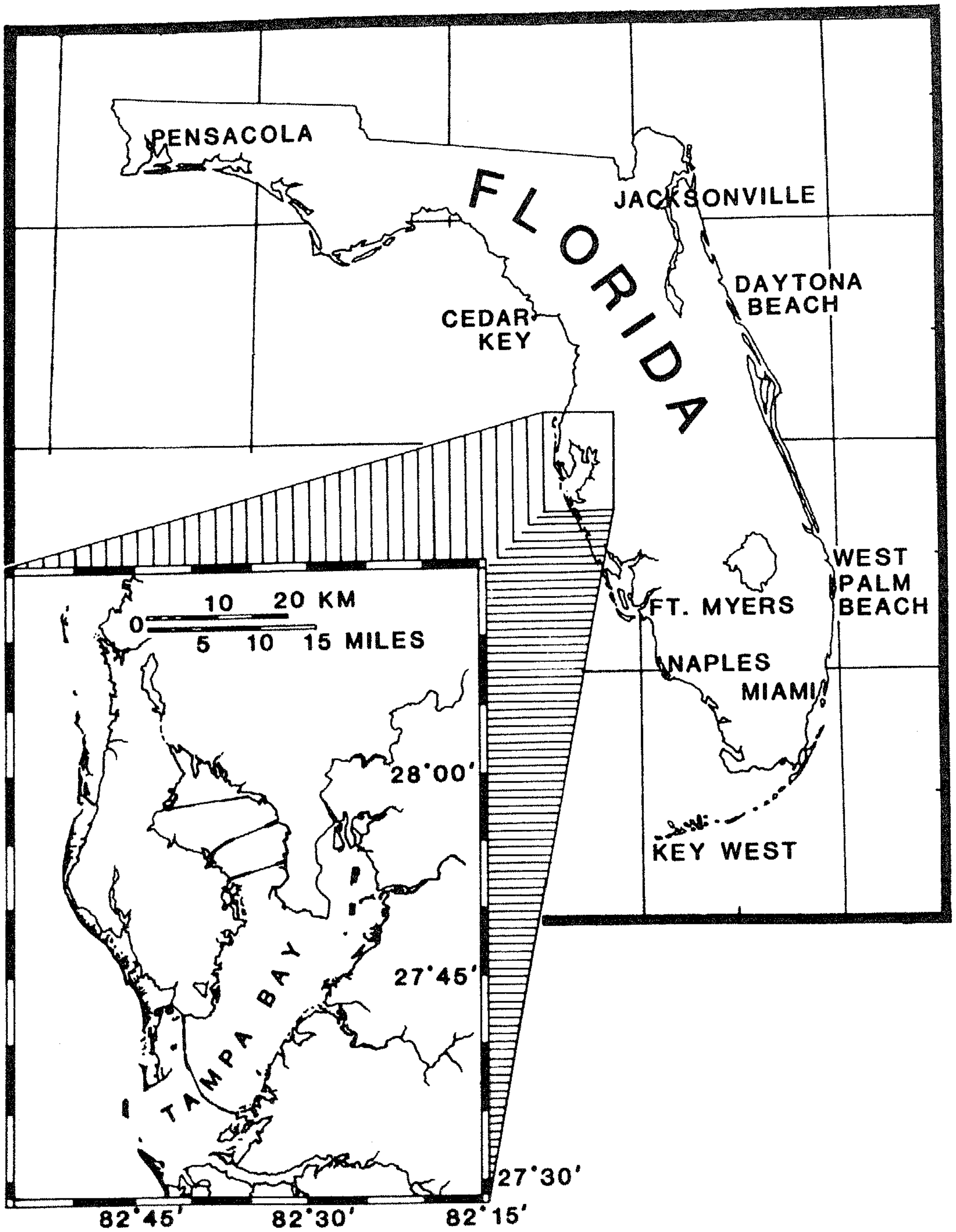


Figure 1. Map of Florida showing the location of Tampa Bay on the peninsular west coast.

Table 1. Surface water discharge to Tampa Bay (Hutchinson 1983).

Drainage Basin	Period of record (years)[a]	Drainage area (mi^2)	Average discharge during May[b] (10^6 gal/day)	Average annual discharge[c] (10^6 gal/day)
Tampa Bay and coastal areas				
Rocky Creek	24	45	8	30
Sweetwater Creek	26	25	4	14
Lake Tarpon Canal	3	65	2	19
Tampa Bypass Canal	19	39	31	37
Ungaged area[d]	--	339	60	222
Hillsborough:				
Hillsborough River	39	690	70	411
Sulphur Springs	18	--	17	27
Alafia:				
Alafia River	45	420	102	297
Little Manatee:				
Little Manatee River	38	211	31	155
Manatee:				
Manatee River	11	350	57	228
Total		2,184	382	1,440

[a] Period of record includes all measurements through 1977.

[b] Data from Conover and Leach (1975). Discharge is linearly adjusted to include ungaged drainage area in each basin.

[c] Discharge in ungaged basins is assumed to be directly proportional to discharge in gaged basins.

[d] Adjusted for diversions by City of Tampa.

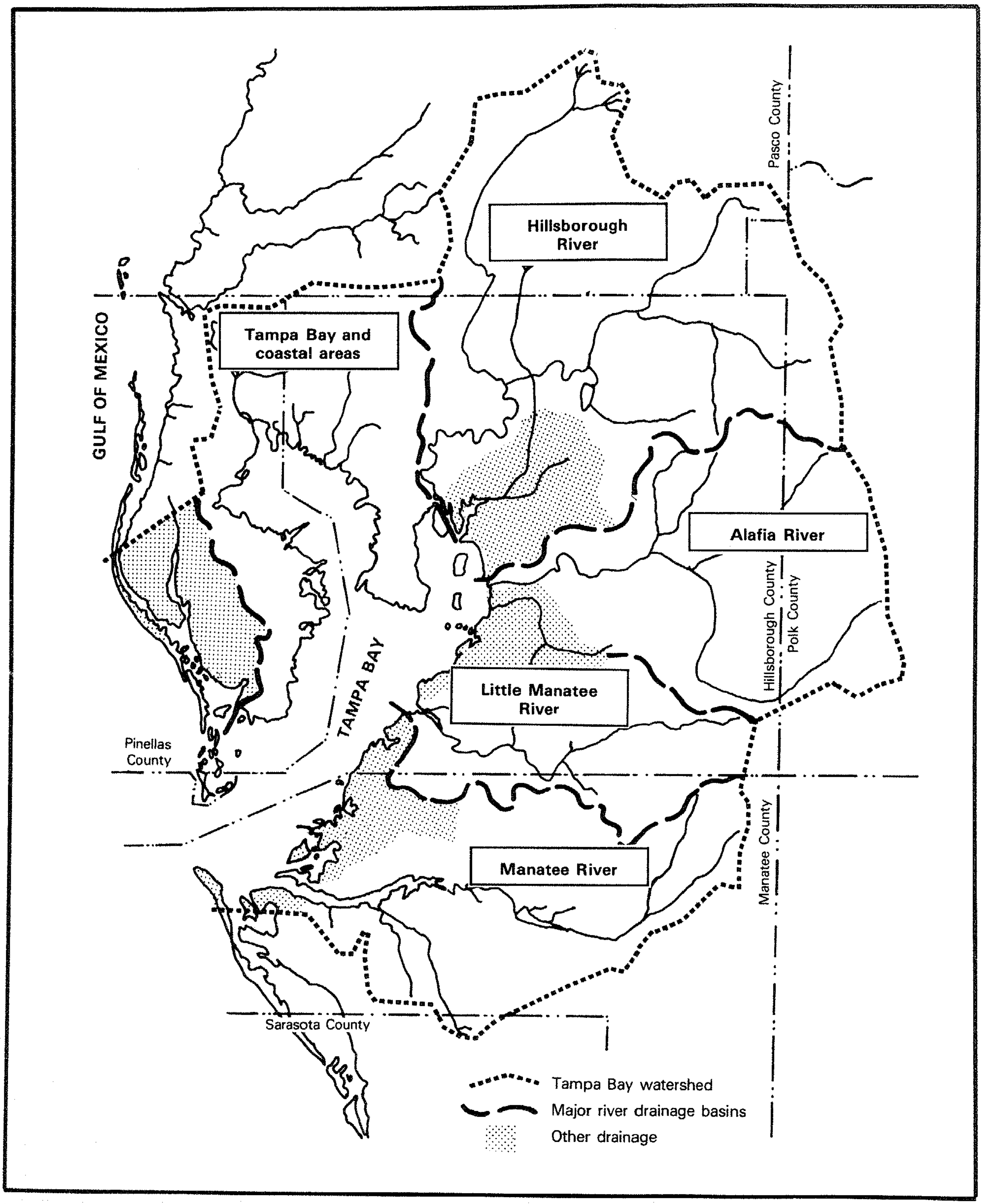


Figure 2. The Tampa Bay area watershed extends into six counties.

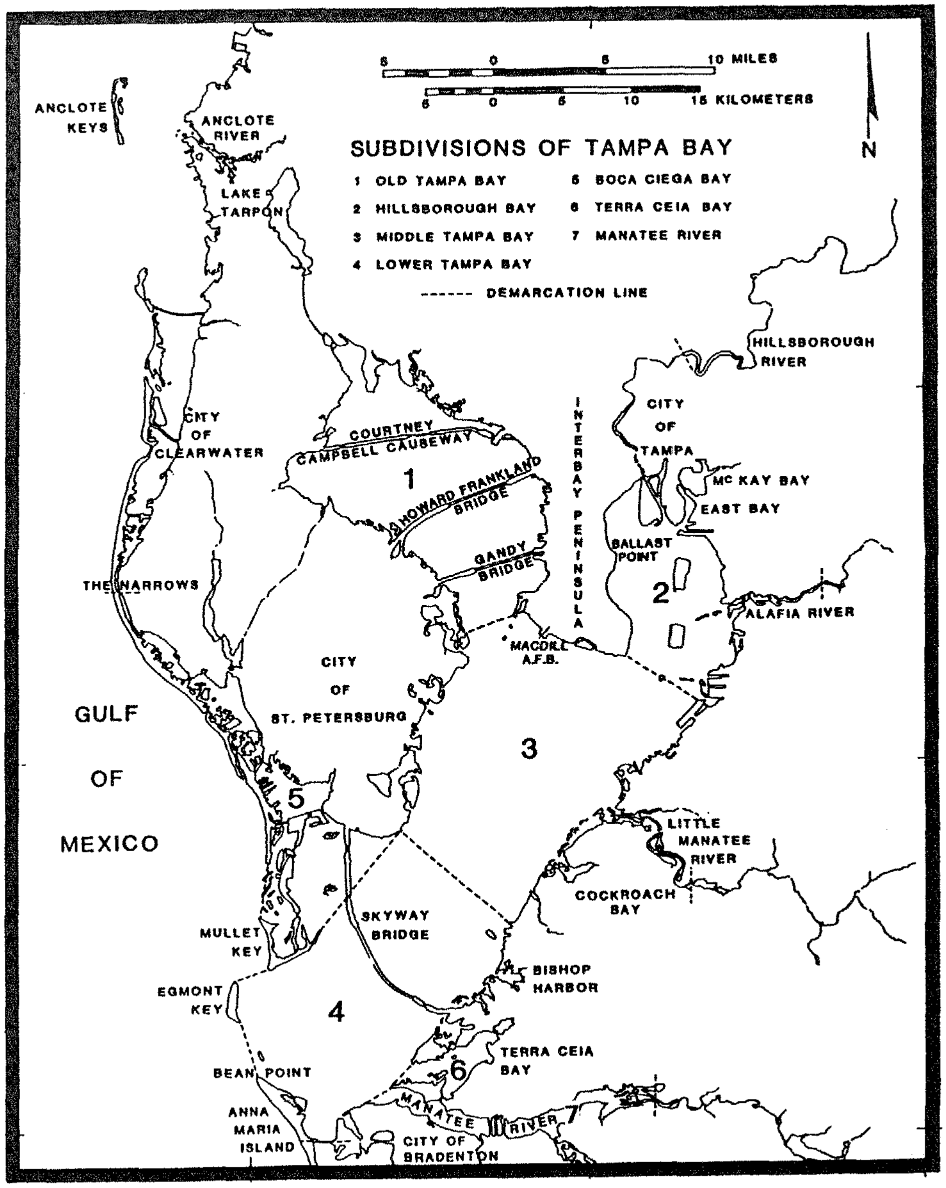


Figure 3. Geographic subdivisions of Tampa Bay (from Lewis and Whitman 1985).

1.4 POTENTIAL CONFLICTS AND IMPACTS

Tampa Bay is an urbanized estuary in which development activities have substantially altered natural processes (Taylor 1973; Simon 1974; Lewis 1977; Tampa Bay Regional Planning Council 1983, 1985). It is estimated that 44% of the original intertidal wetlands and 81% of the original seagrass meadow cover in the Bay have been destroyed either by dredging and filling or pollution (Lewis 1977; Lewis et al. 1985a). Water quality has been degraded in much of the bay because of the current discharge of 7.2×10^{11} l/hr (190×10^9 gal/yr) of treated sewage and industrial wastes, and historical discharges of untreated or poorly treated wastes (Tampa Bay Regional Planning Council, 1978). This figure does not include urban stormwater discharges. Continued expansion of the nation's 7th largest port at Tampa is expected, and the population is increasing by 50% per decade (Tampa Bay Regional Planning Council, 1985).

Table 2. Summary of areal measurements for subdivisions of Tampa Bay (Lewis and Whitman 1985).

	Total area		Open water		Emergent wetland		Length of Shoreline	
Subdivision name[a]	mi^2	km^2	mi^2	km^2	mi^2	km^2	mi^2	km^2
1. Old Tampa Bay	80.5	208.7	73.3	190.0	7.21	18.7	211.1	339.8
2. Hillsborough Bay	40.2	105.3	38.4	100.8	1.76	4.6	207.0	128.6
3. Middle Tampa Bay	119.7	309.9	113.1	292.9	6.55	17.0	163.3	262.8
4. Lower Tampa Bay	95.2	246.6	92.2	238.9	2.96	7.7	75.6	121.6
5. Boca Ciega Bay	35.9	93.1	34.5	89.5	1.38	3.6	180.5	290.4
6. Terra Ceia Bay	8.0	20.6	6.1	15.8	1.86	4.8	25.9	41.6
7. Manatee River	18.6	54.6	12.7	39.3	5.92	15.3	118.7	191.0
Total	398.1	1,038.8	370.3	967.2	27.64	71.7	903.7	1,454.2

[a] Numbers correspond to subdivisions shown in Figure 3.

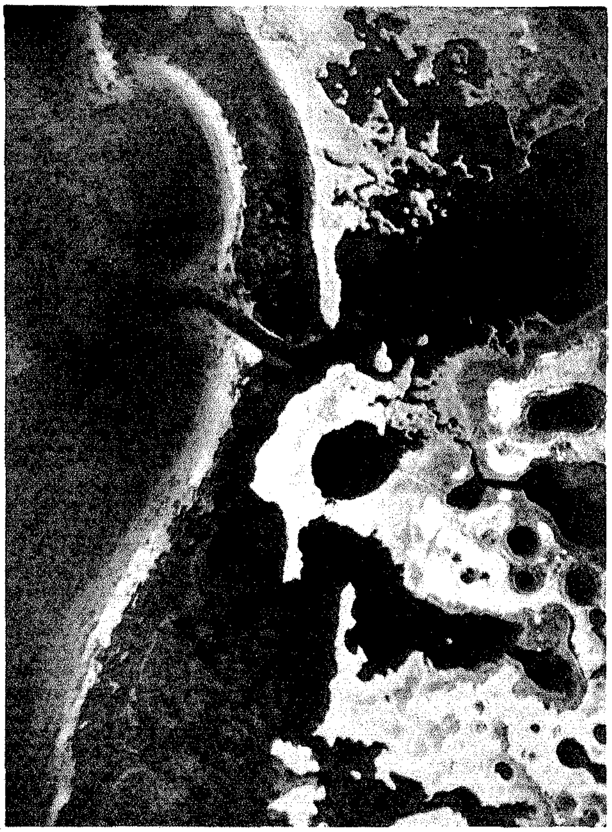


Figure 4. Vertical aerial photograph of the estuarine shelf surrounding Tampa Bay.

With these conflicts becoming more apparent, an attempt to define bay-wide interests and management options for the bay was initiated with the formation of a Tampa Bay Study Committee. Their final report was completed in 1983 (Tampa Bay Regional Planning Council, 1983). The legislatively supported committee submitted an extensive list of management recommendations to the Florida Legislature in spring 1985 (Tampa Bay Regional Planning Council, 1985) and a regional Agency on Bay Management currently is grappling with these complex management issues.

CHAPTER 2. DESCRIPTION OF THE ENVIRONMENT

2.1 GEOLOGICAL ORIGIN AND EVOLUTION

Tampa Bay and Charlotte Harbor to the south are distinctive estuaries insofar as both are large, drowned floodplains of subtropical rivers flowing from the Florida peninsula to the Gulf of Mexico. The bays owe their modern shape and chemistry to the history of the peninsula's formation.

The peninsula and broad Continental Shelf extending west from the Gulf coast make up the Florida Plateau, an accumulation of sediment about 5,000 m thick, over a basement of igneous and metamorphic rocks of Jurassic and Cretaceous age [>100 million years before the present (myBP)] (Rainwater 1960; Applin and Applin 1965). These deep, thick sediments represent the persistence over millions of years of a stable carbonate shoal (like the modern Bahama Banks) of temperate to subtropical nature between the Gulf of Mexico and Atlantic Ocean. Sediments were deposited in shallow coastal waters, reefs formed near old shorelines, and freshwater marshes contributed to beds of marl, limestone, sand, or peat.

Eustatic changes of sea level, subsidence, and folding of the earth's crust created the Peninsular Arch, or "spine" of the peninsula (Figure 5). The arch trends south-southeast and extends from southeastern Georgia through Florida into the Great Bahamas (Chen 1965) and is expressed today as the topographic high east of the Tampa Bay region. A much younger topographic feature, the Ocala Uplift, is a late tertiary (Miocene age, 25 myBP) swell. Tampa Bay is located southwest of the Ocala Uplift. The arch and uplift modify local weather conditions and define runoff characteristics of the watershed.

Two ancient features of negative relief have also affected the geology of the Tampa Bay region. To the north, the ancient Suwanee Channel connected the eastern gulf to the Atlantic Ocean and effectively separated the modern peninsula from North America from the Cretaceous period to the Oligocene epoch (about 25 myBP). One major effect of the channel was its interception of quartz and clay minerals from the continent, allowing carbonate and evaporite sediments to accumulate on the incipient peninsula for several million years (Chen 1965). In places, these accumulations would become mineable as land pebble phosphate. Phosphate mining and shipping are major factors in the management of Tampa Bay today.

Another major structural influence on the geology of west Florida persisted over the same period and also ended in the Eocene time. The South Florida Basin is a downwarp in the area of southern Florida. According to Chen (1965), the basin plunges toward the Gulf, trends between Cuba and the Bahamas, across to the Florida Keys, and from Dade County northwest to Manatee County. Sediments have filled the basin to a depth of 4,000 m (Applin and Applin 1965). Many sedimentary beds in peninsular Florida, including those near the sand surface in the Tampa Bay region, thicken and slope to the south and west because of the prolonged existence of the south Florida Basin. In places, the orientation and thickness of the beds have affected the paths of rivers and the accumulation or flow of underground water.

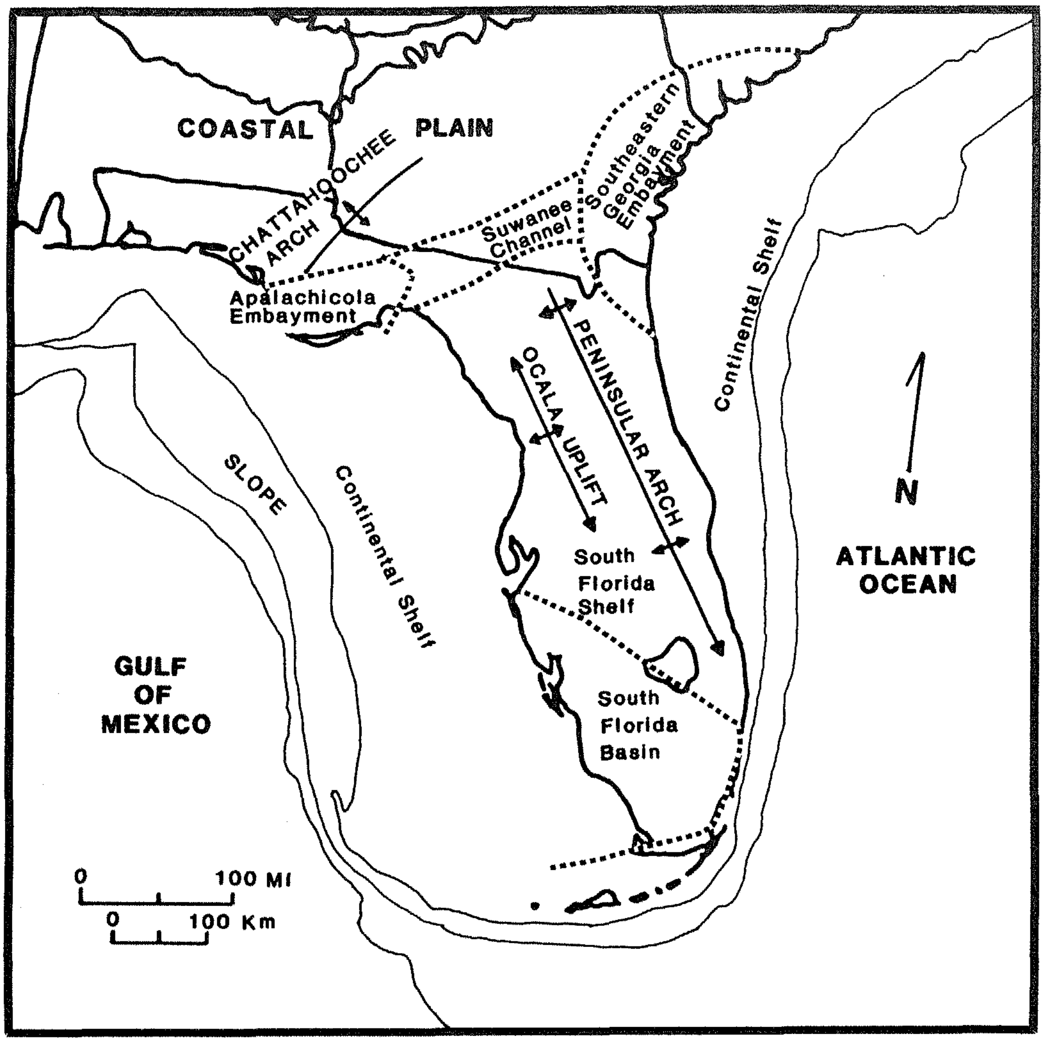


Figure 5. Major structural features of Florida (Chen 1965).

The many thousands of feet of sediments resting upon the basement of the Florida Plateau are organized into distinctive beds or formations. The formations, which contain fossils, minerals, or sediments of particular characteristic sizes, have been assigned ages and are thereby sequenced from very old to recent. In southwest Florida, formations vary in thickness and in the manner of their contact with higher and lower formations. In places, erosion or the absence of a depositional environment has resulted in the absence of one or more formations.

2.1.1. Geological Formations Relevant to Tampa Bay

None of the geological formations bearing water or phosphate, exposed in or near the bay, or contributing to terrace soils are older than about 50 million years (Eocene epoch). As mentioned, Eocene and Oligocene formations contain little quartz or clay minerals, but following the Miocene closure of the Suwanee Channel (Miocene age, 25 myBP) quartz sand, mud, cherts, kaolin, dolomite, phosphate, and siliceous fossils (Ballast Point geodes) became increasingly abundant, and it was during the Miocene that drainage and erosion began to create "modern" Tampa Bay (Stahl 1970).

The oldest and deepest relevant formation is the Lake City Limestone, a 150-m-thick fossilized bed at a depth of 600-800 m (Figure 6). This formation is the lower confining bed of the major artesian ground-water body, the Floridan Aquifer (Brown 1983), and is of an early Eocene age (ca. 50 myBP). A mid-Eocene bed some 200 m thick, the Avon Park Limestone, overlies the Lake City Formation and is the lower water-bearing element of the Floridan, although it is tapped by very few wells because of its depth (400-650 m). The Ocala Limestone is a later Eocene bed 100 m thick and a central aquifer formation. Only one Oligocene Epoch (25-35 myBP) formation occurs, the Suwanee Limestone. Like the

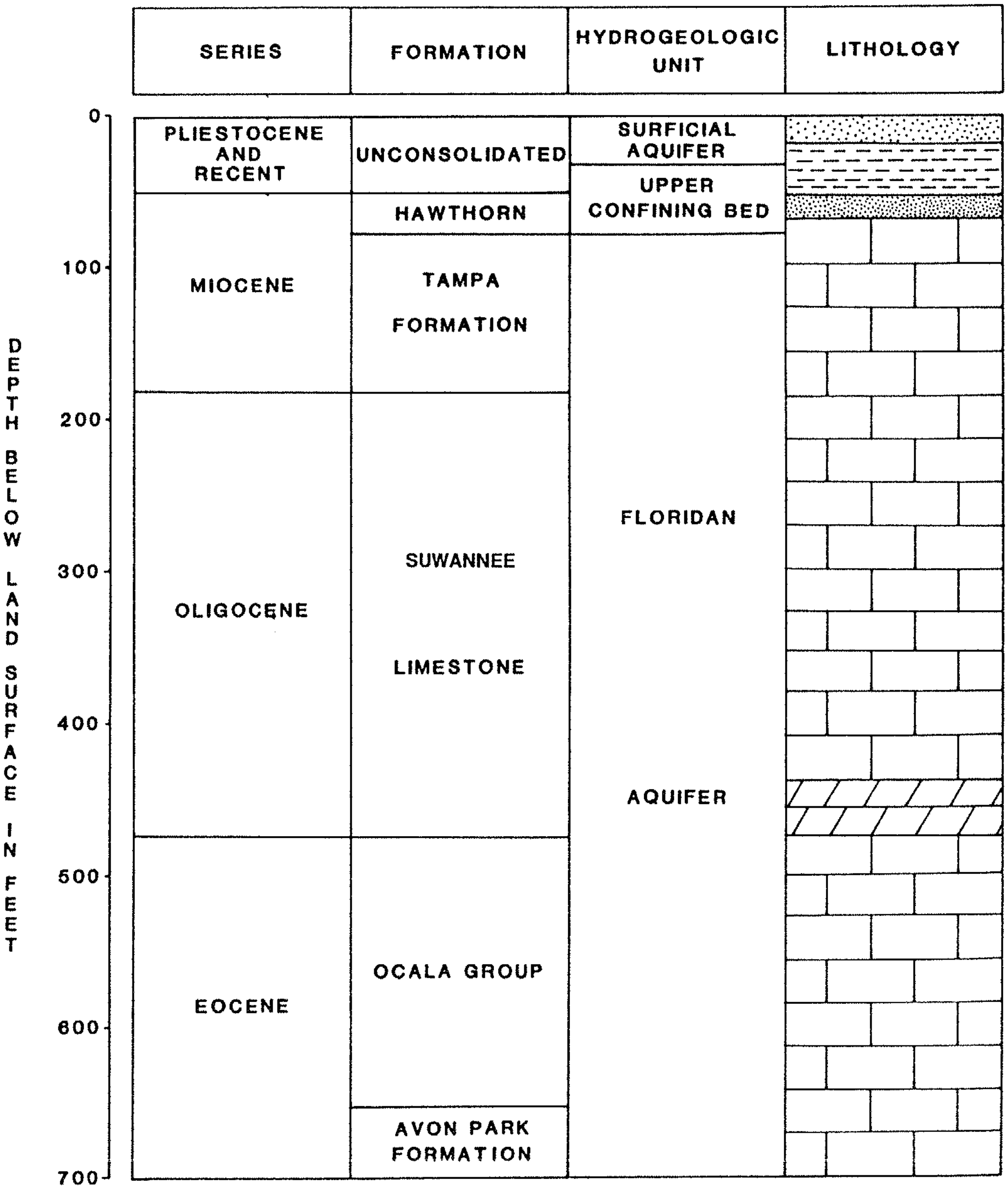


Figure 6. Hydrogeology of the Tampa Bay area (after Wehle 1978).

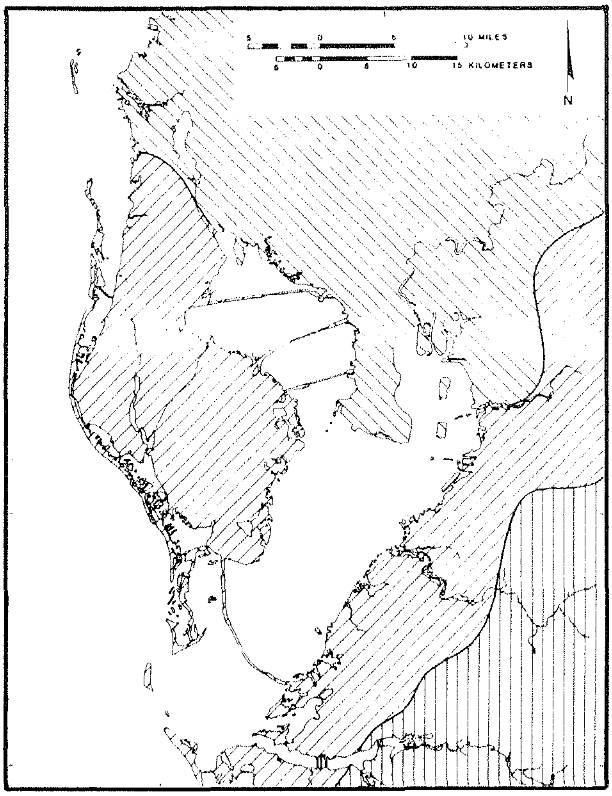
Ocala bed below it, the Suwanee may contain highly mineralized water.

The upper confining beds of the Floridan Aquifer are of Miocene age. The deeper Tampa Limestone Formation (also called the St. Marks) contains phosphatic and silicified beds, often with fossils. Solution cavities are common and water yield can be good because of proximity to the underlying Floridan Aquifer. The top of the Tampa Limestone Formation, and the late Miocene Hawthorn Formation, contain quartz and clay minerals which may carry a minor artesian aquifer containing low mineral loads.

A youthful (late Miocene or Pliocene epoch) Bone Valley Formation of quartz and phosphate sand and gravel overlies the Hawthorn. Mostly east of Tampa Bay the Bone Valley Formation varies in thickness up to 20 m and may be found near the surface to a depth of 30 m. Covering about 5,200 km^2 of the Florida Coastal Plain, this formation is a major source of commercial phosphate. The Bone Valley Formation, or different formations near the surface at other places, may be covered by as much as 40 m of undifferentiated sand, clay, or marl of Pleistocene (1-3 myBP) or recent age. Along with older sediments of the interior, the more recent coastal sands have been extensively modified by past stands of sea level, weathering, and development of a karst topography and can sustain a freshwater aquifer. The location of formations around the bay is shown in Figure 7. The formations generally dip toward the south and thicken toward the south and east following the configuration of the ancient South Florida Basin, because of erosion during periods of higher sea level. The Hawthorn Formation is a thin veneer under much of Hillsborough County and is missing completely from the bed of the Hillsborough River.

2.1.2. The Effects of Glaciation

While no glaciers ever formed on the Florida Peninsula, their effect on the west central coast was profound. The great glaciations (Table 3) occurred during the Pleistocene Epoch, beginning about 3 million years ago.



LEGEND:	SERIES	STAGE	FORMATION
▨	MIOCENE	ALUMBLUFF	HAWTHORN
▧	MIOCENE	TAMPA	ST. MARKS
▥	MIOCENE	CHOCTAWACHEE	BONE VALLEY

Figure 7. Geologic formations of the Tampa Bay area (Roush 1985).

Sea level dropped during glaciations and rose during interglacial periods--so much so that the peninsula was greatly exposed or inundated. The severity of inundation was moderated with each successive period, so that the peninsula was cut into terraces by erosion during the maximum stand of each corresponding sea level (Figure 8). The terraces resulting from the Sangamon interglacial period shaped the land surface around the bay. The terraces are most conspicuous between the Alafia and Little Manatee Rivers, but die out on the south valley wall of the Alafia (White 1970); they are still evident on the east side of Pinellas

Table 3. Relation of glacial periods to terraces near Tampa Bay (adapted from Wilhelm and Ewing 1972).

Glacial (erosional) period	Maximum advance (years BP)	Interglacial deposition period	Terrace	Elevation (ft[a])
Late Wisconsin	40,000			
			Silver Bluff	+ 6
		Peorian	Pamlico	+ 25
Early Wisconsin	110,000	Sangamon	Talbot	+ 42
			Fenholloway	+ 70
			Wicomico	+100
Illinoian	300,000			
			Okeefenokee	
		Yarmouth	Sunderland	+170
			Coharie	+215
Kansas	660,000			
		Aftonian	Brandywine	+270

[a] Above sea level.

County (Roush 1985). By the late Wisconsin, transgressing and receding seas had etched and filled rivers, mixed carbonate and quartz sediments across the coastal plain of west Florida, and cut the Tampa Valley, which was filled in during the Holocene (Recent) rise of the sea (Figure 9).

In general, surface sands in terraces above the Pamlico Terrace are regarded as pre-Pleistocene (Brooks 1974) and terrace, coastal, and bay sediments are Pleistocene or later. Soils surrounding the bay are derived from carbonate-rich siliceous sands of marine origin rather than phosphatic or organic mixtures with silica. Phosphatic soils are most prevalent in Hillsborough County, representing about 5% of the total county area. About one-fourth of all soils in Hillsborough County and nearly one-half in Manatee County are of the Leon fine sand type. In Pinellas County, Myakka fine sand is most abundant, making up about one-fifth of the soils. Both these soils are dominated by primarily 0.10- to 0.25-mm sand, with less than 5% silt or clay. Analyses have shown that the finest particles have quartz, montmorillonite, and kaolinite as their principal minerals (Roush 1985).

The absence of fine-grained terrestrial sediment and soils accounts for the low sediment loads in tributaries to the bay and for the relatively small amount of silt-clay in bay sediment. Sediments were delivered to the bay when rivers were competent during lower stands of sea level. Now, tributaries to the bay are at grade and neither transport much sediment nor downcut their beds (Goodell and Gorsline 1961). Of five original rivers, only the Hillsborough built a delta at its entry to the bay (a marsh displaced by Davis Island), perhaps because of the river's relative recency (White 1958).

2.1.3. Development of the Modern Bay

The shape of Tampa Bay is the result of movements in the course of rivers and a

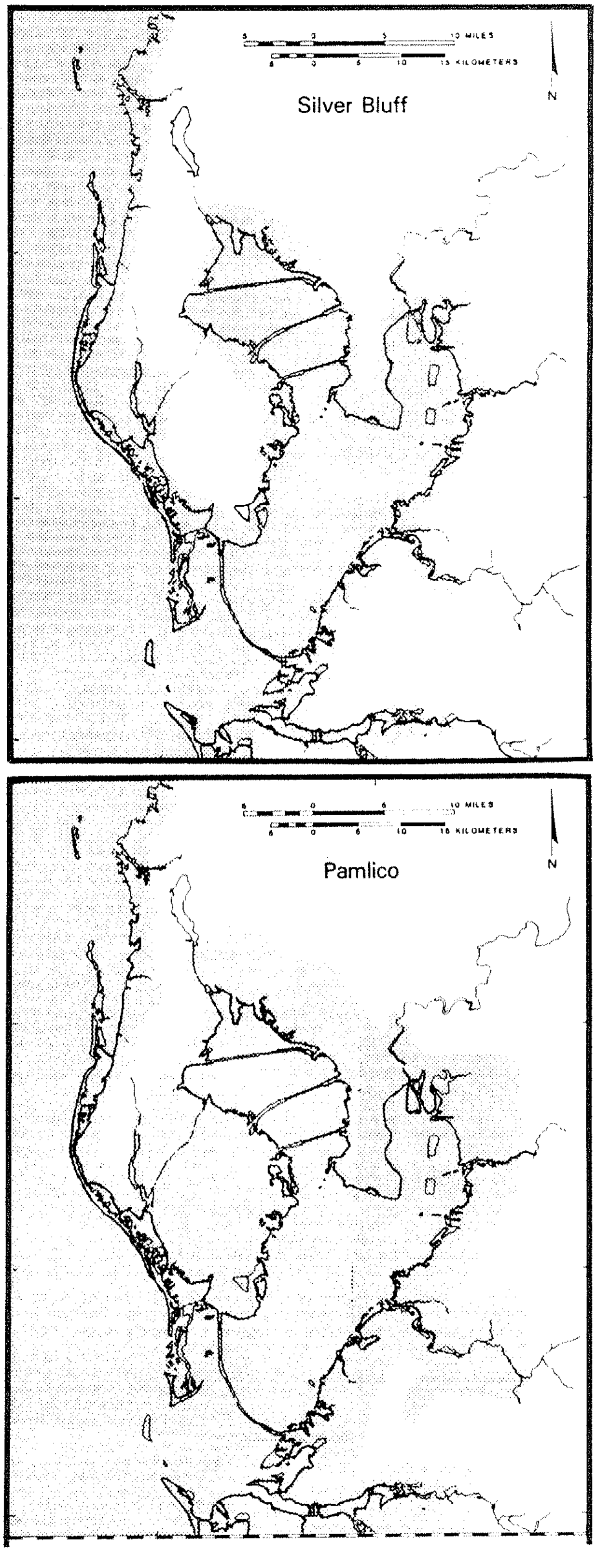


Figure 8. Approximate stands of Wisconsin sea level (Stahl 1970).

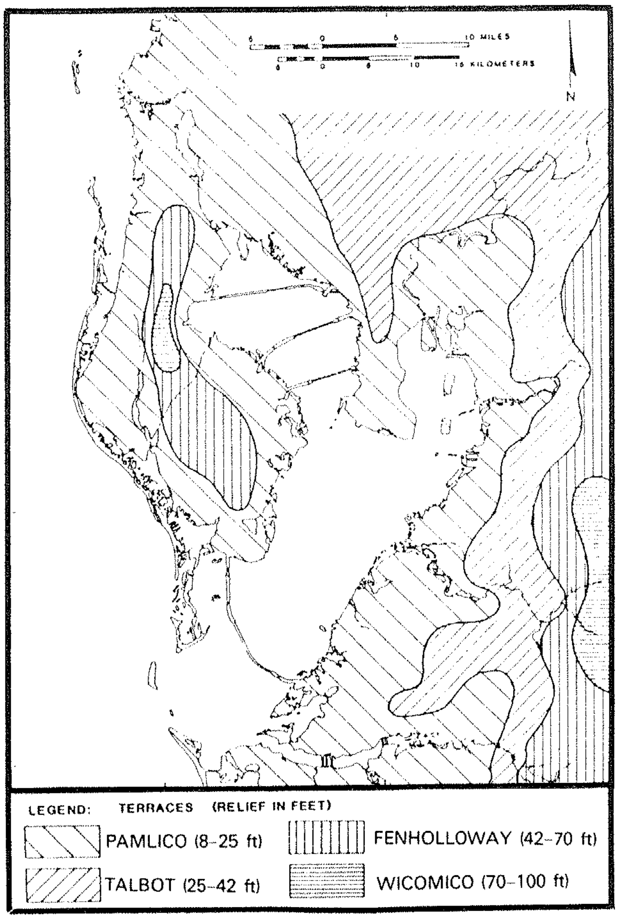


Figure 9. Terraces of the Tampa Bay area (Roush 1985).

long period of rising sea level. Doyle (1985) reported ancient river channels buried beneath Tampa Bay; one such channel underlies the southern end of the Pinellas Peninsula (Stahl 1970). When sea level was lower, the Hillsborough, Palm, and Alafia Rivers probably converged in a basin now called Hillsborough Bay; the combined streams probably flowed southwesterly toward Egmont Key. The Manatee River is thought to have been independent of the ancestral Tampa Basin Stream, flowing westerly to the gulf near Anna Maria (Stahl 1970).

The recent geology of the upper bays remains a puzzle. Old Tampa Bay may represent an open passage from the bay to the gulf located north of an island of old terraces in Pinellas County. The upper bay may have been etched by the Anclote

River in earlier days (Stahl 1970), or by discharges of Lake Tarpon (Hutchinson 1983), which until recently was a brackish tidal body connected underground to the gulf (Hunn 1975). Equally problematic is the relationship between the Withlacoochee and Hillsborough Rivers (and perhaps the Palm River). Even today, waters of the Withlacoochee overflow into the Hillsborough River drainage, and both rivers are regarded as youthful geological features (White 1958, 1970). Boca Ciega Bay is only about 5,000 years old and resulted primarily from longshore sediment transport and barrier island formation (Stahl 1970).

Sediments in Tampa Bay are quartzitic with carbonate mixtures. Bay sediments derive from reworking of terrace deposits, in situ production and weathering of shell, and inshore movement of gulf sediment. Immense deposits of oyster shell underlie Hillsborough Bay and have been mined for many years for fill.

Sea level has risen during the past 10,000 years at a diminishing, slow rate (Figure 10). In the past 4,500 years the sea has risen about 3 m with some fluctuations (Brooks 1974), about 30 cm of the rise occurring from 1550-1850, and 20-25 cm of it since 1870 (Swanson 1974). The rising sea has etched the estuarine shorelines of the bay, confused zonation patterns in mangrove forests (Estevez and Mosura 1985), structured the direction and rate of longshore sediment movement on the gulf beaches, and trapped sediments in the bay. According to Brooks (1974), "backfilling of the estuary from sediments derived from offshore began about 8,000 years ago. Considering the fact that the average depth of the bay is now less than ten feet, the thickness and volume of recent sediments are astounding." Meade suggested that weak estuaries such as Tampa Bay export little fine sediment, a point supported by mathematical models (Ross et al. 1984).

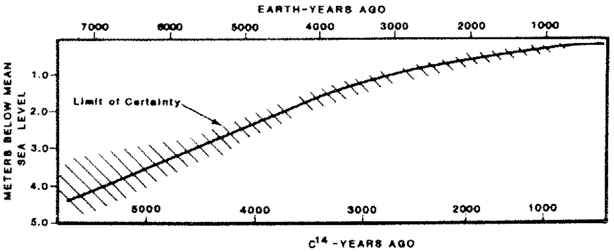


Figure 10. Sea level on the southwest Florida coast (Scholl and Stuvier 1967).

2.2 THE HYDROLOGIC CYCLE

The amount of freshwater in Tampa Bay and hence the salinity of the bay depend at any given time on positive effects of rainfall, runoff, and ground water efflux, and negative effects of evapotranspiration, consumptive uses, and ground water influx (Figure 11).

The Tampa Bay Region is located in a zone of transition between a temperate, continental climate and a tropical, Caribbean one. Centrally located on the west peninsular coast, the bay area is protected from oceanic influences by the Peninsular Arch to the east and the broad Continental Shelf to the west. Although the bay area is a well-documented biogeographic divide (Long and Lakela 1971; McCoy and Bell 1985), latitudinal gradients of weather are gradual. According to Jordon (1972), the only abrupt weather changes along the entire eastern gulf occur at the coastline where oceanic and land-dominated forces clash.

The bay is affected by warm, relatively humid summers resulting from the Bermuda high pressure cell and by mild, relatively dry winters when continental air masses prevail. Because moderate amounts of rain fall in the spring, it is useful to distinguish three categories of weather from an ecological point of view. The warm, dry period occurs from late April to mid-June. The warm, wet period coincides with summer and early fall. The cold period spans November to April and becomes progressively drier, although cold fronts may cause short periods of heavy rain in January or February.

Little is known of micro-meteorological conditions around Tampa Bay proper, which is protected from frontal passages by gradual terraces around more than 300° of its perimeter (being open to the gulf on the southwest). The upper

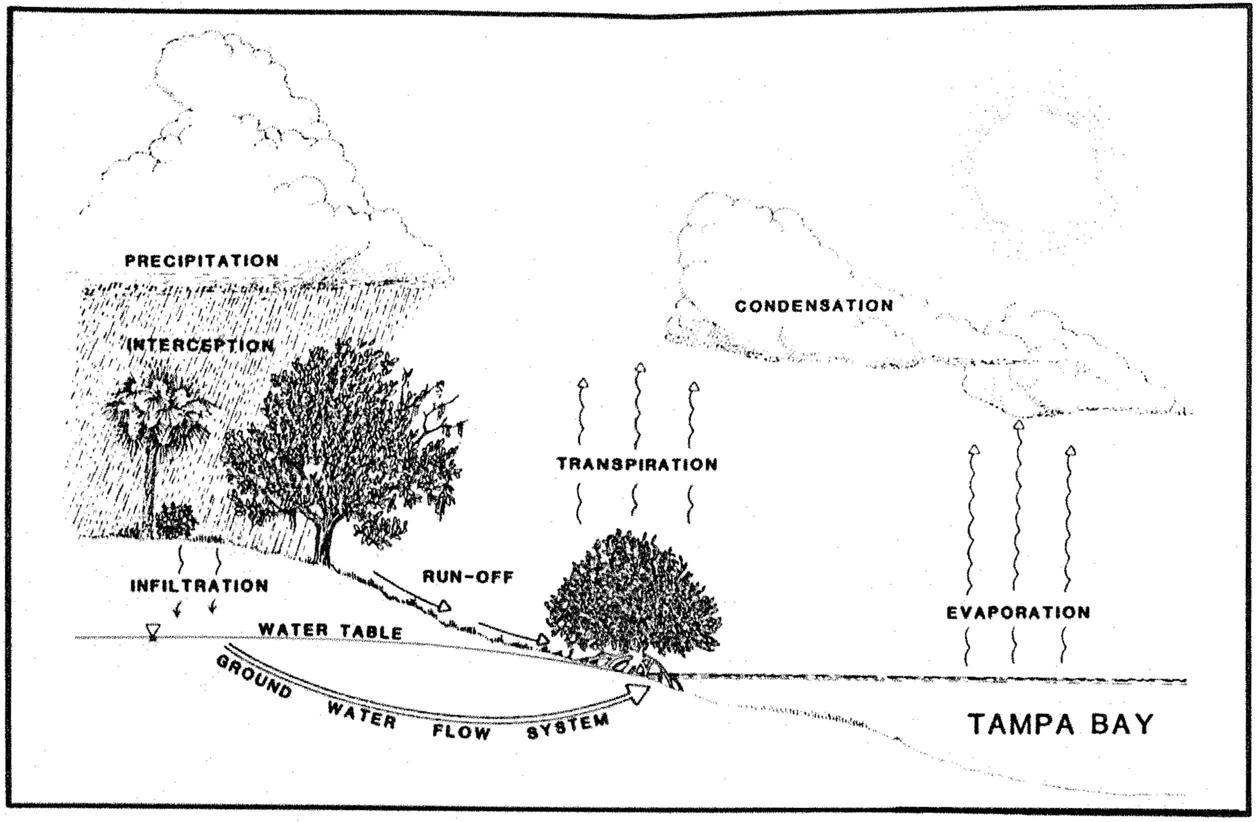


Figure 11. Generalized hydrologic cycle for the Tampa Bay area (from Culbreath et al. 1985).

bays are divided by a low peninsula and have their longest fetches perpendicular to one another; the whole bay is separated from the gulf by the Pinellas Peninsula, which has a maximum elevation of 30 m and falls rapidly across Pleistocene terraces into Old Tampa Bay. Land north of the bay is mostly open and very wet. Land to the east and south is also open but better drained.

2.2.1 Insolation and Cloudiness

Tampa Bay is subject to an average of 66% of the sunshine possible in a year. Average daily solar radiation is 444 gm-cal/cm^2 (Langleys), with a January low (311 gm-cal/cm^2) and May high (599 gm-cal/cm^2). Insolation is closely related to evapotranspiration (Figure 12).

Mean annual cloud cover varies from 40% to 60% because of convective showers in summer and extratropical fronts in winter. Cumulus clouds, the most common low-level formations, result from winter sea-air temperature differences and summer land-sea temperature gradients (Leipper 1954, Jordan 1972).

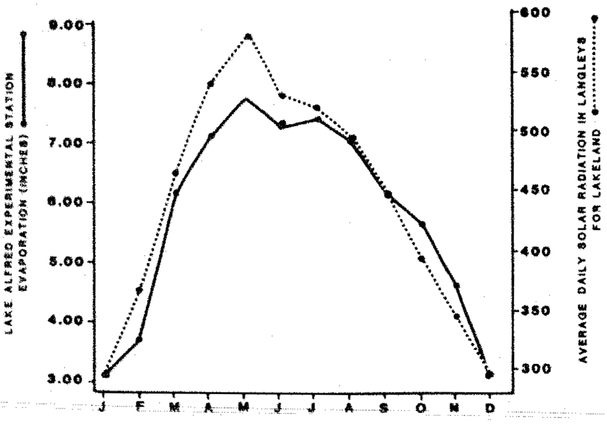


Figure 12. Mean monthly pan evaporation and solar insolation near Tampa (after Drew et al., unpubl.).

2.2.2 Atmospheric Pressure and Wind

Pressure varies diurnally and seasonally. A daily minimum pressure in the early morning is followed by a late morning maximum and evening minimum, then by a lesser nocturnal maximum. This atmospheric pressure cycle resembles the mixture of diurnal and semidiurnal oceanic tides in the bay. Superimposed over the daily variations is a seasonal pattern, albeit a modest one even in winter because of the effects of the Bermuda cell. Mean monthly pressure rises steadily from September to January then declines through spring. Mean annual pressure at sea level is 1017.7 millibars.

Low pressure centers are of local, tropical or continental origin and range in magnitude from evanescent fronts to tropical storms and hurricanes. Jordan (1973) reported the occurrence of about one low pressure center moving ashore on the Florida gulf coast per year over a 15-year period (excluding tropical cyclones and hurricanes). No seasonal variation in frequency of the centers was evident.

Rapid pressure changes accompany "northers," periods of 1 to 3 or 4 days when windspeeds exceed 20 knots. Between 15 and 20 northers pass Tampa Bay each year, mostly between November and March (Leipper 1954).

The intrusion of cold winter air into the bay area is accompanied by northwesterly winds, although north and northeasterly winds prevail between frontal passages from October to February (NOAA 1982). Winter wind speeds do not vary significantly from summer speeds. The range of mean monthly windspeed varies by only 2.2 knots; the annual mean wind velocity (resultant vector) is 7.5 knots, from the east. Periods of higher wind occur during summer squalls, hurricanes, and tornadoes. The highest official windspeed, SE 65.2 knots, was recorded for a 5-minute period at Tampa during the Labor Day hurricane of 1935. Although tornadoes are more common in the bay area than elsewhere in Florida (mean occurrence of 27 tornado-days/year), no data on the speeds of winds associated with tornadoes are available.

2.2.3. Temperature

Wooten (1985) summarized temperature data for the Tampa Bay area. Mean annual temperature based on four decades of records at Tampa is 22.3°C. Mean monthly low and high temperatures are 16.0°C and 27.8°C in January and August, respectively. Warming is most rapid in March-April and cooling most rapid in October - November (Figure 13). Extreme low and high temperatures are -7.8°C (1962) and 36.7°C.

Temperature trends vary around the bay area. Air temperatures in St. Petersburg are moderated by proximity to the Gulf of Mexico, whereas temperatures become more extreme inland along the floodplains of major rivers.

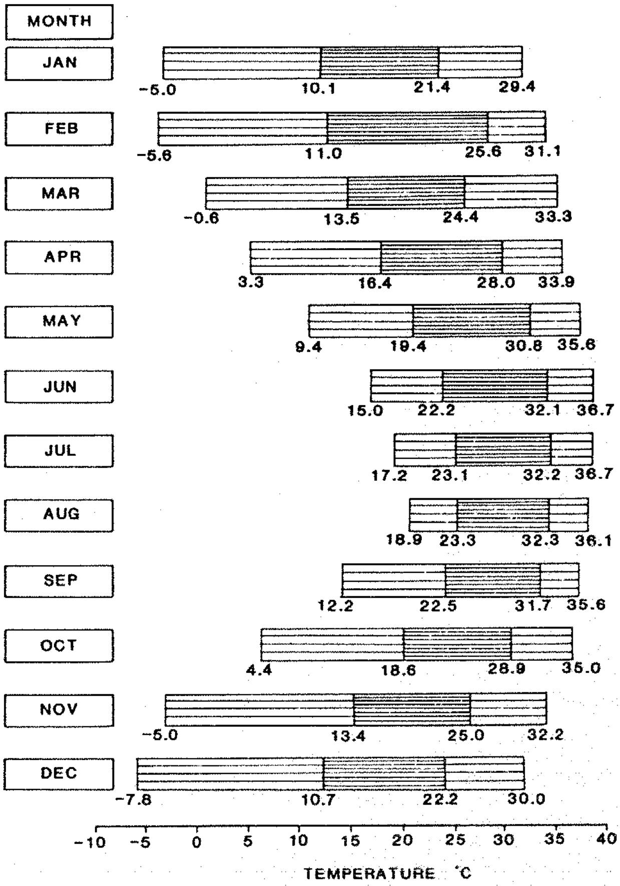


Figure 13. Mean monthly temperature and extremes for Tampa Bay (Wooten 1985).

2.2.4. Evapotranspiration and Relative Humidity

Evaporative and transpirative flux data for the actual bay are lacking, but Simon (1974) reported 162.6 cm of Class A pan evaporation, and Vishner and Hughes (1969) gave lake evaporation rates of 127-132 cm/yr for the area surrounding Tampa Bay and described a "surplus water" gradient from 0 on the coast to about 15 cm in the upper Hillsborough River Basin. Seasonal variations in evaporation are given by Figure 12. Quantitative data on evapotranspiration rates in major biotic communities in and around the bay are needed.

Relative humidity computed as monthly means at Tampa range from 53% to 80%. Lowest mean relative humidity occurs in November, and the highest monthly average is in August. In a typical day, mornings are more humid than afternoons, and dew will form in a typical evening (Wooten 1985).

2.2.5. Fog and Rain

Heavy fog occurs on 23 to 25 days/yr, mostly from November to March. Ground fogs are more common in basins and river corridors, and all fogs are more common at night than in the daytime.

Monthly rainfall patterns and the existence of a slight peak of rainfall in March are illustrated in Figure 14. About 60% of all rainfall occurs in the wet season of June through September, a period when some rain fell even in the driest of years. Wooten (1985) noted that rainfall was above average from the 1930's to the 1950's and has been below average since the 1960's. Henry and Dicks (1984) verified long-term drought patterns in the southeastern United States but pointed out that weather in central and south Florida (beginning in the area of Tampa Bay) has not correlated well with the southeast region with respect to rainfall, especially in the 1960-1980 period.

Light showers are more common than heavy rains. Rainfall at Tampa averaged 123.7 cm for the period 1943-82. The wettest and driest years were 1959 and 1956, with 194.5 cm and 73.4 cm, respectively. The lowest monthly mean rainfall (trace amounts) occurred in January (1950), April (1967 and 1981), and November (1960). The highest monthly mean rainfall was in July 1960, when 52.3 cm of rain was recorded at Tampa. Palmer (1978) determined that mean annual rainfall increases concentrically from Tampa (Figure 15).

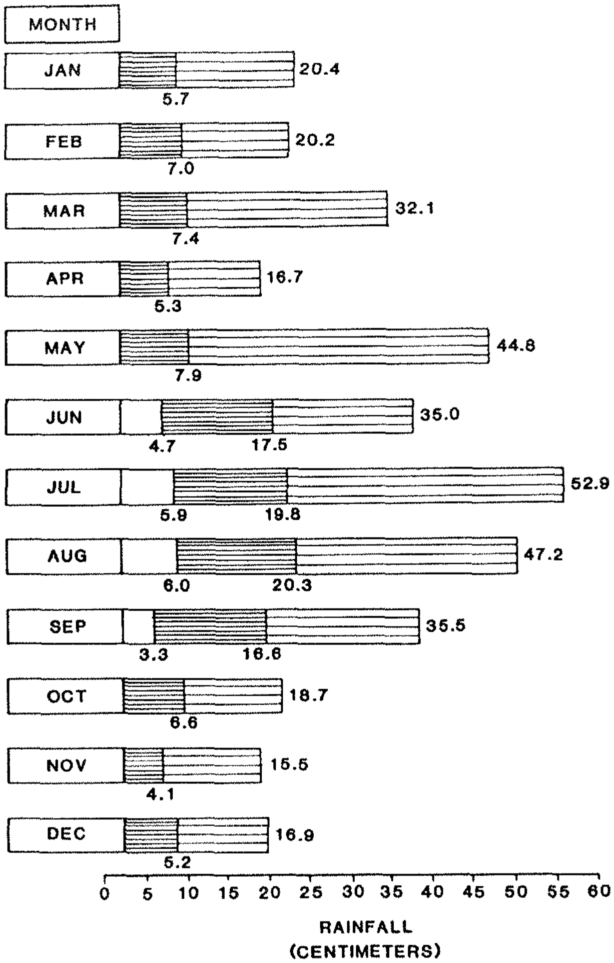


Figure 14. Mean monthly rainfall and extremes for Tampa Bay (Wooten 1985).

2.2.6. Thunderstorms and Hurricanes

Thunderstorms are a common element of bay-area weather. About 60-100 occur in an average year, over 85-90 days, with the largest number from June through September. Offshore storms are more common at night, whereas inland thunderstorms occur more often during the day due to convective patterns in the lower atmosphere.

Tropical cyclones (tropical storms and hurricanes) are much less frequent (Table 4). Most of these storms enter the bay area from the southeast to southwest. From 1901 to 1971, 93 tropical cyclones crossed the Florida west coast from Apalachicola south to Venice; 70 struck from August through October. Tampa Bay has not been directly hit by a tropical cyclone since 1848, when the pioneer city of Tampa was nearly destroyed. However, near hits have caused storm surges of more than 3 m; the highest storm surge was recorded in 1921 when a 3.2-m surge above mean low water flooded coastal areas. Today, flood zoning recognizes elevations of 2.5-4.0 m as the limit to storm surges with a recurrence probability of 100 years.

Ecological effects of large storms on Tampa Bay and adjacent areas are not well studied but are likely to include raising of water tables, replenishing of soil moisture, flushing of tributaries and redistribution of sediments, dispersal of propagules, export of organic matter from

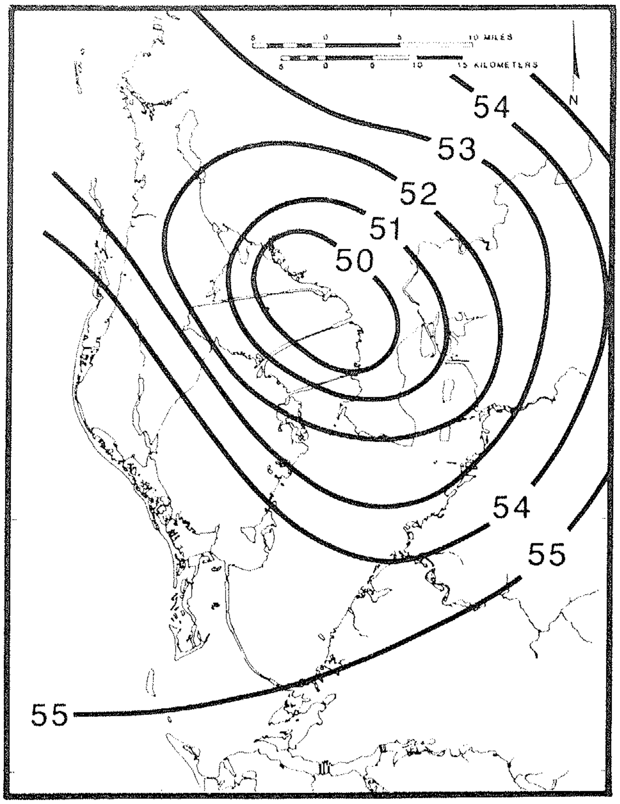


Figure 15. Mean annual rainfall in inches across the Tampa Bay region (Palmer 1978).

Table 4. Tropical cyclones for past 50 years near Tampa Bay (H = hurricane; TS = tropical storm) (Wooten 1985).

Type storm	Month-year	Path with respect to Tampa Bay
TS	Sept. 1930	Moved over northern shores of Bay.
TS	Aug. 1933	Moved westward 45 km south of Bay.
TS	Sept. 1933	Moved northwestward 75 km NE of Bay.
H	Sept. 1935	Moved northward 75 km west of Bay.
TS	July 1937	Moved northeastward across Bay.
TS	Sept. 1941	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	Sept. 1945	Moved northward 75 km E of Bay.
H	Oct. 1947	Moved northward 10 km inland of Pinellas coast.
H	Sept. 1950	Moved eastward 50 km N of Bay.
H	Sept. 1960	Moved northward 55 km E of Bay.
H	Oct. 1968	Moved northeastward 60 km N of Bay.
H	Sept. 1985	Moved northward 90 km W of Bay.

tidal marshes and forests, and the temporary extirpation of estuarine biota.

2.3 SURFACE AND GROUND WATERS

2.3.1. Overview of Tributaries to Tampa Bay

Four natural rivers--the Hillsborough, Alafia, Little Manatee and Manatee--flow to Tampa Bay. Another, the Palm River, once drained lands between the Hillsborough and Alafia Rivers, but has been completely channelized and controlled since 1970 and now is called the Tampa Bypass Canal. The Lake Tarpon outlet to Old Tampa Bay is a significant human-made tributary completed in 1971. The Hillsborough and Manatee (and its tributary, the Braden River) are impounded as municipal reservoirs. Some of the flow of the Little Manatee is withdrawn for power plant cooling water, but it is otherwise regarded to be the least disturbed river flowing to Tampa Bay. The Alafia has been affected by phosphate mining and processing and is impounded at places.

The four rivers all rise to the east of Tampa Bay and flow 65-80 km southwest or west, falling an average of about 10-40 cm/km. The Hillsborough watershed is largest, 1,684 km^2, followed by the Alafia (1,088 km^2); Manatee (907 km^2) and Little Manatee (570 km^2) (Turner 1979). From north to south, their respective floodplains are progressively wider and tidally affected over longer distances. Thus, tidal action may be detected in the Hillsborough River at kilometer 17.7 where the river is dammed and at kilometer 16.0 in the Alafia River (Menke et al. 1961). The Little Manatee River is tidal to kilometer 24.0, and the Manatee is tidal at least to Rye Bridge (kilometer 30.0) (Manatee Co. Utilities and Camp, Dresser & McKee, Inc. 1984). Intertidal habitats (e.g., oyster bars, marsh shorelines, islands) are correspondingly more abundant in the rivers farther south.

The northern rivers (Hillsborough, Alafia) are more urbanized than the southern ones, which still contain more than 90% of their respective watersheds in wetlands, forest, range or farmland (Table 5). The Little Manatee Watershed has been urbanized or laid barren less than the others.

2.3.2. Flows

Tampa Bay as a whole has a 4,623-km^2 basin and receives about 3.8 billion liters of runoff daily, with most (77%) flowing into Hillsborough Bay. Approximately 85% of all flow to the bay consist of the discharges of the four

Table 5. Land use characteristics (% total watershed area) of four authentic rivers flowing to Tampa Bay (from FDER 1982).

Land use	Hillsborough Upper	Hillsborough Lower	Alafia	Little Manatee	Manatee
Agriculture	52.3	40.0	35.9	45.9	38.3
Range	16.1	17.1	17.1	34.9	41.3
Forest	2.8	1.0	13.5	7.4	3.6
Wetland	13.9	17.2	9.2	7.5	3.6
Urban	12.6	21.5	10.4	2.7	5.4
Barren	1.3	1.1	11.5	0.4	0.6

rivers (Figure 16). The mean annual discharge of the Hillsborough (580 x 10^9 l/year) exceeds the others (Alafia: 425 x 10^9 l/year; Manatee: 260 x 10^9 l/year; Little Manatee: 225 x 10^9 l/year) (Dooris and Dooris 1985). If discharge and watershed are compared, the Alafia and Little Manatee Rivers yield more water

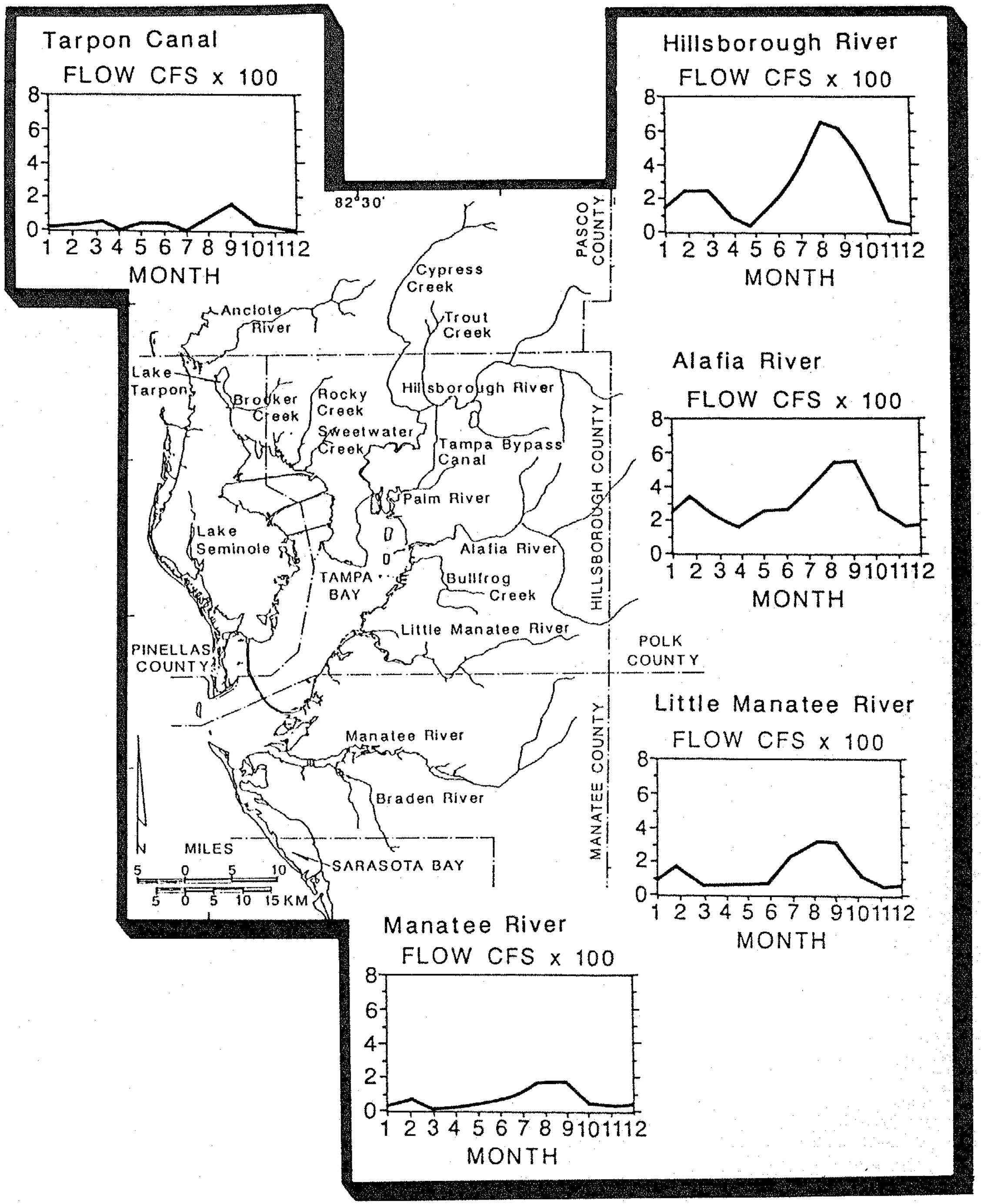


Figure 16. Mean monthly flow in major tributaries to Tampa Bay (adapted from Drew et al., unpubl.).

(1.0 and 1.1 ratio of mean annual flow to area, respectively) than the Hillsborough (0.9) or Manatee Rivers (0.7).

Numerous lesser tributaries and three major flood control channels also drain into Tampa Bay (Figure 17). Many unrated creeks and streams drain 2,279 km^2 of coastal watershed between river basins; several of these have been canalized, filled, or modified beyond rehabilitation. Three restorable streams are Double Branch Creek in upper Old Tampa Bay, Bullfrog Creek south of the Alafia River, and Piney Point Creek near Port Manatee. Other tidal streams entering into rivers have not been modified as much as the urban streams.

Of the 15% of total annual flow attributable to other tributaries, about two-thirds is contributed by flood-control channels; the Tampa Bypass Canal (former Palm River) is the largest of these streams (about 105 x 10^9 l/yr). This canal flows southwesterly from the upper Hillsborough River Basin through Harney, where it is connected by a control structure to the river and continues to McKay Bay. Part of its base flow is ground water, since it intercepts the Floridan Aquifer (Motz 1975). The flood-control channels are tidal only up to their saltwater barriers; the lesser streams are more tidal, but urbanized.

2.3.3. Constituent Concentrations and Loads

It does not automatically follow that rivers with the greatest flows are the greatest sources of material to Tampa Bay. Table 6 illustrates the ranking of major streams by flow, selected concentrations of nutrients and other constituents, and their corresponding loads (Dooris and Dooris 1985). Flow and conductivity ranks are correlated for most rivers except the Lake Tarpon Outfall and Hillsborough River, and flows are inversely related to overall dissolved oxygen content.

Total phosphorus concentrations are highest in the Alafia River, and that river delivers more phosphorus to Tampa Bay than any other (Figure 18). It is followed in rank for both concentration

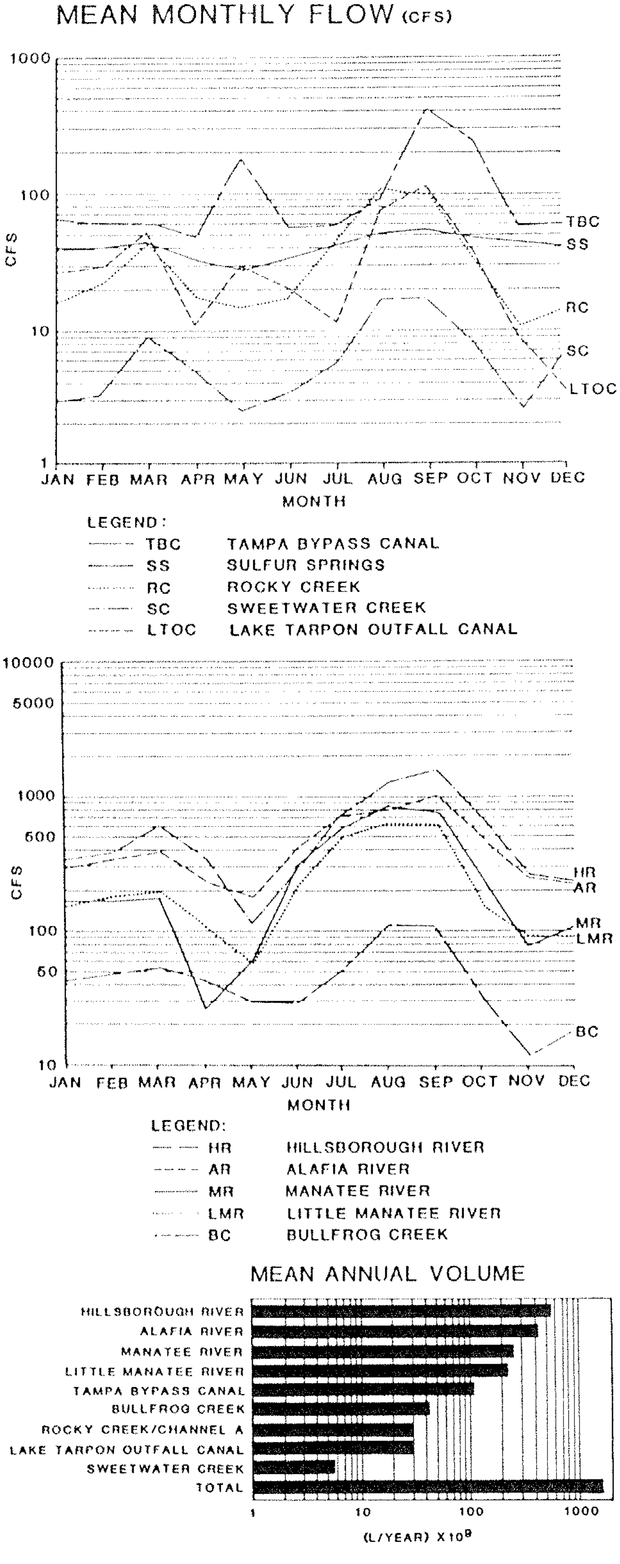


Figure 17. Mean monthly flows in major and minor tributaries, and mean annual volume delivered to Tampa Bay (Dooris and Dooris 1985).

Table 6. Rank of Tampa Bay tributaries by flow and load. Conc. = concentration (Dooris and Dooris 1985).

	Rank (1 highest) by								
				Total P		Total Org N		Fluoride	
Stream	Flow	Cond.[a]	D.O.[b]	Conc.	Load	Conc.	Load	Conc.	Load
L. Tarpon Outfall	6	2	1	6	6	2	6	N.D.[c]	N.D.
Hillsborough River	1	4	5	3	2	5	3	3	2
Tampa Bypass Canal	5	6	3	5	5	3	4	4	5
Alafia River	2	3	4	1	1	4	2	1	1
Little Manatee River	4	5	2	4	4	5	5	2	3
Manatee River	3	1	6	2	3	1	1	3	4

[a] Cond. = conductivity.
[b] D.O. = dissolved oxygen concentrations.
[c] N.D. = no data.

and load by the Hillsborough and Manatee Rivers, the Little Manatee, and the human-made canals. Total organic nitrogen is highest in the Manatee River (either by concentration or load), even though its flow rank is third; total loads of organic nitrogen in the Alafia and Hillsborough Rivers follow. Judging from its rank by oxygen content, the Little Manatee River delivers less oxygen demanding material to Tampa Bay than any other natural river.

Fluoride concentrations and loads to Tampa Bay reflect natural background levels of fluoride-containing phosphate deposits, as well as the activity of industries that mine and process the phosphate (Toler 1967). Mean fluoride concentrations are uniformly low, usually less than 2.0 mg/l as mean values, for all streams but the Alafia. The Alafia River has had enormously high levels of fluoride, discharging up to 10 tonnes of fluoride per day to Hillsborough Bay in the 1960's. Concentrations and loads in the river have been declining since then, although total loading via the Alafia River is still one or two orders of magnitude greater than loading by other streams.

Data from Moon (1985) on loads from permitted point sources indicate that waste discharges to the Alafia River render it the greatest source of phosphorus and fluoride to the Bay. Point discharges are also implicated by the same data as the reason for the Manatee River's distinction as the largest source of organic nitrogen. On the other hand, the Little Manatee River is distinguished as the bay's healthiest natural river, at least insofar as dissolved oxygen, nutrients, and fluoride are concerned.

Moon (1985) also reported on flows and loads from point sources directly to waters of Tampa Bay. Although the historic coastal basin between rivers was small and therefore relatively unimportant as a source of nutrients, new coastal urbanization and anthropogenic discharges

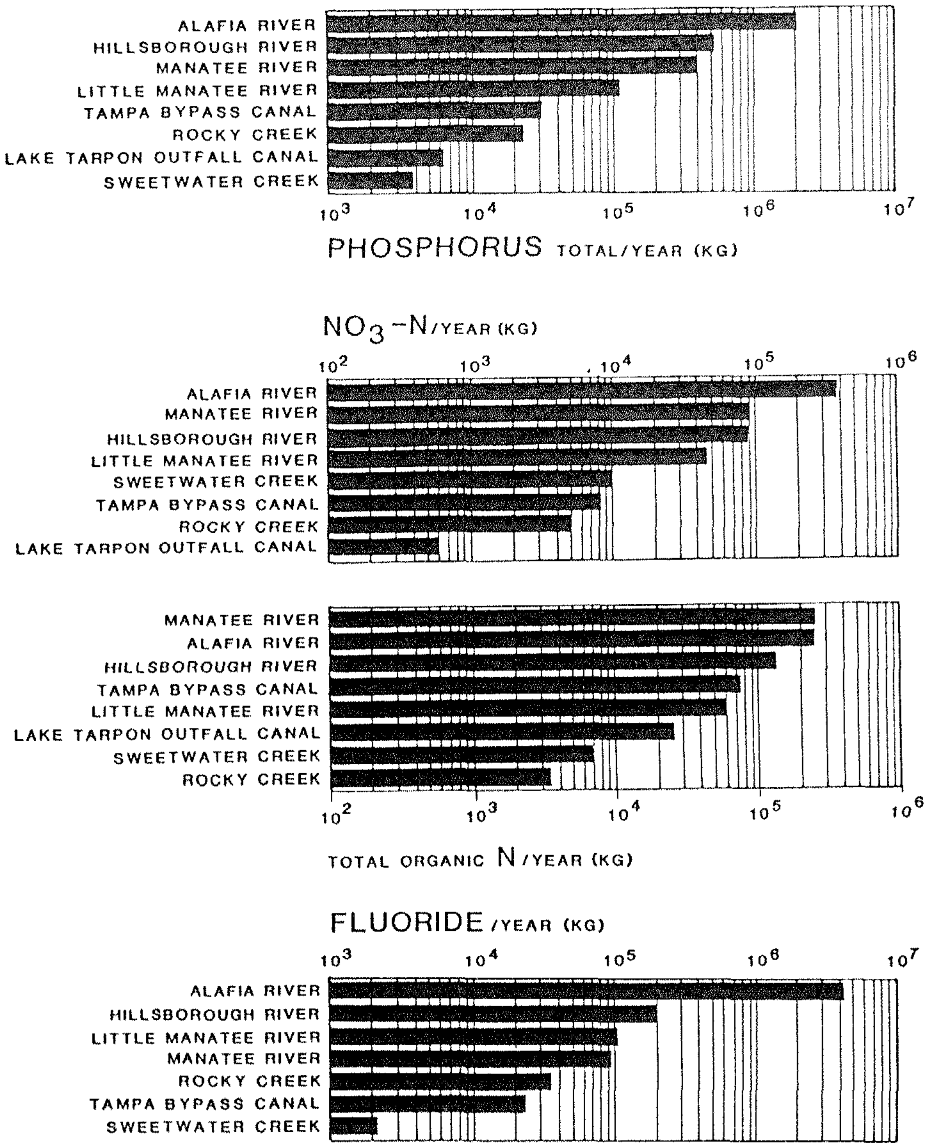


Figure 18. Mean annual constituent loads to Tampa Bay (Dooris and Dooris 1985).

from these local areas collectively constitute a significant source of flow and load. Moon (1985) calculated that about one-fourth of all point-source flows go directly into the bay, and that such sources deliver about 839,160 kg of phosphorus and 1,360,800 kg of nitrogen/yr (or 78% and 85% of all anthropogenic loads of these nutrients in the bay, respectively).

2.3.4. Structure of Ground-water Systems Under the Bay

The major confined aquifer below Tampa Bay is the Floridan Aquifer. This water-bearing series of formations (Figure 19) is approximately 300 m thick in Hillsborough County north of the bay and 400 m thick in Manatee County south of the bay. The Floridan is confined to varying

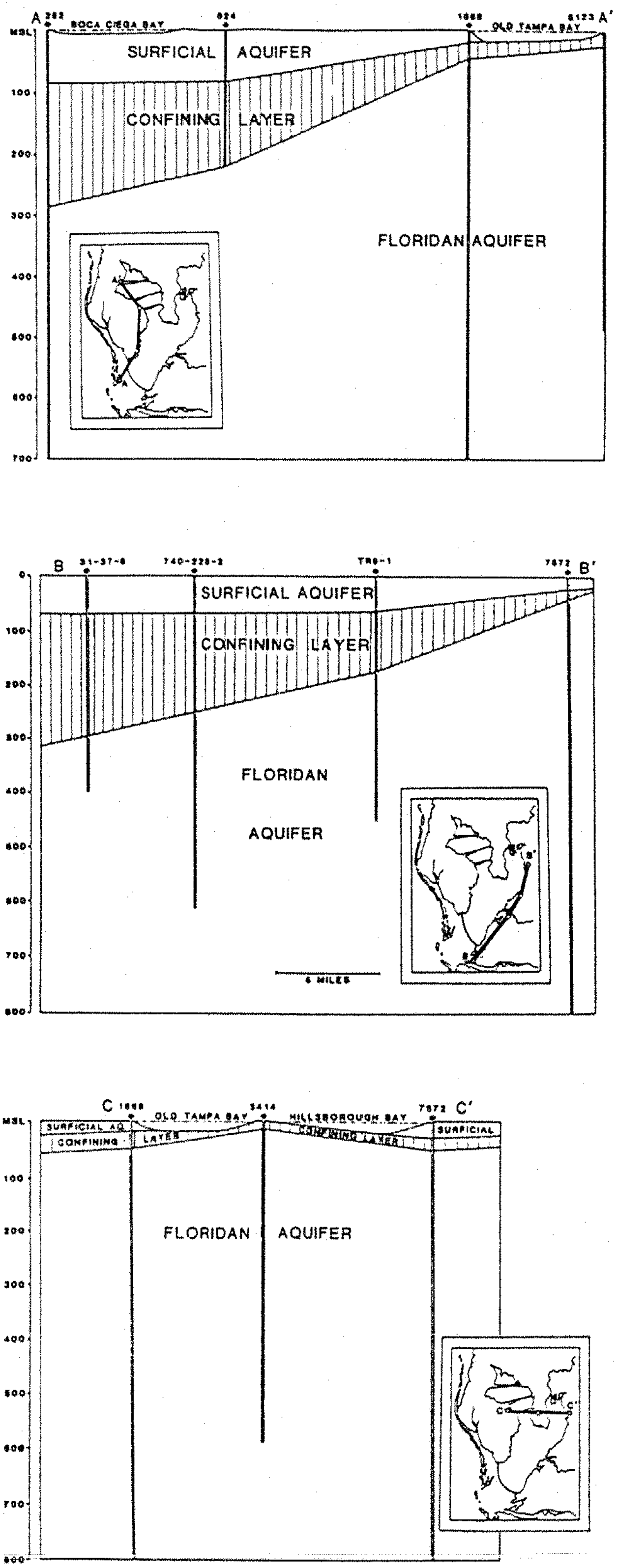


Figure 19. Relation of surficial and Floridan aquifers to Tampa Bay along three axes (Culbreath et al. 1985).

degrees by the overlying Hawthorn Formation, a late Miocene deposit that thickens and dips toward the south under the bay.

Recharge to the Floridan Aquifer occurs primarily northeast of Tampa Bay where formations are at or near the surface, as in the Green Swamp (Ryder 1982). Upper Old Tampa Bay and Hillsborough Bay are likely areas of vertical leakage, both upward and downward, due to the semipermeable nature of the confining beds of the Hawthorn. Recharge to the Floridan in Manatee County is primarily from inland areas east of the coast.

Undifferentiated sands, silts, and clays of Pleistocene and Recent times overlie the Hawthorn and hold water derived from local percolation. This surficial aquifer is 7-15 m thick throughout most of the bay area but is reduced to a thin veneer or is absent under Tampa Bay. Consequently, the thickness and imperviousness of the Hawthorn Formation controls hydrologic connections between the Bay and Floridan Aquifer.

2.3.5. Ground-Water Discharges to Tampa Bay

Ground waters are discharged to Tampa Bay from the surficial (water-table) and confined (Floridan) aquifers. Discharges from these sources are controlled by the relationship of actual or potential water surface levels and land surface, and leakage. Figure 20 illustrates the movement of surficial waters to the bay and the effect of streams on direction of movement (Culbreath et al. 1985). Although data from Manatee County are not illustrated, surficial discharges to the bay are significant (Hyde 1975).

Surficial discharges to the bay are seasonal and greatest during and after the wet season. The roles of ground water discharge in bay ecology are poorly understood, but for discussion purposes can be postulated as (1) attenuating surface flows and constituent loads; (2) prolonging estuarine conditions along shorelines and in marshes or mangrove forests, and (3) creating favorable

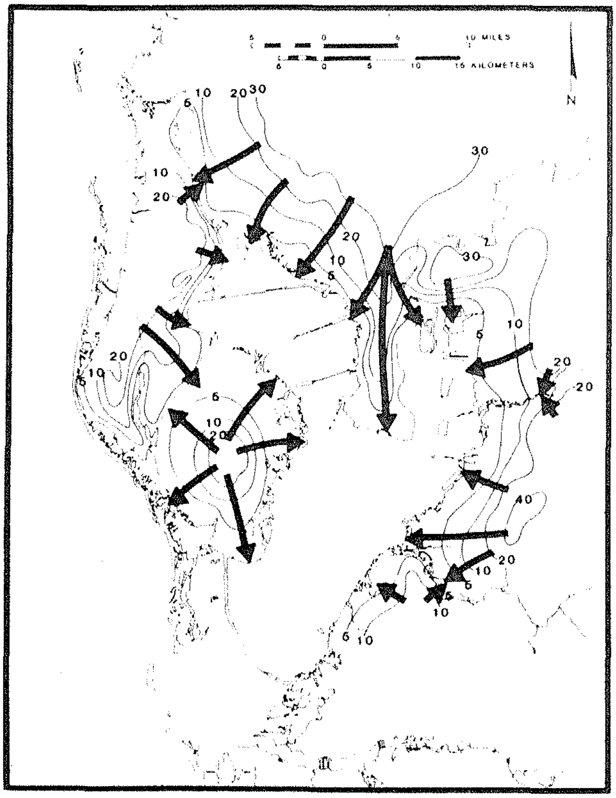


Figure 20. Generalized flow in the surficial aquifer, September 1980 (Culbreath et al. 1985).

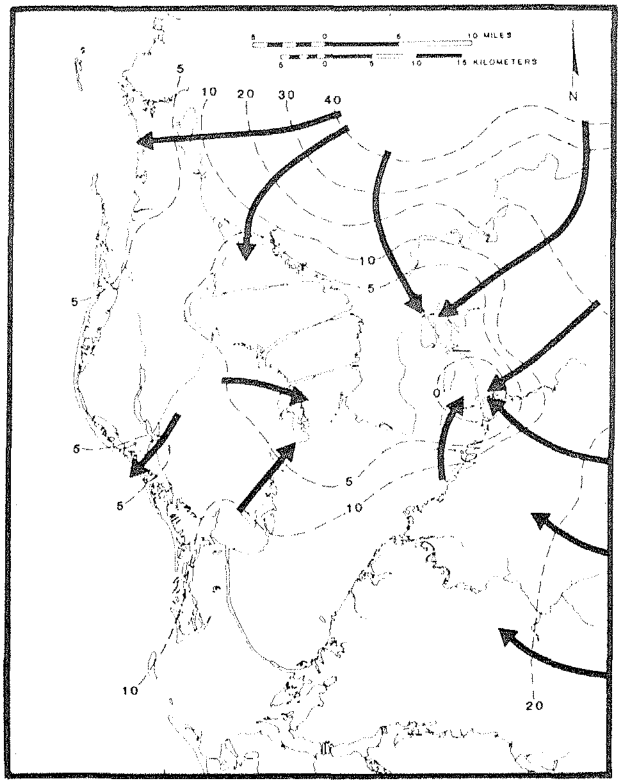


Figure 21. Generalized flow in the Floridan aquifer, September 1980 (Culbreath et al. 1985).

refugia and nursery areas for marine life in tidal creeks. Drainage of uplands around the bay has concentrated the different flows of surficial discharge, routed it to major stormwater outlets, and so altered the hydrology and constituent loads of artificial tributaries that many functions of diffuse flows have probably been lost.

The physical interaction of the Floridan Aquifer and Tampa Bay and its ecological consequences also are poorly known. Figure 21 illustrates aquifer water moving toward and under the bay. Ryder (1982) estimated that 8.7 billion l/day of ground water are released from the Floridan Aquifer in southwest Florida, an "immense area of upward leakage." Although 90% of the leakage is in the form of springs, 10% occurs in the coastal area as diffuse leakage.

There are about a dozen springs in the Tampa Bay area, although no submarine ones are known (Rosenau et al. 1977). Pinellas County has two dormant springs relevant to the bay, Phillippi and Espiritu Santo Springs. The Hillsborough River Basin contains Purity, Sulphur, Eureka, Lettuce Lake, and Six Mile Springs. Buckhorn, Messer, and Lithia Springs are located in the Alafia River. No springs are reported in the Little Manatee and Manatee Rivers; this is consistent with the increased thickness of confining layers. Together, these and lesser springs contribute an average of 3.5 m^3/s of discharge, but all of it either is consumed or added to the flows of their respective rivers.

On the other hand, artesian flow is widespread around Tampa Bay and probably was substantial prior to development of the region (Ryder 1982). As shown in Figure 22, artesian flow probably occurs in eastern Pinellas County, within the Tampa Bay Bypass Canal (formerly Palm River), the Ruskin area, and coastal

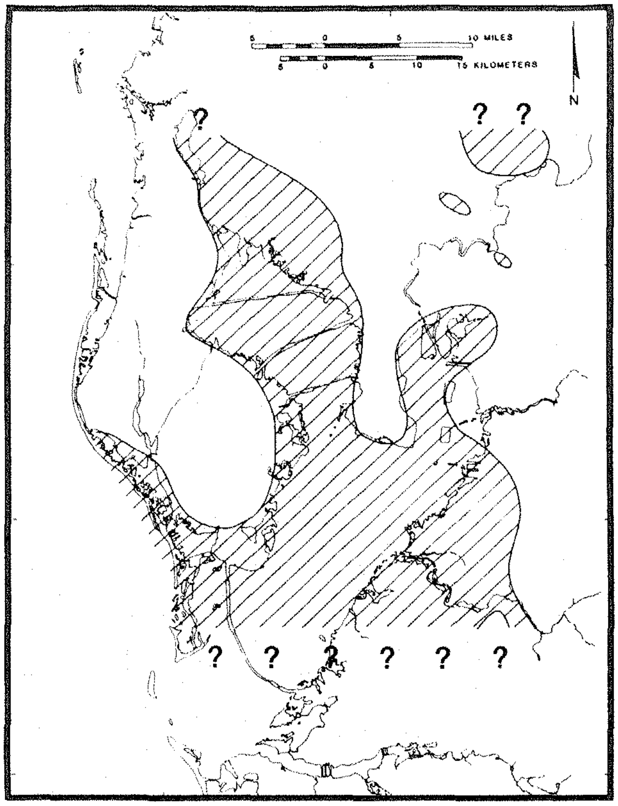


Figure 22. Area of potential discharge from the Floridan aquifer, September 1980 (Culbreath et al. 1985).

Manatee County (Peek 1959; Hyde 1975; Rosenau et al. 1977). Extensive artesian flow has supported truck farming and tropical fish culture from Tampa to Bradenton. In upper Old Tampa Bay, artesian flows into Rookery and Double Branch Creeks were common because the Floridan Aquifer is either poorly confined or unconfined (Mann 1972).

Actual rates of discharge from the Floridan Aquifer depend on potentiometric levels (the level to which water would rise in a confined well open at its bottom to the aquifer) and connections to the bay or ground surface. Long-term potentiometric surface projections based on farming, new and forthcoming mining operations, and municipal consumption are about 9 m below existing levels; this suggests a decreased potential for ground-water movement to the bay (Wilson and Gerhart 1980). Excavation of the Tampa Bypass Canal opened the aquifer, and ship channels probably have done so as well, meaning that vertical fluxes are further still from natural conditions (Motz 1975; Hutchinson 1983).

It is apparent from the data on surface water and ground-water hydrology that much is known about physical conditions relative to freshwater inputs to Tampa Bay, but details of ground-water dynamics and the ecological role of freshwater in the bay are sorely understudied. No one today probably appreciates how wet the Tampa Bay region once was. Until we know the "original" hydrological conditions of the bay, it is likely that efforts to control its chemistry and biology will be misguided.

2.4 HYDROGRAPHIC CHARACTERISTICS OF TAMPA BAY

Tampa Bay is Florida's largest open-water estuary and the second largest after the expansive network of tidal rivers and creeks of the Everglades. The bay covers 967 km^2 and is wider than 16 km in places. With wetlands, total area is about 1,030 km^2. The bay has a bottom area of 794 million m^2, and a volume at mean tide of 3.48 billion m^3 (Ross et al. 1984).

2.4.1. Shape and Shorelines

The main axis of Tampa Bay is southwest to northeast (into Hillsborough Bay) with a northwesterly branch into Old Tampa Bay. Historically, natural shorelines included estuarine sandy beaches (found today at Piney Point), salt barrens (Beacon Key), mangrove-dominated embayments (Cockroach Bay), low river marshes and bluffs (Little Manatee River), and pine flatwoods (Interbay Peninsula). The only natural rock shoreline remaining in the bay is a coquina outcrop north of the Alafia River near Archie Creek, although others occurred at Ballast Point and elsewhere (Heilprin 1887).

Goodwin (1984) computed changes in physical characteristics within subareas of the bay since 1885 (Figure 23; Table 7). The area of Tampa Bay has been reduced by 3.6%, with most (3.0%)

occurring before 1972. Hillsborough Bay's surface area was reduced by 13.6%, primarily by residential and port-related filling. Lower Tampa Bay has lost 1.9% of its total area, but this figure would be considerably higher if middle and upper Boca Ciega Bay were included (Lindall and Trent 1975). The loss of bay area from filling occurred mostly along shorelines and shallow areas of high biological productivity. Definitive data on shoreline loss by type are not yet available for Tampa Bay, but a preliminary estimate of 44% loss in total mangrove acreage illustrates the relative importance of the lost area (Lewis 1977). In Charlotte Harbor to the south, Harris et al. (1983) calculated that during 1945-1982 mangrove acreage actually increased by 10%, so losses in Tampa Bay have been considerable.

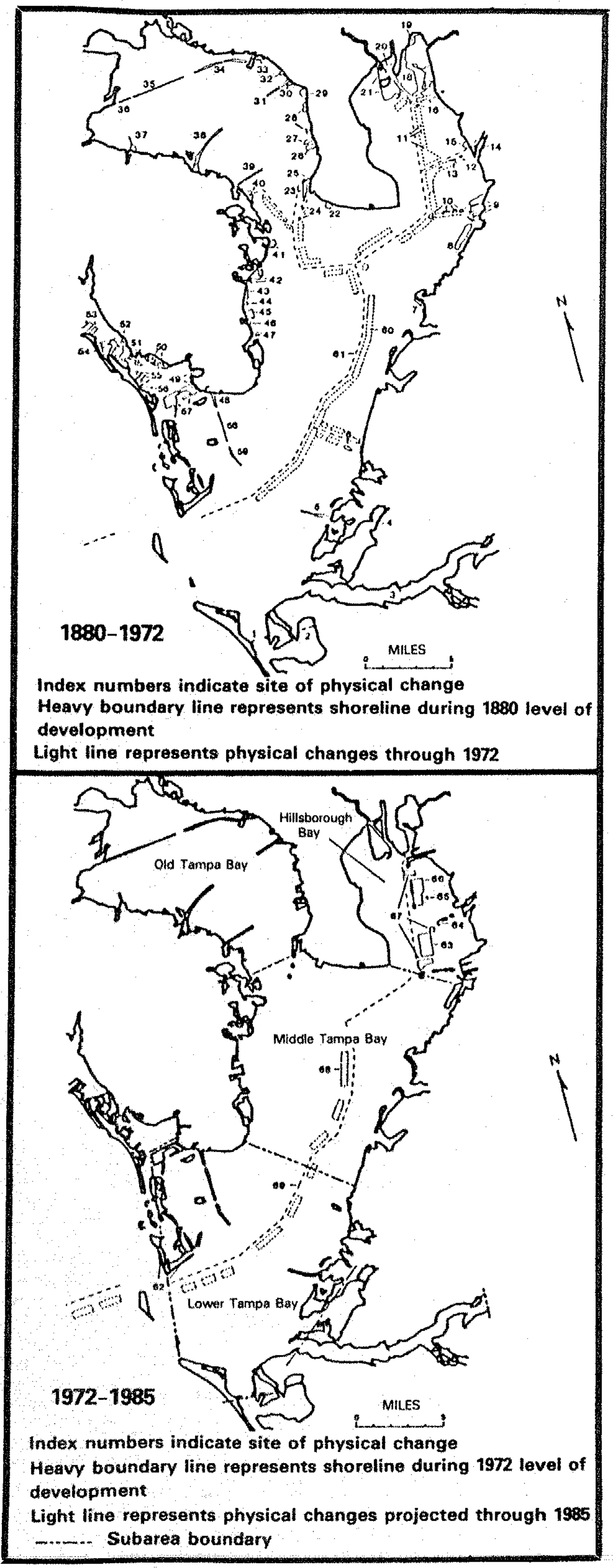
2.4.2. Depth

The bay contains at least three terraces or wave-cut benches associated with lower sea-level stands, with the deepest water in lower Tampa Bay. Egmont Channel at the mouth of Tampa Bay is the deepest inlet and has a natural depth of 27.4 m. A 96-km-long ship channel (dredged to 13 m) is the longest bathymetric feature on the Florida west coast.

Tampa Bay is a shallow body of water, with a modal depth of 3.0 m and 90% of its area shallower than 6.7 m (Olson and Morrill 1955). Mean depths have been reported as 4.1 m for the bay as a whole at "mean tide," and 3.7 m (Goodwin 1984) based on supplemental data (Rosenshein et al. 1977). Differences in estimates are due to definitions used in compiling data and bay development such as the ship channel and related spoil islands. According to Goodwin (1984), the mean depth of Tampa Bay has increased more than 5% during the past century with an increase of almost 30% in Hillsborough Bay. Most of the increased relief took place before 1972 as a result of early channel projects.

2.4.3. Bottom Features

The primary bottom type in Tampa Bay is unconsolidated sediment, or so-called



Index numbers indicate site of physical change
Heavy boundary line represents shoreline during 1880 level of development
Light line represents physical changes through 1972

Index numbers indicate site of physical change
Heavy boundary line represents shoreline during 1972 level of development
Light line represents physical changes projected through 1985
------- Subarea boundary

Figure 23. Areas of physical change in Tampa Bay since 1880 (Goodwin 1984).

Table 7. Physical characteristics of major subareas of Tampa Bay for 1880, 1972, and projected 1985 levels of development (Goodwin 1984).

Physical Characteristics/Area	Year			Percent change		
	1880	1972	1985	1880-1972	1972-1985	1880-1985
Surface area (mi^2)						
Lower Tampa Bay	128.4	126.1	125.9	- 1.8	- 0.2	- 1.9
Middle Tampa Bay	111.2	109.5	109.5	- 1.5	0	- 1.5
Old Tampa Bay	77.8	74.8	74.8	- 3.8	0	- 3.8
Hillsborough Bay	42.7	38.8	36.9	- 9.1	- 4.9	-13.6
Tampa Bay	360.2	349.2	347.2	- 3.0	- 0.6	- 3.6
Water volume (mi^2 ft)						
Lower Tampa Bay	1,572	1,578	1,578	+ 0.4	0	+ 0.4
Middle Tampa Bay	1,475	1,481	1,481	+ 0.5	0	+ 0.5
Old Tampa Bay	689	695	695	+ 0.9	0	+ 0.9
Hillsborough Bay	352	373	388	+ 6.0	+ 4.0	+10.2
Tampa Bay	4,088	4,128	4,142	+ 1.0	+ 0.3	+ 1.3
Average depth (ft)						
Lower Tampa Bay	12.2	12.2	12.5	+ 2.4	0	+ 2.4
Middle Tampa Bay	13.3	13.5	13.5	+ 1.5	0	+ 1.5
Old Tampa Bay	8.9	9.3	9.3	+ 4.5	0	+ 4.5
Hillsborough Bay	8.2	9.6	10.5	+17.1	+ 9.4	+28.0
Tampa Bay	11.3	11.8	11.9	+ 4.4	+ 0.8	+ 5.3
Tidal prism (mi^2 ft) computed at seaward end of:						
Lower Tampa Bay	792	764	761	- 3.5	- 0.4	- 3.9
Middle Tampa Bay	570	548	541	- 3.8	- 1.3	- 5.1
Old Tampa Bay	205	195	194	- 4.9	- 0.5	- 5.4
Hillsborough Bay	116	105	98	- 9.5	- 6.7	-15.5

soft bottom. Goodell and Gorsline (1961) gave details on this type of bay sediment. The actual area of soft, unvegetated bottom is not known but in Charlotte Harbor it represents about 80%-85% of the total area (Estevez 1981) and is presumed to be of similar extent in Tampa Bay. Examples of soft bottom include expansive tidal flats in McKay Bay, shallow basins in Terra Ceia Bay, the undulating flocculent substratum in Hillsborough Bay, and the offshore bars along the lower bay. Some soft bottom supports grassbeds. About 30,970 ha of grassbeds once existed in Tampa Bay, but such vegetated bottoms have declined by 81%.

Recent estimates of oyster coverage in the bay are limited to those by McNulty et al. (1972), who gave a total of 3,352 ha. This value probably was much greater a century ago before shell was harvested for fill. Numerous earthworks around the bay suggest intriguingly large acreages of oysters in prehistory (Goggin and Sturtevant 1964). Hard or live bottom occurs in the lower bay and near Gandy Bridge, but in unknown amounts. These areas of rocky relief are populated by colonial invertebrates such as sponges and tunicates. Attached macroalgae are diverse and plentiful, and the areas may serve as nurseries for juvenile fishes. Hard bottom is common where tidal currents have removed overlying sands from limestone, coquina, or other rock.

The final bottom channels are either natural or dredged. Egmont Channel is incised into rock (Wm. H. Taft, Worcester Polytechnic Institute, pers. comm.) and parts of the main ship channel are cut into limestone in middle and upper Hillsborough Bay (Hutchinson 1983). Smaller channels lead to docking areas and emerge from river mouths.

2.4.4. Sea Level and Tides

Water level in Tampa Bay varies as a function of long term oceanic change, multiple year cycles, and solunar tidal action. Wind and storms also affect the level of bay waters.

Long-term trends. Sea level is rising in Tampa Bay, although estimates of the rates of apparent rise vary. Marmer (1951) estimated a mean rate of 0.91 cm/yr rise in sea level at Cedar Key. This is equal to a rise of 91 cm/century. Bruun (1962) estimated a rate of 0.30 cm/yr on the west coast of Florida for 1930-60, or a rate of 30 cm/century. Hicks and Shofnos (1965) set the Cedar Key rate at 0.27 cm for 1939-62, the same as for Key West over a period of 49 years. This rate equals a rise of 27 cm/century. Hicks (1972b) gave a rate for Cedar Key from 1940-70 of 0.03 cm/yr, for a rate of only 3.0 cm/century. Provost (1974) gave a rate of 21 cm/century for Tampa Bay.

Not all of the observed rise in sea level has been due to oceanic changes, since subsidence of land contributes to a relative transgression of the sea. Nonetheless, the combined effect of a rising sea and sinking coastline is ecologically significant. In the Florida Everglades the rise of the sea (relative to land) has caused a dissection of the mangrove coast in the Ten Thousand Islands, and even today seaward islands are drowning while the forest moves inland (Scholl and Stuvier 1967). Shorelines of Tampa Bay are eroding slowly, partly because of sea-level rise (Estevez and Mosura 1985), and the loss of bars bayward of intertidal seagrass beds may be declining for the same reason (Hands 1983). Over a longer period of time, sea-level rise will cause an infilling of Tampa Bay (Brooks 1974) and realignment of shorelines (Bruun 1962).

During the next 50 years we foresee a loss of seaward mangrove shorelines similar to the loss during the past 50 years and an invasion by these trees into lands now only inundated by the highest tides. However, since much of the shoreline has been bulkheaded at or above current mean high water, there will be little habitat for these trees to invade, resulting in a "pinching out" of this zone of intertidal, fringing vegetation.

A redetermination of tidal datum planes in Tampa Bay was made during the past 10 years by the National Ocean Survey. Relative to the reference of the National Geodetic Vertical Datum, these tidal planes are higher than their predecessors, which were derived from 1929 data. Unfortunately, these new tidal planes are not commonly used by surveyors or engineers (or regulatory agencies), so that shoreline projects are being designed too low on the shoreline and too close to ecologically valuable intertidal areas.

Annual trends. Tides vary daily and the cycle of tides in Tampa Bay has a lunar period, but underlying these changes is an annual variation of ecological importance, particularly for intertidal organisms. Sea level is highest in August-October because of oceanic changes, the movement of coastal currents, warming of the sea, runoff, and solar and lunar effects. It is lowest in January and February, so the most rapid change in sea level is in November and December. The difference between sea level during these extremes is about 24 cm (Marmer 1951).

Provost (1974) showed that tides of the same amplitude inundate fixed intertidal marsh points differently, depending on annual sea-level changes. Estevez (1978) presented inundation curves for Cockroach Bay (Figure 24) and found that organisms located at mean high water were submerged 55% of the time in October but only 18% of the time in February. The range of submergence (October through February) at mean tide was 80%-50% and only 96%-80% at mean low water. Estevez (1978) interpreted ecological data on red mangrove root-borers on the basis of these changes. Others working in the intertidal zone should keep this variation in mind,

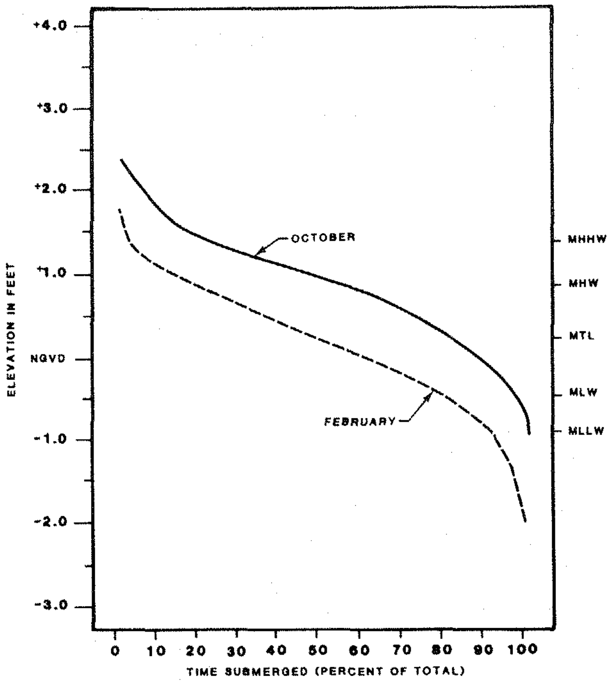


Figure 24. Seasonal changes in tidal duration curves at Cockroach Bay (Estevez 1978).

especially when interpreting positional data.

Tides. Tides in Tampa Bay are a mixture of lunar (semidiurnal) and solar (diurnal) tidal types (Goodwin and Michaelis 1976). The average tidal range is 0.67 m, although, as noted above, annual sea level variation results in the shifting of this range vertically in relation to the shore. Tides propagate uniformly from the Gulf of Mexico into the bay (e.g., tidal cycles are delayed but not distorted much at different points up the bay). Tidal changes relative to St. Petersburg are given in Table 8.

Typical tides in Tampa Bay are illustrated in Figure 25 (Goodwin 1984). When tides are mixed, a "lower" low tide is followed by a "lower" high tide, then by a "higher" low and "higher" high tide. Southwesterly winds heighten tides and northerly winds lower tides by 1.0-1.5 m, depending on wind strength and duration. The storm surge, although technically not a tidal wave, is also wind driven and may accentuate tidal variations. Figure 26 illustrates the relative frequency of occurrence of total tide height resulting from astronomic, barometric, and storm surge forces for gulf beaches on the Pinellas Peninsula. Relative to mean sea level a 1.5-1.8 m "tide" recurs on an

Table 8. Tide relations in Tampa Bay.

	Change relative to St. Petersburg				
	High tide		Low tide		
Place	Height[a]	Time[b]	Height	Time	Range (ft)
Egmont Key	*0.9[c]	-2:27	*0.9	-2:24	2.1
Shell Point	0	+0:08	0	+0:17	2.3
Hillsborough Bay	+0.5	+0:07	+0.1	+0:26	2.8
Safety Harbor	+0.5	+1:38	0.0	+1:55	2.8

[a] Relative to mean lower low water.
[b] Hours:minutes.
[c] Asterisk identifies a value to be multiplied by predicted height at St. Petersburg.

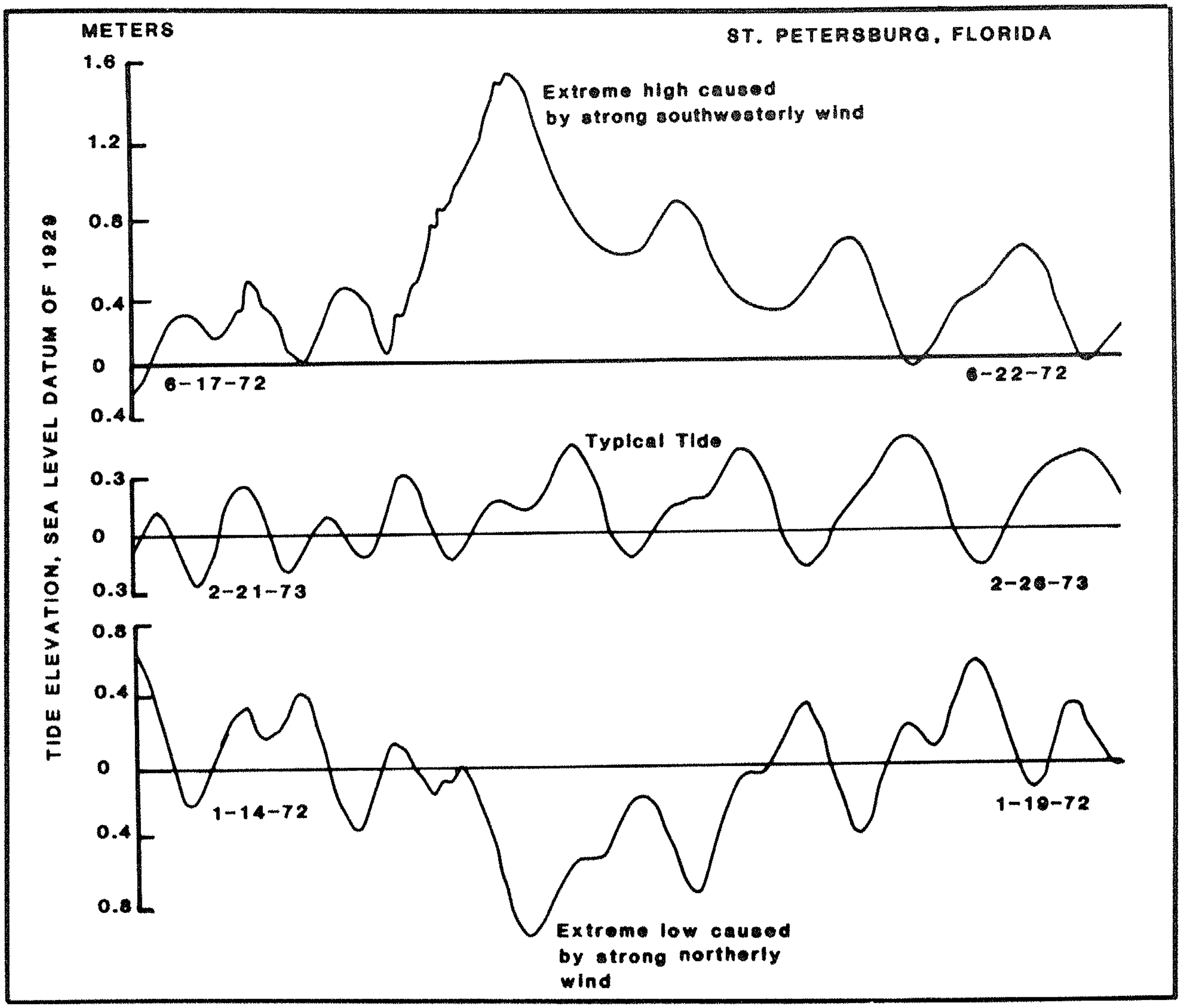


Figure 25. Typical and extreme tides in Tampa Bay (Goodwin 1984).

average of 10 years; 2.5 m heights recur on a 25-year cycle.

2.4.5. Circulation and Flushing

Circulation refers to the paths taken by water currents and their constituents due to tidal forces, runoff, wind, and other effects. Flushing is the net retention or export of water or waterborne material after circulation has occurred over a period of interest. Goodwin (1984) examined circulation and flushing of Tampa Bay for the period 1880-1985.

Both circulation and flushing in estuaries are determined largely by the relationship of freshwater inflow to tidal volume. Total inflow to Tampa Bay is about 45 m^3/s, much less than the average tidal flow at mid-tidal cycle of 25,500 m^3/s. Thus, Tampa Bay as a whole may be considered a neutral or mildly positive estuary which, because of bathymetry and low inflows, is vertically well mixed and generally unstratified with regard to salinity (Dinardi 1978).

The tidal prism, or volume of water in the bay between slack waters, is greatest in Lower Tampa Bay and least in

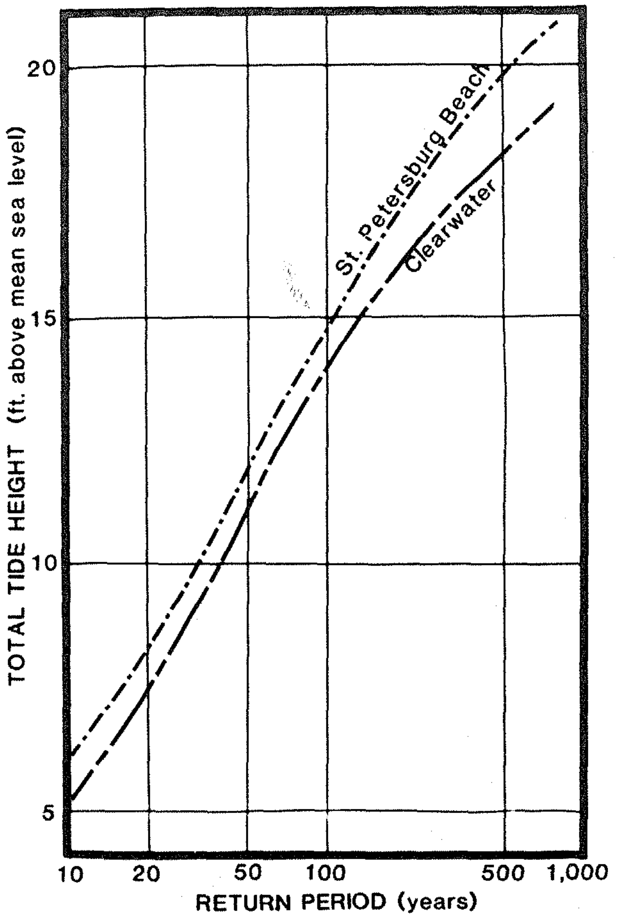


Figure 26. Total tide height (ft) above MSL versus return period in years (NOAA 1975). Curves applicable to St. Petersburg Beach—Clearwater coastline.

the northern arms of the bay. In 1880, respective prisms at their seaward ends were 1,006 km^2-m for the lower bay, 724 km^2-m for the mid-bay, 260 km^2-m for Old Tampa Bay, and 147 km^2-m for Hillsborough Bay. As discussed below, these values have changed because of dredging and filling, especially in Hillsborough Bay, in all cases decreasing even though bay volume has increased.

<u>Currents</u>. Typical current speeds range from 1.2-1.8 m/s at the entrance to Tampa Bay, to less than 0.14 m/s in Hillsborough Bay. Ebb tidal current speeds are greater than flood currents, reflecting the faster rate of water-level change on ebb tide. Winds and runoff may increase current speeds under extreme conditions.

The pattern of currents in Tampa Bay is known for flood and ebb cycles, although it is useful to note Goodwin's (1984) caveat that there are no fixed patterns of circulation in any estuary. In general, flood tidal currents enter Tampa Bay by the openings of the Sunshine Skyway Causeway and separate to the east and west shores of middle Tampa Bay (Figure 27). Lesser speeds occur near shorelines and in the center of the middle bay. Water is transported at a diminishing rate into Old Tampa Bay to, but not much beyond, the Courtney Campbell Causeway. Transport into Hillsborough Bay is minimal. The pattern is basically reversed on falling tide except that water transport in the central part of the midbay is greater.

<u>Net circulation</u>. Average flooding and ebbing currents offset each other over a complete tidal cycle except for a residual movement specific to each bay area. The residual transport is a measure of net circulation that will occur as long as similar tidal and other conditions prevail. Work by Ross et al. (1984) and Goodwin (1984) has done much to advance our knowledge of net circulation in Tampa Bay, and provided very interesting results (Figure 28).

First, there is a pronounced gradient in residual water transport (net circulation) from the bay entrance to upper bay areas. At the entrance, residual magnitudes are about 525 m^3/s, compared to 30 m^3/s in Old Tampa Bay and 15 m^3/s in Hillsborough Bay. Second, net circulation in Hillsborough Bay always has been poor and, until recent channel dredging, was attributable more to river discharge than to other factors. Third, at least 20 gyres are present in the bay. The gyres are circular features of tide-induced circulation which form when wind and density stratification are absent. The gyres range in diameter from 1.5 to 10.0 km and adjoin neighboring gyres with opposite flow--much like a series of gears.

The presence of gyres in Tampa Bay has been known for several years, although their actual influence remains untested . Ross (1975) suggested a correlation between the size and location of gyres

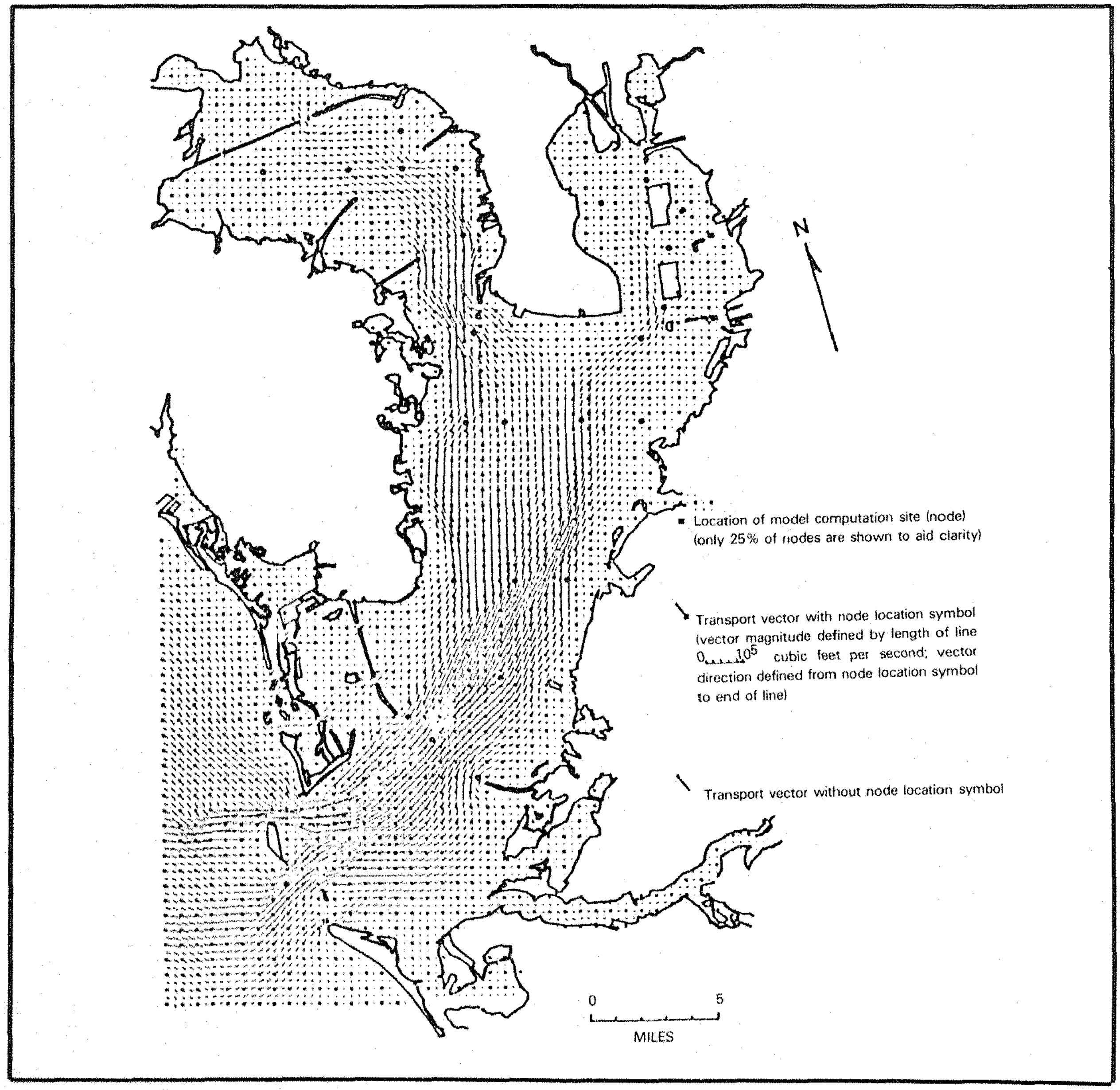


Figure 27. Water movement during a typical flood tide in 1985 (Goodwin 1984).

with sedimentary features and possibly macrofauna. Several unanswered questions regarding gyre dynamics remain: (1) Do they develop for sufficient periods to affect water quality, plankton dispersion, or pollutant transport? (2) Are their effects permanent or overwhelmed by wind or other short-term events? and (3) Do gyres present problems or opportunities for resource management?

Goodwin (1984) compared tide-induced residual transport to average tributary inflow to identify eight significantly different circulation zones (Figures 29 and 30). Overall, circulation is high in Zones 1 and 4, low in Zones 3, 6, and 8, and variable in other zones. Zone 4 (Upper Tampa Bay) is an area of naturally high rates of exchange with Hillsborough and Old Tampa Bays, but is separated from

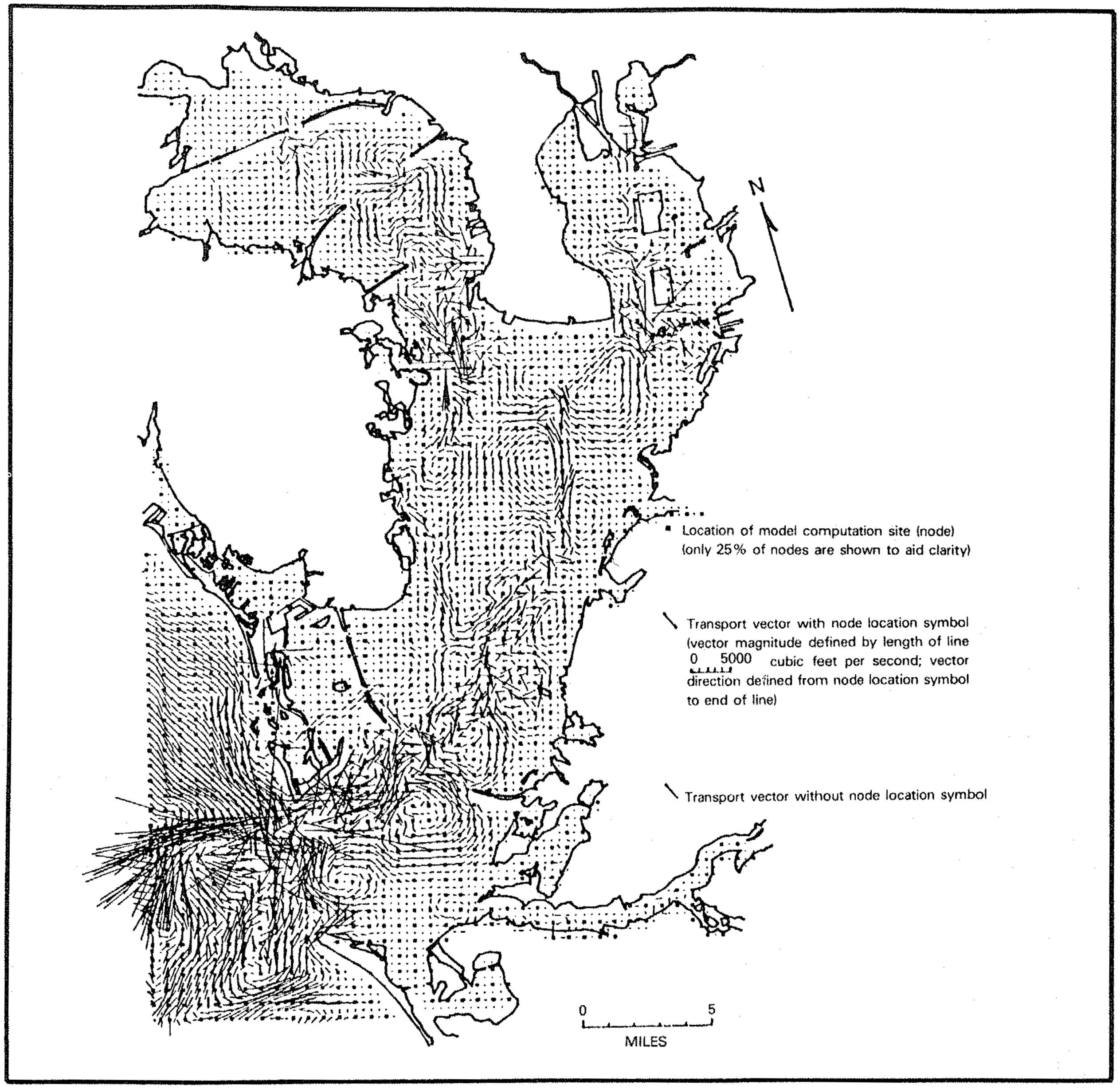


Figure 28. Residual water movement after a complete tide cycle in 1985 (Goodwin 1984).

Lower Tampa Bay by Zone 3, an area of natural quiescence. The poorest circulation in Tampa Bay is in Zone 6, Upper Hillsborough Bay, despite improvements caused by channel dredging.

Flushing. Goodwin (1984) modeled transport of phosphorus (due to high concentrations throughout the bay in 1975) to assess constituent transport. The residual transport may be treated as "flushing" in the popular sense, since it reflects the tendency of the bay to export undesirable material. Tide induced flushing, however, is the flushing of a constituent minus transport caused by tributary flow (Figure 31). Highest phosphorus concentrations were 2.5 mg/l in Hillsborough Bay and 0.8 mg/l in Old Tampa Bay, compared to less than 0.2 mg/l at the

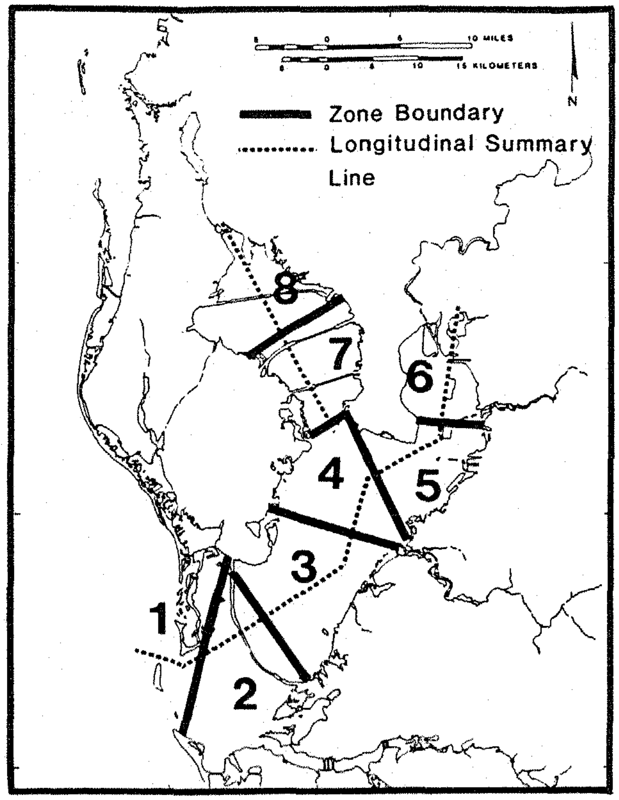


Figure 29. Major circulation zones in Tampa Bay (Goodwin 1984).

bay entrance. Flood and ebb transport resembled tidal water transport, reaching maximum values in the midbay and low values in the upper arms of the bay. Residual constituent transport vectors assumed circular features similar to circulation gyres, although magnitudes of transport were affected by the concentration gradient. The ship channel gained importance for constituent transport, and the importance of tributary flows for constituent flushing from Tampa Bay remained high.

<u>Changes since 1880</u>. Goodwin (1984) concluded that historic and recent alterations to the physical dimensions of Tampa Bay have been responsible for the following:

(1) decreased surface area and tidal prism, especially in Hillsborough Bay;
(2) increased depth and volume, especially in Hillsborough Bay;
(3) large (more than 100%) changes in flood and ebb tide transport caused by causeways and filling of upper Hillsborough Bay;
(4) large (more than 100%) changes in net circulation in Old Tampa Bay and Hillsborough Bay; and
(5) increased inland (trapping) and seaward (export) exchange caused by tidally induced flushing.

Overall, Goodwin's work underscores three important conclusions, i.e., that physical changes to the bay have caused significant effects in circulation and flushing; Hillsborough Bay was naturally an area of poor flushing (and was thus the worst place for municipal and industrial waste to have been discharged); and the continued flow of freshwater to Tampa Bay and especially Hillsborough Bay is essential to maintain flushing, even though the volume is low compared to the average tidal prism. Most of these same conclusions regarding Hillsborough Bay also apply to Old Tampa Bay.

2.5 CHEMISTRY OF THE BAY

Numerous studies of water chemistry in Tampa Bay are available as reviews (Fanning and Bell 1985), reports (Goetz and Goodwin 1980), data presentations (Hillsborough County Environmental Protection Commission 1972-84), and unpublished data. Less information is available on sediment chemistry, but that which is available largely corroborates trends and patterns depicted by water-quality data.

Selected physical and chemical properties of bay waters and sediment are reviewed in this section from an ecological perspective, i.e., as a description of the environment inhabited by estuarine plants and animals. Readers interested more in water quality and human uses of the bay should realize that subsequent comments support four conclusions, namely:

(1) Tampa Bay is not grossly "polluted", certainly not beyond the point of rehabilitation;
(2) Parts of the bay are "cleaner" than others for natural as well as cultural reasons;

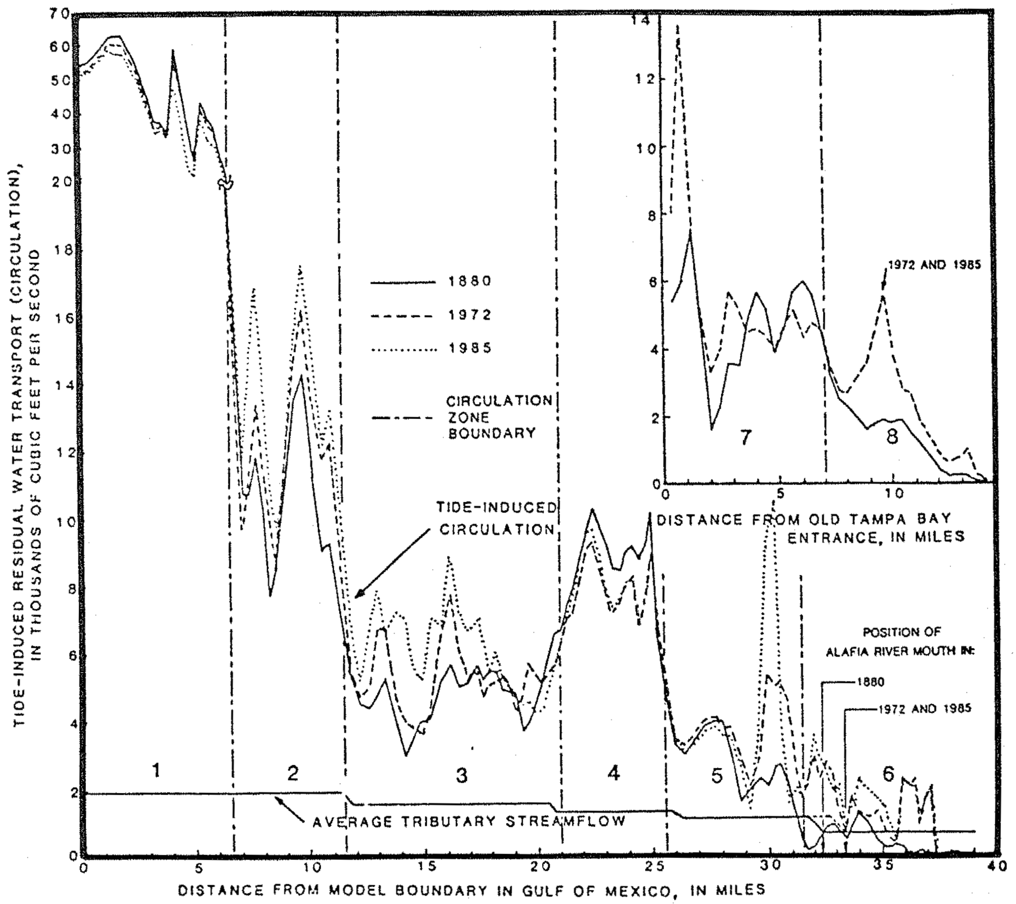


Figure 30. Average tributary streamflow and tide-induced circulation along longitudinal summary lines (see Figure 29) for 1880, 1972, and 1985 levels of development.

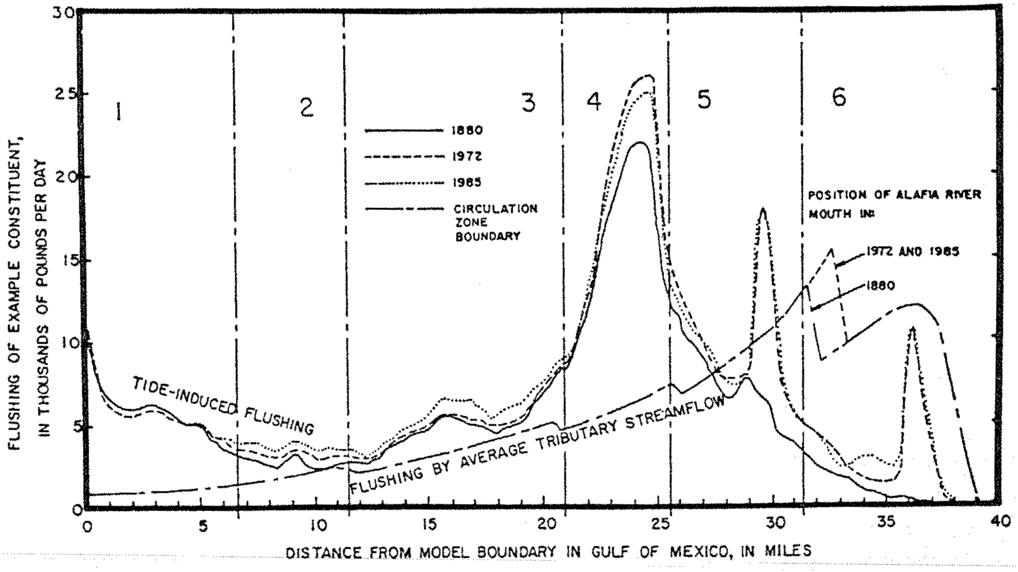


Figure 31. Tide-induced and streamflow flushing of example constituent along longitudinal summary line (see Figure 29), from lower Tampa Bay to Hillsborough Bay, for 1880, 1972, and 1985 levels of development.

(3) Levels of some pollutants in the bay have been declining over the past decade, while others have increased; and
(4) The overall "quality" of bay zones is the same whether judged by ecological or human-use criteria.

2.5.1. General Water Quality of Tampa Bay

Water quality refers to the fitness of water for human and natural uses and can be described by concentrations of specific parameters (such as bacteria) or by the relation of observed concentrations to State standards (allowable levels of bacteria). Several parameters are important from the standpoint of human uses of the bay. The Hillsborough County Environmental Protection Commission (HCEPC) has monitored such parameters throughout Tampa Bay monthly since 1972. The HCEPC summarizes monitoring data in a series of annual reports in which a "general water quality index" for Tampa Bay is presented. Values of the index range from excellent (collectively low values) to undesirable (collectively high values) and are based on ranked averaged values for total coliform bacteria, turbidity, chlorophyll a and organic carbon or biochemical oxygen demand (Figure 32).

Water quality in McKay and Hillsborough Bays has been undesirable since monitoring began. The HCEPC attributed low water quality in Hillsborough Bay to domestic (City of Tampa) and industrial wastes. The influence of Hillsborough Bay upon Tampa Bay extends along the eastern shore to the area offshore from the Little Manatee River, reflected in most years since 1978 as fair to poor water quality. General water quality in and near the Cockroach Bay Aquatic Preserve has been excellent or good, except for fair to poor ratings near the Little Manatee River due to the seasonal influence of river discharge.

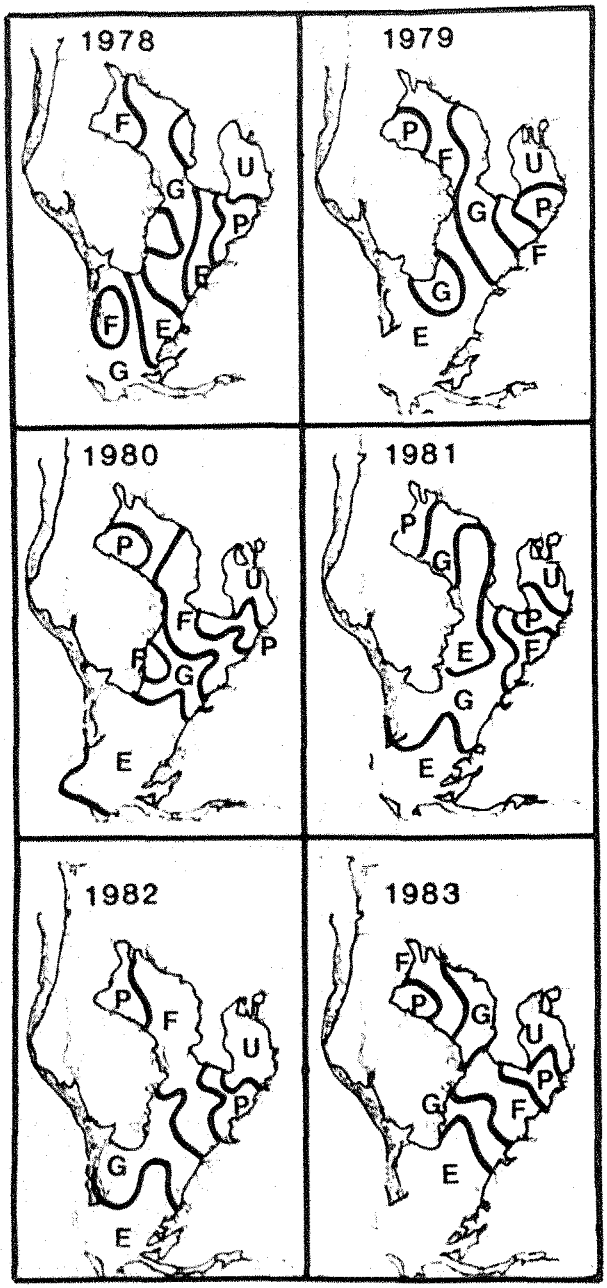


Figure 32. Trends in general water quality for body contact in Tampa Bay since 1977 (HCEPC 1978-1983). E, excellent; G, good; F, fair; P, poor; U, undesirable.

Conditions in Old Tampa Bay are mixed because of better water exchange, but water quality on the western and northern shores has been deteriorating. In 1978 the western shore north of I-275 was fair and only the water in the northeast corner of Old Tampa Bay was undesirable for human contact and recreation. By 1983 water quality along the entire western shore north of I-275 had declined to poor and more of the open bay was only fair. The HCEPC attributed declines in water quality to discharge of insufficiently treated domestic waste.

The waters of Pinellas County off the St. Petersburg municipal waterfront have improved from poor (1977) to fair (1978, 1981) or better in other years because of reductions in that city's domestic waste discharges. Water quality in the lower bay generally is good to excellent, although the HCEPC documented a decline to poor in 1978 because of increased turbidity caused by harbor deepening. In summary, general water quality is good to excellent for much of Tampa Bay, declining in Old Tampa Bay, and undesirable in Hillsborough Bay. Point sources, especially sewage treatment plant effluent, greatly affect water quality but improved effluents have resulted in improved water quality.

2.5.2. Hydrographic Parameters

Temperature. Water temperature ranges from 11°C-32°C in subtidal areas and more widely intertidally. The HCEPC data indicate very few localized areas of exceptionally low water temperature. Lower Boca Ciega Bay, eastern Hillsborough Bay, and eastern Old Tampa Bay may have above-average maximum temperatures, but overall the bay is thermally homogeneous. Mean annual variation for the bay is 16°C-30°C.

Ten years of mean annual data are shown in Figure 33, which illustrate the temperature characteristics of four bay sectors. Old Tampa Bay is usually cooler

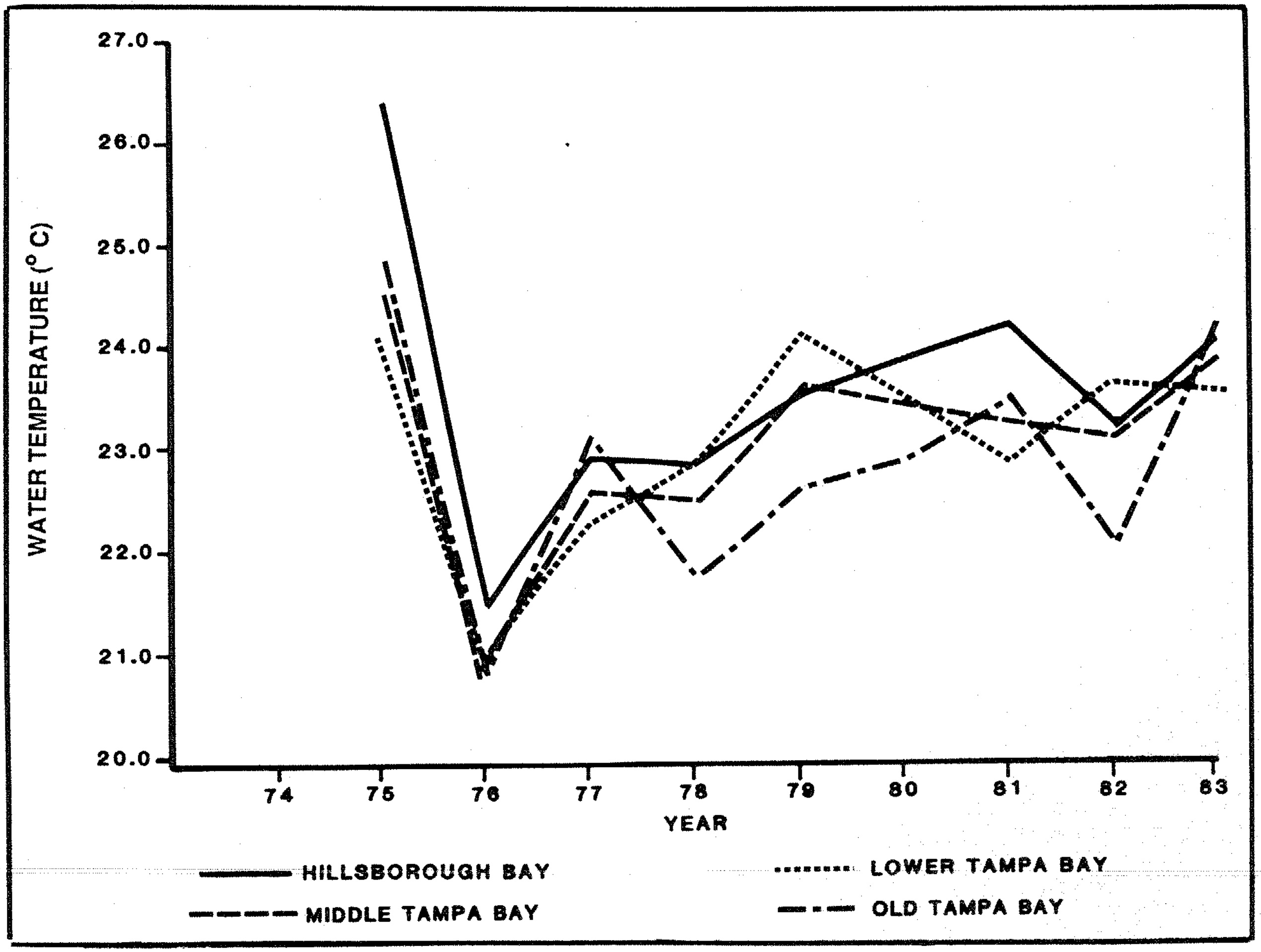


Figure 33. Mid-depth water temperature in areas of Tampa Bay since 1975 (HCEPC 1984).

than Hillsborough Bay by 1°C-2°C, and all bay sectors have been warming since 1976.

Localized thermal plumes near power plants create elevated temperatures that vary most from background water temperatures in winter. The ecological hazard of thermal plumes in a subtropical estuary like Tampa Bay is greater in summer when extra heat drives water temperature beyond the upper thermal tolerance of many species, usually about 32°C-35°C. The cumulative effect of power plant discharges of heat to Tampa Bay has not been studied.

Salinity. Salinity of bay waters is determined by tides and runoff. The extent to which oceanic salinity is reduced by runoff and the range of salinities observed at any place in the bay are ecologically important for two reasons. First, salinity gradients set up gradients of conservative and non-conservative constituents. Conservative constituents are those for which observed concentrations can be explained on the basis of physical relationships such as solubility, diffusion, advective transport, or settling. Examples of conservative constituents in the bay include heat, color, fluoride, and probably total phosphorus. Nonconservative factors are biologically alterable and vary indirectly or not at all with salinity; some examples are dissolved oxygen, some molecular forms of nitrogen, and chlorophyll.

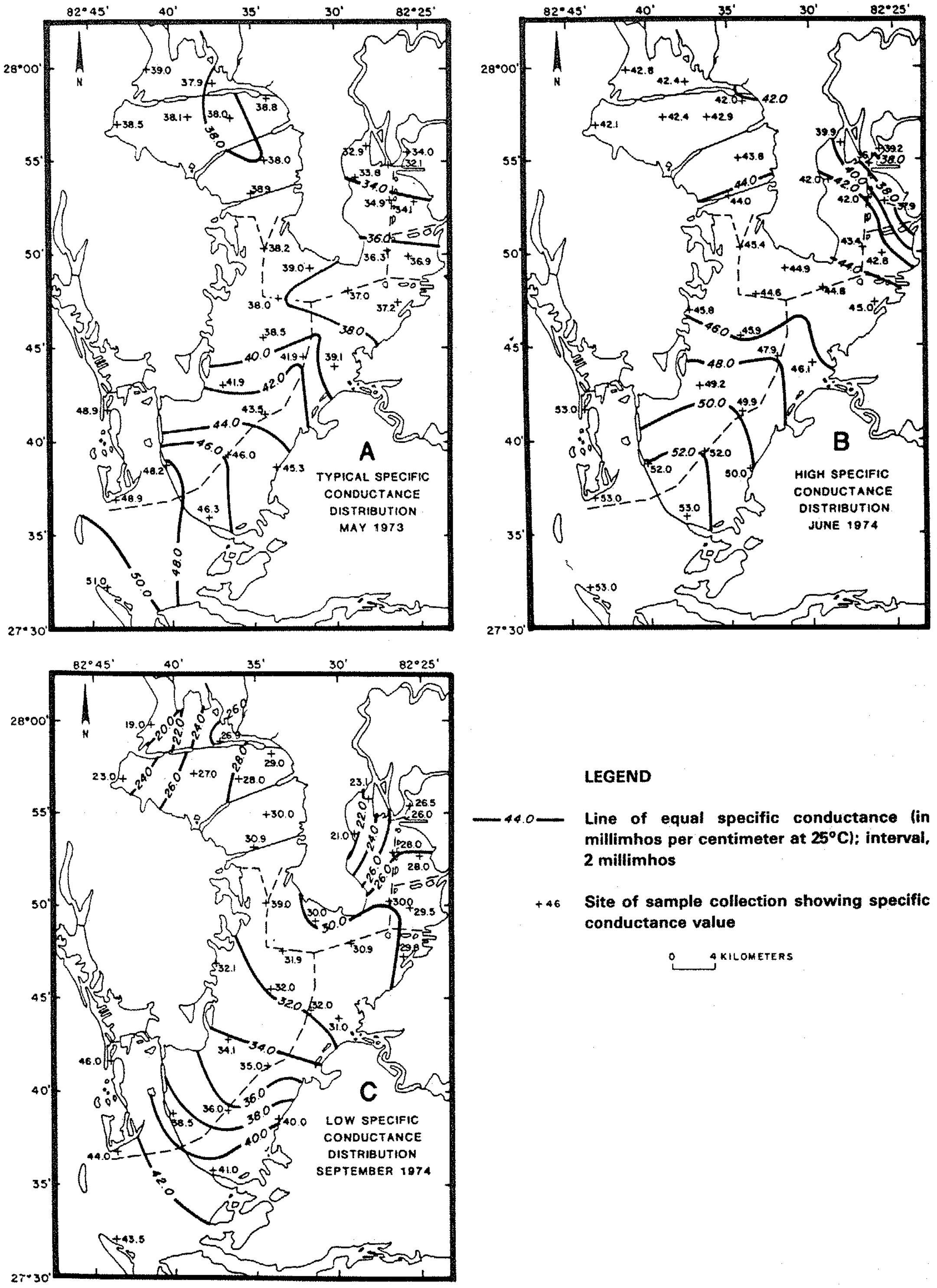
Salinity is equally important as an ecological factor for establishing areas within the bay which are inhabitable for some species but not others, and as a guide to predictable resources such as feeding or nursery grounds. Exclusion of oyster predators by low, varying salinity is a well-known example (Bahr and Lanier 1981). Spawning migrations by a variety of sport and commercial fishes and invertebrates are another.

Salinity in the Gulf of Mexico ranges from 22.6 to 39.0 parts per thousand (ppt) and averages 34.1 ppt. In lower Tampa Bay, Terra Ceia Bay to the east has an average salinity of 24.5 ppt and the widest range of any bay area--1.0 to 33.7 ppt (Simon 1974). Hillsborough Bay is fresher than Old Tampa Bay (means of 20.9 and 22.5 ppt, respectively), although the range of salinity in Old Tampa Bay is greater by 5-10 ppt.

Vertical differences in salinity usually are slight, although Finucane and Dragovich (1966) reported a one time vertical gradient of 19.6 ppt, thought by Simon (1974) to be the greatest known difference. The HCEPC data since 1977 reveal a mean annual vertical salinity gradient of 2 ppt or less for most bay areas with a range from 0.3 to 7.7 ppt in mean annual vertical difference. East Bay, a deep area between McKay and Hillsborough Bays, is more stratified with respect to salinity than most places in the bay. Vertical salinity gradients in East Bay are established by Tampa Bypass Canal discharge into the shallow waters of McKay Bay, which empties into Hillsborough Bay as warm, brackish water and overlies cooler, denser water transported northward in the main ship channel.

Shipping channels have facilitated the movement of both tidal and freshwaters. Goetz and Goodwin (1980) reported inland movement of isohales near the main shipping channel during flood tides and seaward movement during ebb tides (Figure 34). Giovanelli (1981) studied the influence of Alafia River discharge on salinity in lower Hillsborough Bay. The configuration of the dredged channel and spoils results in significant mixing at the river mouth. A 25% reduction in specific conductance resulted from a 17-fold increase in river discharge.

Dissolved oxygen. The amount of gaseous oxygen dissolved in water depends on temperature, salinity, degree of physical mixing, and the consumption or production of oxygen by organisms or chemical processes. Cold freshwater is physically capable of holding more oxygen than warm salt water, for example, and respiration by plants and animals can depress oxygen concentrations to hazardous levels after a long, still night when photosynthesis has stopped and oxygenation due to mixing is low. Anoxic conditions occur when no oxygen is left in solution. Anoxia may be tolerated by facultative anaerobes (organisms with alternate



LEGEND

—44.0— Line of equal specific conductance (in millimhos per centimeter at 25°C); interval, 2 millimhos

+46 Site of sample collection showing specific conductance value

Figure 34. Typical (A), high (B), and low (C) specific-conductance distributions in Tampa Bay (Goetz and Goodwin 1980).

respiratory systems) but results in death or displacement of most life. The State of Florida considers an oxygen concentration of 4 mg/l to be the minimum necessary for protection of marine life. Simon (1974) cited several documented cases of anoxia and associated fish kills in Tampa Bay.

Simon (1974) gave a baywide range for dissolved oxygen of 0.9-11.6 mg/l and a yearly mean for the entire system of 5.9 mg/l. Greater extremes have since been documented. Vertical gradients of oxygen are much more pronounced than salinity in Tampa Bay, especially in deep water and in Hillsborough Bay. Figure 35 illustrates average differences between surface and bottom dissolved oxygen levels in relation to depth for HCEPC data from 1981 through 1983 at stations in Hillsborough Bay. Strong vertical gradients are induced by high oxygen demands of organic sediments and by accumulations of photosynthetic plankton near the surface, which shade deeper waters (Ross et al. 1984). Self-shading is known for other estuaries but is not well studied in Tampa Bay. More study of depth- stratified levels of dissolved oxygen will be needed to evaluate impacts of harbor deepening and eutrophication.

Phytoplankton blooms are most frequent and prolonged in Hillsborough Bay, so dissolved oxygen extremes are larger than in other bay sectors. Minimum values are lower in Hillsborough Bay because of depth (as above), reduced fetch (Ross et al. 1984), plankton respiration (HCEPC data) and benthic demands (McClelland 1984). Simon (1974) gave mean and range data for dissolved oxygen in several bay areas (Table 9).

Goetz and Goodwin (1980) showed higher dissolved oxygen values and lower variability in Old Tampa Bay than Hillsborough Bay; this agrees with HCEPC data for 11 years of monitoring. Using HCEPC second minimum data for dissolved oxygen at the bottom for comparison (Figure 36), Hillsborough Bay has the most oxygen stress, followed by the east shore

Table 9. Dissolved oxygen concentrations for bay areas (Simon 1974).

	Concentration of dissolved oxygen	
Section	Mean (mg/l)	Range (mg/l)
Old Tampa Bay	6.3	2.7-10.6
Hillsborough Bay	6.4	0.9-11.6
Upper Tampa Bay	5.8	1.1- 8.1
Lower Tampa Bay	5.7	1.4- 8.5
Boca Ciega Bay	5.4	1.6-10.6

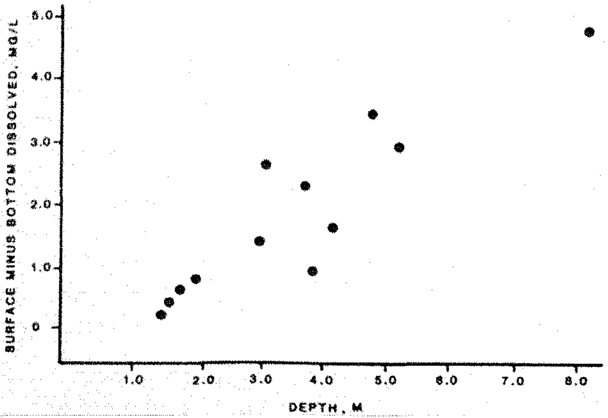


Figure 35. Stratification of dissolved oxygen (surface-bottom values) in Hillsborough Bay in relation to depth, 1981 through 1983.

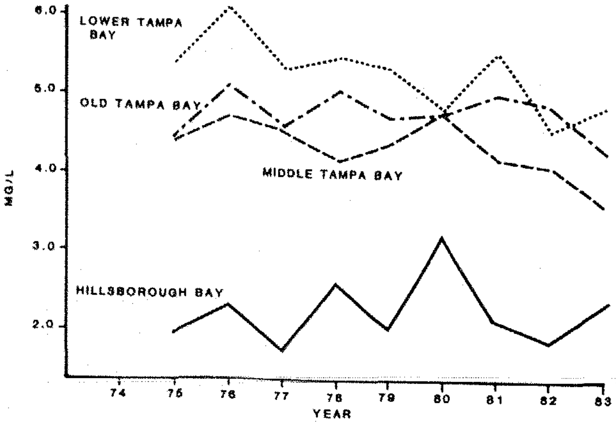


Figure 36. Mean annual dissolved oxygen near the bottom in Tampa Bay (HCEPC 1984).

of upper Tampa Bay (Ruskin - Apollo Beach). The eastern shore of Old Tampa Bay north of Interstate 275 also is relatively low in dissolved oxygen.

Dissolved oxygen concentrations vary diurnally (because of depth, light, and temperature) and seasonally (because of temperature). Bottom levels are highest in January and lowest in June through August (Figure 37). Bottom dissolved oxygen levels in Hillsborough Bay violate existing state standards 60 to 90 days each year. Dissolved oxygen in Old Tampa Bay covaries in range and pattern with Tampa Bay, but Hillsborough Bay is almost always lower. During the past decade, bottom oxygen levels have declined slightly and surface levels have increased at bay areas other than Hillsborough Bay.

Bottom oxygen conditions regulate benthic fauna composition. In Hillsborough Bay annual anoxia affects density and diversity patterns of benthic invertebrates (Santos and Simon 1980a). Anoxia in residential canals also causes fish kills (HCEPC 1984). The extent to which anoxic or near anoxic conditions in Tampa Bay are natural or cultural in origin is not known, but all circumstantial evidence implicates municipal wastes as the primary factor.

Light. Light regulates productivity of phytoplankton and seagrasses in estuaries (Odum et al. 1974), although an appreciation that light is a limit to productivity in Tampa Bay (or other shallow, inshore waters of the Florida gulf coast) is recent (McClelland 1984). Much data on transparency and light-attenuating factors are available.

Secchi disk measurements are available from the 1950's to the present. Unpublished studies in Sarasota Bay, immediately south of Anna Maria Sound, determined that 25%-30% of incident light in the photo-synthetically active range (PAR) of wavelengths penetrated to the Secchi depth (0.5-10.0 m), irrespective of water mass. The amount of light required to sustain benthic algae and seagrass in Tampa Bay is not known, but for discussion's sake can be set conservatively as light available at the Secchi depth. This implies areas where real depth exceeds Secchi depth would not receive enough light to support benthic vegetation.

Several years of HCEPC monitoring (Figure 38) reveal that the least transparent waters of Tampa Bay occur regularly in Hillsborough Bay and much of Old Tampa Bay, where mean annual light penetration is less than 1.3 m (Figure 39). Mean depths in these bay areas are 3.2 m and 2.8 m, respectively. Light penetration improves in Tampa Bay except near the eastern shore in summer and is deepest near the bay entrance (greater than 2.8 m mean annual light penetration).

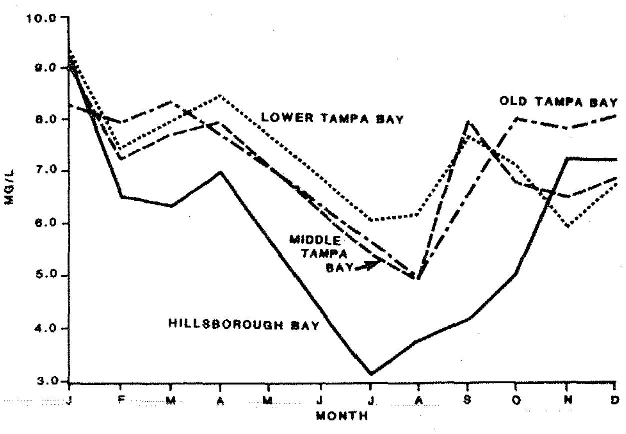


Figure 37. Mean monthly dissolved oxygen in 1982 near the bottom in Tampa Bay (HCEPC 1984).

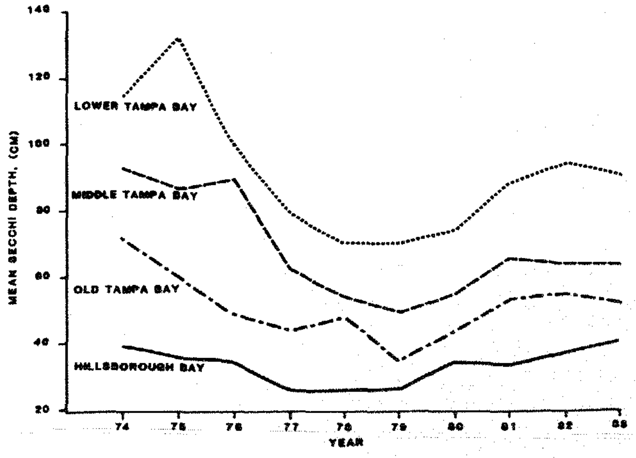


Figure 38. Mean annual effective (Secchi) light penetration in Tampa Bay (HECPC 1984).

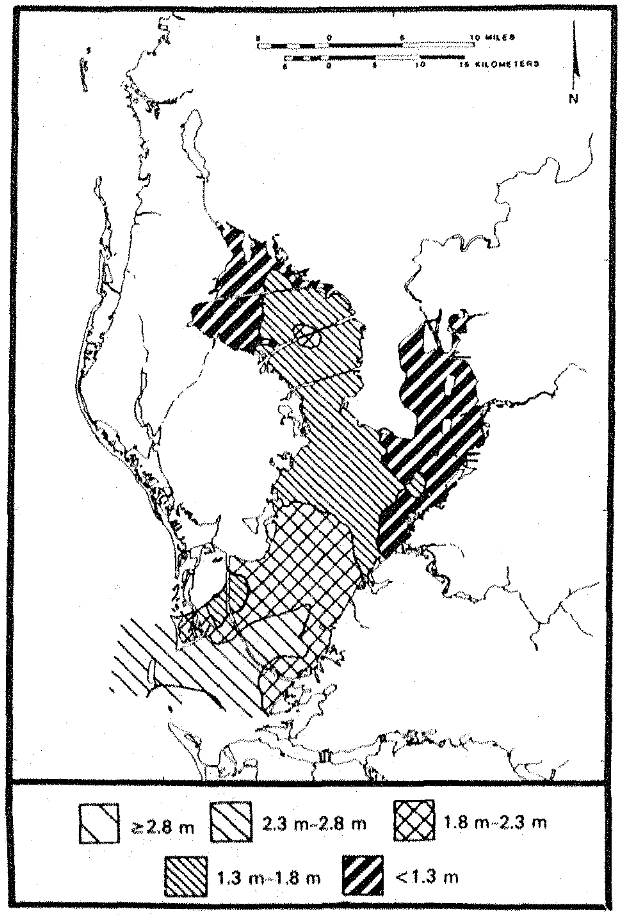


Figure 39. Mean annual effective (Secchi) light penetration in 1982 (HCEPC 1984).

Effective light penetration varies seasonally (Figure 40) in relation to runoff, phytoplankton blooms, and other factors. Transparency was greatest in January through March and decayed during April-September, so that by the fourth quarter of the year mean Secchi depths were less than 2.0 m everywhere north of the Sunshine Skyway Bridge.

Attenuation of light is caused by scattering and absorption. Color, chlorophyll, turbidity, and organic carbon are parameters useful in identifying causes of attenuation. Color is caused primarily by discharge of natural metallic ions, tannins, lignins, and other organic molecules from rivers and forested embayments such as Cockroach Bay. Color is greatest during the wet season. Patterns and trends of color in areas of Tampa Bay resemble those described for Secchi data, indicating the importance of color as a factor in transparency (Figure 41).

Chlorophyll in phytoplankton absorbs light, and the cells containing it scatter light. Chlorophyll a has been measured at middepth by the HCEPC. Pigment concentrations are highest (greater than 20 µg/l) in Hillsborough Bay and along the eastern shoreline south to Ruskin. Low values (less than 5 µg/l) are typical in lower Tampa Bay. Mean annual pigment concentrations in Old Tampa Bay vary and are usually highest near the Largo Inlet. The contribution of phytoplankton to light attenuation is probably understated by concentrations measured at middepth, since all HCEPC collections are made in daylight, when more plankton usually is near the surface. A complete understanding of light dynamics in the bay will require synoptic Secchi disk, transmissivity, and surface chemistry data (including chlorophyll), since only the water column above the Secchi depth is photically relevant.

Chlorophyll is a partial indicator of overall turbidity. Another indicator is total suspended solids, which are usually quantified as the weight of all filterable material in suspension (total solids) or the weight of organic material in suspension (volatile solids). Turbidity may also be measured as the loss of light through a water column (Jackson Turbidity Units or JTU) or normal scattering of light (nephelometric turbidity units or NTU). The latter units are roughly equivalent. Goodwin and Michaelis (1981) related these turbidity measures for Tampa Bay (Figure 42) by the expressions:

$$\text{Volatile solids} = 0.456\ (\text{suspended solids})$$

$$\text{Nephelometric turbidity} = 0.265\ (\text{suspended solids})^{1.155}$$

$$(\text{Cm. Transparency} - 10) \times \text{Nephelometric turbidity} = 500.$$

It follows from these relations that suspended solids in the bay are (a) largely organic; and (b) contribute to variation in nephelometric turbidity, which in turn varies as the hyperbolic inverse of transparency (Secchi depth).

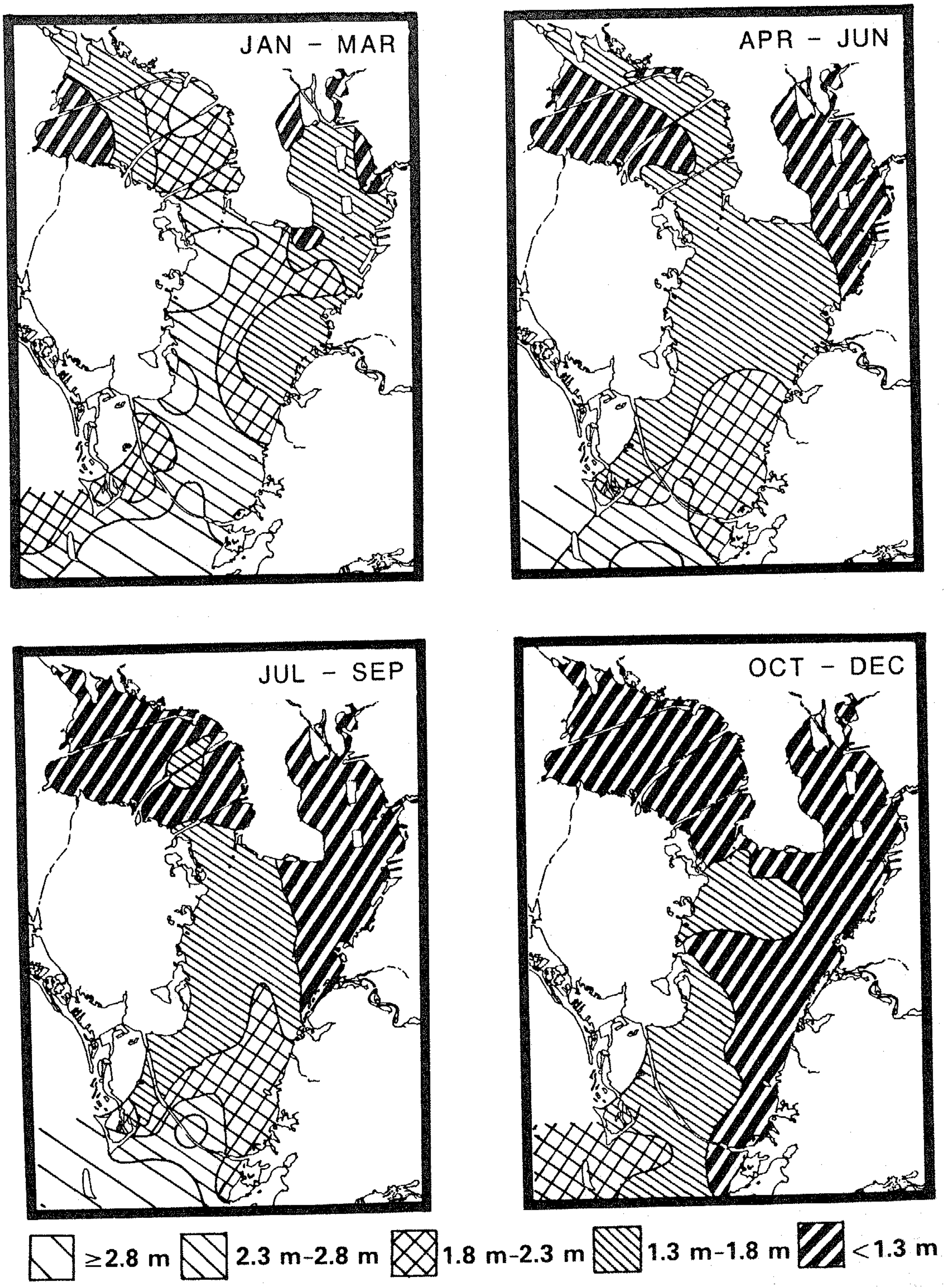
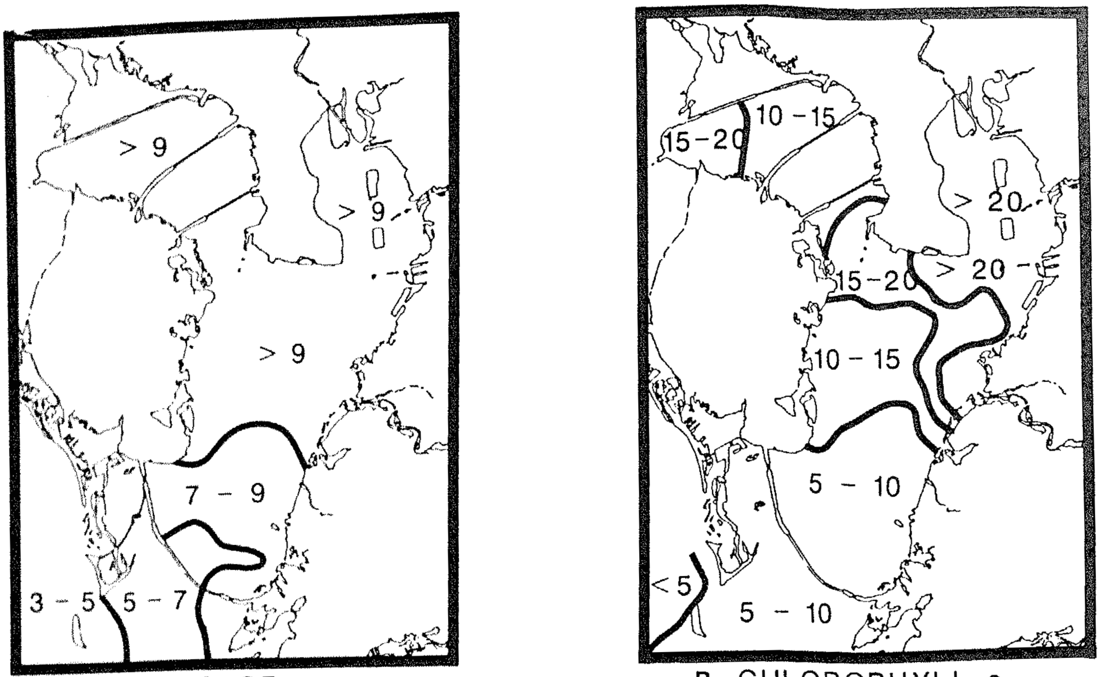
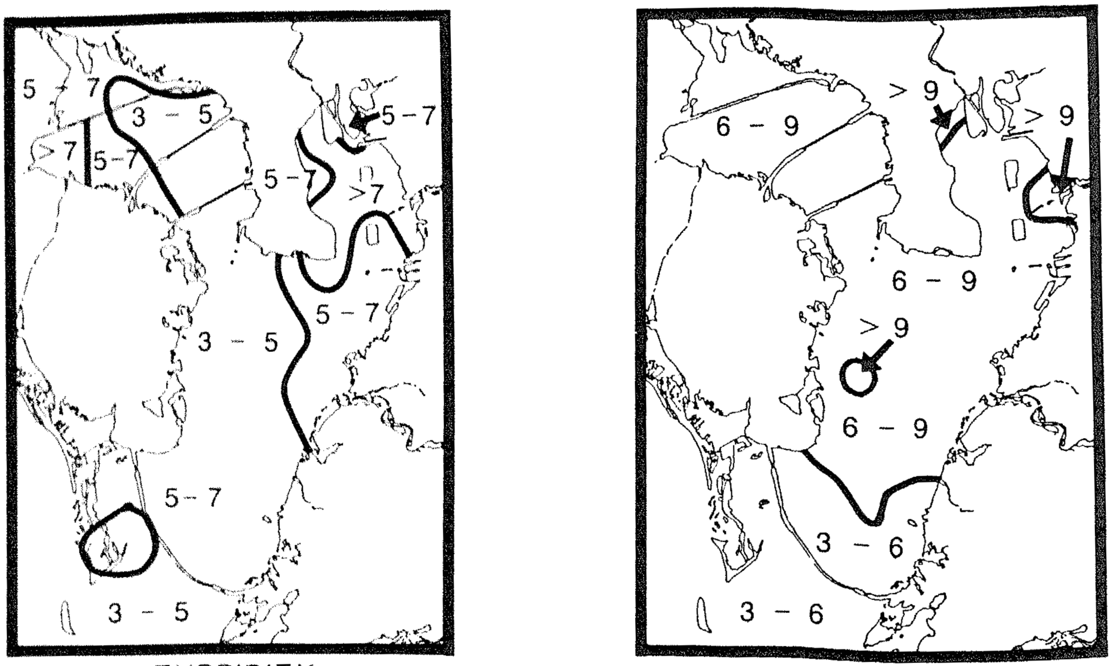


Figure 40. Changes in mean seasonal (Secchi) light penetration in 1983 (HCEPC 1984).



A COLOR (Platinum-Cobalt Units)

B CHLOROPHYLL a (µg/l)



C TURBIDITY (NTU)

D ORGANIC CARBON (mg/l)

Figure 41. Bay-wide distributions of light related parameters in 1982 (HCEPC 1984).

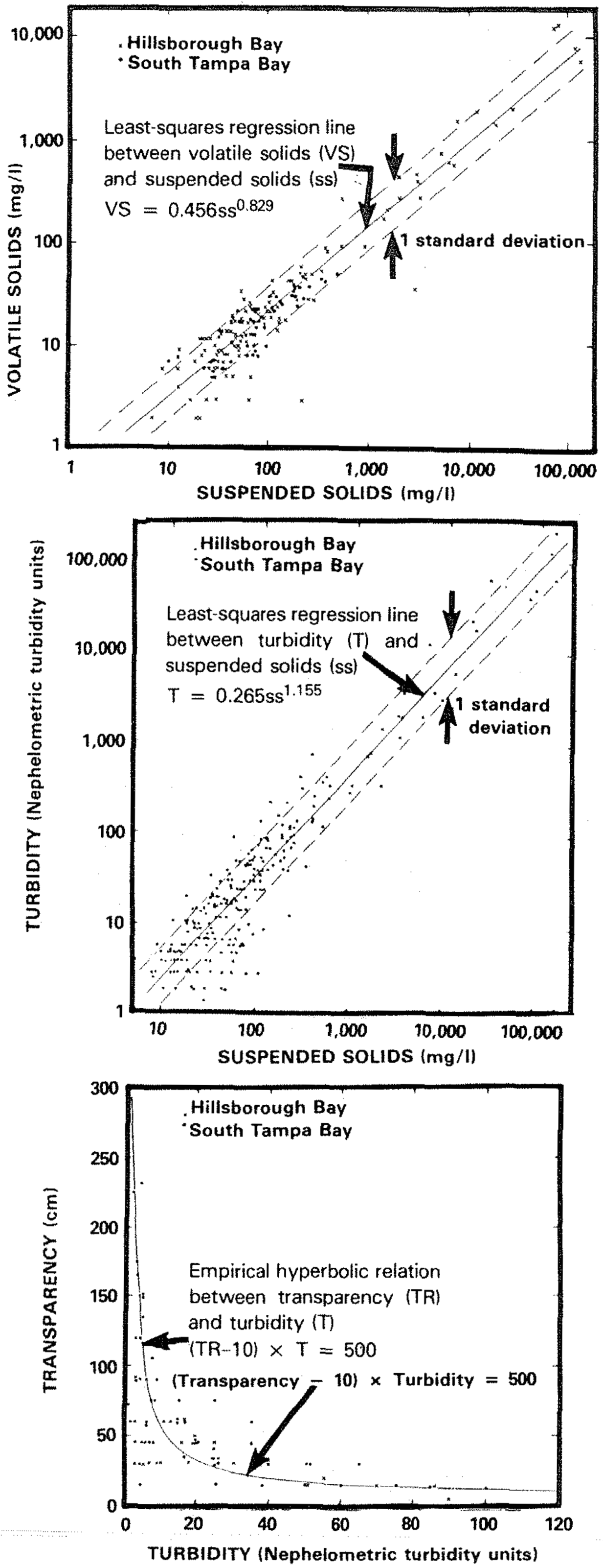


Figure 42. Relation of organic solids to transparency in Tampa Bay (Goodwin and Michaelis 1981).

Based on HCEPC data, nephelometric turbidity usually is greatest in Hillsborough Bay and Largo Inlet (Figure 41C), although relatively high values are possible near Mullet Key. Otherwise, mean annual turbidity for bay waters is 3-5 NTU. For the past decade, mean annual turbidity has ranged from 3.3 to 7.3 NTU for all bay sectors. The year 1980 was exceptional for low turbidity throughout the bay. Mean annual Secchi depths were about 1 m, mean annual color and turbidity were lower than for any other year on record. Chlorophyll was lower than previous years but still greater than 20.0 µg/l.

The 1980 data and 10-year trends suggest that transparency in lower Tampa Bay is controlled by nonplanktonic turbidity, whereas plankton (as chlorophyll a) controls transparency in Hillsborough Bay. Lower Tampa Bay mean annual transparency declined during 1975-79 and rose thereafter (HCEPC 1984). Chlorophyll a and color were relatively constant for the same period, whereas turbidity rose from a 1975 low and peaked in 1978. We conclude that turbidity in the lower bay was either mineral or nonliving organic matter. In Hillsborough Bay transparency has been low and annual means have increased slightly. Transparency and chlorophyll data are relatively high and steady compared to color and turbidity, indicating that phytoplankton is the major factor controlling light penetration.

Turbidity is caused by ship traffic (Goetz and Goodwin 1980), suspension of bottom sediments by currents and runoff, sewage outfalls and dredging (HCEPC 1977-84). The extent to which dredging changes turbidity levels is much disputed. Using HCEPC and other data, Goodwin and Michaelis (1981) concluded that harbor deepening did not raise mean turbidity levels in Hillsborough Bay or lower Tampa Bay, but that seasonal turbidity minima may have been slightly raised (Figure 43). Scientists at HCEPC interpret their data much differently:

> Relatively high values [of turbidity] in the vicinity of Mullet Key were the result of dredging operations occurring in that area as

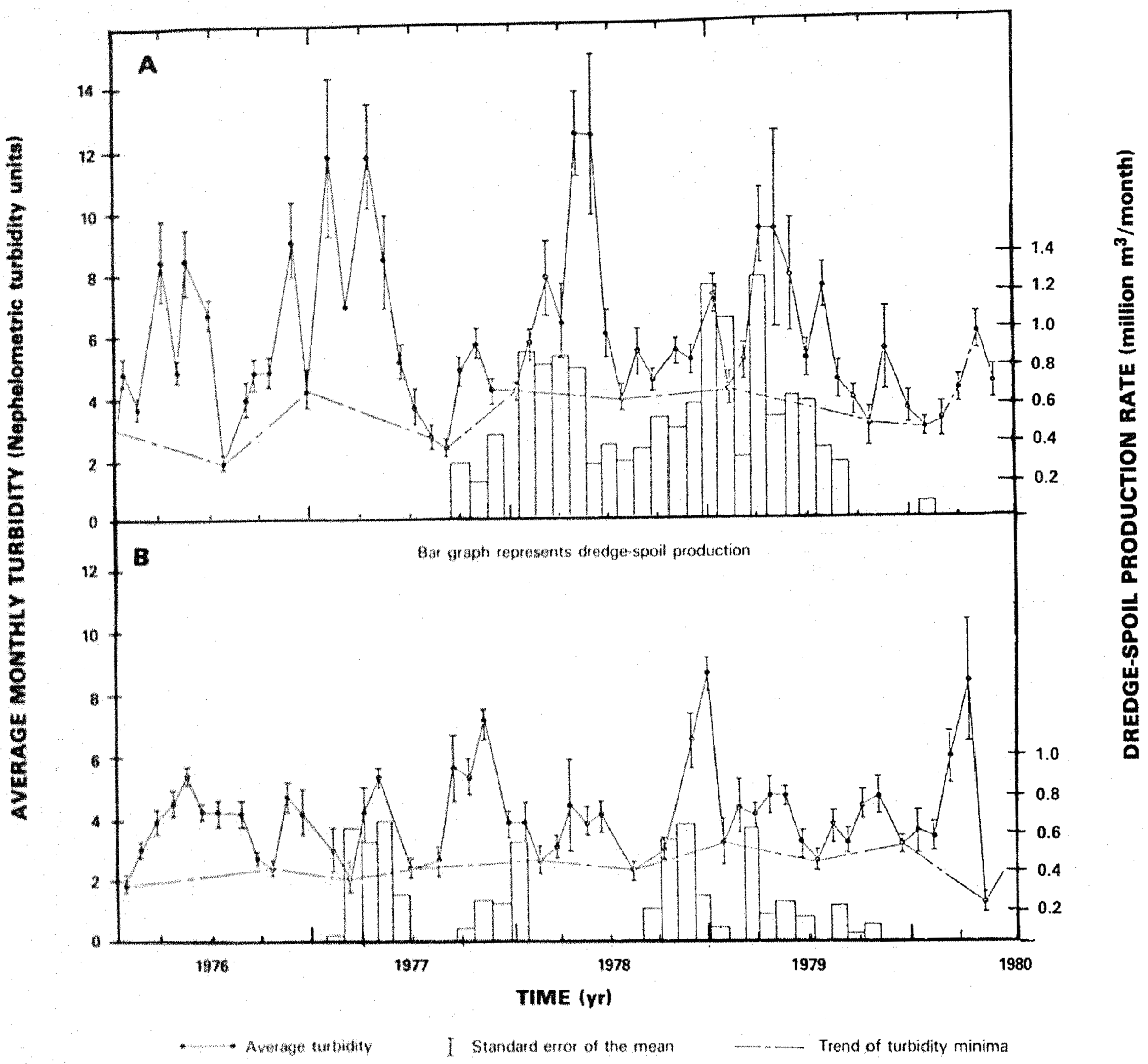


Figure 43. Average monthly turbidity and monthly dredge-spoil production rate in (A) Hillsborough Bay, and (B) South Tampa Bay (Goodwin and Michaelis 1981).

part of the Tampa Harbor Deepening Project. (1977);

Turbidity patterns throughout the Tampa Bay Basin were affected by dredging activities associated with harbor deepening. The Bay will continue to be affected to varying degrees as the project continues. (1978, 1979);

During 1980 and 1981 [another bay section] was dredged, adversely affecting light climate in upper Tampa Bay and lower Hillsborough Bay. (1981);

No dredging occurred in the area during 1982 and 1983 which may account for the improvement in light climate. (1984)

Disagreement on the effects of dredging results in part from the different time frames used in each investigation, and also because neither study was designed nor executed to monitor dredging effects over local areas within the bay.

2.5.3. Nutrients

Phosphorus and nitrogen in elemental form and in molecular combination with other common elements are taken up by estuarine plants and animals for use in metabolism, structural growth, and reproduction. When an increase in availability of these substances stimulates biological activity, they are inferred to be limiting nutrients. In some cases silica can limit phytoplankton growth and organic carbon may limit secondary production.

Forms and amounts of phosphorus and nitrogen in Tampa Bay have received the most study due to their role in stimulating excessive algal growth. In 1967, the Federal Water Pollution Control Administration (FWPCA 1969) studied odor in Hillsborough Bay and concluded the following:

(1) Massive amounts of carbonaceous organic material, phosphorus, and nitrogen were discharged by the Alafia and Hillsborough Rivers, Tampa and MacDill Air Force Base sewage treatment plants, and phosphate chemical plants.

(2) Phosphorus, nitrogen, and chlorophyll levels indicated rapid eutrophication, including changes to sediment chemistry in Hillsborough Bay.

(3) Eutrophic conditions stimulated blooms of the macroalgae Gracilaria, which decomposed along residential shorelines.

(4) Nitrogen availability was limiting still greater production of phytoplankton and Gracilaria.

Phosphorus. Fanning and Bell (1985) stated "Compared to other estuaries and coastal waters, Tampa Bay is considerably enriched in phosphate. In fact, no other major estuarine or coastal area we know of even comes close to having as high a phosphate concentration." Their analysis confirmed the ranking of Hillsborough Bay as highest in phosphate concentration, followed by upper Tampa Bay, Old Tampa Bay, lower Tampa Bay, and Boca Ciega Bay. Fanning and Bell (1985) detected little evidence for seasonality in phosphate trends except for the possibility of a minor winter minimum. Simon (1974) cited Taylor and Saloman (1968), Saloman and Taylor (1972) and data from the Hillsborough County Environmental Protection Commission to document a progressive enrichment of total phosphorus from 1952 to 1972. There has been a reduction in mean annual phosphate concentration in Hillsborough Bay and other bay segments since 1972 (Figure 44).

The Alafia River is regarded as the primary source of phosphorus to Hillsborough Bay, due to naturally high background levels, upstream discharges of mining and beneficiation operations, phosphate chemical processing at the river mouth, and leaking during loading of ships. There is, however, not much evidence supporting the view that naturally high levels of phosphate in the Alafia River basin cause elevated levels

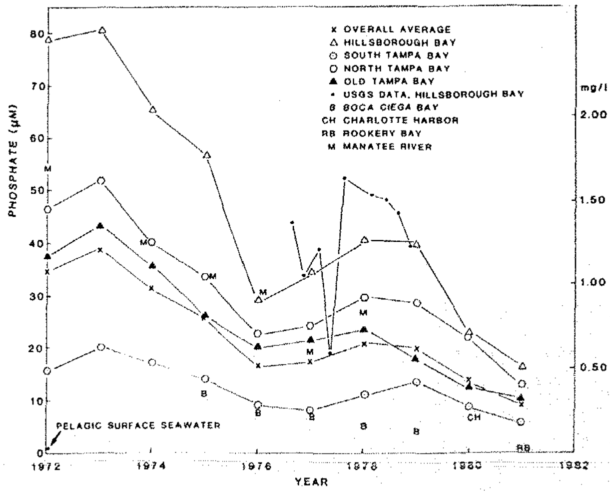


Figure 44. Trend in phosphate concentrations in Tampa Bay, 1972-1981 (Fanning and Bell 1985).

of the nutrient in Tampa Bay as opposed to Hillsborough Bay. The Little Manatee River drains similar geological formations but concentrations and loads of phosphorus are very much lower (Florida Department of Environmental Regulation 1982; Dooris and Dooris 1985). The primary sources of phosphorus to Hillsborough Bay have been discharges by the phosphate industry (Toler 1967). Recycling of process and nonprocess wastewater by the industry has resulted in a decline in total phosphorus loading to the Alafia River for the past decade, a trend also reflected in fluoride concentrations.

Ross et al. (1984) suggested a mass balance for phosphate in which 1.07 x 10^7 kg are in storage (plants, animals, sediments, and waters); inputs result from rain (45 kg/day), point and nonpoint sources (11,110 kg/day) and benthic flux (9,300 kg/day); and exports result from tidal exchange (-19,960 kg/day), benthic flux (-22,120 kg/day) and other routes (-1,510 kg/day). Interesting aspects of this proposal are the ratio of storage to exchange, the relative balance of imports and exports, and the net loading of phosphate to sediments. Fanning and Bell (1985) speculated that tributary loads of phosphorus to the bay may be able to replace phosphate in the water column of the bay in about 1 month or less, and that sedimentary sources could cause the same replacement in 30-300 days. They conclude that the input and flow of phosphorus through the biological system of the bay could be tremendous, and they urge more study on the subject.

Nitrogen. Nitrogen is generally regarded as the limiting macronutrient for primary production in Tampa Bay. Nitrogen occurs in seawater as a dissolved gas and as complex organic molecules such as protein. Organically bound nitrogen is a source for animals and large amounts can occur in municipal effluents. Ammonia (NH_3 and NH_4+), made in the breakdown of organic nitrogen and by fixation of gaseous nitrogen, is a preferred nitrogen source for algae. Both ammonia and organic nitrogen can be transformed by bacteria into nitrate (NO_3-) via the intermediate nitrite (NO_2-). Aerobic decomposition of organic nitrogen ends with nitrate. Concentrations of nitrogen may be presented as the sum of endpoint forms, e.g., total Kjeldahl nitrogen equals ammonia plus organic nitrogen. Also, nitrate alone or with nitrite has been reported by some investigators.

Simon (1974) identified municipal sewage treatment plants as the primary source of nitrogen to Tampa Bay. Mean annual loading of nitrate to Tampa Bay is greatest from the Alafia River (about 3.9 x 10^5 kg/yr) followed by the Manatee and Hillsborough Rivers (each about 9 x 10^4 kg/yr). On the other hand, the Manatee and Alafia Rivers contribute nearly the same amount of organic nitrogen, 2.5 x 10^5 kg/yr, followed by the Hillsborough River (2 x 10^5 kg/yr) (Dooris and Dooris 1985). High levels of organic nitrogen in the Manatee River have been caused by the Bradenton sewage treatment plant and pulp effluent from a citrus processing plant (DeGrove 1984). Municipal sewage treatment plants elsewhere around the bay are significant nitrogen sources (McClelland 1984).

A careful geographic comparison of nitrogen species from 1972 to 1976 was made by Goetz and Goodwin (1980). Mean organic nitrogen ranged from 0.5-1.0 mg/l in Old Tampa Bay, around 0.5 mg/l in upper Tampa Bay and at or below the same level in the lower bay (Figure 45). In all three areas, seasonal and year-to-year variation was low. On the other hand, mean organic nitrogen concentration in Hillsborough Bay ranged from 0.75 to 1.25 mg/l, and temporal variation was greater. Nitrite and nitrate concentrations were similarly low and steady everywhere in the bay, except in Hillsborough Bay. Ammonia levels were variable in all zones. Seasonal minima were less than 0.1 mg/l in most places but more than 0.1 mg/l in Hillsborough Bay. Seasonality was evident for total inorganic nitrogen, which decreases substantially after rainy seasons; reasons for this trend are unclear (Fanning and Bell 1985).

Past nitrogen levels in Hillsborough Bay were greater than in other estuaries (FWPCA 1969) but inorganic nitrogen for the bay as a whole is only slightly higher than reported elsewhere (Fanning and Bell 1985). However, ammonia is more abundant relative to other inorganic forms than in

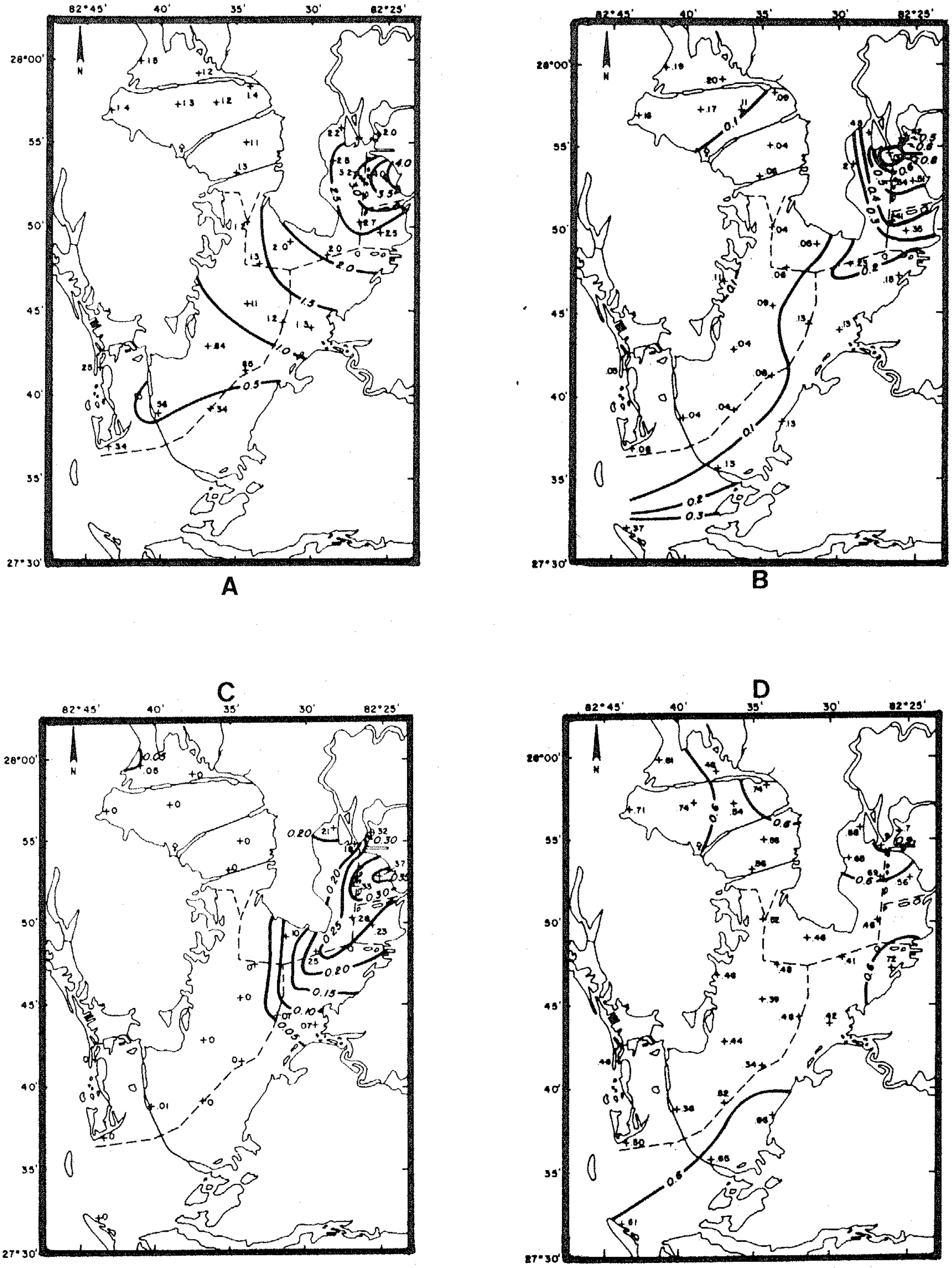


Figure 45. Nutrient distributions (mg/l) in Tampa Bay. (A) Ortho-P, Sept. 1972; (B) NH_4, Dec. 1973; (C) NO_3, Dec. 1972; (D) Organic-N, Dec. 1973 (Goetz and Goodwin 1980).

many other estuaries. Fanning and Bell reported a mean ratio of NH_3 to total inorganic nitrogen of 0.84 (range 0.54-0.99).

Ross et al. (1984) outlined the dimensions of a preliminary nitrogen budget for Tampa Bay. They suggested a nitrogen storage of 3.87×10^7 kg, inputs from rain and cultural sources, (21,470 kg/day) and benthic releases (55,750 kg/day). Exports occur in tidal exchange (-16,100 kg/day), biological losses (-8,140 kg/day), and benthic uptake (-53,000 kg/day). By these estimates the benthos is a net source of nitrogen and is acting as a sink for phosphorus. Fanning and Bell (1985) computed a rapid turnover rate for nitrite and nitrate through Tampa Bay of about 1.4 months, due to runoff. They also estimated that benthic releases of ammonia could replace the overlying ammonia in 14 days.

Nutrient relationships. Fanning and Bell (1985) calculated a ratio of nitrogen to phosphorus of 0.3 in 1972 and 1.3 in 1981 and concluded that phytoplankton have been nitrogen-limited since 1972. They cautioned against an interpretation that nitrogen limitation has declined; rather, lower phosphate levels indicate that plants may be consuming more of the available phosphate. McClelland (1984) found correlations of organic and total nitrogen, ortho and total phosphorus, and orthophosphorus and chlorophyll a, but concluded that all were trivial relationships.

2.5.4. Sediments

Despite the fact that since the 1950's sediment composition and chemistry have been known to influence ecological conditions in Tampa Bay (Dawson 1953, Hutton et al. 1956) comparatively little is known of sediment structure or dynamics. The most authoritative, descriptive work, by Goodell and Gorsline (1961), is 25 years old. Methods for sediment-water nutrient exchange are recent and have been used only in small areas of the bay during the past few years.

Granulometry. Sedimentary types correspond with bathymetric features of Tampa Bay (Goodell and Gorsline 1961). In sand and grass flats less than 2 m deep, mean grain size was 2.92 phi and sediment was 2.7% carbonate. In deeper natural channels more than 6 m deep, mean grain size was 2.05 phi and sediment was 25.2% carbonate. Lagoonal beaches were about 28% carbonate, whereas mangrove beaches contained no carbonate.

Mean grain size decreased from 2.2 phi at the entrance to Tampa Bay to 3.20 phi at its head (Figure 46). Mean carbonate content decreased from 16% to 2% over the same distance. Deeper waters in lower Tampa Bay had coarser sediments that contained more carbonate than average. Hillsborough Bay had finer sediment than average (mostly silt), and sediments between Interbay Peninsula and Big Bend had above-average amounts of carbonate. Organic content and sorting increased from the southeast side of lower Tampa Bay to the northwest corner of Old Tampa Bay, in a pattern almost 90^o to the plane of mean grain size. These results were interpreted as evidence for two sedimentary populations, terrigenous and biogenic, which are of similar density and travel together.

Chemistry. Organic carbon and nitrogen and total phosphate distributions in Hillsborough Bay sediments were determined in 1968 by FWPCA (1969). All three constituents were in greatest concentration at the mouth of the Alafia River. Organic carbon and nitrogen concentrations were also high at Hookers Point and south of Long Shoal, east of the MacDill Air Force Base sewage treatment plant outfall. These distributions may be different in 1985, because of extensive dredging and filling by the U.S. Army Corps of Engineers and improved municipal effluent quality, but Hillsborough Bay is still an area of exceptional oxygen demand and uptake of ammonia and orthophosphate (McClelland 1984). Shoreline areas of Old Tampa Bay also have rapid flux rates with regard to these parameters (Figures 47 through 49).

McClelland (1984) gave rates for constituent release from sediments in Hillsborough Bay as 58.75 $mg/m^2/day$ (ammonia), 40.43 $mg/m^2/day$ (total

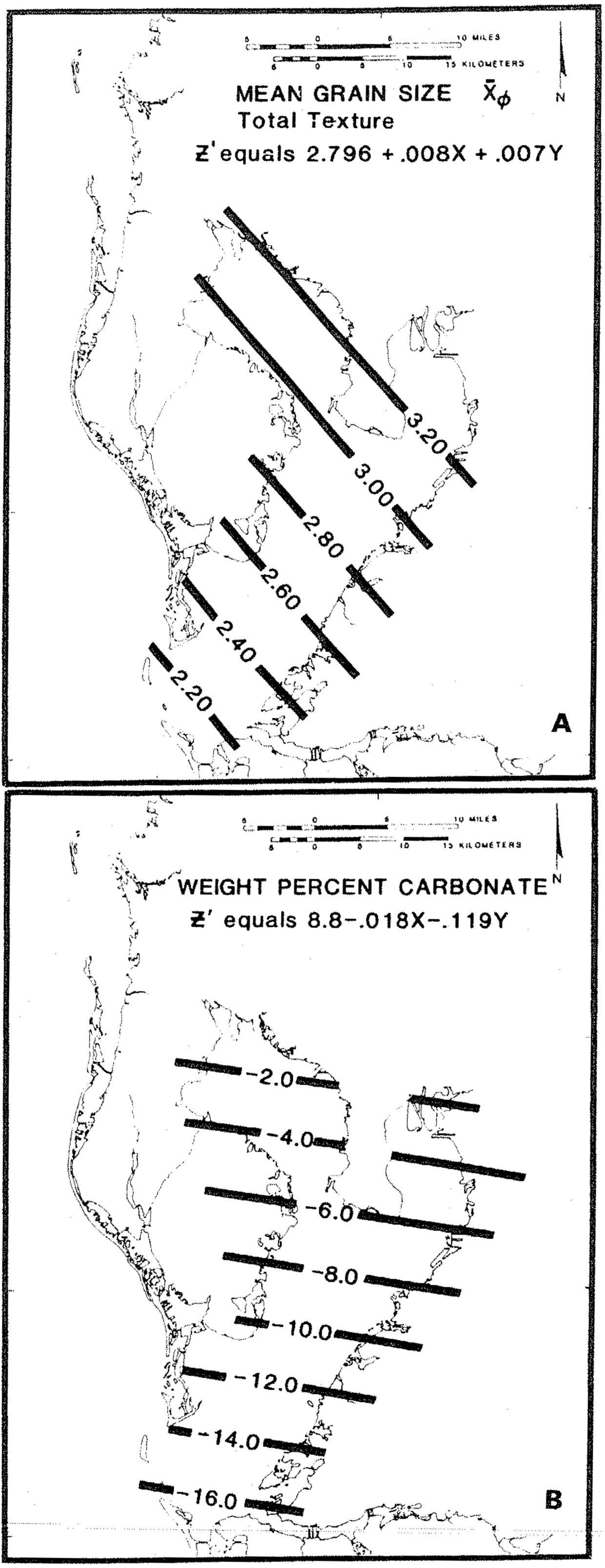


Figure 46. Regional trend in (A) mean sediment grain size (phi) and (B) weight percent of carbonates in Tampa Bay (Goodell and Gorsline 1961).

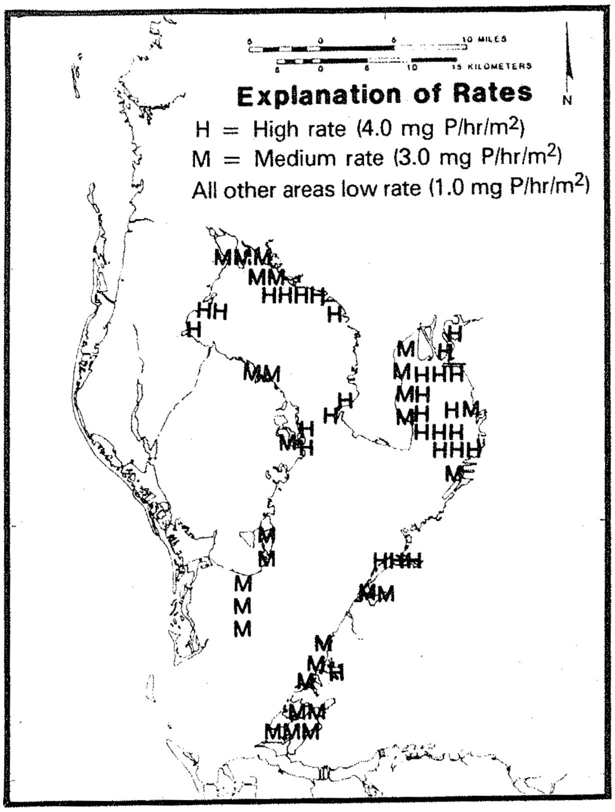


Figure 47. Orthophosphate uptake by bay sediments (McClelland 1984).

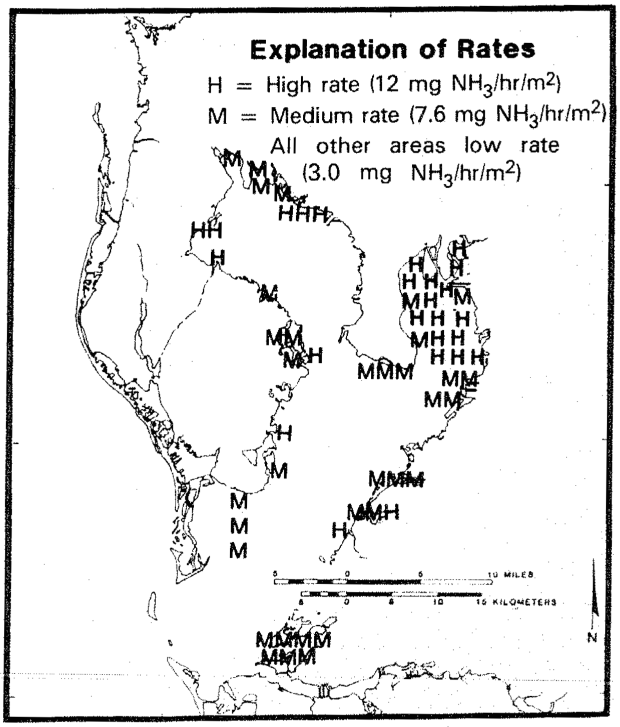


Figure 48. Ammonia uptake by bay sediments (McClelland 1984).

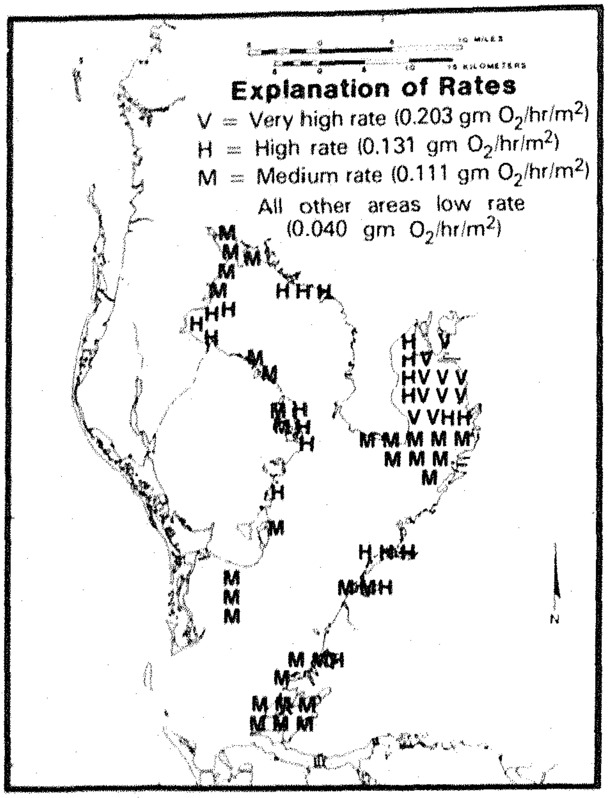


Figure 49. Dissolved oxygen uptake by bay sediments (McClelland 1984).

phosphate), and 10.88 mg/m^2/day (total nitrogen). Constituent uptake rates characteristic of the sediments in Hillsborough Bay were 699.12 mg/m^2/day (total organic carbon); 6.8 mg/m^2/day (nitrites and nitrates) and 0.54-9.10 g/m^2/day (oxygen). Ross et al. (1984) used the same data to compute a baywide net flux of 2,750 kg nitrogen/day from sediments, and an incorporation of 12,823 kg phosphorus/day into sediments.

2.6 AREA SUMMARIES

2.6.1. Hillsborough Bay

Hillsborough Bay is the best studied area of Tampa Bay. This area is the deepest, most poorly flushed area; it has lowest average salinities and is affected most by freshwater input (from 3 rivers). As a result, salinity stratification occurs more often in Hillsborough Bay than elsewhere, but such conditions are not extreme. On the other hand, vertical gradients in dissolved oxygen are strong; oxygen levels vary greatly due to phytoplankton blooms and sediment demands; and long periods of anoxia are common. Benthic faunal communities reflect oxygen stress. Benthic nutrient fluxes are probably important in regulating water-column dynamics. Phosphate and fluoride levels have been very high in the past but are declining. Harbor projects may have improved circulation but flushing remains poor.

2.6.2 Old Tampa Bay

This area is cooler than Hillsborough Bay but not as brackish. Inflows of freshwater have been modified extensively and shoreline areas are rapidly being urbanized. Old Tampa Bay is relatively shallow, and waters south of the Courtney Campbell Causeway are moderately well flushed. Waters north of the causeway and in the Largo Inlet area have exhibited signs of eutrophication during the past decade. Because of development in the area and water quality projections by McClelland (1984) there is great concern that sediment conditions and water quality will deteriorate rapidly by the year 2000.

2.6.3 Middle Tampa Bay

This area of geographical transition is also where physical and chemical gradients between the lower and upper bays are pronounced. Circulation is good, although flushing is variable depending on location. The eastern shore is not as highly developed as the western shore but is influenced in wet years by Hillsborough Bay and inadequate sewage treatment. General water quality off St. Petersburg has been erratic and may foreshadow deterioration. Loss of transparency is a particular threat to this area, because seagrass loss has not been severe but may increase as light declines.

2.6.4 Lower Tampa Bay

Because of its proximity to the Gulf of Mexico, this area continues to be least affected by cultural influences. Circulation and flushing are comparatively good. Temperature and salinity ranges are lower than in upper bay areas. Oxygen and transparency levels are high. Overall water quality is high and better where the area meets all other areas, except Boca Ciega Bay. The waters of lower Tampa Bay are threatened most by maintenance and deepening of channels in the north and nutrient enrichment in the south.

2.6.5 Boca Ciega Bay

This area was investigated by the U.S. Bureau of Commercial Fisheries in the 1950's and 1960's, when it was subject to extensive dredging and filling for residential waterfront property development. Simon (1974) summarized the early studies, but except for Geo-Marine, Inc. (1973) few recent data are reported. The bay has been channelized and filled extensively. Anaerobic sediments are found in poorly flushed canals and other areas. Nutrient concentrations are high and increased during the past decade because of sewage plant effluents and stormwaters. Light penetration is poor much of the time and phytoplankton blooms cause erratic oxygen variations.

2.6.6. Terra Ceia Bay and the Manatee River

These areas have warmer winter air temperatures and as a result have the largest mangroves in Tampa Bay. Terra Ceia Bay and surrounding waters (including Bishop Harbor) were declared an aquatic preserve by the State of Florida in 1984 because of high overall environmental quality. The bay is subject to oxygen and transparency depressions in the wet season due to runoff, but in this area such trends are natural. Conditions in the Manatee River are poorer than Terra Ceia Bay but the river as a whole is in good condition. Sediments near Bradenton are organic and anoxic because of municipal and industrial effluent; nutrients in the middle river are consequently high and phytoplankton blooms reduce oxygen levels to lower than State standards. Withdrawal of freshwater from the Manatee River and its tributary, the Braden River, pose serious threats to the integrity of this environment by eliminating dry-season flows and reducing wet-season flows. The Manatee River delivers more organic nitrogen to Tampa Bay than any other river, and additional loading is likely to occur.

2.7 COMPARISON OF TAMPA BAY TO CHARLOTTE HARBOR

The natural history of Charlotte Harbor was reviewed by Taylor (1974) and Estevez (1981). Comparisons to Tampa Bay are based on these reviews, which should be consulted for references to original literature.

Charlotte Harbor and its adjacent estuarine waters are about 70 square miles smaller than Tampa Bay. The harbor has nearly the same original shoreline. Like the bay, the harbor is Y-shaped, but its upper reaches are much narrower. Their mean depths are comparable, as are their relative depth distributions. The harbor has a more extensive lagoonal system than Tampa Bay (and for that reason had about two to three times more original seagrass acreage). Sediment composition is very similar in the two estuaries.

The climate around Charlotte Harbor is warmer but only slightly wetter than Tampa Bay. However, runoff to the harbor and adjacent inshore waters is about one-third greater, or twice as great if the Caloosahatchee River is considered. The Myakka River resembles the Little Manatee River in Tampa Bay, because both have low flows and periods of no flow, but no bay counterpart exists for the Peace River. Discharges from the Peace River cause a pronounced density stratification throughout much of the harbor, which is accompanied by vertical oxygen gradients and anoxia. Density stratification distinguishes Charlotte Harbor from Tampa Bay, and oxygen dynamics in the harbor resemble that seen in Hillsborough Bay. The latter area's dominant and characteristic phytoplankton blooms are also shared by the upper and middle portions of Charlotte Harbor.

Dissolved oxygen levels are similar in Charlotte Harbor and Tampa Bay, a fact which deserves considerable investigation insofar as ecological consequences are concerned because the bays have much different salinity structures. In addition, low oxygen levels in Tampa Bay are thought to be caused by human activities rather than natural forces, but it may be that biota in the two bays respond to reduced oxygen in comparable ways. Total nitrogen levels are roughly comparable, but total phosphorus is many times higher in Tampa Bay than in Charlotte Harbor.

It follows from this brief comparison that Tampa Bay is not physically unlike a nearby estuary except for different salinity structure. Moreover, dissolved oxygen and nutrient data for the two systems are intriguing both where they agree and differ. Additional comparative studies are needed to understand the extent to which undesirable conditions in Tampa Bay are ecologically relevant, significant, or reversible. It may be that widely held views about the two systems--or even the definition of pollution in subtropical estuaries--need to be revised.

CHAPTER 3. BIOLOGICAL CHARACTERISTICS

3.1 PHYTOPLANKTON

Phytoplankton are microscopic floating plants which are classified by size or taxonomic group. The smallest phytoplankton (ultraplankton) are less than 5 µm in diameter; some of the larger forms in Tampa Bay may be up to 2 mm in diameter. There are four principal groups of phytoplankton in Tampa Bay (Steidinger and Gardiner 1985): phytomicroflagellates, diatoms (Figure 50), dinoflagellates, and blue-green algae. The early studies of phytoplankton in Tampa Bay (Marshall 1956, Pomeroy 1960, Dragovich and Kelly 1964, 1966, Taylor 1970, Turner 1972) have been summarized by Steidinger and Gardiner (1985). These studies were initiated in response to the problem of blooms (cell counts usually greater than 50,000 per liter) of toxic dinoflagellates (*Ptychodiscus brevis*), known as "red tides," particularly the massive blooms of 1946-1947. The findings of all studies to date can be summarized as follows:

(1) A north-to-south, or head-to-mouth, gradient exists in phytoplankton species numbers. In general as one moves from the less saline upper portions of the bay to the more saline, lower portions of the bay, water clarity and phytoplankton species numbers (or "diversity") increase, while nutrient levels, chlorophyll *a*, and total phytoplankton cell counts decrease. The frequency of phytoplankton blooms and the eutrophic and turbid nature of the upper bay, particularly Hillsborough Bay, have been a common observation in recent years (Federal Water Pollution Control Administration 1969; Simon 1974).

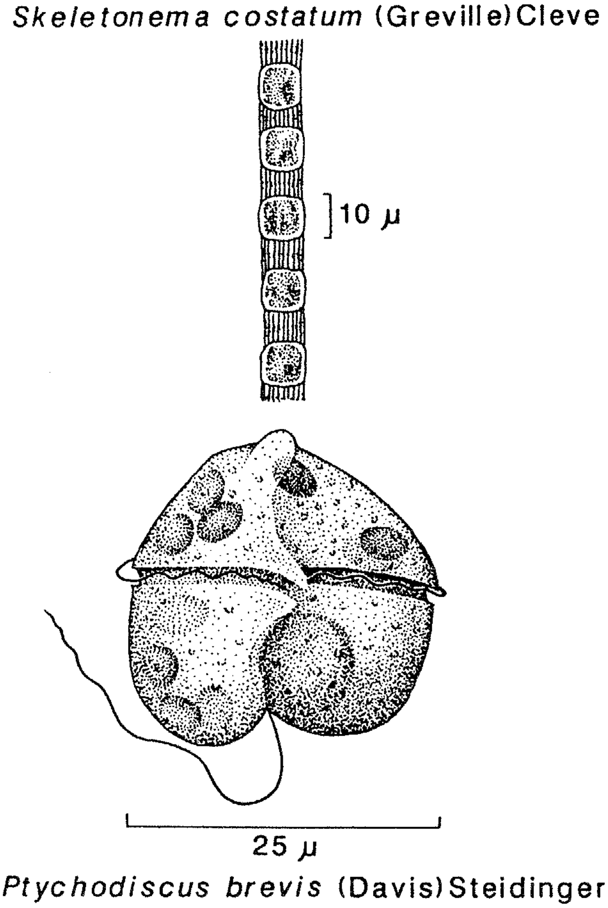


Figure 50. Typical Tampa Bay phytoplankton. *Skeletonema costatum* is a diatom and *Ptychodiscus brevis* a dinoflagellate.

(2) Nanoplankton (5-20 µm) are generally the dominant size class of the phytoplankton. Small diatoms and microflagellates predominate, except when certain seasonal, monospecific blooms of species of blue-green algae (*Schizothrix*) or dinoflagellates (*Gymnodinium nelsonii*, *Ceratium*

hircus, Procentrum micans, Gonyaulax spp. and others) dominate in Hillsborough Bay and Middle Tampa Bay.

(3) At least 272 species of phytoplankton occur in the bay; the majority (167 of 272) are diatoms (Steidinger and Gardiner 1985). The species fall into two cosmopolitan classes: those characteristic of temperate and warm waters and those characteristic of warm water only. The most dominant planktonic species is the diatom Skeletonema costatum. Numerically, it dominates samples taken between January and May and again in the fall. Other diatoms (Rhizosolenia spp., Chaetoceros spp.) are dominant during late spring and summer. Localized blooms of the blue-green alga Schizothrix calcicola and some dinoflagellate species (Gonyaulax monilata) can complicate this general pattern.

(4) Short-term fluctuations in species composition and standing crop are common. Seven-fold to ten-fold differences in biomass are reported within one tidal cycle.

(5) The majority of the bloom species are resident in the bay (autochthonous) but significant blooms occasionally occur due to species which invade from the Gulf of Mexico (allochthonous). Blooms of the toxic Ptychodiscus brevis originate 16-60 km offshore of the mouth of the bay for reasons as yet unclear, and are carried into the bay. Between 1946 and 1982, such invasions occurred at least 12 times (Steidinger and Gardiner 1985). In 1963 and 1971 the bloom extended into the upper reaches of the bay and resulted in massive fish kills. Many factors are implicated in algal blooms including salinity regimes, availability of an inoculum, and low rates of mixing of bay waters. For example, higher than normal salinities in the upper bay (up to 31 ppt) during 1963, and 1971 allowed P. brevis to survive and bloom after invasion from the ocean (Steidinger and Gardiner 1985). For the blue-green algae Schizothrix, temperature and high light tolerance are also important. Johansson et al. (1985) noted that Schizothrix displaced Skeletonema and other diatoms at peak summer water temperatures above 30°C, but was virtually absent between late winter and early summer.

(6) Many of the previous studies utilized analytical procedures which limit the quantitative comparison of all data; some uniform sampling strategy and analytical procedures are needed to make future data more usable (Steidinger and Gardiner 1985). Quarterly sampling and ignoring the nanoplankton in taxonomic and production studies are two of the problem areas.

Primary production studies on phytoplankton in Tampa Bay have been summarized by Johansson et al. (1985). Table 10 lists the annual rates reported in several studies using three different methods. Whether the different values over time reflect a real increase in primary production by phytoplankton or simply the results of different methodologies cannot be determined at present. Earlier data may be of limited value due to the methodology used (lack of grinding), which produces a probable underestimation of chlorophyll a in eutrophic waters; however, it is reasonable to assume a real increase in phytoplankton production due to eutrophication (Johansson et al. 1985). Annual production of 340 g C/m^2 is suggested as a reasonable estimate for phytoplankton primary production in the deeper portions of Tampa Bay and 50 g C/m^2 for shallower portions based upon the available data (Johansson et al. 1985).

3.2 BENTHIC MICROALGAE

Benthic microalgae are species of algae, similar to the phytoplankton, that live on surfaces (sediment, seagrass blades, rocks) instead of being suspended in the water column. Steidinger and Gardiner (1985) noted that benthic microalgae have received very little attention in Tampa Bay, even though they may be a significant source of food for

Table 10. Estimated annual phytoplankton production rates in the Tampa Bay system (g C/m^2/yr) (Johansson et al. 1985).

Dates and methods	Old Tampa Bay	Hillsborough Bay	Middle Tampa Bay	Lower Tampa Bay
1968 Chlorophyll + light	170	270	170	120
1965-67 Oxygen	430	610	440	220
1969-72 Chlorophyll + light	290	580	490	180
1973-83 Carbon isotope	--	620	620	--

many organisms. Primary production rates of 100-200 g C/m^2 have been reported for benthic microalgal communities on shallow mudflats (Steidinger and Gardiner 1985). In addition, bacteria and microalgae are commonly the first colonizers on newly produced seagrass leaves and are grazed by organisms living on seagrass blades (Zieman 1982).

Benthic dinoflagellates (Amphidinium, Thecadinium, Polykrikos, Scrippsiella) can be numerous in sediments. Durako et al. (1982) demonstrated high rates of oxygen production by such benthic dinoflagellates in a Tampa Bay seagrass bed.

3.3 EPIPHYTIC MICROALGAE

Epiphytic (living on plants) microalgae are treated here as a group separate from the other benthic algae because of their apparent importance in food webs in other Florida estuarine systems (Fry 1984), and because those found growing on seagrass leaves in Tampa Bay have received some study (Dawes 1985). The most common epiphytes are species of Champia, Lomentaria, Polysiphonia, Acrochaetium, Fosliella, Hypnea, Spyridia, Cladosiphon, Ectocarpus, and Cladophora. The epiphytic brown algae are typically more common in winter. Although no detailed seasonal and taxonomic studies have been made on the algal epiphytic community in Tampa Bay, studies elsewhere in Florida (Humm 1964; Ballantine and Humm 1975; Hall and Eiseman 1981) have revealed a diverse population of these algae on seagrass blades; up to 113 species have been identified during a 1 year study. The possible importance of epiphytic algae in the food web and the general health of seagrasses in a eutrophic estuary like Tampa Bay will be discussed later. It is enough to note here that the abundant caridean shrimp and amphipods found in Tampa Bay seagrass meadows have been shown elsewhere to depend heavily upon seagrass algal epiphytes as a source of food (Ewald 1969; Zimmerman et al. 1979; Van Montfrans et al. 1982; Orth and Van Montfrans 1984). It is likely that the same dependence will be found here.

3.4 ATTACHED AND DRIFT MACROALGAE

Macroalgae are abundant in Tampa Bay and the 221 identified species from the bay represent a greater diversity than that reported for any other estuary in Florida (Dawes 1985). Red and green algae predominate, with brown algae being more abundant in the winter and early spring, though still not predominant. Ninety-nine species of red algae, 68 species of green algae, 30 species of brown algae, and 1 Xanthophycean alga are listed by Dawes. Dominant genera include *Gracilaria*, *Ulva*, *Hypnea*, and *Acanthophora*. Although blue-green algae have not been extensively studied, about 30 species are believed to occur.

The ecological role of macroalgae in the bay has not been studied. In other parts of Florida, the drift algal assemblage (*Ulva* spp., *Gracilaria tikvahiae*, *Hypnea* spp., *Acanthophora spicifera*) commonly seen in the bay has been reported to provide fish and invertebrate habitat (Kulczycki et al. 1981) and possibly food, both by being directly consumed and as attachment sites for epiphytic algae that also are directly consumed (Zimmerman et al. 1979; Lewis 1982b).

Most studies of macroalgae in the bay have been taxonomic or physiological in nature (Dawes 1985); have focused on the overabundance of certain pollution indicator species (*Ulva* spp., *Gracilaria* spp.) which cause aesthetic problems (Federal Water Pollution Control Administration 1969); have been implicated in the elimination of seagrass meadows from certain parts of the bay (Guist and Humm 1976); or have anecdotally reported consumption of macroalgae by manatees (Lewis et al. 1984). The Federal Water Pollution Control Administration (1969) studied the abundance and distribution of macroalgae in Hillsborough and Old Tampa Bay to determine the source of odor problems reported by residents along the western shore of Hillsborough Bay. The study concluded that the odors were caused by excessive nutrient concentrations which led to massive blooms of the macroalga *Gracilaria tikvahiae*. This species, in turn, was killed by normal salinity reductions during times of heavy rainfall and decayed to produce the odor.

More recently, after a period when a relatively low standing crop of macroalgae was observed--in conjunction with the upgrading of treatments by major dischargers--a bloom of algae occurred in 1982. As a result, a 1-year study of the distribution and abundance of macroalgae in Hillsborough Bay was funded by the City of Tampa (Mangrove Systems, Inc. 1985). The results of that study indicated that large blooms of macroalgae still are occurring in Hillsborough Bay, and that seasonal and large-scale, year-to-year variations may occur for reasons not well understood. Figure 51 shows the total estimated dry weight standing crop of macroalgae in Hillsborough Bay based upon quantitative sampling at eight permanent and three to four floating stations sampled monthly between February 1983 and April 1984. Normal year-to-year water temperature variations may be important. In any case, nutrient concentrations in the upper portions of the bay do not appear to have been reduced enough to limit the macroalgal blooms.

Rates of primary production by Tampa Bay macroalgae of approximately 70 g C/m^2/yr have been measured in both laboratory and field experiments (Hoffman and Dawes 1980, Dawes 1985). The data are very sparse, and much additional work, particularly seasonal field measurements, is needed.

3.5 SEAGRASS MEADOWS

Seagrasses are submerged flowering plants with true roots and stems (Figure 52) and are quite different from "seaweeds" (macroalgae), nonflowering algal species without true roots. Lewis

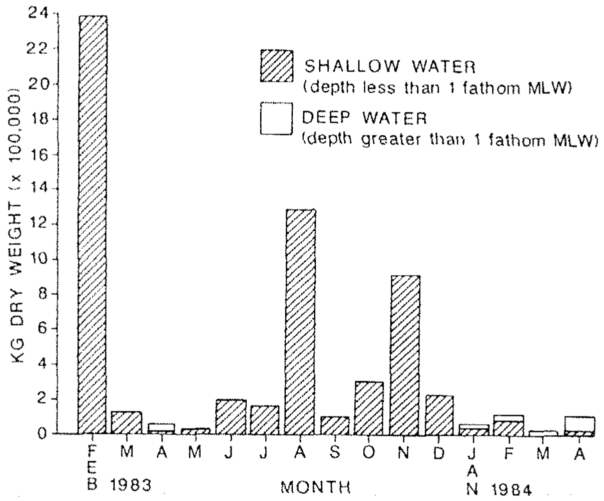


Figure 51. Estimated total drift algae standing crops in Hillsborough Bay during February 1983—April 1984 (Mangrove Systems, Inc. 1985).

Figure 52. Underwater photograph of flowering turtle grass (*Thalassia testudinum*), off Snake Key in Lower Tampa Bay.

et al. 1985a) reported that five of the seven species of seagrasses known from Florida are found in Tampa Bay: Thalassia testudinum (turtle grass); Syringodium filiforme (manatee grass); Halodule wrightii (shoal grass); Ruppia maritima (widgeon grass); and Halophila engelmannii (star grass).

Seagrass meadows now cover 5,750 ha of the bottom of the bay (Figure 53). Based upon historical aerial photography and maps, it is estimated that seagrasses once covered 30,970 ha of the bay (Figure 54). This 81% loss has had severe effects on the bay's fisheries (Lombardo and Lewis 1985).

Box cores taken at 18 stations in the bay over a 1-year period (Lewis et al. 1985a) showed that seagrass meadows in Tampa Bay are largely monospecific, with approximately 40% being turtle grass, 35% shoal grass, 15% manatee grass, and 10% widgeon grass. Star grass was seen infrequently. Lewis et al. (1985a) defined five types of seagrass meadows in the bay based on location, form, and species composition (Figure 55): (1) mid-bay shoal perennial - MBS(P); (2) healthy fringe perennial - HF(P); (3) stressed fringe perennial - SF(P); (4) ephemeral - E; and (5) colonizing perennial - C(P). The idealized cross sections in Figure 56 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 human-induced stress, as illustrated by the arrows in Figure 55. A brief description of each seagrass meadow type follows.

Mid-bay shoal perennial (Figure 55 and 57). These meadows are generally composed of Halodule, Thalassia and Syringodium. Ruppia rarely is 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 (Figures 55 and 58). These meadows are the most common meadow type in the bay and extend from around 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. 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 (1960b) as a "central declivity." 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. The offshore bar may be critical in intercepting waves and reducing storm and boat wake damage to these seagrass meadows. Its complete loss may make replanting of seagrasses and the restoration of the fringe meadows very difficult. A typical cross section through a healthy fringe perennial seagrass meadow is diagrammed in Figure 57.

Stressed fringe perennial (Figure 55). These meadows are similar to healthy

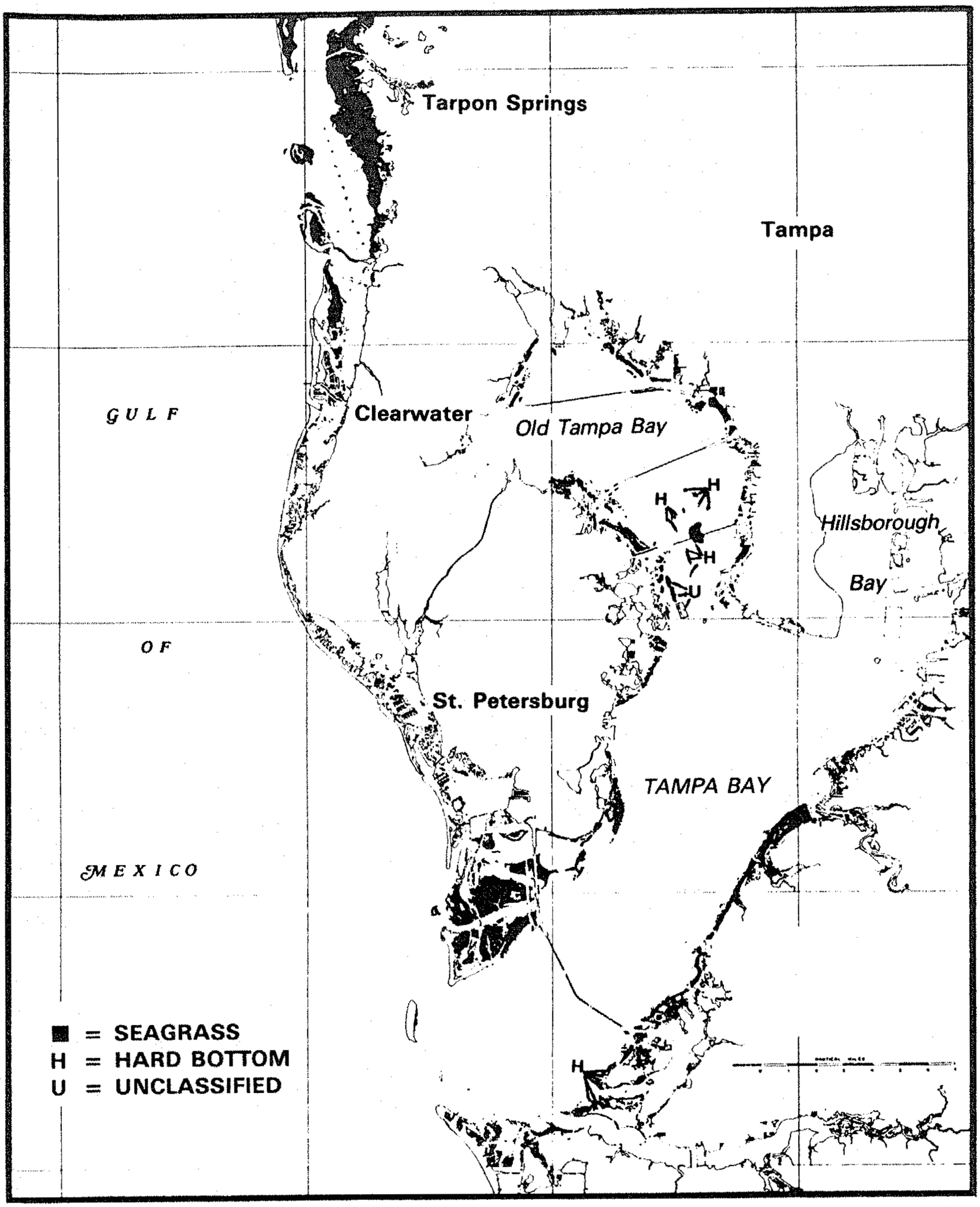


Figure 53. Seagrass meadow coverage in Tampa Bay, 1985 (from Lewis et al. 1985a).

Figure 54. Estimated historical seagrass meadow coverage in Tampa Bay, c. 1879 (from Lewis et al. 1985a).

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. This type of meadow generally occurs in areas closer to Hillsborough Bay where a tenfold increase in average chlorophyll a values (compared to Tampa Bay) is typical.

Ephemeral (Figure 55). 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 was 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 which presently is the case in most of Hillsborough Bay.

Colonizing perennial (Figures 55 and 59). This meadow type commonly is found in a narrow band in the euphotic zone of human-made fills such as Courtney Campbell Causeway (Figure 59), 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. Only Ruppia shows large-scale sexual reproduction and seed production in Tampa Bay (Lewis et al. 1985a). Seed production by the other four species is rare to nonexistent, and therefore, these seagrasses colonize by dispersal of shoots or rhizomes produced asexually through fragmentation. Because of the exposed nature of the human-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 possible that these float into unvegetated areas, attach through new root formation, and establish new meadows. Thalassia produces relatively fewer detached shoots and 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 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.

As noted by Lewis et al. (1985a), most of the work to date on seagrass meadows in Tampa Bay has concentrated on descriptive biology (distribution, reproduction, infaunal communities). The elucidation of the functional role of seagrass meadows in the bay in terms of value as a food source (direct herbivory, detrital, drift and epiphytic algal component) and habitat is

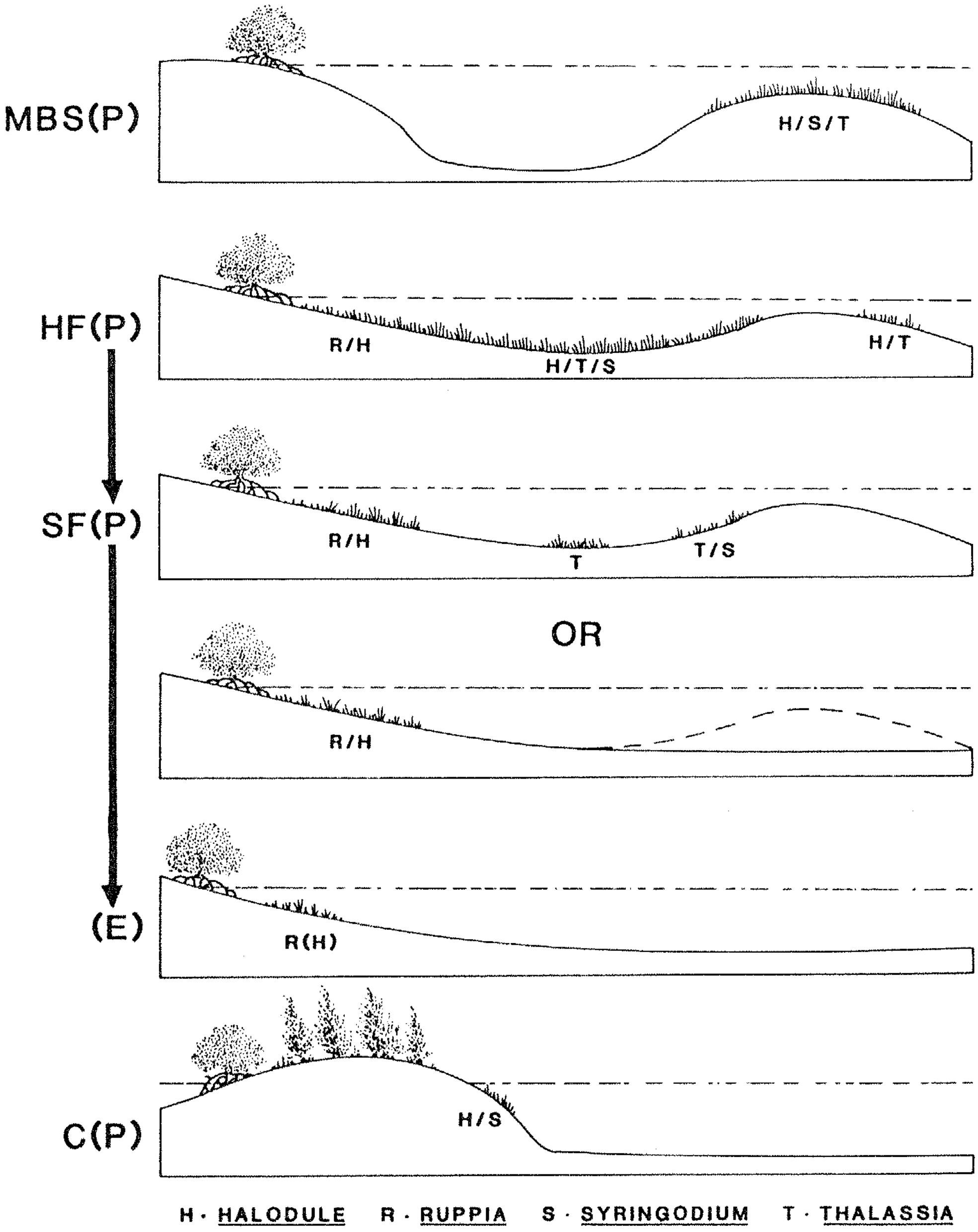


Figure 55. Seagrass meadow types in Tampa Bay as described in Lewis et al. 1985a.

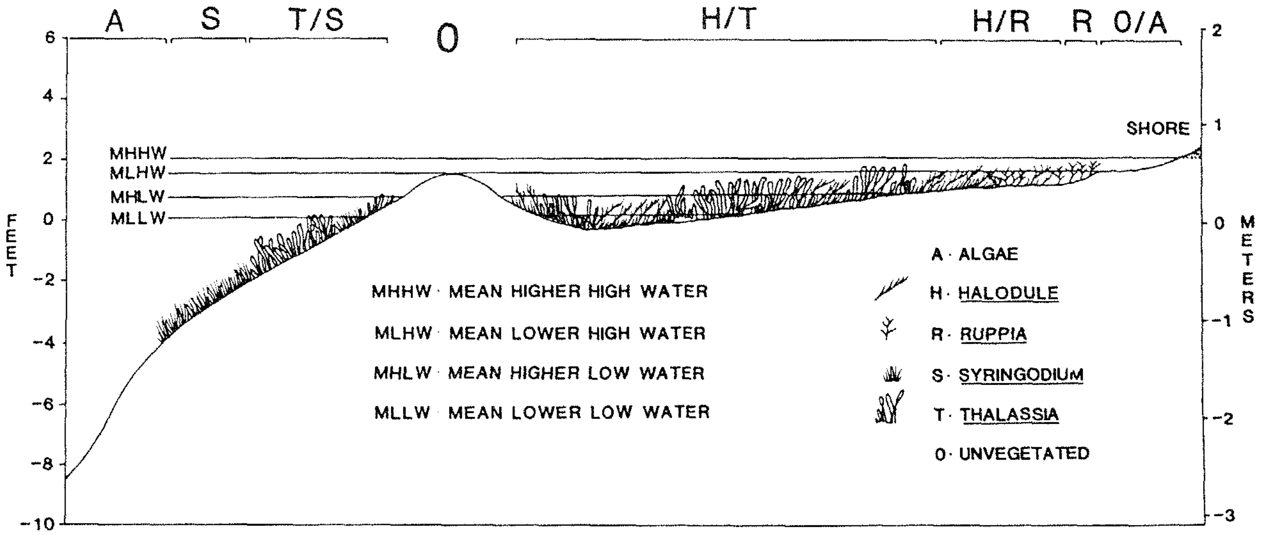


Figure 56. Typical seagrass meadow zonation in Tampa Bay (from Lewis et al. 1985a).

Figure 57. Aerial photograph of a perennial healthy fringe seagrass meadow offshore of Bishops Harbor, Lower Tampa Bay.

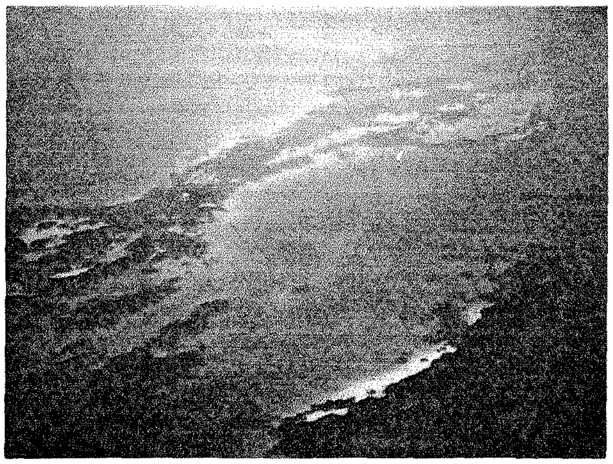


Figure 58. Aerial photograph of a perennial mid-bay shoal seagrass meadow, Lower Tampa Bay.

being initiated only now, primarily in relation to larval fish use. Even estimates of total primary production by seagrasses are hampered by the lack of comprehensive baywide seasonal data.

Using oxygen production measurements, Pomeroy (1960) calculated that turtle grass and manatee grass production in lower Tampa Bay was 500 g C/m^2/yr. This technique is no longer considered to be accurate because recycling of oxygen in the lacunal spaces of seagrasses introduces error (Hartman and Brown 1966). For purposes of calculating baywide seagrass production, a mean value of 2 g C/m^2/day (730 g C/m^2/yr) may be used based upon Zieman's (1982) commonly used seagrass production range of 1-4 g C/m^2/day.

Heffernan and Gibson (1985), using the ^{14}C technique and a special chamber (Heffernan and Gibson 1983) reported

Figure 59. Aerial photograph of a perennial colonizing seagrass meadow, south side of Courtney Campbell Causeway, Old Tampa Bay.

productivity rates for two sampling periods (October and February 1982). Gravimetric rates (g C/g dry wt/hr) ranged from 72.6 to 95.0 in October and from 3.0 to 9.6 in February. Areal rates (g $C/m^2/hr$) ranged from a high of 5.2 in October to as low as 0.004 in February. Significantly, they noted that Tampa Bay seagrasses had more epiphytic biomass than seagrass in the Bahamas or the Indian River Lagoon. For example, in February an average of 76% of the weight of a seagrass blade in Tampa Bay was composed of epiphytes, while only 29% and 26% of leaf weights in the Indian River Lagoon and the Bahamas, respectively, were composed of epiphytes. These preliminary data may indicate significant stress on seagrasses in Tampa Bay due to eutrophication and competition for light similar to that previously reported for the Indian River (Rice et al. 1983), Rhode Island (Harlin and Thorne-Miller 1981) and Australia (Cambridge 1975, 1979).

It is likely that seagrass meadows in Tampa Bay are important habitat for benthic invertebrates and certain species of juvenile fish. Virnstein et al. (1983) noted in their studies in the Indian River that seagrass meadows had a density of infaunal invertebrates three times that of unvegetated sediments, and that epifaunal organisms were 13 times as abundant in seagrass as in sandy areas. Zieman (1982) noted that eight sciaenid species have been associated with seagrass meadows in southwestern Florida and that the spotted seatrout (Cynoscion nebulosus), the spot (Leiostomus xanthurus), and the silver perch (Bairdiella chrysoura) are commonly found in seagrass beds as juveniles. The sheepshead (Archosargus probatocephalus) and the snook (Centropomus undecimalis) also use seagrass meadows as habitat during their life cycles (Odum and Heald 1970; Gilmore et al. 1983).

Similar data for seagrass meadows in Tampa Bay are sparse, but the existing data support the importance of seagrass meadows as habitat for fish and invertebrates. Studies of fish populations in Tampa indicate that seagrass meadows are one of several important nursery habitats for juvenile fish species (Springer and Woodburn 1960; Comp 1985). Collections by Springer and Woodburn (1960) at two areas containing mixed seagrass and algae had the highest number of species (108 and 93, respectively, of a total of 253 species). The lowest species numbers (48) were reported for a sandy beach (unvegetated) station.

Taylor and Saloman (1968) (in documenting the filling of 1,400 ha of bay bottom in Boca Ciega Bay and the loss of 1,133 t of annual standing crop of seagrasses) estimated infaunal biomass for well-vegetated bay bottoms to be 137 g dry wt/m^2 in comparison to 12 g dry wt/m^2 for unvegetated bay bottoms. Godcharles (1971) reported the results of testing a commercial hydraulic soft-shell clam dredge at six experimental sites in Middle and Lower Tampa Bay, Boca Ciega Bay, and just offshore of Mullet and Egmont Keys. He listed 142 species of macroinvertebrates and 47 species of fish collected from these sites using the dredge, a trynet, and a benthic plug sampler. Figure 60 summarizes the numbers of species in each group and the percentage of the total number of species found at each site. Three of the sites were heavily vegetated with seagrass, a fourth had a mixture of algae (Caulerpa) and seagrass, and two were unvegetated. It is apparent from Figure 60 that four to five times more invertebrate species and ten times as many fish species were found

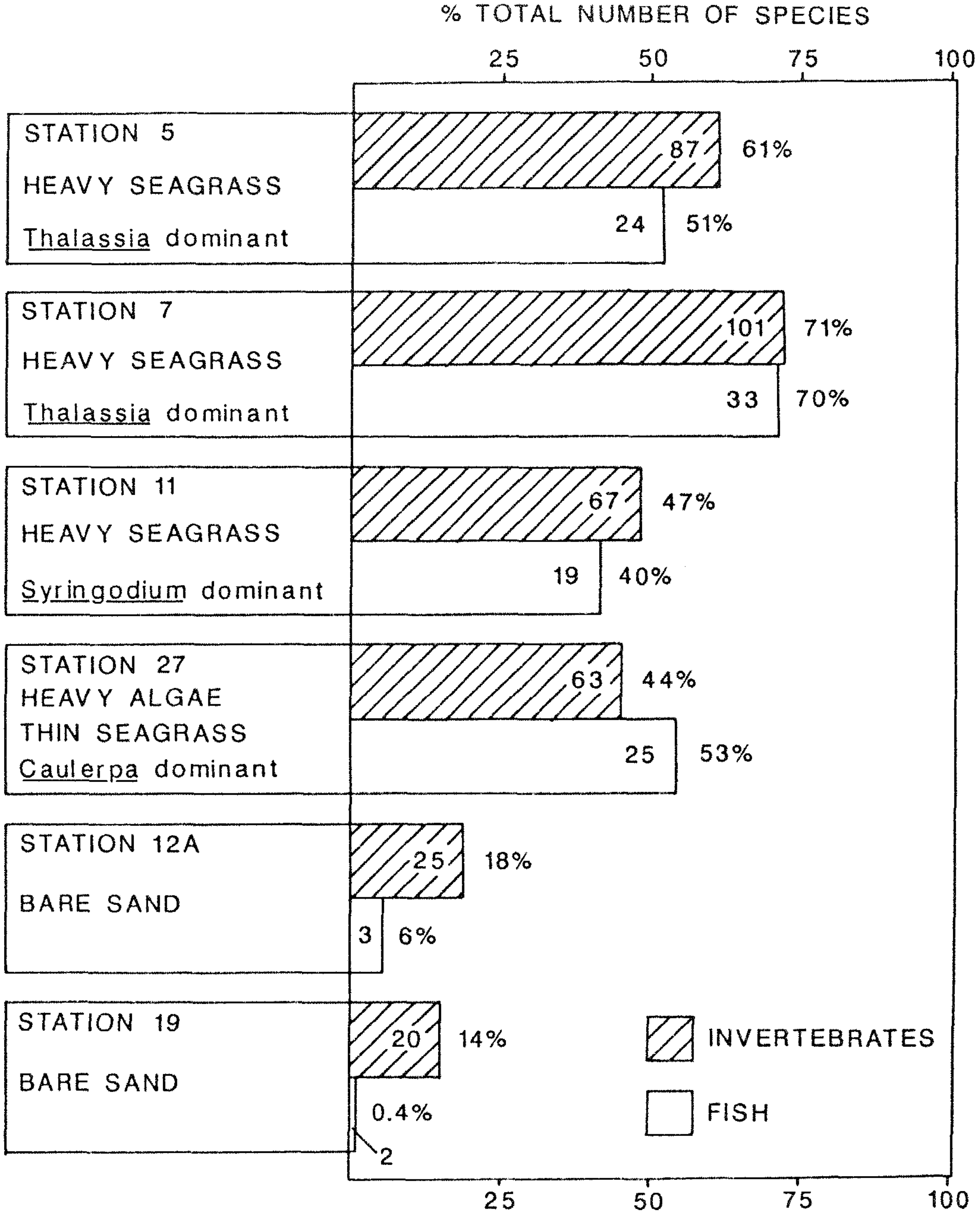


Figure 60. Comparison of the numbers of species (crude diversity) of fish and invertebrates collected from dense seagrass, sparse seagrass, and bare sand stations in Lower Tampa Bay (original data from Godcharles and Jaap 1973).

at the sites dominated by turtle grass as were collected in the unvegetated areas. Even the manatee grass-dominated site and the mixed algae and seagrass site commonly had three times as many invertebrate species and nine times as many fish species as the unvegetated sites.

Godcharles (1971) and Godcharles and Jaap (1973) also noted that the areas of seagrass that were dredged did not recover during the study. One of the sites had shown no natural seagrass recolonization 36 months after the original seagrass cover was removed by the clam dredge.

This observation confirms that of Phillips (1960a), Zieman (1976), and Phillips and Lewis (1983) that natural recolonization of excavated areas in existing seagrass meadows is slow. It is not unusual for 3-5 years to elapse before recovery is visible in a turtle grass meadow; complete recovery might take 10 years or more, depending on the size of the denuded site. This assumes the area is undisturbed during the recovery period. Repeated scarring by boat propellers, for example, can delay recovery or lead to the loss of an even larger area of seagrasss.

3.6 TIDAL MARSHES

About 7,200 ha of emergent wetlands border Tampa Bay (Lewis and Whitman 1985). They are located at 14 major sites as mapped by Estevez and Mosura (1985) (Figure 61). These sites are: (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. The vegetation of these emergent wetlands consists of various mixtures of five major plant species (Figure 62), two of which are tidal marsh species: black needlerush (*Juncus roemerianus*) and smooth cordgrass (*Spartina alterniflora*). Minor species in these tidal marshes include leather fern (*Acrostichum danaeofolium*) and the brackish water cattail (*Typha domingensis*). A typical Tampa Bay tidal marsh is shown in Figure 63.

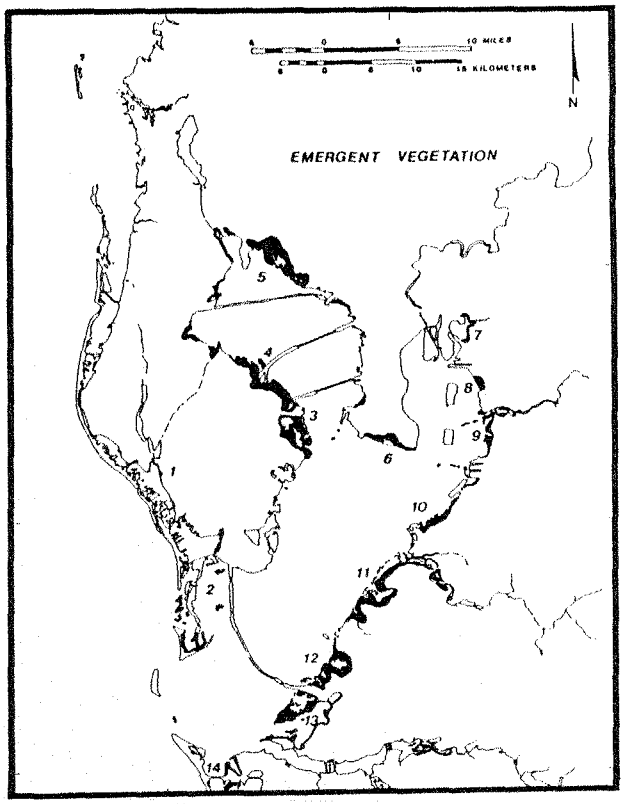


Figure 61. The generalized distribution of mangrove forests and tidal marshes in Tampa Bay. Names of numbered areas are listed in text (from Estevez and Mosura 1985).

Estimates of the percentage of the total emergent wetlands which are tidal marsh vary from 10% to 18% (Estevez and Mosura 1985; Ed Pendleton, U.S. Fish and Wildlife Service, Slidell, Louisiana; pers. comm.). Mangroves are the dominant vegetation, but periodic freezes allow substantial areas of tidal marsh to persist as cold-sensitive mangroves are pruned or killed (Estevez and Mosura 1985).

Estevez and Mosura (1985) noted that "regrettably little is known of the organization or functioning of tidal marshes in Tampa Bay." Decomposed marsh plant fragments, known as detritus, have been shown to be important in some estuarine food webs, although considerable controversy exists as to the magnitude of that role (Haines 1976; Nixon 1980; Stout 1984; Durako et al. 1985). The controversy arises from the ambiguous results from isotope studies designed to pinpoint the source of carbon in the diet of specific marsh animals. A diet that includes a mixture of benthic microflora and vascular plant detritus, for example, could give a value halfway in between those expected if only a single carbon source was utilized.

The role of marsh surfaces and creeks as habitat for juvenile and adult fishes, invertebrates, and birds is less controversial, though not well studied (Durako et al. 1985). Subrahmanyam et al. (1976) reported 55 species of

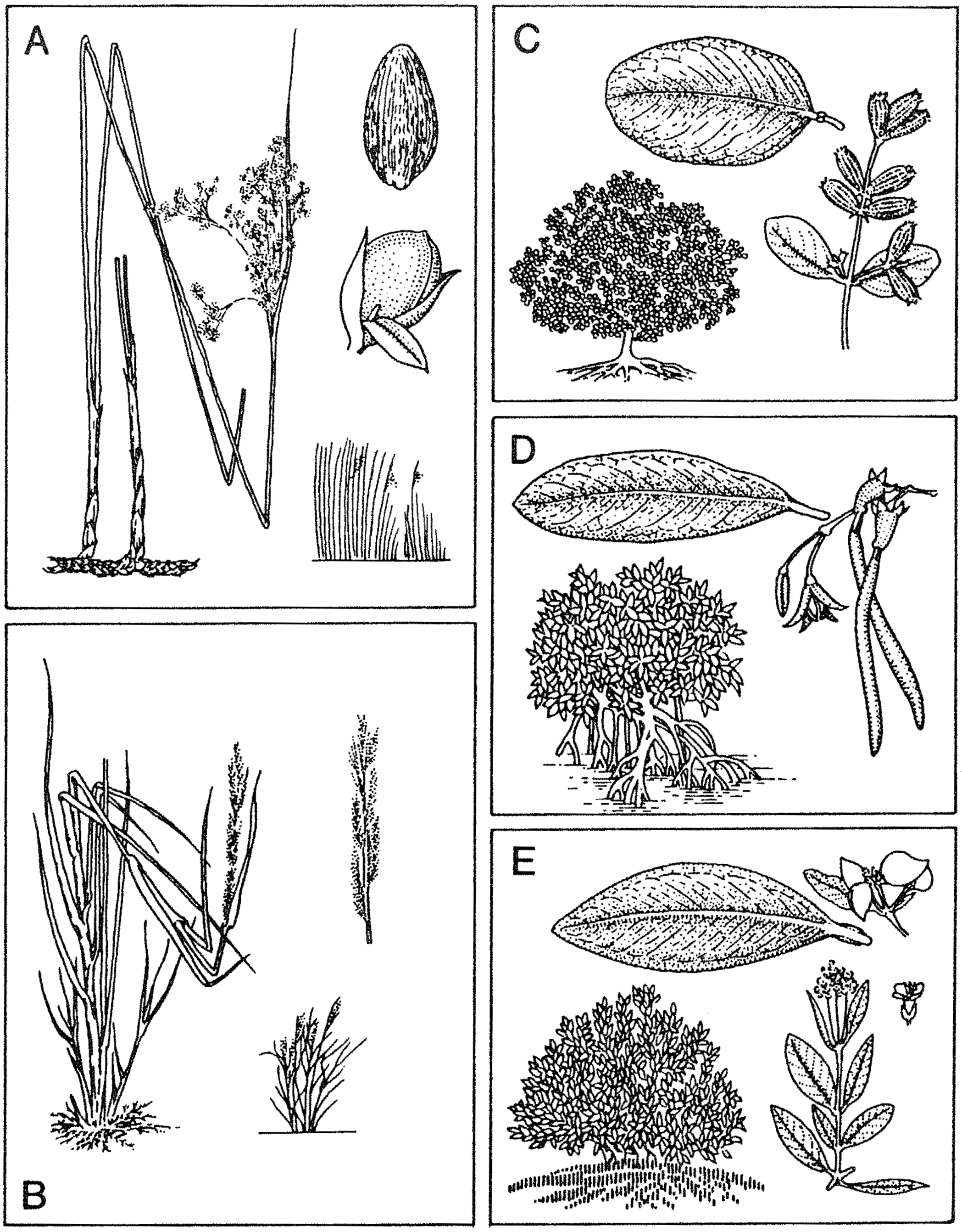


Figure 62. Typical form of the five dominant plant species found in intertidal wetlands of Tampa Bay. A: *Juncus roemerianus*, black needlerush; B: *Spartina alterniflora*, smooth cordgrass; C: *Laguncularia racemosa*, white mangrove; D: *Rhizophora mangle*, red mangrove; E: *Avicennia germinans*, black mangrove (from Estevez and Mosura 1985).

Figure 63. Typical tidal marsh along the shores of Tampa Bay with dominant cover of black needlerush (*Juncus roemerianus*) and a lower elevation fringe of smooth cordgrass (*Spartina alterniflora*).

invertebrates from north Florida tidal marshes. Fish and shellfish species important to Florida's commercial and recreational fisheries, including shrimp, menhaden, blue crabs, and mullet, commonly inhabit tidal marsh creeks (Durako et al. 1985). Fifty-three species of fish, dominated by the killifishes (Fundulus similis, F. grandis, and Cyprinodon variegatus), are present in these marshes (Subrahmanyam and Drake 1975).

Kruczynski et al. (1978) reported primary production values ranging from 390 to 1,140 g dry wt/m^2/yr for needlerush, and 130-700 g dry wt/m^2/yr for smooth cordgrass in north Florida. The overall mean value would be around 600 g dry wt/m^2/yr. No similar productivity data or the previously mentioned habitat data are available for Tampa Bay marshes. This information is particularly important since emergent wetlands restoration and creation efforts in the bay are concentrating on the use of smooth cordgrass (Hoffman et al. 1985).

The reasons for this, discussed by Lewis (1982a, 1982b), include the fact that smooth cordgrass, although not a dominant plant in the bay, has been observed to be a pioneer species on spoil islands in the bay. Smooth cordgrass, in turn, facilitates the invasion of mangrove seeds by stabilizing the substrate and reducing wave energy and is eventually replaced by these mangroves (Lewis and Dunstan 1975a).

Because the frequency of cold weather can cause dieback or kill mangroves on Tampa Bay (Estevez and Mosura 1985), direct planting of mangroves only is not encouraged (Lewis 1982b, Hoffman et al. 1985). The functional roles of both natural and created marshes as sources of energy and as fish and wildlife habitat is thus a high priority research item.

3.7 MANGROVE FORESTS

In contrast to tidal marshes, mangrove forests on the bay have received some study (Estevez and Mosura 1985), although it is primarily descriptive in nature. The forests are composed of three species, red mangrove (Rhizophora mangle); black mangrove (Avicennia germinans); and white mangrove (Laguncularia racemosa) (Figure 62). Unlike mangrove forests further south (Odum and Heald 1972), mangrove forests on Tampa Bay are composed of a mixture of all three species, and while exhibiting natural zonation similar to that described by Davis (1940), have some unique features (Estevez and Mosura 1985, Lewis et al. 1985b).

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. 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:

(1) grow on mainland shorelines of gradual slope;
(2) are exposed to tides but are not daily overwashed;
(3) have sluggish internal water flow on high tides, and minor to no scouring; and
(4) 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 are 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.

Mangroves grow on banks along the mouths of rivers, but we regard these as extensions of the fringe form rather than the "riverine" forest type and are termed "tributary" forests (Table 11). 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 (Estevez and Mosura 1985). 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 composed of a mixture of red and black mangrove, the reds being shorter and denser in aspect. The forests are low, often averaging 2-3 m. Lugo and Zucca (1977) related temperature stress to decreased leaf size and number, and increased tree density. These features are typical of shrub forests in the bay. Limbs of 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. 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.

Table 11. Mangrove tree size by species and forest type in Tampa Bay (Williamson and Mosura 1979).

	Cumulative mean D.B.H.[a] (cm)		
Forest type	Rhizophora	Avicennia	Laguncularia
Fringe	2.69 ± 2.26 (139)[b]	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)

[a] Diameter at breast height.
[b] Numbers in parentheses are sample sizes.

The typical zonation pattern and species makeup along a transect through an undisturbed mangrove forest located on the east side of Middle Tampa Bay (Wolf Branch) are shown in Figure 64 and Table 12. Table 11 gives data for cumulative size expressed as diameter at breast height for three mangrove forest types on the bay. The data for the fringe type are applicable to the Wolf Branch transect. These data indicate that the forests occur over a range of elevations from 0.06 to 0.76 m above mean sea level (MSL), and the lower elevation zones are occupied by red mangroves (Figure 65), which are gradually replaced by black and white mangroves as the elevation increases. There is not a distinct zonation between the black and white mangroves; they intergrade over much of the area of the forest, although the black mangroves extend to a somewhat lower elevation. At the higher elevations normally reached by tides only once or twice a month, only stunted and scattered black mangroves are found; soil salinities can be over 100 ppt due to the evaporation of seawater and residual salt accumulation. In this area of the forest a salt barren, or salina, is found with areas of very salt-tolerant, low-growing vegetation interspersed with barren patches devoid of all vegetation (Figure 66). These plant assemblages are dominated by sea purslane (*Sesuvium portulacastrum*), glasswort (*Salicornia virginica*), saltwort (*Batis maritima*), sea oxeye daisy (*Borrichia frutescens*), sea lavender (*Limonium carolinianum*), and various salt-tolerant grasses.

The latitude of Tampa Bay is near the northern limit of mangroves and low-temperature stress is common in the mangrove forests. Repetitive freezes can intensify temperature effects on the structure of the forest. Initially the canopy is partially destroyed. If another freeze quickly follows, the damaged trees

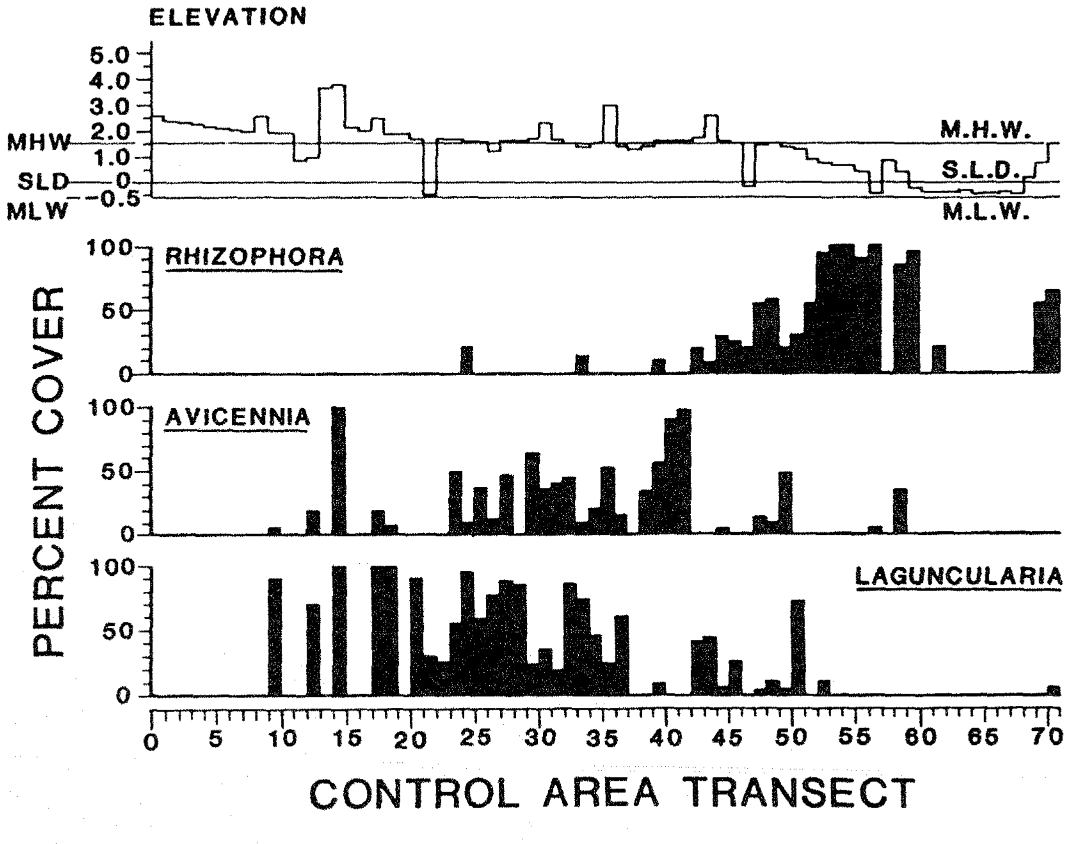


Figure 64. Distribution of mangroves on an undisturbed (control) shoreline near Wolf Creek (20-m sampling intervals). Elevations are shown in feet (from Detwiler et al. 1975).

Table 12. Elevation ranges and mean elevations of 10 plant species found in the control area of an undisturbed mangrove community near Wolf Creek (Detweiler et al. 1975). Elevation in ft above mean sea level.

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 vermicularis	5	+2.2 - +1.6	+1.9

Figure 65. Typical view of fringing red mangroves, Lower Tampa Bay.

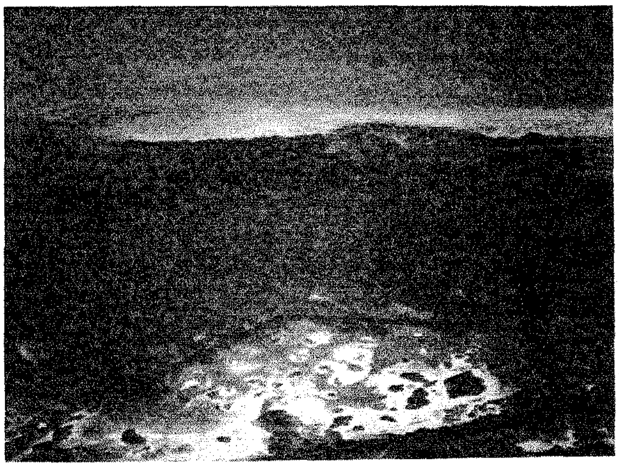


Figure 66. Aerial photograph of view across a mangrove forest bordering Middle Tampa Bay. The pale areas at the bottom are salt barrens.

are killed. In recent years two freezes have occurred relatively close together (1977 and 1983). During January 1977, a minimum temperature of -5°C was reached and snow fell for the first time in over 100 years. The Christmas freeze of 1983 involved 2 days during which the temperature in Tampa fell to -6.7°C followed by a -7.2°C reading the next day. Such low temperatures had not occurred in Tampa since the historical freeze of 1894-95 which dealt a serious blow to the then flourishing citrus industry in Florida (Sanders 1980). These freezes caused significant losses of mangroves and the total area of tidal marsh on the bay may increase as more low-temperature tolerant marsh plants invade areas left barren by the death of the mangroves (Figure 67). During a less severe frost or freeze selective survival of mangroves has been observed, with the black mangrove having the greatest resistance to freeze damage and the white mangrove the least. The black mangrove is typically the largest-diameter tree in the forest (Table 13), particularly in the fringe and overwash forests which are the dominant types in the bay.

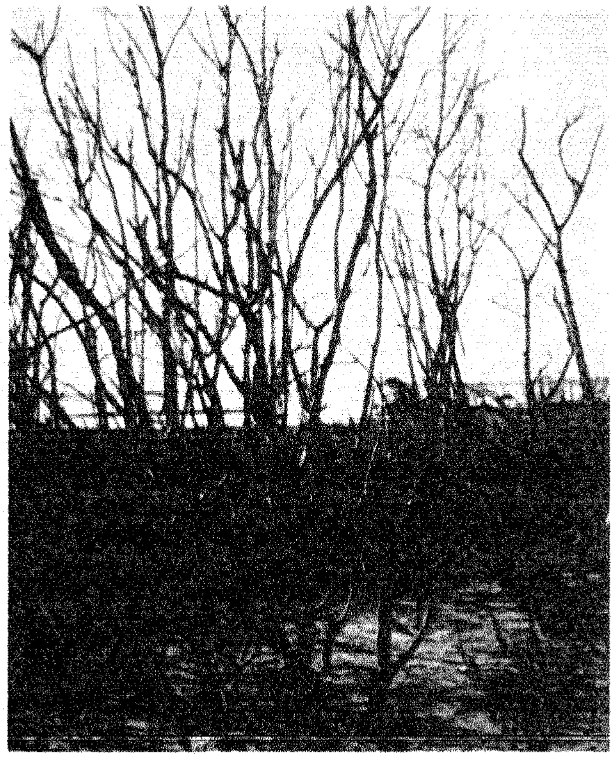


Figure 67. Dead mangroves at Fish Creek in Old Tampa Bay. Low temperatures in 1983 killed this forest of predominantly black and white mangroves.

This size difference is believed to exist because these trees are older, having survived some freezes that killed red and white mangroves. The 1983 freeze was significant in that even some of the large black mangroves which survived earlier freezes were killed or frozen back to the ground. It is likely that the structure of forests on the bay has been significantly altered by these freezes, particularly those in the northern third of the bay, where air temperatures can be as much as 4°C lower than in the southern portion of the bay (Estevez and Mosura 1985). It is not surprising, then, to see a north-to-south gradient in the bay with the better developed mangrove forests in the southern half and the more freeze-damaged forests mixed with tidal marsh species in the northern half.

Primary production rates as measured by litter fall are reported by Estevez and Mosura (1985) to have a mean value of 3.1 g C/m^2/day (11.3 t C/ha/yr) for three sites in Tampa Bay. These values are conservative, since they do not include biomass added to the structure of the forest as the trees grow or metabolic energy losses.

As with tidal marsh research in the bay, functional studies of the role of mangroves as sources of carbon or as habitat are rare. The only functional value that has received some study is the role of mangroves as nesting sites for colonial sea birds and wading birds (Lewis and Dunstan 1975b; Schreiber and Schreiber 1978; Lewis and Lewis 1978; Paul and Woolfenden 1985). Woolfenden and Schreiber (1973) stated that mangrove forests:

> . . . are absolutely essential to the existence of a large number of water birds that breed in Florida, for essentially all of the breeding colonies of pelicans, cormorants, herons, and ibises of saline environs are in mangrove. Not only does mangrove supply breeding sites, but also the nutrients necessary early in

Table 13. Estimated annual production of primary producers based on areal coverage in the Tampa Bay system (modified from Johansson et al. 1985).

Primary producer	Production ($g\ C/m^2/yr$)	Area (km^2)	Total Production ($g\ C/yr \times 10^6$)	Percent of Total
Seagrass and epiphytes	730	57.5	42.0	8.5
Macroalgae	70	100.0	7.0	1.4
Benthic microalgae	150	200.0	30.0	6.0
Mangrove forests	1,132[a]	64.5[b]	73.0	14.7
Tidal marshes	300	10.5[b]	3.2	0.6
Phytoplankton[c]	340	864.0	293.8	59.1
Phytoplankton[d]	50	96.0	48.0	9.7
Riverine forests	ND[e]	ND	ND	ND

[a] Estevez and Mosura 1985.
[b] Assuming 14% of the bays emergent wetlands are tidal marsh.
[c] For bay areas deeper than 2 m.
[d] For bay areas shallower than 2 m.
[e] No data available.

the food webs that lead to the items taken as prey by birds.

Although the necessary habitat utilization studies have not been conducted for Tampa Bay, the value of mangroves to Florida's fisheries is well documented (Lewis et al. 1985b). Mangroves are known to serve as one of several critical habitats in the life history of many fish and shellfish species important in commercial and recreational fisheries, including the pink shrimp (Penaeus duorarum), redfish or red drum (Sciaenops ocellatus), tarpon (Megalops atlanticus), and snook (Centropomus undecimalis) (Odum et al. 1982; Lewis et al. 1985b).

While the frequently flooded lower portions of mangrove forests and tidal marshes are documented to be valuable habitat, the roles of the higher marsh and mangrove forest and tidal salt flats behind the lower elevation habitats are less well understood. Heald et al. (1974) noted that:

> . . . during the dry season, when the high marsh areas are drying rapidly, the deeper, more permanent, ponds within the impoundment provide temporary refuge for retreating fishes. At this point wading bird populations are able to efficiently exploit them.

Richard T. Paul (National Audubon Society, Tampa; pers. comm.) observed the salt flat habitat on Tampa Bay being extensively utilized as foraging and breeding habitat by a variety of forage fish species including Cyprinodon, Fundulus, and Poecilia. In turn, these fish became important food sources for a variety of herons and egrets during times of high tides when the flats were flooded. Paul stated that the reddish egret

(Egretta rufescens), the rarest egret in Florida, is uniquely suited to feed in this habitat because of its active feeding behavior. Further documentation of this habitat value is important.

3.8 RIVERINE FORESTS AND ADJACENT WETLANDS

All major rivers and streams entering the bay have floodplain forests and adjacent wetlands that drain eventually into the bay. These freshwater wetlands serve as the first of a series of filters to cleanse upland drainage before it enters the bay and also act as contributors of dissolved and particulate organic matter and nutrients.

Typical of these wetlands are those bordering the Alafia River. Clewell et al. (1983) described these wetlands as supporting 409 plant species including 84 tree species dominated by red maple (Acer rubrum) and swamp tupelo (Nyssa biflora).

Sipe and Swaney (1974) noted that the acreage of freshwater wetlands of Hillsborough County has declined significantly since historical times. Losses would be expected to reduce the ability of these systems to filter upland runoff, allowing more turbid water to reach the bay. Particulate organic matter inputs to the bay from litter fall in adjacent wetland and terrestrial habitats would also be expected to decline, and nutrient inputs would probably increase as filtration capacity declined. In addition, many streams have been channelized, and even if the wetlands are intact hydraulic exchange with the adjacent water body may be impaired.

Total streamflow input to Tampa Bay is estimated to average 2 x 10^{12} l/yr (Hutchinson 1983). If it can be assumed that total organic carbon concentration (TOC) averages 10 mg C/l (Dooris and Dooris 1985), then TOC input via streamflow would be 2 x 10^7 kg C/yr. TOC measurements of this sort are typically made on unfiltered water samples, but do not take into account bedload transport of organic material derived from adjacent wetlands and uplands or pulse events when large amounts of organic matter may be moved in a relatively short period of time. For this reason, the above input value should be considered conservative.

3.9 TOTAL PRIMARY PRODUCTION AND ORGANIC MATERIAL INPUT

Total net primary production (carbon reduced by photosynthesis) by natural plant communities in Tampa Bay (listed by category in Table 13) is estimated at 478.2 x 10^6 kg/yr. These figures indicate that Tampa Bay can be characterized as a phytoplankton-based system when compared to other sources of net primary production. By virtue of their high annual production, mangroves are the second most important primary producer in the estuary.

In addition to primary production, organic material can be transported to the bay from outside sources by streamflow, sewage discharges, urban runoff from streets, rainfall, and ground-water discharge. These values (listed in Table 14) account for a total input of organic carbon of 92.7 x 10^6 kg/yr, or about 25% of the amount produced by photosynthesis (or marine plants) in the bay. This figure was probably much higher prior to recent improvements in industrial and municipal discharges, and substantial deposits of residual organic matter are still present in bay sediments (Ross et al. 1984). The estimate of Ross et al. for current allochthonous sources of organic carbon is somewhat less than ours (66.7 vs. 92.7 x 10^6 kg/yr).

3.10 SECONDARY PRODUCERS

Secondary producers are the animal communities, either herbivorous or carnivorous, that consume the organic carbon in an area. A very simple Tampa Bay food chain is illustrated in Figure 68. A simplified food web for the bay is shown in Figure 69. Ideally, one should be able to measure the amount of fish or crab biomass produced over a period of time. This is total secondary production. From studies with simpler systems, we know that total secondary production typically cannot exceed 10% of primary production because of inefficiencies in energy

Table 14. Organic inputs to Tampa Bay from allochthonous sources.

Source	10^6 gal/yr	l/yr	mg/l TOC	kg C/yr
Streamflow[a]	1,447	2×10^{12}	10	20.0×10^6
Ground water[b]	100	1.4×10^{11}	0.1	0.014×10^6
Rainfall[b]	1,048	1.5×10^{12}	1.0	1.5×10^6
Municipal and industrial discharge[c]	520	7.1×10^{11}	100	71.2×10^6
Urban runoff[d]	---	---	---	---
Total				92.7×10^6[e]

[a] Modified from Hutchinson 1983.
[b] Hutchinson 1983.
[c] Moon 1985.
[d] Data unavailable.
[e] Without urban runoff data.

transfer and the use of consumed energy to fuel life processes (Odum and Odum 1981). As noted in the section on total primary production and organic carbon input, the available data allow only an approximation of the amount of organic material produced or delivered to the bay. Data on secondary production have not been generated accurately. Ross et al. (1984) estimated fish standing crop in the bay at 271×10^6 kg by multiplying the commercial landing data by a factor of 10. The accuracy of this figure is unknown.

In order to understand how the bay works it will be important to quantify both the types and amounts of primary and secondary production. Simply having large amounts of both may not necessarily be ideal. A bay ecosystem with a large variety of plant and animal species actually may require less organic material input. The typical "green pea soup" appearance in a polluted pond or sewage treatment plant lagoon is an example of high primary production that also indicates an imbalanced system. Proper management of Tampa Bay to provide stable, balanced populations without abnormal algal blooms and fish kills will require a better understanding of both primary and secondary production.

3.11 ZOOPLANKTON

Zooplankton in Tampa Bay are divided into holoplankton (animals who spend their entire lives as plankton) and meroplankton (temporarily planktonic). Copepods are typical holoplankton. Barnacles and oysters are typical meroplankton, spending their early lives floating in the bay until they find a suitable point of attachment (e.g., a mangrove prop root, a boat hull), at which time they metamorphose into their more familiar attached forms. Other meroplankton, e.g., pink shrimp, blue crabs, larval fish and some marine snails, metamorphose into mobile forms.

The most extensive study of zooplankton to date (Hopkins 1977) provides much useful data, but the author emphasized that collections were only taken at the surface of the bay once every 3 months (quarterly) for one year. The data are of limited value in describing long term cycles but are essential as a

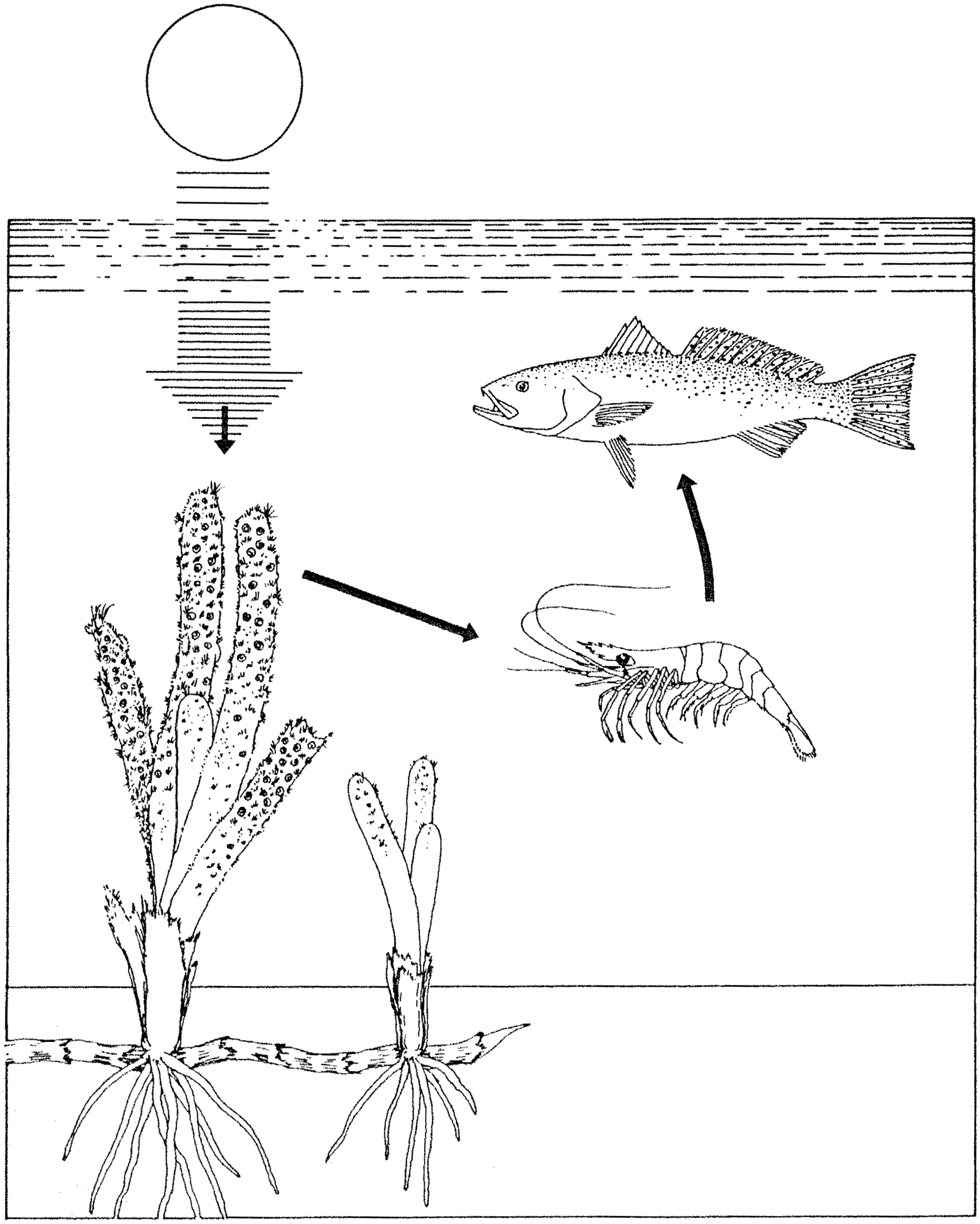


Figure 68. Simple Tampa Bay food chain illustrating energy flow through seagrass epiphytes, caridean shrimp, and spotted seatrout.

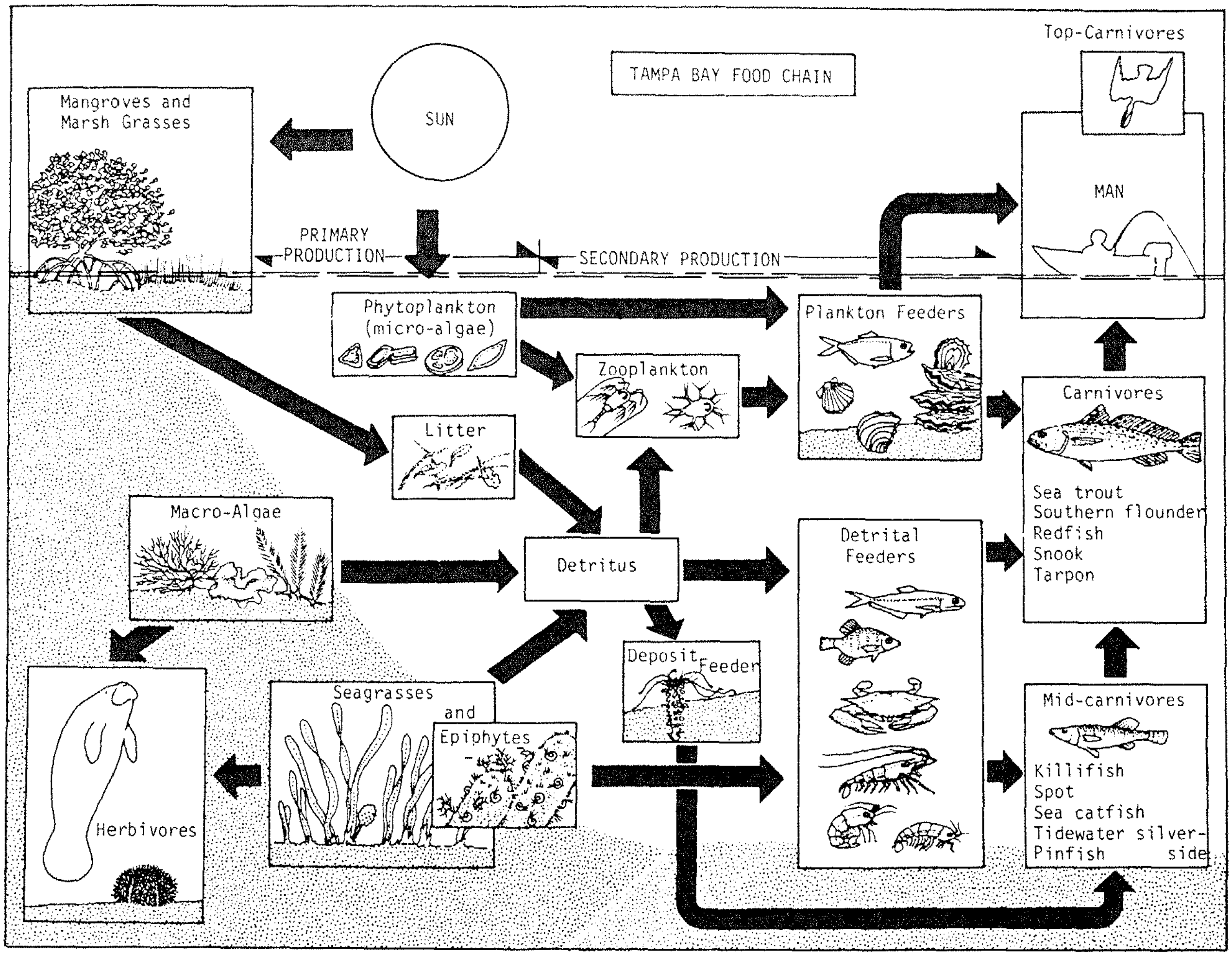


Figure 69. A generalized Tampa Bay food web.

first step in describing the general characteristics of bay zooplankton. Thirty-seven species of holoplankton were identified in the study and were grouped into three categories based upon abundance (Table 15). Mean biomass for all zooplankton was 39.6 mg dry wt/m^3. The dominant species were three copepods (Oithona colcarva, Acartia tonsa, Paracalanus crassirostris), which made up 56% of the zooplankton biomass. The cosmopolitan species Acartia tonsa alone accounted for 30% of total zooplankton biomass. Although no feeding studies for this species have been done in Tampa Bay Conover (1956) and Reeve and Walter (1977) indicated that it is an omnivore, consuming phytoplankton, zooplankton, and detritus.

Researchers have been unable to find a significant relationship between chlorophyll concentration (as a measure of phytoplankton abundance) and numbers of the 10 most abundant holoplankton species (Hopkins 1977). This indicates that phytoplankton occur in numbers greater than those needed to feed the existing population of zooplankton, and that other factors control the maximum population densities of zooplankton, or that other food sources are being utilized.

Holoplankton are important in the diet of larval fish in Tampa Bay, as is further described in the section on fish. For this reason and others, the population dynamics of holoplankton need additional study.

Table 15. Holoplankton commonly found in Tampa Bay grouped by abundance (Turner and Hopkins 1985).

Group	Family	Species
Greater than 1,000/m^3; 60% of total biomass	Copepods	*Oithona colcarva*
		Acartia tonsa
		Paracalanus crassirostris
	Tunicates	*Oikopleura dioica*
100-1,000/m^3; 5% of total biomass	Copepods	*Oithona nana*
		Pseudodiaptomus coronatus
		Othonia simplex
		Labidocera aestiva
		Euterpina acutifrons
	Cladoceran	*Evadne tergestina*
Less than 100/m^3	Copepods	*Eucalanus pileatus*
		Paracalanus quasimodo
		Temora turbinata
		Centropages hamatus
		Centropages velificatus
		Oncaea curta
		Oncaea venusta
		Corycaeus amozonicus
		Corycaeus americanus
		Corycaeus giesbrechtii
		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*

Meroplankton fall into two groups, invertebrate and fish meroplankton (ichthyoplankton). Meroplankton data for Tampa Bay have been summarized by Weiss and Phillips (1985). Hopkins (1977), in sampling for holoplankton, found 19% of total zooplankton numbers and 8% of the total biomass (3.2 g dry wt/m^3) were meroplankton. Table 16 lists his general data for meroplankton abundance. No detailed taxonomic descriptions were attempted for these collections.

Invertebrate meroplankton have been sampled primarily to locate and quantify larvae of invertebrates important in commercial fisheries. Thus, most early studies concentrated on examining samples for pink shrimp (<u>Penaeus duorarum</u>) and stone crab (<u>Menippe mercenaria</u>) larvae. Eldred et al. (1961, 1965) examined the distribution of larval and postlarval penaeid shrimp in the bay area. They reported spawning by the adult shrimp 16-64 km offshore in the Gulf of Mexico between April and June; postlarvae moved inshore and into the bay in July, where they sought seagrass meadows as nursery habitat (Joyce and Eldred 1966). While maturing in the bay, the shrimp may be taken in small commercial roller-frame trawls and sold as bait shrimp, both alive and dead. After the shrimp mature, they migrate from the bay to spawn offshore. During this period, the seafood industry harvests the adults. This life cycle is shown in Figure 70. In addition to pink shrimp, the larvae of penaeid shrimp of the genera <u>Sicyonia</u> and <u>Trachypenaeus</u> have been collected in the bay.

Table 16. Meroplankton species collected by Hopkins (1977).

Group	Size	Type
Group I	>1,000/m^3	Bivalve larvae Barnacle larvae Polychaete larvae Gastropod larvae
Group II	100-1,000/m^3	Echinoderm larvae Bryozoan larvae Decapod larvae
Group III	<100/m^3	Polyclad larvae Phoronid larvae Brachipod larvae Enteropneust larvae Ascidian larvae Cephalochordate larvae
Fish eggs	<500/m^3	

Stone crabs are believed to spawn within the bay, and very young larvae are abundant during spring and summer in zooplankton samples (Weiss et al. 1979). Nursery areas in the bay include seagrass beds, oyster bars, live bottoms, and artificial reefs and riprap shorelines. Although blue crabs (<u>Callinectes sapidus</u>) are important in local commercial fisheries, no work on their life history has been done in the bay.

Blanchet et al. (1977) and Phillips and Blanchet (1980) examined meroplankton at stations in Hillsborough and Middle Tampa Bays and found 105 invertebrate species, of which 86 were decapod crustaceans. Table 17 lists the most abundant of the species found, in decreasing order. The pinnotherid crab, <u>Pinnixia sayana</u>, was the most abundant, averaging 35% of the total invertebrate larvae collected. Xanthid crabs were second in abundance.

It is important to note that the dominant meroplankton species in the bay (Table 16) are <u>not</u> penaeid shrimp or other decapods but are bivalve, polychaete, and gastropod larvae. Thus, the latter species, and not the ones most studied, may be more important in terms of biomass and energy transfer to other consumers. This hypothesis is suggested by the fact that polychaetes and mollusks are the dominant infauna in the bay.

Ichthyoplankton include the eggs and larvae of fish. Routine sampling for ichthyoplankton can provide data to determine the life history of a particular species. For example, if both eggs and larvae of a given species are found in sufficient numbers in the bay, the bay serves as both a spawning ground and nursery area for the species. Finding only larvae and postlarvae may indicate that spawning occurs offshore in the Gulf of Mexico, with larvae migrating into the bay to utilize it as a nursery area.

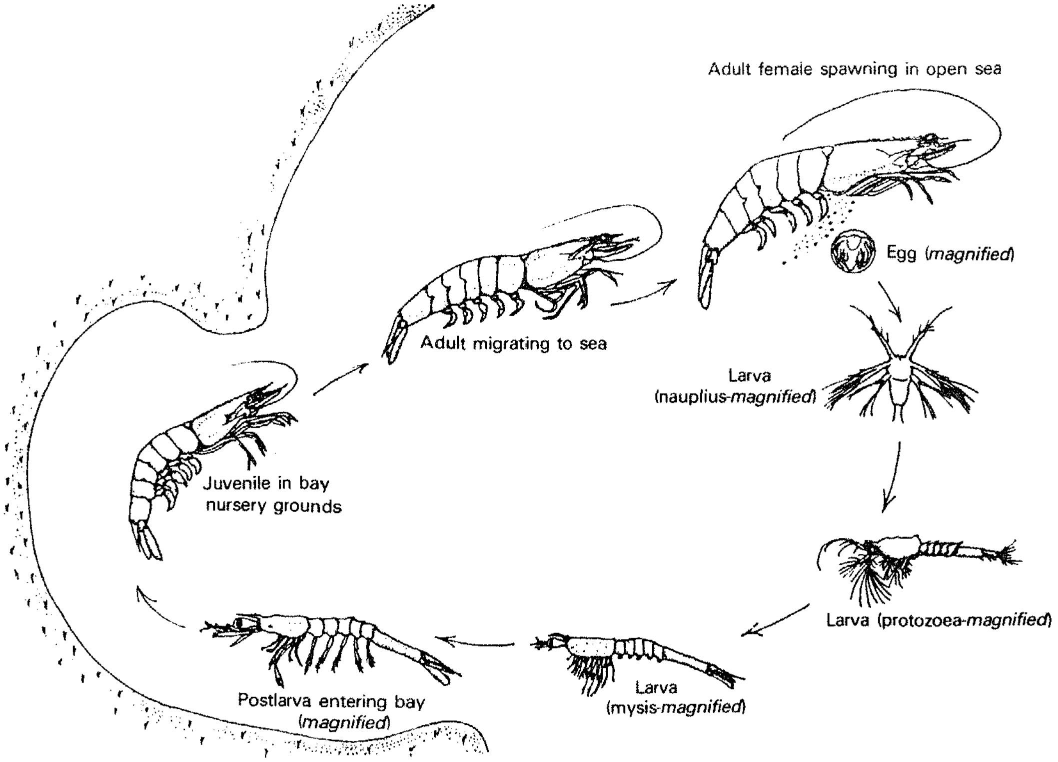


Figure 70. Life cycle of the pink shrimp (*Penaeus duorarum*), illustrating the use of inshore estuarine habitat as nursery areas (Joyce and Eldred 1966).

Table 17. Dominant meroplankton species collected by Blanchet et al. (1977) and Phillips and Blanchet (1980).

Family	Species
Decapods	*Pinnixia sayana* *Eurypanopeus depressus* *Hexapanopeus angustifrons* *Upogebia affinis* *Menippe mercenaria* *Rhithropanopeus harrisii* *Panopeus herbstii* *Neopanope texana*
Penaeids	*Penaeus duorarum* *Sicyonia* sp. *Trachypenaeus* sp.

Weiss and Phillips (1985) listed the dominant ichthyoplankton from three surveys (Table 18). In all three surveys the groups dominant as eggs were anchovy (Engraulidae) and drum (Sciaenidae). In addition to these two families of fish, gobies (Gobiidae), sardines (*Harengula*), sheepshead (*Archosargus*) and pigfish (*Orthopristis*) were common as both eggs and larvae.

The seasonal occurrence of the two dominant ichthyoplankton groups is illustrated in Figure 71. The greatest densities of eggs occurred in spring and the greatest diversity of larvae in the summer months. The bimodal peaks of larval densities are theorized by Weiss and Phillips (1985) to represent a protracted spawning season. Winter collections were dominated by blenny (Blennidae) and gobies (Gobiidae), although numbers usually were low.

Table 18. Dominant fish egg and larval taxa as percentage of all eggs or larvae collected from three ichthyoplankton surveys in Tampa Bay (Weiss and Phillips 1985).

Lower Hillsborough Bay (1976)		Lower Hillsborough Bay (1979)		Upper Old Tampa Bay (1978)	
		Eggs			
Engraulidae[a]	73.1	Engraulidae	51.1	Engraulidae	82.2
Sciaenidae[b]	26.1	Sciaenidae	48.7	Sciaenidae	15.4
Carangidae[c]	0.4	Soleidae[d]	0.1	Soleidae	1.1
		Larvae			
Anchoa spp.	87.4	*A. mitchilli*	74.4	*Anchoa* sp.	83.6
Sciaenidae	3.9	*H. jaguana*	16.3	Gobiidae[f]	13.3
Gobiidae	2.7	Sciaenidae	3.1	Sciaenidae	1.1
Pomadasyidae[e]	2.1	Blennidae	1.5	Atherinidae[g]	1.1
Carangidae	1.1	*Prionotus* sp.	0.9	Blennidae[h]	0.3

[a] Anchovies.
[b] Drums.
[c] Jacks.
[d] Soles.
[e] Grunts.
[f] Gobies.
[g] Silversides.
[h] Blennies.

3.12 BENTHOS

The benthic community consists of animals that live in the sediment as infauna by burrowing or forming permanent or semi-permanent tubes extending just above the sediment surface; animals that live on the sediment surface either as mobile epifauna or sedentary epifauna; and animals that form specialized communities such as oyster reefs or live-bottom communities.

Taylor (1973) and Simon (1974) summarized the benthic studies conducted in Tampa Bay. Early work (Hutton et al. 1956; Bullock and Boss 1963; Dragovich and Kelly 1964) listed species from random collections and identified 82 species of invertebrates from the bay. The National Marine Fisheries Service conducted more intensive sampling starting in 1963 along a series of transects containing more than 400 stations. From this work and a number of more recent intensive quantitative infaunal studies related to red-tide effects and pollution studies (Bloom et al. 1970; Dauer and Simon 1976; Dauer and Conner 1980; Santos and Simon 1980a, 1980b; Dauer 1984) a fairly detailed understanding of the species composition and seasonal variations in density of the macroinfauna (retained on a 0.5-mm sieve) has developed. Work has just begun on the meiofauna (small organisms from 0.5 mm to 0.063 mm in size (Bell and Coen 1982); and the larger mobile and sedentary epifauna still need more study, as do the fauna associated with seagrasses, mangroves, and marshes.

Benthic studies have resulted in the following general conclusions regarding this group of invertebrates in Tampa Bay:

1. The estuary supports "an extremely abundant and diverse assemblage of bottom organisms, except in Hillsborough Bay, dredged regions of Boca Ciega Bay, and a system of inland canals developed in upper Tampa Bay" (Taylor 1973). Taylor

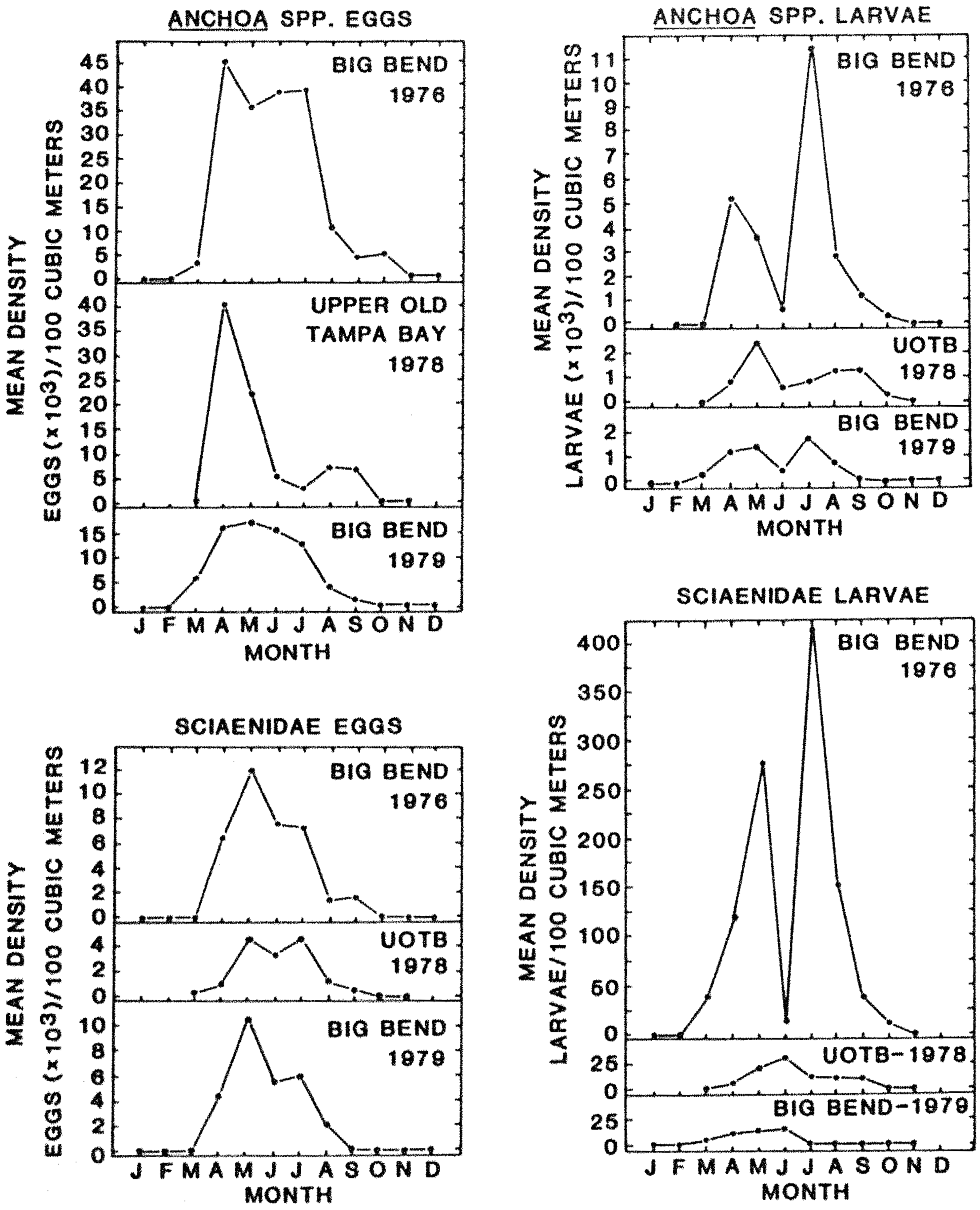


Figure 71. Mean densities of *Anchoa* spp. (anchovy) and Sciaenidae (drum) eggs and larvae reported in three studies of Tampa Bay ichthyoplankton (from Weiss and Phillips 1985).

listed 207 species of polychaetes, 231 species of mollusks, and 29 species of echinoderms found in the bay. Simon and Mahadevan (1985) stated that approximately 1,200 infaunal and epifaunal benthic species (excluding the meiofauna) occur in the bay.

2. Seasonal fluctuations in the abundance and diversity of these organisms are pronounced. Seasonal variability in benthic populations is high and densities can range from 0 to 200,000/m^2 (Figure 72), particularly in areas of pollution-related stress.

3. Seagrass beds have declined with a concomitant decrease in faunal diversity. As discussed earlier, seagrass meadows in Tampa Bay have not been sampled extensively for invertebrates, but existing data indicate they typically support a greater number and diversity of benthic invertebrates than do unvegetated areas (Figure 60) (Santos and Simon 1974). The 81% decline in seagrass meadow coverage in the bay would thus be expected to have greatly reduced the populations of invertebrates.

4. Opportunistic and "pollution indicator" species are abundant, particularly in Hillsborough Bay where pollution problems have been well documented for many years. Both Santos and Simon (1980a) and Dauer (1984) noted that parts of the bay periodically undergo catastrophic disturbance due to anoxia (no oxygen). This condition was first

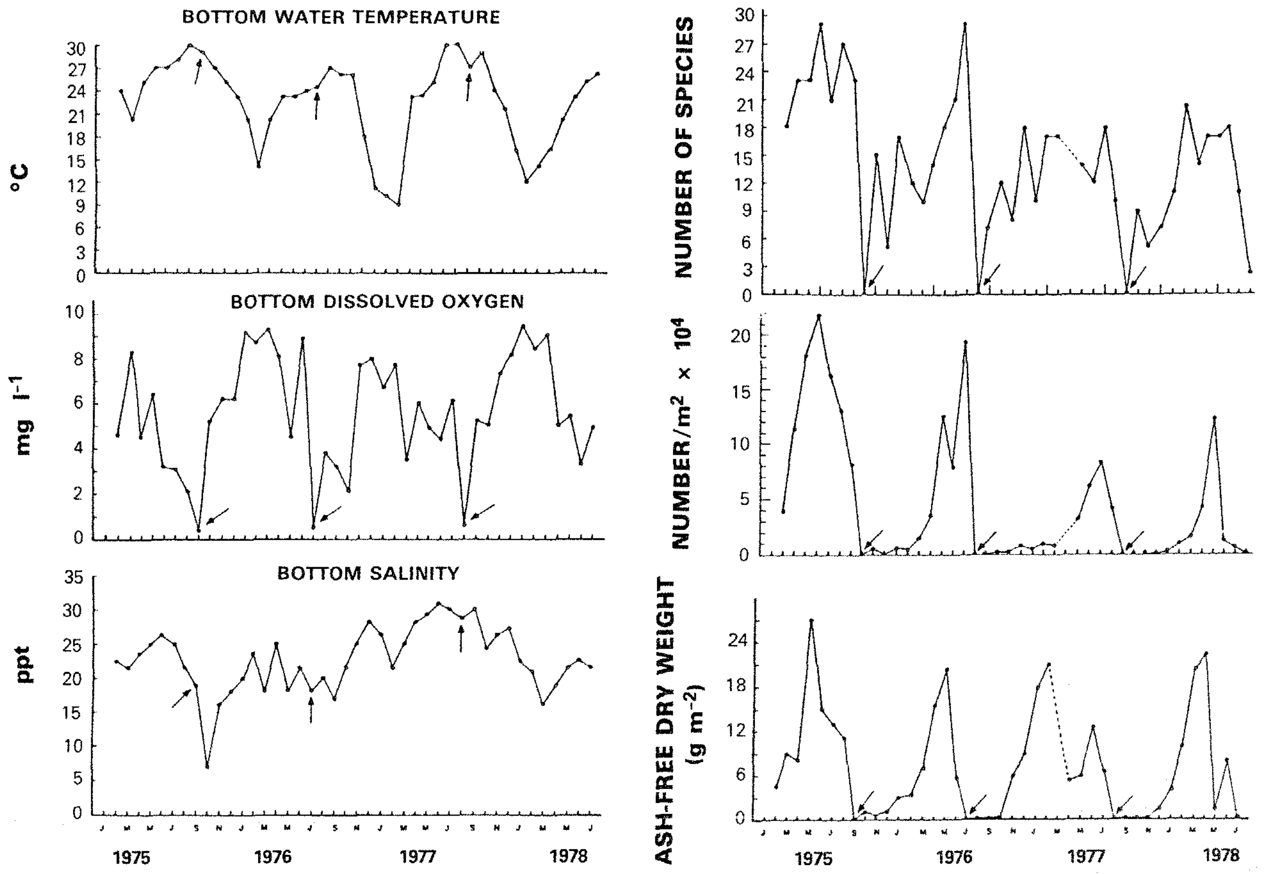


Figure 72. Trends in environmental parameters and benthic invertebrates, Hillsborough Bay 1975-78 (from Santos and Simon 1980b).

documented by the Federal Water Pollution Administration (1969) and the National Marine Fisheries Laboratory (Taylor et al. 1970) during the mid 1960's and is similar to conditions reported for Chesapeake Bay (Officer et al. 1984) as far back as the 1930's.

If the anoxic area is small, as happens if large amounts of drifting macroalgae (Ulva) wash into the intertidal zone and decay, densities of the 10 most common polychaete species can be reduced by up to 89% (Dauer 1984). A rapid recovery to control or higher densities also can occur; Dauer attributed this to the high proportion of opportunistic species with high reproductive potential. These include the polychaetes Capitella capitata, Heteromastus filiformis, Nereis succinea, Polydora ligni, and Streblospio benedicti.

For larger scale defaunation due to anoxia in deeper water (4-5 m), similar rapid recovery rates for the eight dominant (95% of the density) invertebrates were observed for three annual summer periods of low (<1.0 mg/l) oxygen (Figure 72). Following a fourth event, however, recovery was not observed during the 10 weeks of sampling before the study ended (Santos and Simon 1980a). The eight dominant invertebrates included two mollusks (Mysella planulata, Mulinia lateralis), two amphipods (Ampelisca abdita, Grandidierella bonnieroides), a cumacean (Cyclaspis sp.), and three polychaetes (Streblospio benedicti, Mediomastus californiensis, Nereis succinea). Maximum densities were reached during late spring or early summer at over 200,000 individuals/m^2 (Figure 72). The populations crashed to 0 typically in July-August of each year as bottom water temperatures reached maximum values (27°C-29°C) and dissolved oxygen reached minimum values (<1 mg/l).

Sampling 45 stations in Hillsborough Bay during August and September of 1963 revealed no live mollusks at 19 stations. Only 18 stations had one or more of the dominant species, (Mulinia lateralis, Amygdalum papyria, Nassarius vibex, Tagelus plebeius), and only 8 stations had healthy mollusk populations (Taylor et al. 1970). The depauperate molluscan fauna was attributed to periodic anoxia and inability to recolonize.

Hillsborough County Environmental Protection Commission (1982) reported that through 1981 "Hillsborough Bay has consistently had the lowest minimum dissolved oxygen levels at the bottom indicating a stressed benthic environment," and noted further that it has also had the highest maximum dissolved oxygen levels at the surface, indicating algal bloom conditions. It appears these conditions have continued for at least two decades.

While it is interesting to note the rapid recovery of pollution tolerant species in some areas of the bay subjected to stress, Dauer (1984) noted that "species that are long-lived or that take several years to reach maturity (e.g., many species of bivalves and decapods) will recover at a much slower rate." Such species include invertebrates of importance to commercial and recreational fisheries such as the blue crab (Callinectes sapidus), the American oyster (Crassostrea virginica), and the hard-shelled clam (Mercenaria campechiensis). In addition, fish species which consume benthic invertebrates, such as the redfish (Sciaenops ocellatus), can be expected to exhibit population declines as their food supply is eliminated periodically.

5. Sediment type appears to be a controlling factor in determining infaunal distribution in the bay. Bloom et al. (1972) sampled along three shallow shoreline transects in Tampa Bay, each with a distinct sediment type (mud, sand, muddy sand). They concluded that benthic assemblages along two of the transects were distinct, and the assemblage along the third was a

composite of the other two. The dominant species for the various assemblages are listed in Table 19.

The data from Bloom et al. confirmed a correlation between infaunal trophic type and sediment type: suspension feeders (e.g. Tagelus, a bivalve mollusk) being largely confined to sandy or firm mud bottoms (station 1(U+M), Table 19), while deposit feeders (e.g., Ophiophragmus, a brittle star) attain higher densities on soft, muddy substrata (station 2U, Table 19).

6. A general increase in species richness and decrease in total population abundance are evident on a north-to-south gradient in the bay. Simon (1979) sampled at three locations along a north-to-south gradient for 11 months in 1978. These locations were at Bullfrog Creek (north station), Little Manatee River (middle station) and Cockroach Bay (south station). The largest number of species (119) was found at the southern station and the smallest number (69) at the northern station (Table 20). The middle station had an intermediate number (104). A similar pattern was found in mean biomass (weight) of the organisms collected. Density values were variable and did not indicate a strong gradient. As noted before, however, previous studies at even more northerly stations in Hillsborough Bay have found densities of more than 200,000 individuals/m^2 (Figure 72). The precise cause

Table 19. Major and minor species components for the invertebrate assemblages identified by Bloom et al. (1972) along three transects each with three stations (U = upper; M = middle; L = lower) in Old Tampa Bay. Data for Station 3U omitted.

Assemblages by station	Median grain size (mm)	Major species	% Total organisms	Minor species	% Total organisms
1 (U+M)	0.152	Tagelus divisus	71.9	Macoma constricta	3.1
1 L	0.118	Arabella iricolor Nassarius vibex Kinbergonuphis simoni Ophiophragmus filograneus Prunum apicinum	30.8 10.6 20.1 12.4 14.6	Diopatra cuprea	1.1
2 U	0.232	Ophiophragmus filograneus	25.3	Branchiostoma caribbaeum	5.7
2 (M+L)	0.174	Branchiostoma caribbaeum Acanthohaustorius sp.	40.4 21.8	Diopatra cuprea Nassarius vibex Ophiophragmus filograneus Pinnixia sp.	1.3 4.8 2.6 2.1
3 (M+L)	0.208	Diopatra cuprea Nassarius vibex kinbergonuphis simoni Upogebia affinis	4.9 24.6 34.5 5.1	Macoma constricta Pinnixia sp. Tagelus divisus	3.8 1.4 2.5

Table 20. Summary of benthic infaunal data from three sites along a north to south gradient in Tampa Bay (from Simon 1979).

Site	Mean no. of species	Mean density/m^2	Mean biomass (g/m^2)
Bullfrog Creek (north station)	69	5,955	13.4
Little Manatee River (middle station)	104	11,440	7.7
Cockroach Bay (south station)	119	6,766	4.9

of these gradients has not been examined in detail. The generally finer-grained and more organically rich upper bay sediments may be responsible for high densities of a few pollution-tolerant species, while the lower bay sediments with larger grain size and fewer adjacent pollution sources may support fewer numbers of more diverse but less pollution-tolerant species.

Two other benthic communities, oyster reefs and live bottom reefs, occur in Tampa Bay. Although oyster reefs in Tampa Bay have not been studied, Bahr and Lanier (1981) provided a comprehensive discussion of their ecology along the south Atlantic coast, and much of their general discussion would apply to the reefs in the bay. The oyster reef community really consists of a group of invertebrates and some resident fish. Bahr and Lanier (1981) listed 42 species of invertebrates associated with oyster reefs in Georgia. Most of the same species are known to occur in the bay and it is likely they would be found associated with the oyster reef community. The surface area of shell available for epifauna has been estimated to be at least 50 m^2/m^2 of substratum (Bahr and Lanier 1981).

As with the Georgia oyster reefs, the reefs in Tampa Bay typically are located just offshore of the natural intertidal mangroves and marshes; the reef can become colonized by these plants as it accretes and reaches a sufficient elevation to support colonizing mangrove or marsh plant seeds or other propagules (approximately 0.3 to 0.6 m above mean sea level). In addition to the group of organisms listed by Bahr and Lanier (1981), Tabb et al. (1962) noted the occurrence of the crown conch (Melongena corona), a blenny (Chasmodes saburae), and a goby (Gobiosoma robustum) on oyster reefs in northern Florida Bay. The same organisms are common in Tampa Bay oyster reefs.

Lund (1957) stated that an acre of oysters could biodeposit 280 tons/acre/yr of sediment. Considering the problems with turbidity in Tampa Bay (Hillsborough County Environmental Protection Commission 1982, Lewis et al. 1985b), the role of oysters in maintaining and improving water quality certainly needs examination.

Most of the existing intertidal and subtidal oyster reefs occur in areas of the bay that currently are closed to shellfish harvesting. Areas still open to harvesting (Lower Tampa Bay) are located in the higher-salinity waters of the bay far removed from the major developed areas; however, oysters flourish in the lower-salinity areas where they are protected from predation (Old Tampa Bay and Hillsborough Bay). Historically, oysters were an important fishery resource in the bay, but are not commercially harvested today. Sewage discharges, urban runoff, and septic tank leakage have raised coliform bacteria counts in most of the bay to such levels that, while the oysters and other filter-feeding mollusks may be present, they are unsafe to eat.

Live-bottom communities consist of assemblages of sessile invertebrates such as sea fans, sea whips, hydroids, anemones, tunicates, sponges, bryozoans, and hard corals, usually attached to a natural exposed rock or reef formation. Derrenbacker and Lewis (1985) first reported on these communities in Tampa Bay. The communities contain a high diversity of animals and plants (Figure 73) and are unusual in Tampa Bay because most of the bottom is sandy or muddy and supports little attached plant or animal life.

Two types of live bottom communities have been identified. The first, located in higher salinity portions of the bay, consists of an assemblage which includes a sea whip (Leptogorgia virgulata), the loggerhead sponge (Spheciospongia vesparia), boring sponges (Cliona spp.), tunicates, a hard coral (Siderastrea radians), and various algae including Sargassum filipendulum and Caulerpa mexicana. The second type is found in a more variable and lower-salinity regime in the upper bay and consists of fewer species, with the hard coral, the loggerhead sponge, and several of the algae species being absent. Sheepshead (Archosargus probatocephalus) are abundant around these reef areas. Because of the difficulty of locating and mapping these areas, it is likely that other reef areas are present in the bay but have not been located to date. The ecological role of these reefs in the bay is not known. Their importance as habitat has been reported for other areas (Hedgepeth 1954; Grussendorf 1981; Wenner et al. 1983), and it is likely they serve an equally important role in Tampa Bay.

Figure 73. Underwater photograph of a natural rock reef in Lower Tampa Bay. The sponges are *Cliona* species.

3.13 FISH

Springer and Woodburn (1960) listed 253 species of fish found in the Tampa Bay area. Additional studies raised the total number to 312 (Springer and McErlean 1961; Moe and Martin 1965). Comp (1985) noted that many of these species were offshore species and would likely never be found in the bay. He prepared a list of 203 species which were actually collected within the bay. He believed that only 125 of these could be considered common inhabitants, and although the list indicates a diverse fish assemblage, 10 or fewer species usually made up the majority of the fish caught in sampling programs. Table 21 lists the 10 most common fish in Tampa Bay in terms of numerical abundance in collections made with standard gear. As both Springer and Woodburn and Comp emphasized, the standard gear used for sampling of fishes in the bay is biased toward capturing smaller, less mobile species. Sharks and rays, for example, are abundant in Tampa Bay, but due to their mobility and size are sampled rarely. Even mullet are probably undersampled, although they are one of the most abundant species in the bay.

According to Springer and Woodburn (1960), of the 10 dominant species only two (pinfish and mullet) exhibit any degree of direct dependence on plant material in their diets. The rest consume a very similar range of items, including copepods, mysids, ostracods, amphipods, small mollusks, polychaetes, and insects or insect larvae. To our knowledge, the only quantitative data on the diets of fish in Tampa Bay are being generated by the Florida Department of Natural Resources, Marine Research Laboratory, in

Table 21. The 10 dominant fish species in Tampa Bay listed in approximate order of abundance with notation as to area of the bay where found (modified from Springer and Woodburn 1960; Finucane 1966; Comp 1985).

Species	Coastal beaches (high salinity)	Lower Tampa Bay (medium to high salinity)	Middle Tampa Bay (medium salinity)	Hillsborough and McKay Bays (low salinity)
Tidewater silverside Menidia peninsulae	X	X	X	X
Bay anchovy Anchoa mitchilli		X	X	X
Scaled sardine Harengula jaguana	X		X	X
Striped mullet Mugil cephalus		X	X	X
Pinfish Lagodon rhomboides		X	X	X
Longnose killifish Fundulus similis		X	X	X
Spot Leiostomus xanthurus		X	X	X
Silver perch Bairdiella chrysoura		X	X	
Silver jenny Eucinostomus gula		X	X	
Code goby Gobiosoma robustum		X	X	

St. Petersburg as part of an ongoing study titled "Early Life History of Sciaenids in Tampa Bay." Figure 74 was provided by the Department and illustrates the changing diet of juvenile red drum (Sciaenops ocellatus) from a planktonic stage (up to 10 mm) to a late juvenile stage (130 mm). The diet gradually shifts from the smaller zooplankton (copepods) at sizes less than 10 mm, to larger zooplankton and epifauna (mysids and amphipods) between 10 and 120 mm in size, finally shifting to larger epifauna and small fish at the maximum size sampled (130 mm). This generalized change in feeding habits with growth is characteristic of most fish (Livingston 1982, 1984) and is referred to as the "ontogenetic trophic unit" concept.

Although the specific importance of a given food varies with species, it is obvious that the maintenance of a healthy and diverse fish population depends upon healthy populations of their required food items and the habitat needed for their early life stages.

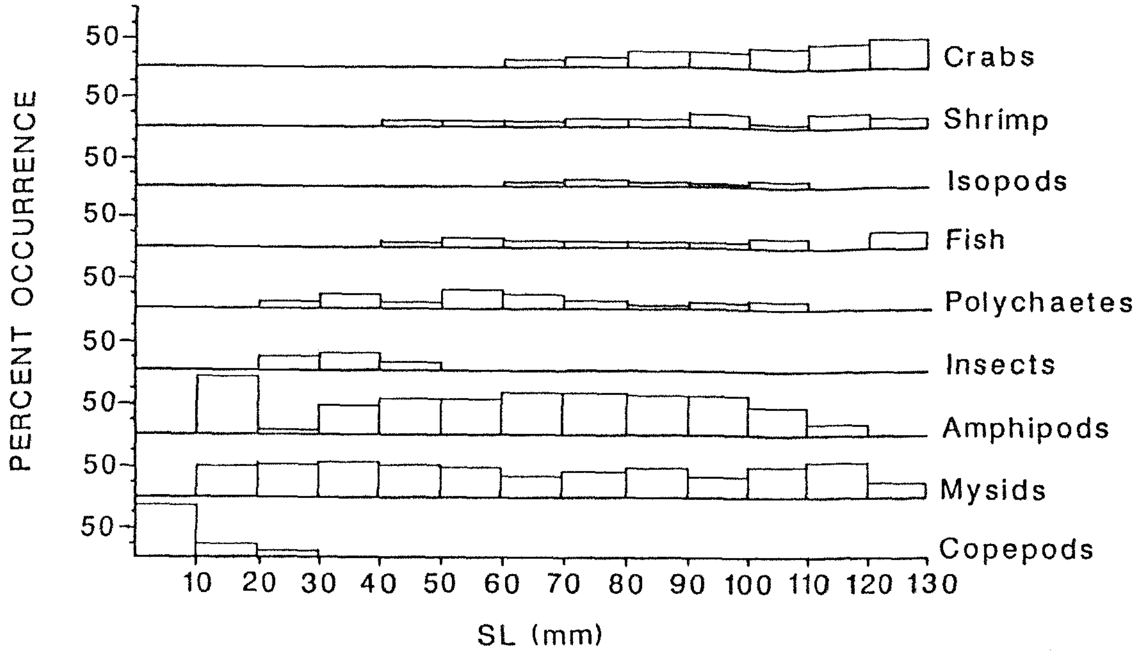


Figure 74. Stomach content analysis of juvenile Tampa Bay red drum (*Sciaenops ocellatus*) up to 130 mm in length (courtesy of Florida Department of Natural Resources).

As noted before, the two species in the top 10 that have some dependence on plant materials are the pinfish and the mullet. The pinfish exhibits a choice of food items similar to those of the other common species up to a size of 120 mm (Livingston 1982, 1984). At this size it appears to start consuming large quantities of seagrass and algae, although considerable controversy has surrounded the question of whether it actually depends on the plant material as an energy source or consumes it accidently as it pursues its prey in vegetated habitats. Springer and Woodburn (1960) observed that 11 of 57 pinfish stomachs they examined contained "exclusively or almost exclusively masses of Diplanthera (Halodule wrightii or shoal grass) and one contained mostly Enteromorpha (an alga)." They stated "we feel that pinfish ingest plant material deliberately". Fry (1984) found that of nine fish species associated with seagrass meadows in the Indian River, Florida, only one, the pinfish, had delta ^{13}C values (a measure of dietary sources of food) that indicated consumption of seagrass leaves and associated epiphytic algae. The striped mullet feed by ingesting surface mud layers or grazing on surface attached algae. Diatoms, dinoflagellates, plant detritus, and copepods comprise their diet as adults. Larvae and small juveniles feed on zooplankton (Harris et al. 1983).

Larger adults of some of the top 10 species (Table 21) may consume juveniles of other fish species, but because of their generally small size as adults their diet does not change greatly from that already outlined, and other fish are not important as food items. Adults of larger, more predatory species of fish, on the other hand, typically depend upon the top 10 as their main source of food. Many of the species in this category are of importance to recreational and commercial fisheries and include tarpon (Megalops atlanticus), snook (Centropomus undecimalis), cobia (Rachycentron canadum), spotted seatrout (Cynoscion nebulosus), sand seatrout (Cynoscion arenarius), and various species of sharks. Other important fish species appear to depend on invertebrates as their main source of food. These include the red drum, black drum (Pogonias cromis), gag grouper (Mycteroperca microlepis), and catfish (Arius felis, Bagre marinus).

Tampa Bay is a nursery area for the larvae and juveniles of both resident and migratory fish species (Table 22). Most spawning occurs during the spring and early summer in either the nearby gulf or the bay proper, usually in higher-salinity areas. Spotted seatrout appear to choose deeper water areas adjacent to seagrass meadows within the bay (Mark Leiby, Florida Department of Natural Resources, St. Petersburg, pers. comm.). A secondary peak occurs during the fall and usually involves fewer species. During and following these spawning periods, the

Table 22. Fish species reported as utilizing Tampa Bay as a nursery area (Springer and Woodburn 1960; Sykes and Finucane 1966; Comp 1985).

Species name	Common name
Carcharhinus limbatus	Blacktip shark
Sphyrna tiburo	Bonnethead shark
Dasyatis americana	Southern stingray
Dasyatis sabina	Atlantic stingray
Dasyatis sayi	Bluntnose stingray
Gymnura micrura	Smooth butterfly ray
Rhinoptera bonasus	Cownose ray
Elops saurus	Ladyfish
Megalops atlanticus	Tarpon
Myrophis punctatus	Speckled worm eel
Brevoortia patronus	Gulf menhaden
Brevoortia smithi	Yellowfin menhaden
Harengula jaguana	Scaled sardine
Opisthonema oglinum	Atlantic thread herring
Anchoa hepsetus	Striped anchovy
Anchoa mitchilli	Bay anchovy
Arius felis	Hardhead catfish
Bagre marinus	Gafftopsail catfish
Opsanus beta	Gulf toadfish
Hyporhamphus unifasciatus	Halfbeak
Strongylura marina	Atlantic needlefish
Strongylura notata	Redfin needlefish
Adinia xenica	Diamond killifish
Cyprinodon variegatus	Sheepshead minnow
Floridichthys carpio	Goldspotted killifish
Fundulus confluentus	Marsh killifish
Fundulus grandis	Gulf killifish
Fundulus similis	Longnose killifish
Lucania parva	Rainwater killifish
Gambusia affinis	Mosquitofish
Poecilia latipinna	Sailfin molly
Membras martinica	Rough silverside
Menidia peninsulae	Tidewater silverside
Hippocampus erectus	Lined seahorse
Hippocampus zosterae	Dwarf seahorse
Micrognathus criniger	Fringed pipefish
Syngnathus floridae	Dusky pipefish
Syngnathus louisianae	Chain pipefish
Syngnathus scovelli	Gulf pipefish

(continued)

Table 22. Concluded.

Species name	Common name
Centropomus undecimalis	Snook
Epinephelus itajara	Jewfish
Epinephelus morio	Red grouper
Mycteroperca microlepis	Gag
Rachycentron canadum	Cobia
Mugil cephalus	Striped mullet
Mugil curema	White mullet
Mugil trichodon	Fantail mullet
Chasmodes saburrae	Florida blenny
Hypsoblennius hentzi	Feather blenny
Gobiosoma bosci	Naked goby
Gobiosoma robustum	Code goby
Microgobius gulosus	Clown goby
Scomberomorus maculatus	Spanish mackerel
Prionotus scitulus	Leopard searobin
Prionotus tribulus	Bighead searobin
Paralichthys albigutta	Gulf flounder
Achirus lineatus	Lined sole
Trinectes maculatus	Hogchoker
Symphurus plagiusa	Blackcheek tonguefish
Caranx hippos	Crevalle jack
Lutjanus griseus	Gray snapper
Lutjanus synagris	Lane snapper
Diapterus plumeiri	Striped mojarra
Eucinostomus argenteus	Spotfin mojarra
Eucinostomus gula	Silver jenny
Gerres cinereus	Yellowfin mojarra
Archosargus probatocephalus	Sheepshead
Lagodon rhomboides	Pinfish
Bairdiella chrysoura	Silver perch
Cynoscion arenarius	Sand seatrout
Cynoscion nebulosus	Spotted seatrout
Leiostomus xanthurus	Spot
Menticirrhus americanus	Southern kingfish
Menticirrhus saxatilis	Northern kingfish
Micropogonias undulatus	Atlantic croaker
Pogonias cromis	Black drum
Sciaenops ocellatus	Red drum
Chaetodipterus faber	Atlantic spadefish
Chilomycterus schoepfi	Striped burrfish

larval and juvenile fish typically migrate into shallow, protected, low-salinity nursery areas of the bay to feed and mature (Figure 75) (Comp 1985; Lewis et al. 1985b). One exception may be the larval spotted seatrout, which seeks out seagrass meadows for nursery area. Seagrass meadows in the lower-salinity areas of the bay (Hillsborough Bay, Upper Old Tampa Bay) have largely disappeared in recent years (Figure 53) and thus the primary nursery area for this species may have been severely reduced. The major decline in the commercial catch of spotted seatrout in the bay (Lombardo and Lewis 1985) may be a result of this loss of nursery habitat.

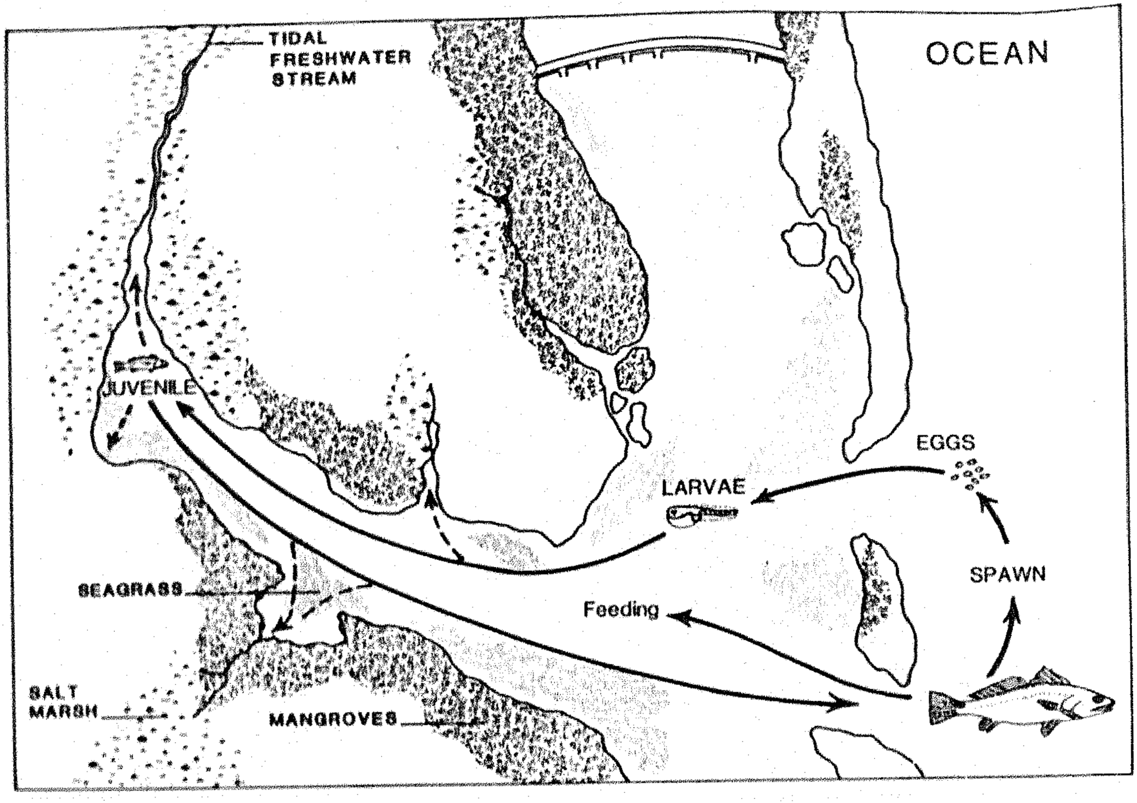


Figure 75. Life cycle of the red drum (*Sciaenops ocellatus*) along Florida's Gulf coast (Lewis et al. 1985b).

Finucane (1966) and Sykes and Finucane (1966) sampled at 50 stations around the bay for more than 4 years (Figure 76) and found the silver perch and the bay anchovy were the most common species in deep-water samples. The tidewater silverside, spot, and pinfish were the most common species in shallow water. They further noted that 21 species of commercially important fish and two species of commercially important invertebrates used the estuary as a nursery area. The results of this study are summarized in Figures 76 and 77. The difference in numbers of immature fish between sampling area III (Old Tampa Bay) and area IV (Hillsborough Bay), of similar size and exhibiting similar salinity and temperature patterns, was attributed to the loss of nursery habitat and greater discharge of pollutants into Hillsborough Bay.

3.14 REPTILES

Only two species of marine reptiles are common in the bay, the diamondback terrapin (Malaclemys terrapin macrospilota) and the mangrove water snake (Nerodia fasciata compressicauda). Both are common in localized areas, but have not been studied. Loggerhead turtles (Caretta caretta) occasionally are observed in the bay on the gulf side of Egmont Key (Reynolds and Patton 1985).

3.15 BIRDS

Seabirds and wading birds are a very visible and important component of the animal life of the bay. Because they are relatively easy to observe, counts and species observations are abundant (Woolfenden and Schreiber 1973; Dunstan and Lewis 1974; Lewis and Lewis 1978; Schreiber and Schreiber 1978; Schreiber 1979; Paul and Woolfenden 1985).

Table 23 lists 83 species of birds associated with marine habitats in the bay. Many of these use certain bay habitats for nesting and raising young (Figure 78), and also wade in the shallows (Figure 79) or dive in deeper waters to feed on fish and invertebrates.

The brown pelican (Pelecanus occidentalus) is particularly well studied (Woolfenden and Schreiber 1973; Schreiber and Schreiber 1983). The adults nest in the canopy of mangroves on natural or artificial islands in the bay where they are protected from mammalian predators (e.g., raccoon, Procyon lotor) which typically do not swim across water barriers. Success of nestlings is tied vitally to the food supply that the adults can collect. A young pelican needs 264 kg of fish to mature to the point where it can fly and begin to feed itself. Adults require about 2.5 kg of fish/day (Woolfenden and Schreiber 1973).

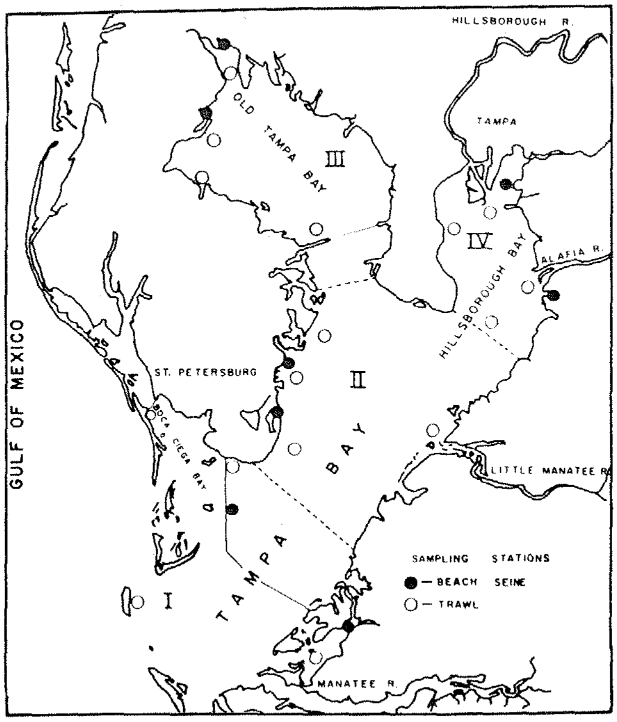


Figure 76. Stations and subareas of Tampa Bay sampled by the Bureau of Commercial Fisheries (National Marine Fisheries Service), August 1961—June 1984 (Finucane 1966).

1, 2, 3, 4 - Winter, Spring, Summer, Fall
□ <50 ◪ 50-100 ■ >100

	AREA I				AREA II				AREA III				AREA IV			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
SILVER MULLET *Mugil curema*							□									
SILVER MULLET *Mugil trichodon*	□	□	□	□		□			□	□		□		□		□
STRIPED MULLET *Mugil cephalus*	□	□	□	□	■	■	□		■	■	■	□		◪	◪	□
GAG *Mycteroperca microlepis*			□													
CREVALLE JACK *Caranx hippos*			□													
PERMIT *Trachinotus sp.*				□												
SPOT *Leiostomus xanthurus*	■	■	□	□	■	■	□	□	■	■	■	□	■	□	□	□
SPOTTED SEATROUT *Cynoscion nebulosus*	□		□	□	□		□	□			■	□	□		□	□
MOJARRA *Eucinostomus gula*	□	□	■	■	◪	■	◪	■	□				□	□		□
MOJARRA *Eucinostomus argenteus*			□	■		◪	□	■	◪	□	□	◪	□	□	□	□
MOJARRA *Diapterus plumieri*			□	□				□			■	■			□	□
BLUE CRAB *Callinectes sapidus*	□	□	□	□	□	□	□	□	□	◪	□	□	□	□	□	□
RED DRUM *Sciaenops ocellata*	□	□		□	□	□		□	□	□		□	□			□
WHITE SEATROUT *Cynoscion arenarius*	□	□	□	□			□		□	□	■	□	□	□	□	□
SHEEPSHEAD *Archosargus probatocephalus*	□		□	□		□	□	□			□		□		□	□
PINK SHRIMP *Penaeus duorarum*	□	□	■	■	□	□	■	■	□	□	□	□		□	□	□
BLACK DRUM *Pogonias cromis*			□	□							□				□	
MENHADEN *Brevoortia patronus*		□	□							■	□	□		□		
MENHADEN *Brevoortia smithi*			□							■	□			□	■	□

Figure 77. Occurrence of immature commercially important fish and shellfish in Tampa Bay, by season and area; see also Figures 3 and 76 (Finucane 1966).

Table 23. Birds associated with marine environments of Tampa Bay (Local status: W—wintering, T—transient, P—permanent, B—breeding) (modified from Dunstan and Lewis 1974).

Species name	Common name	Local status
Podiceps auritus	Horned grebe	W
Pelecanus occidentalis[b,c]	Brown pelican	P
P. erythrorhynchos	White pelican	W
Fregata magnificens[d]	Magnificent frigatebird	W
Phalacrocorax auritus	Double-crested cormorant	P
Anas fulvigula	Mottled duck	P
A. acuta	Northern pintail	W
A. americana	American wigeon	W
A. clypeata	Northern shoveler	W
A. discors	Blue-winged teal	W
A. crecca	Green-winged teal	W
Aythya valisineria	Canvasback	W
A. affinis	Lesser scaup	W
Mergus serrator	Red-breasted merganser	W
Cathartes aura	Turkey vulture	P
Coragyps atratus	Black vulture	P
Circus cyaneus	Marsh hawk	W
Haliaeetus leucocephalus[a,c]	Bald eagle	P
Pandion haliaetus	Opsrey	P
Casmerodius albus	Great egret	P
Egretta thula[c]	Snowy egret	P
E. rufescens[f]	Reddish egret	P
E. tricolore	Tricolored heron	P
E. caeruleae	Little blue heron	P
Bubulcus ibis	Cattle egret	P
Ardea herodias	Great blue heron	P
Butorides striatus	Green-backed heron	P
Nycticorax nycticorax	Black-crowned night heron	P
Nyctanassa violaceus	Yellow-crowned night heron	P
Plegadis falcinellus	Glossy ibis	P
Eudocimus albus	White ibis	P
Ajaia ajaja	Roseate spoonbill	W
Mycteria americana	Wood stork	P
Rallus longirostris	Clapper rail	P
Gallinula chloropus	Common moorhen	P
Fulica americana	American coot	W
Haematopus palliatus[d]	American oystercatcher	P
Himantopus mexicanus	Black-necked stilt	B
Pluvialis squatarola	Black-bellied plover	W
Charadrius semipalmatus	Semipalmated plover	W
C. wilsonia	Wilson's plover	P
Limosa fedoa	Marbled godwit	W
Actitis macularia	Spotted sandpiper	W
Catoptrophorus semipalmatus	Willet	P
Tringa melanoleuca	Greater yellowlegs	W
Tringa flavipes	Lesser yellowlegs	W
Limnodromus griseus	Short-billed dowitcher	W
L. scolopaceus	Long-billed dowitcher	W
Arenaria interpres	Ruddy turnstone	W

(continued)

Table 23. Concluded.

Species name	Common name	Local status
Calidris canutus	Red knot	T
Calidris alpinna	Dunlin	W
C. alba	Sanderling	W
C. minutilla	Least sandpiper	W
C. pusilla	Semipalmated sandpiper	W
C. mauri	Western sandpiper	W
Larus marinus	Great black-backed gull	T
L. argentatus	Herring gull	W
L. delawarensis	Ring-billed gull	W
L. atricilla	Laughing gull	P
L. philadelphia	Bonaparte's gull	W
Sterna antillarum[d]	Least tern	B
S. forsteri	Forster's tern	W
S. sandvicensis	Sandwich tern	W
S. maximus	Royal tern	W
S. caspia	Caspian tern	P
Chlidonias niger	Black tern	T
Rhynchops niger	Black skimmer	P
Zenaida macroura	Mourning dove	P
Columbina passerina	Common ground dove	P
Chordeiles minor	Common nighthawk	B
Ceryle alcyon	Belted kingfisher	W
Corvus ossifragus	Fish crow	P
Mimus polyglottos	Northern mockingbird	P
Toxostoma rufum	Brown thrasher	P
Lanius ludovicianus	Loggerhead shrike	P
Dendroica discolor	Prairie warbler	P
Agelaius phoeniceus	Red-winged blackbird	P
Cardinalis cardinalis	Northern cardinal	P
Pipilo erythrophthalmus	Rufous-sided towhee	P
Coccyzus minor	Mangrove cuckoo	P
Tyrannus dominicensis	Gray kingbird	P
Vireo altiloquus	Black-whiskered vireo	P

[a] Federally listed as endangered.
[b] Federally listed as threatened.
[c] Endangered - Florida Committee on Rare and Endangered Plants and Animals (FCREPA).
[d] Threatened - FCREPA.
[e] Species of special concern - FCREPA.
[f] Rare - FCREPA.

Woolfenden and Schreiber noted that "We would expect any factor decreasing the availability of the major fish genera (Brevoortia, Mugil, Sardinela, Lagodon, Anchoviella, Cyprinodon, Cynoscion, and Menidia) eaten by pelicans would have drastic deleterious effects on the bird population." Many other bird species depend on the same fish species for food.

The total breeding population of colonial birds in Tampa Bay is estimated to be 75,000 pairs, two-thirds of which are laughing gulls (Paul and Woolfenden

Figure 78. Brown pelican with young in nest in mangroves, Lower Tampa Bay.

Figure 79. Shore birds and wading birds feeding in McKay Bay.

1985). The laughing gull population is estimated to be one-third of the entire breeding population in the southeast United States. The brown pelican population of 2,700-3,000 breeding pairs represents nearly one-third of the entire Florida population of such birds. In 1983 an estimated 10,200 pairs of white ibis were present in one large colony at the Alafia River (Paul and Woolfenden 1985).

McKay Bay (Figure 3) in the northeast corner of Tampa Bay, typically supports a winter population of almost 25,000 marine birds, which during 11 years of censusing has included 75 species. Almost 80% of these birds are of five species: lesser scaup, ruddy duck, dunlin, short-billed dowitcher, and western sandpiper (Paul and Woolfenden 1985).

Although some species which formerly nested in the bay have returned recently (reddish egret in 1974, roseate spoonbill in 1975), recent population declines in many species are apparent. Paul and Woolfenden listed red tides, parasite outbreaks, dredge and fill activities, pesticide use, and oil spills as having generally negative effects on bird abundance. Waterfowl surveys of the bay have indicated a sharp decline in the wintering population of lesser scaup, from 105,900 in 1976 to 8,400 in 1979. Major dredging in Hillsborough Bay is implicated as a possible cause of the decline, since over 400 ha of open water habitat was lost during this period because of spoil island creation.

3.16 MARINE MAMMALS

Reynolds and Patton (1985) have summarized the existing information on marine mammals of the Tampa Bay area. Only two species normally are found within the bay, the bottlenose dolphin (Tursiops truncatus) and the West Indian manatee (Trichechus manatus). The bottlenose dolphin is a year-round resident and the local population is estimated at 100-200 individuals, found in small herds of 3-6 animals (Reynolds and Patton 1985). Little research beyond aerial surveys of populations has been done on this species in the bay.

In a baywide survey over a period of 1 year (Patton 1980) found that numbers of manatees varied seasonally; a maximum of 55 was observed in the winter. They appeared to aggregate around industrial thermal discharges into the bay. The largest single aggregation was 42 individuals observed around the mouth of the Alafia River in February 1980. Lewis et al. (1984) observed manatees feeding on macroalgae in the same area in January 1981.

CHAPTER 4. ECOLOGICAL INTERRELATIONSHIPS

4.1 INTRODUCTION

This chapter is short because of the general absence of studies on ecological interrelationships in the bay. Unlike studies in Apalachicola Bay (Livingston 1984), most scientific work in Tampa Bay basically has been descriptive or has concentrated on a single structural or functional aspect of the bay's ecology. Therefore, we use the best available data from Tampa Bay studies and better data from other studies to address four topics concerning ecological interrelationships: (1) energy sources; (2) abiotic controls in communities; (3) plant and animal interactions; and (4) fisheries habitats.

4.2 ENERGY SOURCES

The flow of energy from the sun through plants to the animal communities of the bay is illustrated in Figures 68 and 69. These graphic representations are based largely upon studies from other estuaries. For example, the utilization of epiphytic algae as an energy source by caridean shrimp, and their use in turn as food for spotted seatrout (Figure 68) is based upon the work of Tabb (1961), Carr and Adams (1973), Kitting et al. (1984), and Virnstein et al. (1983), none of which was done in Tampa Bay.

None of the boxes or arrows in Figure 69 have numbers associated with them because the specific quantities of energy contributed to various animal groups by the major plant types have not been made. Table 13 lists phytoplankton as the source of 68.8% of the bay's primary production. This does not mean that phytoplankton provide 68.8% of the energy consumed by animals in the bay, because the quantity of energy captured by phytoplanktonic photosynthesis that is subsequently lost to sedimentation and flushing from the bay is unknown. Because of eutrophication, it is likely that much phytoplankton productivity is incorporated as organic deposits in the bottom of the bay and may contribute to anoxic conditions reported in Hillsborough Bay (Figure 80). Similar events have been attributed to high phytoplankton productivity in Chesapeake Bay (Officer et al. 1984).

The elucidation of the role of the bay's plant communities, including phytoplankton, in providing energy to support animal communities remains a necessary, but as yet unstudied, research need for the bay.

4.3 ABIOTIC CONTROLS IN COMMUNITIES

The annual cycles of temperature and rainfall, and the common events of hurricanes, drought, and frost are the basic controlling factors for all life cycles in the bay. However, no attempts have yet been made to statistically correlate physical factors to biological

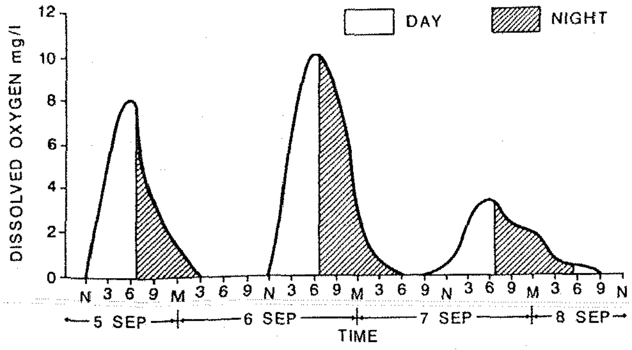


Figure 80. Anoxic conditions in Hillsborough Bay (from Federal Water Pollution Control 1969).

variables in the bay. Within the analyses of some individual studies (Figure 72) distinct correlations are demonstrated. Without these analyses, conclusions as to cause and effect in bay processes can be erroneous. An example is the general anecdotal observation that water clarity in the bay is improving; this is often attributed to improved sewage treatment at such plants as the City of Tampa's Hookers Point facility. Trends in water clarity (Figure 38) and chlorophyll a (Hillsborough County Environmental Protection Commission, unpubl. data) tend to support these observations. What is not taken into account is the fact that several recent winters have been the coolest in 100 years, and rainfall has been less than average. Both of these climatological features potentially could contribute to reduced phytoplankton populations and increased water clarity.

For example, Flint (1985), in examining eleven years of biotic and abiotic data for Corpus Christi Bay, noted that episodic events (floods, hurricanes) stimulated estuarine productivity and thus represented a significant forcing factor to the estuary. He stated that "without the reconstruction of a long-term data set . . . these perceptions of ecosystem function could not have been developed" (p. 168).

Unfortunately, we do not have simultaneous, long-term data sets of abiotic and biotic information from which to draw similar information about Tampa Bay. Although large amounts of abiotic data are collected, there has been no similar effort toward the collection of concurrent biotic community data. The problems of understanding the role of physical parameters in bay processes are immense but without that understanding, decisions on bay management will continue to be made on the basis of symptomatic, rather than causative, considerations.

4.4 PLANT AND ANIMAL INTERACTIONS

In addition to their role as sources of energy, plant communities in the bay are important as habitat. Certain species are found in particular habitats at specific times of the year. For example, brown pelicans seek out mangrove islands for nesting during the spring (Paul and Woolfenden 1985), and young pinfish are found in large numbers in seagrass meadows (Springer and Woodburn 1960) at about the same time. Quantitative sampling for fauna has been limited largely to benthic infauna in unvegetated habitats (see Section 3.12). The studies by Santos and Simon (1974) of polychaetes in a seagrass meadow and Lewis (1983) on invertebrates in a mangrove forest are two of the few exceptions.

The assumption is made that the loss of certain vegetated habitats has contributed to declines in fish and wildlife in the bay (Hoffman et al. 1985; Lewis et al. 1985b; Paul and Woolfenden 1985) and that reestablishment of these plant communities would restore fish and wildlife populations to some higher numbers (Hoffman et al. 1985). Though most scientists would not disagree with these general assumptions, supporting data are not available for Tampa Bay. More importantly, the direction of restoration efforts should have a sound scientific basis in order to produce measurable results.

4.5 FISHERIES HABITATS

Fish and shellfish of commercial and recreational importance in Tampa Bay include mullet, blue crabs, hard shell clams, tarpon, snook, and spotted seatrout (Lombardo and Lewis 1985). The harvest of these species is a particularly visible and important part of the value of the bay as perceived by most citizens.

As noted above, it has been assumed that declines in fisheries habitats (seagrass meadows, mangrove forests, and tidal marshes) are a major cause of these apparent declines. We say "apparent" because again, the data to support these declines are largely anecdotal or have other problems (see Lombardo and Lewis 1985).

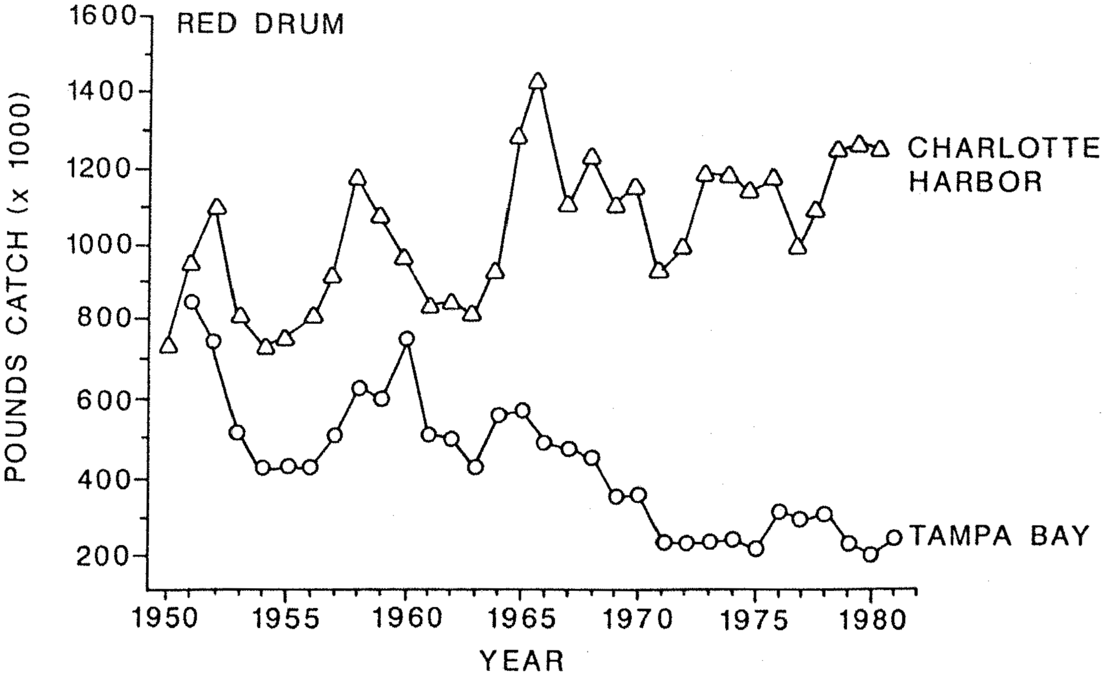
Lewis (1977) reports that total emergent marine wetlands (tidal marshes and mangrove forests) on Tampa Bay have declined from historical coverage (ca. 1876) of 10,053 ha to a current coverage (ca. 1976) of 5,630 ha, a loss of 44% of the original areal cover. Much of that loss was due to dredging and filling of shallow intertidal areas to create waterfront residential sites and commercial port-related facilities. Significant areas of seagrass meadows were also removed during these same dredge and fill projects (Taylor and Saloman 1968). As noted in Section 3.5, only 19% (5,750 ha) of the original seagrass acreage in Tampa Bay remains.

If these areas are in fact necessary to support healthy populations of harvestable fishery resources, one would expect that some evidence of declining harvests would appear. In fact, commercial landings of species dependent upon tidal marshes, mangrove forests, and seagrass meadows have declined, in some cases dramatically (Lombardo and Lewis 1985). When compared with another estuary of similar size, but with much less habitat loss (Charlotte Harbor), commercial landings data for spotted seatrout and red drum indicate a declining harvestable resource (Figure 81). There are limitations to the value of commercial landings data [as discussed by Lombardo and Lewis (1985) and Harris et al. (1983)], but as an indicator of fisheries harvest trends, we believe the data are useful. Commercial landings of both red drum and spotted seatrout have remained stable or have shown slight increases during the period of record (1952-82) in Charlotte Harbor (Figure 81). During the same period the areal cover of mangroves has increased by 10% (from 20,860 to 22,928 ha), while seagrass acreage has declined by 29% (from 33,586 ha to 23,682 ha; Harris et al. 1983). As previously mentioned, losses of seagrasses (-81%) and mangroves and marshes (-44%) in Tampa Bay have been much greater. A relationship between areal cover of important nursery habitat or food sources and the resulting harvestable fishery resources has been postulated and supported by data from several sources worldwide (Turner 1977, 1982). Thus, the marked decline in the commercial landings of spotted seatrout and the markedly lower harvests of redfish in Tampa Bay, when compared with those from Charlotte Harbor, support the concept of the value of these habitats in maintaining healthy and productive fishery resources. Although similar quantitative data are not available for recreational fishery harvests, the general expressions of recreational fishermen when interviewed are (1) fishery harvests are declining; and (2) causes are perceived to include overharvesting, habitat loss, and poor water quality (Bell et al. 1982).

The first major fish survey of Tampa Bay occurred during 1958-59 (Springer and Woodburn 1960). Comp (1985, p. 412) discussed those data and more recent studies and noted:

> Due to the sampling limitations . . . 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 . . . . However, most of the recent studies have been restricted to relatively small areas . . . so the results obtained cannot be extrapolated and used to determine the stability of the fish abundance or community structure throughout the bay.

We do not know whether fish populations have declined because of habitat loss. The previous discussion hints at a connection but the necessary data are not available. Will large-scale habitat restoration increase fish and shellfish populations? Again we do not know. The role of pollutant discharge to the bay in controlling fisheries abundance may be as critical as habitat alteration (see Summers et al. 1985 and Polgar et al. 1985). With hundreds of thousands of dollars projected for expenditure to restore what are assumed to be habitats important to fish, we must provide for more scientific analyses of these efforts.



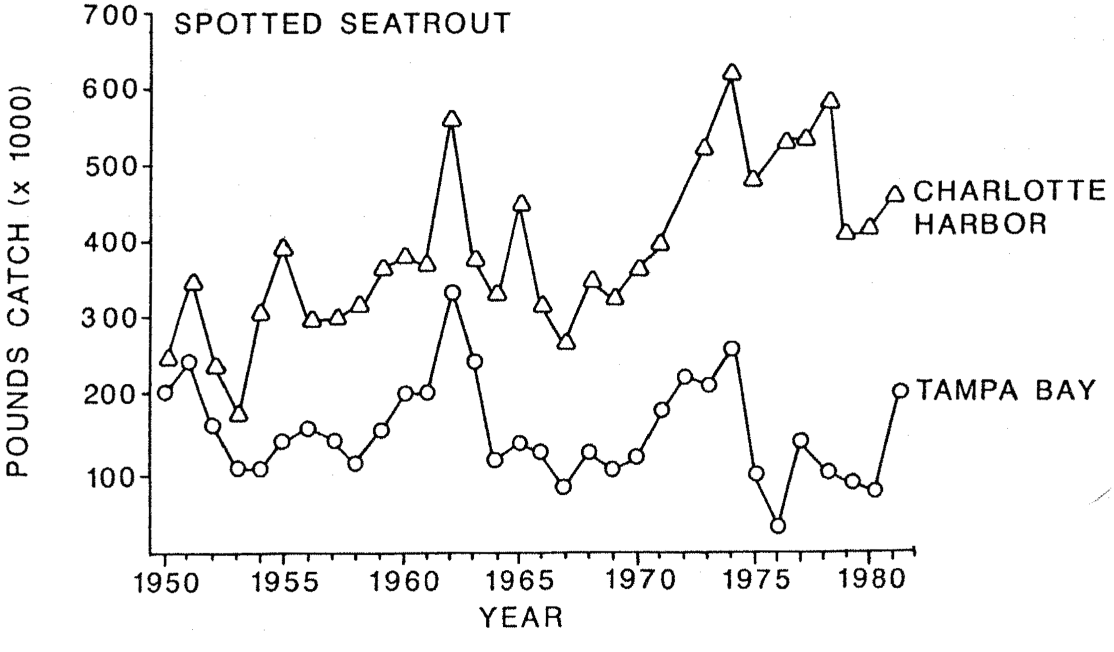


Figure 81. Commercial landings of red drum and spotted seatrout.

CHAPTER 5. MANAGEMENT

5.1 INTRODUCTION

Accounts of the decline in natural resources of Tampa Bay began about 100 years ago (Heilprin 1887; Smeltz 1897). Although other such observations were made in the following decades, communities around Tampa Bay continued to grow and thrive under the seemingly limitless subsidies provided by the bay. Fisheries seemed inexhaustible (although sturgeon were extirpated from the bay by 1900). The Hillsborough River was dammed to produce electricity at a time when the impacts of instream dams were not known, and during the great residental boom a "worthless" marsh in Hillsborough Bay was filled to make the Davis Islands. Entrepreneurs created a bridge and a causeway from Tampa to Pinellas County across Old Tampa Bay in the 1920's. Congress had authorized deepening of the ship channel and Tampa port area more than once by the onset of the Depression, and the phosphate industry was using the Alafia River as a source of rock and a waste dump as early as 1929. Increased shipping activity after the war made it necessary to deepen the bay several more times, and waterfront lots were created to house the growing population. The Manatee and Braden Rivers were dammed to supply water in the south-bay area opened for growth by the new Sunshine Skyway Bridge. Power plants ringed the bay, generating electricity for phosphate mines and new communities and discharging thermal effluent in shallow waters of the bay. McKay Bay became a center for heavy shipping and industry, and overtaxed sewage systems of Bradenton, Tampa, and St. Petersburg usually overflowed during the rainy season, causing raw sewage to flow to the region's rivers and the bay.

The first modern recognition of the bay's decline occurred more than 30 years ago and came from the U.S. Public Health Service (Galtstoff 1954, pp. 564-565):

> Pollution of the Tampa Bay drainage is caused by municipal discharges serving more than 300,000 persons and by industrial waste from 6 upstream phosphate mines, several citrus canneries, and miscellaneous plants. The larger cities in the resort area either do not have treatment facilities or have inadequate ones . . . . Tampa Bay is grossly polluted, and bathing waters in Clearwater Harbor and St. Joseph Sound have been affected adversely. Several large shellfishing areas are closed to the taking of shellfish because of pollution.

The first suggestion that controls on eutrophication and dredging impacts were needed came in 1969. The Federal Water Pollution Control Administration (1969) recommended a water quality management plan and waste abatement program to control odor and other pollution symptoms in Hillsborough Bay, and a master plan for dredging and filling in the bay. None of these important baywide management strategies have been implemented to date, although the report did lead to the provision of major federal funding for upgrading the City of Tampa's Hookers Point sewage treatment plant from primary to advanced waste treatment capabilities. Therefore, it is not surprising that no other aspect of natural resources management in Tampa Bay is addressed comprehensively, given that the 1969 recommendations have not been implemented.

Concerned citizens around Tampa Bay have sought bay-wide management during the past 20 years. In 1968, a conference sponsored by the University of South

Florida recommended that present bay bottom area or mean bay dimensions below mean high water should not be reduced, and present bay bottom should not be modified except for navigation channels. The group also recommended limits to municipal wastewater discharges and establishment of a bay-wide management committee (University of South Florida 1970). No action was taken regarding the first conclusion but a local act of the Florida Legislature did implement stringent limits on sewage treatment plant effluents which were maintained for a decade but have since been relaxed. Another local act actually created a Tampa Bay Conservation and Development Commission in 1970 (Chap. 70-524 Florida Statutes). Unfortunately, the Commission never met.

In 1982, the first scientific symposium on Tampa Bay was held at the University of South Florida. The 4- day conference involved topical presentations by 50 invited speakers (Treat et al. 1985). They concluded that (1) Tampa Bay can be comprehended as a single ecological system; (2) the bay is immensely resistant to environmental challenges, when impacts are removed; (3) a clear pattern of decline is evident in some measures of ecological condition; and (4) the management needs of Tampa Bay are relatively clear, and if implemented in a comprehensive and bay-wide manner, would result in tangible improvements to the bay and its usefulness to people.

That same year the Tampa Bay Regional Planning Council established the Tampa Bay Study Committee to identify and verify bay management issues. After 19 months of work, the Committee reported on a total of 42 problems and issues (Table 24). The

Table 24. Resource management issues in Tampa Bay (modified from TBRPC 1983).

Rank	Issue
1.	Lack of funding for bay management projects.
2.	Loss of seagrass meadows.
3.	Nonpoint discharge entering the bay.
4.	Lack of baywide management plan for dredging, spoiling, and spoil island maintenance.
5.	Hazardous waste disposal management.
6.	Inadequate enforcement of existing environmental regulations.
7.	Septage wastes.
8.	Need for management of aquatic preserves in bay.
9.	Need for seagrass and mangrove habitat creation.
10.	Limiting municipal and industrial discharges.
11.	Ineffective wetlands regulation.
12.	Need for ecosystem level of management for rivers and tidal creek systems.

(continued)

Table 24. Continued.

Rank	Issue
13.	Inadequate predictions of bay's ability to assimilate wastes.
14.	Lack of knowledge on size of fishery stocks and relative impact of power plants, fishing pressure, and other stresses.
15.	Need for perpetual maintenance of hazardous material dump at a phosphate processing plant on bay shoreline.
16.	Effective and fair regulation of sport and commercial fishing.
17.	Documenting the economic importance of Tampa Bay.
18.	Educating an ecologically uninformed public to the value of a healthy bay.
19.	Provision of public access to bay and giving priority in shoreline development to water-dependent uses.
20.	Providing load relief for overburdened sewage treatment facilities.
21.	Improving water quality where recreational uses are presently prohibited.
22.	Establishing guidelines for stormwater controls in redevelopment of urban areas.
23.	Elimination of duplication and gaps in environmental rules and regulations.
24.	Development of a resource management plan for McKay Bay.
25.	Classifying all bay waters for shellfish sanitation and improving conditions in presently closed areas.
26.	Determining the extent of, and controlling as necessary, destruction of larval and juvenile fishes entrained by power plants.
27.	Rehabilitation of Little Redfish Creek.
28.	Developing a readiness plan for public acquisition of vulnerable private lands along the shoreline following extensive hurricane damage.
29.	Developing a mitigation bank so that impacts can be offset rather than ignored (by agencies) or quietly accepted (by public).
30.	Providing for management of natural shorelines in upper Old Tampa Bay.
31.	Securing competent management for the Passage Key National Wildlife Refuge.

(continued)

Table 24. Concluded.

Rank	Issue
32.	Rehabilitating Boca Ciega Bay.
33.	Developing management systems for urban waterfronts.
34.	Restoring tidal portions of "Channel A," a major human-made drainageway emptying into upper Old Tampa Bay.
35.	Improving localized water quality problems through the use of one-way gates, tidal pumps, and other passive systems.
36.	Reconciling conflicts among user groups in the bay area.
37.	Need for a proactive, environmentally sound and implementable marina siting policy.
38. & 39.	Environmental concerns associated with bridge construction.
40.	Provision of launching sites for sailboats.
41.	Odor.
42.	Preventing cumulative water quality problems in the Manatee River due to relict, existing, and proposed bridge crossings.

issues may be grouped into categories of eutrophication, dredge and fill, habitat management, contaminants, fisheries, development and recreation, and regulation. In 1984, the Florida Legislature established the Tampa Bay Management Study Commission to identify specific methods to remedy each of the issues. This commission recommended that a coordinating body be established within the Tampa Bay Regional Planning Council, to be named the Agency on Bay Management. Following the submittal of the Commission's report in 1985 (Tampa Bay Regional Planning Council 1985), the Agency was established. The Agency serves a planning and coordinating role for other bay managers. In addition, the Agency is attempting to oversee the implementation of remedies to problems identified in previous studies.

Nearly six million dollars worth of studies and new programs have been suggested, including a comprehensive fisheries research, monitoring and regulation program ($1,067,000); the completion and refinement of the Tampa Bay wasteload allocation study ($1,000,000); comprehensive seagrass monitoring, research and restoration ($825,000); the establishment of a shellfish sanitary survey team in the Tampa Bay area ($600,000); permanent management staffing of the three Tampa Bay area aquatic preserves ($550,000); a study of toxic contamination in the Tampa Bay estuary ($500,000); a regional public education campaign regarding non-point sources and water pollution in Tampa Bay ($400,000); and increased compliance monitoring of point source discharges into Tampa Bay ($270,000). None of these recommended studies has been funded and the 45-member Agency on Bay Management is currently hampered by a lack of stable funding, the absence of any full-time staff, and the lack of regulatory "teeth."

In addition to these recommended expenditures and general policies regarding Tampa Bay, the Commission recommended and the Agency is supporting a number of other legislative actions. These included the following:

(1) requiring saltwater recreational fishing licenses;
(2) consolidating and standardizing all local fishing laws and regulations;
(3) requiring existing development to retrofit stormwater discharge facilities when redevelopment occurs;
(4) preventing the dredging or spoiling of any significant areas of previously undisturbed bay bottom;
(5) requiring developers to purchase sewage treatment capacity rights and prohibiting the issuance of an interceptor permit unless the municipality can demonstrate adequate sewage treatment capacity;
(6) requiring advanced wastewater treatment of all municipal discharges to Tampa Bay, prior to the completion of the wasteload allocation study;
(7) creating an Aquatic Preserve Management Trust Fund derived from submerged land lease fees; and
(8) creation of a Tampa Bay habitat mitigation bank.

In its closing remarks, the Tampa Bay Regional Planning Council (1985) stated:

> It is recognized that the ultimate success of the recommended Agency on Bay Management within the Tampa Bay Regional Planning Council will be dependent upon the overall strengthening of state growth management legislation.
>
> In the absence of significant strengthening of state growth management legislation in the near future, the Tampa Bay Management Study Commission recommends that the Legislature initiate the development of enabling legislation for the establishment of a Tampa Bay Management Authority . . . .

Political arguments against the establishment of a Tampa Bay management authority with regulatory powers, however, remain quite strong. Many powerful interests around the bay view the proposal as adding "another layer of bureaucracy" to an already complex and sluggish environmental permitting system. It is for this reason that the Tampa Bay Management Study Commission decided against the recommendation of establishing an empowered bay management authority, even though the majority of members felt that in the long term, this alternative would be needed to effectively accomplish all stated bay management goals and objectives.

The final form and effect of bay management strategies remains unsettled, but at least attempts have begun. More importantly, the site-specific and process-specific issues have been identified, and their remedies are being pursued by the Agency on Bay Management. The following sections outline what resource managers or scientists new to the region should be told are the most important management issues related to Tampa Bay. Whether the Agency will be able to have a measurable impact on the major problem areas remains to be seen. A stable funding source and some permanent full-time staff are essential to even begin to seek real results. As of this writing, support has not been provided to the Agency.

5.2 IMPORTANT MANAGEMENT ISSUES

5.2.1 Dredge and Fill

As noted in Section 2.4.1, the total surface area of the bay has been reduced by 3.6% (33.67 km^2) because of the dredging of navigation channels and the filling of shallow intertidal or deeper open-water areas for power generation sites, residential, port, or transportation development. If all this filled land was concentrated in one place, it would constitute an area the size of all the Interbay Peninsula south of Ballast Point, including all of MacDill Air Force Base and surrounding submerged land out to the 2-m depth contour (Figure 82). Although this 3.6% reduction does not seem large, nor does it approach the 65% reduction in the size of San Francisco Bay (Odell 1972; Nichols et al. 1986), the dredge and fill activities in Tampa Bay were concentrated in areas of mangrove forest, tidal marsh, and seagrass meadows on the estuarine shelf of the bay. This

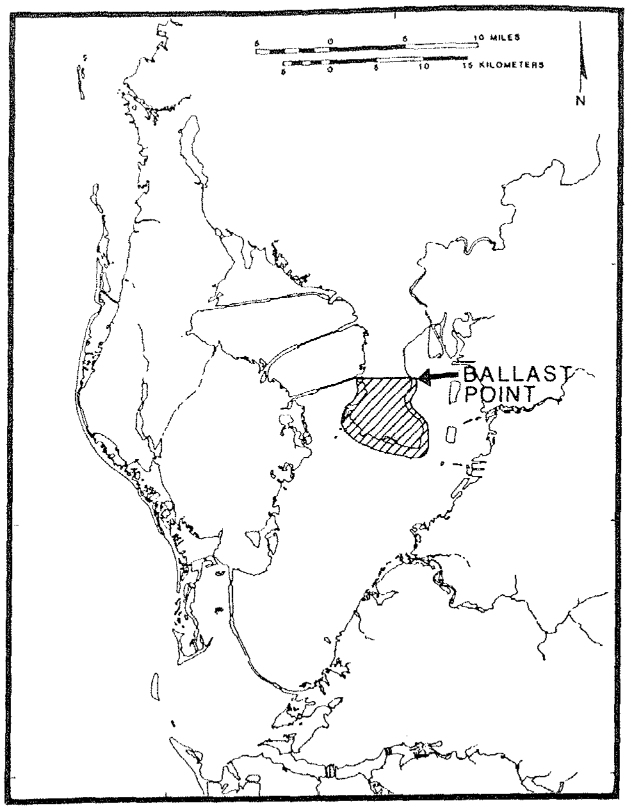


Figure 82. If all the submerged lands dredged and filled in Tampa Bay since 1880 were collected in one place, the area would equal all of the Interbay Peninsula south of Ballast Point, and surrounding shallow waters above a depth of 2 meters.

concentration resulted in the filling or excavation of 44% of the bay's marsh and mangrove habitat (Lewis 1977) and contributed, through direct excavation or burial and increased water turbidity, to the loss of 81% of the bay's seagrasses (Lewis et al. 1985a). Goodwin (1984) attributed about 11% of the alterations to causeways, 15% each to residential and commercial development, and 60% to port development including channels, filled sites, and dredged material (spoil) disposal sites.

Because of scientific documentation in the early 1970's of the value of tidal wetlands as wildlife and fisheries habitat, the type of dredge and fill projects which routinely were permitted by regulatory agencies in the 1950's and 1960's no longer are permitted, and any proposed project undergoes close scrutiny. The last major dredge and fill project in the bay was the Tampa Harbor Deepening Project, which involved the dredging of over 55,000,000 m^3 of material to deepen (from 10 to 13 m) and widen the main ship channel, and included the creation of two large (total 445 ha) diked disposal islands (Lewis 1977; Fehring 1983, 1985). These islands were specifically located away from sensitive shallow water habitats because of economic concerns, but it is unlikely that any future disposal islands will be constructed because of environmental concerns. A considerable amount of controversy surrounded this project, particularly with regard to inflexible policies of the U.S. Army Corps of Engineers and the Tampa Port Authority with regard to disposal alternatives, monitoring, and compliance with environmental regulations.

As Fehring (1983, 1985) and the Tampa Bay Regional Planning Council (1985) noted, the future problems associated with dredge and fill work in Tampa Bay will revolve around developing a long-term navigation channel maintenance dredging and disposal program, combined with a wetlands mitigation and restoration program for the bay.

Approximately 841,000 m^3 of channel and berth maintenance material needs to be dredged annually from the main ship channel and the Port of Tampa. Additional unknown amounts will need removal from Bayboro Harbor and Port Manatee (Tampa Bay Regional Planning Council 1985). Considerable controversy has arisen over disposal sites for this material. A designated offshore disposal area 33 km off the mouth of the bay in the Gulf of Mexico is under consideration for disposal of maintenance material. The two diked disposal islands in Hillsborough Bay also are scheduled for use for disposal of finer-grained material from that part of the harbor. The Tampa Bay Management Study Commission supported the use of some of the better (larger grain size) dredged material for marsh creation in Hillsborough Bay (Tampa Bay Regional Planning Council 1985). Unfortunately, no significant progress has been made towards implementing a bay-wide dredged material disposal program, and disagreements and delays will likely result when dredging is needed again.

Mitigation, or the reduction or elimination of negative environmental impacts, has been a commonly required action by regulatory agencies as part of their permitting process in Tampa Bay. Lewis et al. (1979), Fehring (1983) and Hoffman et al. (1985) discussed a number of mitigation projects related to dredging and filling. Most included planting or transplanting wetland vegetation onto dredged material islands, grading of upland sites to wetland elevations, or restoration of sites following temporary fill placement. Figure 83 illustrates a typical smooth cordgrass marsh creation project.

Hoffman et al. (1985) listed 16 intertidal mitigation or restoration projects and 10 subtidal seagrass restoration attempts in the bay through 1982. Now there are probably three times as many intertidal plantings. Few additional seagrass plantings have been attempted.

Hoffman et al. (1985) noted that both the success of plantings and the quality of the restored or created habitat vary widely. The most beneficial plantings in terms of habitat value appear to be

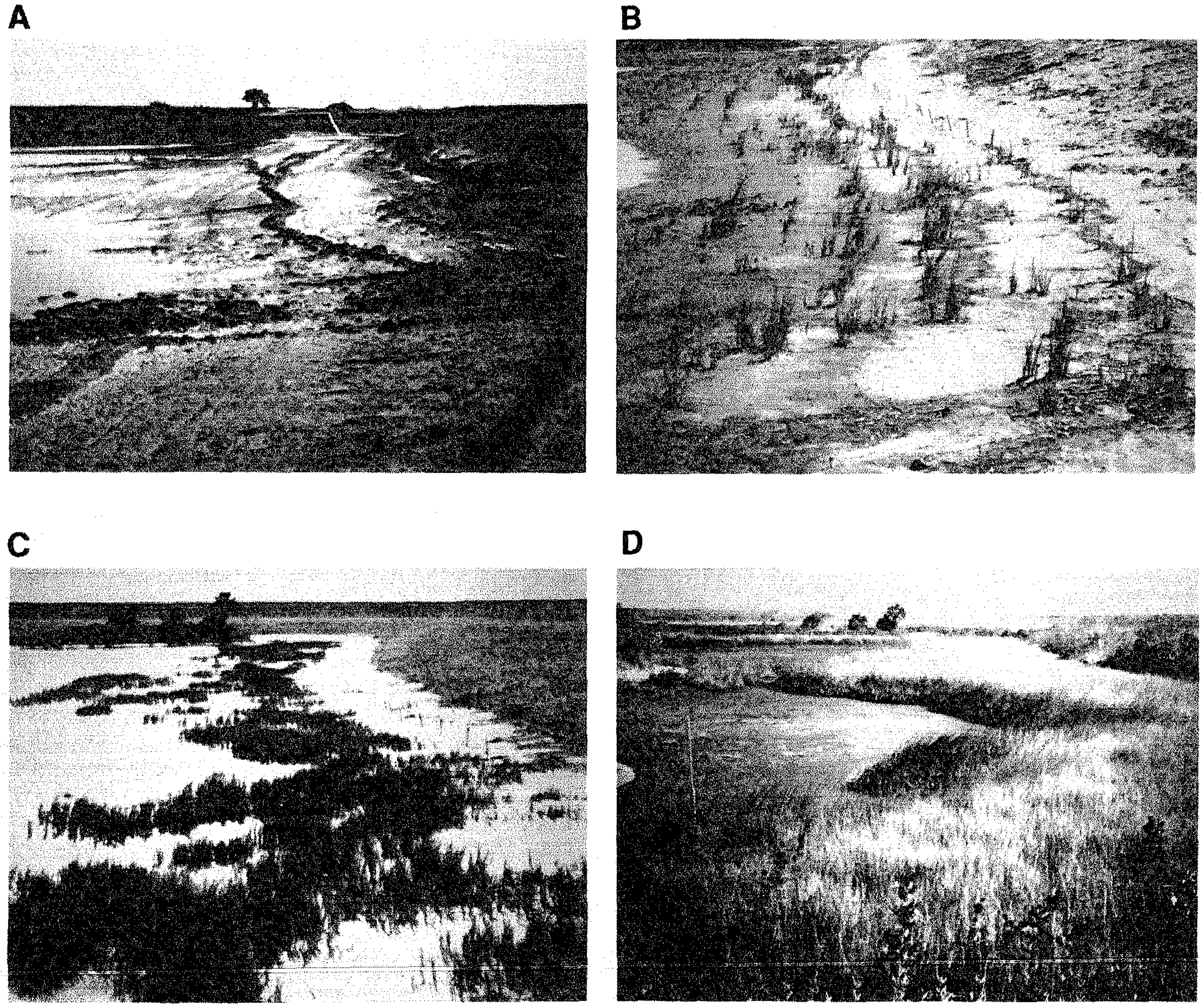


Figure 83. Tidal marsh creation on Tampa Bay. A, Completed site excavation (April 1978); B, Six months later (October 1978); C, One year later (April 1979); D, Nineteen months later (November 1979).

"larger continuous plantings which are remote from human interference" (p. 649).

Fehring (1983) discussed the possible value of mitigation "banking" in dredge and fill projects where a centralized mitigation plan based upon the best scientific understanding of the estuary in question, combined with estuary-specific resource management goals, could allow larger, more controlled areas to be designated as mitigation sites. This would permit more economical use of limited funds, since the per hectare cost of mitigation declines with increasing size of the project. It would also ensure success of the mitigation project, since the work could be done and approved prior to the filling of the wetland under examination in the permit process. There is presently no provision for mitigation banking in Florida, but the adoption of rules governing the mitigation process is pending, and the opportunity to develop such a system may lead to its use in Tampa Bay.

5.2.2 Fisheries

ODES TO BIVALVES

Oysters growing on trees! . . . by the by, the lower bay is the finest oyster-ground on the continent . . . . I have not eaten such oysters anywhere.
--George A. McCall, 1824

The oysters are caught in the bay and are larger and finer than any I ever saw.
--Clement Clairborne Clay, 1851

Ate Rocky Point oysters for two days.
--Diary of Henry Metcalf, February 17, 1885

Tampa Bay oysters are fine and sell for one dollar a barrel at the wharf.
--Tampa Tribune, March 9, 1887

Tampa Bay, once a glory of the state, is filth. It's a mess. There will never be an oyster in Tampa Bay again.
--Sports Illustrated, 1981
(Mormino and Pizzo 1983)

Sports Illustrated's observation that "there will never be an oyster in Tampa Bay" is a bit exaggerated, but fishery harvests from the bay are not what they used to be. Harvests of oysters from the bay were second only to those of the still-productive Apalachicola Bay for most of the 19th century. In 1942, 60,500 l of oyster meat were landed in Pinellas County; in 1951 1,877 l, but by 1970 the industry was gone. The last commercial harvest of scallops from the bay apparently occurred in 1960 with 5,800 l reported, most not from the bay but from the St. Joseph's Sound area north of Clearwater. Bay scallop harvests from Manatee and Hillsborough Counties collapsed in 1952.

Tampa Bay commercial finfish landings peaked in 1964 when a total of more than 8,000,000 kilograms were landed (Figure 84; Lombardo and Lewis 1985). Since then, there has been a steady decline with current harvest levels at about 5 million kilograms per year. Several of the sought-after species such as spotted seatrout (Cynoscion nebulosus) and red drum (Sciaenops ocellatus) show signs of much lower availability to commercial fishermen than landing data indicate for Charlotte Harbor, a smaller but healthier estuary south of Tampa Bay (Figure 81).

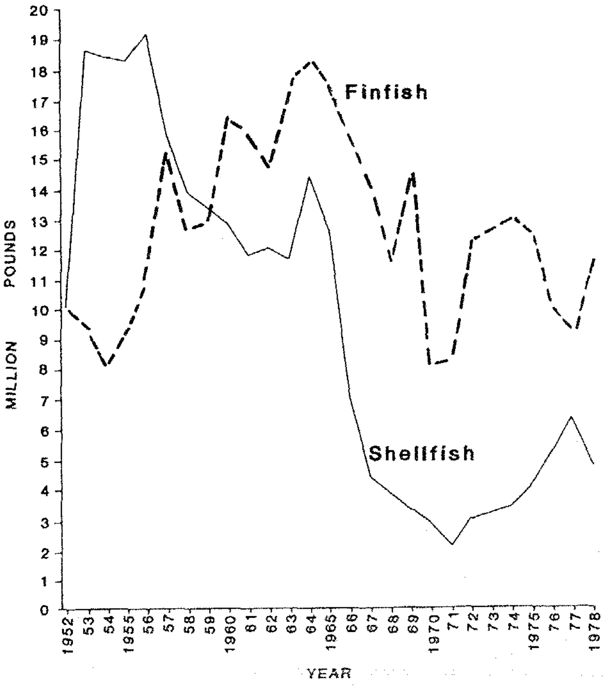


Figure 84. Tampa Bay commercial shellfish and finfish landings.

Shellfish landings peaked in 1956 with almost 9,000,000 kilograms reported. Significant declines in reported landings have occurred since then with a low of 900,000 kilograms in 1971 (Figure 84). Recent increases in landings are largely from the offshore fishery for calico scallops (Argopecten gibbus), not from increased estuarine harvests.

None of these data document the reported declines in recreational fishery harvest from the bay, because data are not collected systematically on this fishery. A four-part newspaper series on "Fishing Tampa Bay" published in February 1985, contained these typical comments:

> Most of the shrimp, crabs, and manatees are gone, crowded out by shoreline development, canal dredging, pesticide and nutrient-rich stormwater runoff, and municipal sewage. Fish are still available, but they are not as abundant as they once were . . . "Mark my word" he said, "unless the water is cleaned, pollution stopped and bag limits set for recreational and commercial catches, fishing will be mostly a thing of the past by the year 2000" (Keefer 1985).

More accurate documentation of trends in the recreational harvest is needed, but it is generally agreed that the trend is not upward. A proposed $7.00 statewide resident recreational fishing license would go a long way toward providing funding for better documentation and necessary research and habitat management and restoration.

5.2.3 Freshwater Flow to the Bay

The importance of freshwater flow into the bay often is overlooked. More than 60 years of marine research (Gunter 1961, 1967) have shown conclusively that low-salinity estuarine water combined with the physical protection and energy sources supplied by marine plants, constitutes the primary nursery habitat for most of the commercially and recreationally important fish and shellfish species in the Gulf of Mexico. Despite this understanding, it is a common misconception of the average citizen and politician that freshwater discharged to the bay is "wasted" and should be diverted for industrial, agricultural, or domestic use.

With the population of the Tampa Bay area at 1.7 million in 1985 and projected to reach 2.5 million by the end of the century, public demand for increased diversion of freshwater is increasing. Already, routine water shortages occur every summer before the onset of the rainy season in June.

The words of Gunter (1961), therefore, need to be strongly re-emphasized:

> A number of workers on the Gulf coast have demonstrated that a great many of the important marine animals of that area have similar life histories. The adults spawn offshore and the young move back into the estuaries where they grow up in low-salinity waters; after a time they return to the sea and the larger adults of many species are found only in the sea.
>
> The preponderant macro-organisms, both in numbers of species and individuals, are mostly motile species which undergo the general type of life history described above. In southern waters these are the mullet, menhaden, croakers, shrimp and crabs. Vast numbers of these animals may be found in estuaries at one time or another and in general the very smallest sizes are found in the lower salinities. Estuaries are predominantly nursery grounds.

As discussed in Section 3.13, Finucane (1966) and Sykes and Finucane (1966) reported that 23 species of fish and shellfish of major importance in Gulf of Mexico commercial fisheries utilize Tampa Bay as a nursery area. These include pink shrimp, blue crabs, oysters, menhaden, Spanish mackerel, mullet, spotted seatrout, and red drum. If the fish species important as food items for these commercial species and species important to the recreational fishermen, such as snook and tarpon, are included, the list of fish species utilizing Tampa Bay as a nursery area totals 80 (Table

22). Inclusion of prey species would boost the total even more.

In comparing various parts of the bay, Sykes and Finucane (1966) noted that portions of the bay with the lowest salinities and the necessary marine wetlands provided the best nursery habitat (Old Tampa Bay). A similar area with reduced salinities but without significant marine wetlands (Hillsborough Bay) no longer was a productive nursery area. These observations emphasize the importance of marine wetland habitat restoration in low-salinity areas such as Hillsborough Bay to increase nursery habitat.

Another major point is that freshwater must be allowed to naturally enter the bay in quantities necessary to lower salinities within vegetated habitats, not just a lower salinity anywhere. These critical vegetated areas and adjacent water areas need to be identified and mapped in order to be protected.

This issue needs immediate attention. We hypothesize that the tidal brackish to tidal freshwater marshes dominated by black needlerush mixed with freshwater plants, located in the upper portions of tidal creeks and streams such as Double Branch Creek and the Alafia, Little Manatee, Manatee and Braden Rivers, ultimately will be identified as some of this critical nursery habitat. Gilmore et al. (1983), for example, identified peripheral tidal freshwater streams draining into salt marshes as the prime nursery habitat for snook in the Indian River. During their study, 692 juvenile snook with a mean standard length of 27.5 mm were collected from such habitats. The fresh to brackish water mosquito fish (Gambusia affinis) was the most important identifiable food item in the gut contents of juvenile snook 40 to 60 days old collected during that study. We predict similar results in Tampa Bay. A study of juvenile snook nursery habitats is presently being conducted by the Florida Department of Natural Resources and Mote Marine Laboratory. Similar studies are underway for redfish, as noted in Section 3.13.

With such a wealth of available information, we urge that plans to divert additional flows of freshwater away from the bay receive careful biological study. Unfortunately this is not the case, as illustrated by the recent request of Manatee County to increase its current 100 million l/day withdrawal from the headwaters of the Manatee River (Lake Manatee) by 25%. The request was examined by the Southwest Florida Water Management District which is responsible for regulating water resources in the Tampa Bay watershed. The District is legally capable of considering estuarine impacts of tributary alterations and has taken the lead in planning and research on the subject. In this case, however, in establishing a "minimum flow" needed to the estuary, the District required no identification of impact from historical withdrawals on the estuarine nursery function of the freshwater tidal streams, and only asked that studies be done to establish that no significant change occur from existing conditions (e.g., 100 million l/day). These studies looked at existing water quality and plant community distribution, but did not examine any biological factors related to the estuarine nursery habitat role that the mapped vegetation might be providing (Manatee County Utilities Dept., 1984). Additional withdrawls were permitted, and undocumented changes may have occurred. Another nearby project, expansion of Braden River reservoir and increased withdrawal, was permitted without the benefit of any estuarine study, whatsoever.

Such site-specific decision-making must cease if the efforts to improve commercial and recreational fishing in Tampa Bay through regulation of the fishermen are not to be offset by subtle and not-so-subtle habitat modification. Optimum flows for all the tributaries to Tampa Bay need to be established based upon studies of the biology as well as the water quality of these systems. Particular emphasis should be placed on salinity patterns in tidal areas. In addition, sewage effluent reuse needs to be increased to reduce the demand for new potable water sources. Much potable water is truly "wasted" on lawn irrigation, when recycled effluent would be a much better source of such water.

5.2.4 Eutrophication

Eutrophication is defined as the process of increasing dissolved nutrient concentrations to a point where nutrient enrichment produces certain characteristic responses in a water body. These responses include algal blooms, noxious odors, declines in dissolved oxygen, and periodic fish kills. Such characteristic responses had been observed in Tampa Bay, particularly Hillsborough Bay, for 20 years prior to the Federal Water Pollution Control Administration (1969) study of the problem and documentation of nutrient enrichment from partially treated sewage discharges as the primary cause.

Subsequently, over $100 million was spent to upgrade the Hookers Point sewage treatment facility from primary to advanced or tertiary treatment (Garrity et al. 1985). The upgraded plant came on line in 1979. After that, other studies done by the Florida Department of Environmental Regulation, McClelland (1984), the U.S. Geological Survey, and the City of Tampa (Giovanelli and Murdoch 1985) concluded that urban runoff from streets and parking lots could contribute up to 25% of the biochemical oxygen demand, 35% of the suspended solids, and 15% of the nitrogen loading to Hillsborough Bay (Table 25).

An additional aspect to the problem was added by Fanning and Bell (1985) when they suggested that nutrient fluxes from the bay's sediments could be important as sources of nutrients to the water column. Table 26 (from their paper) illustrated that ammonia (NH_3) in Tampa Bay reached values higher than those found in other studied estuaries. In addition, the ratio of ammonia to total inorganic nitrogen ($NO_3^- + NO_2^- + NH_3$) was quite high (0.84±0.12) as noted in Section 2.5.3. Although declines in phosphorus concentrations have been documented for

Table 25. Estimated short term pollutant loadings to Hillsborough Bay by source (from Giovanelli and Murdoch 1985).

	Percent of short-term pollution load by source:			
Load source	Biochemical oxygen demand	Suspended solids	Total nitrogen	Total phosphorus
URBAN RUNOFF[a]				
Dry season	25	35	15	5
Wet season	15	20	10	1
RIVER FLOWS[b]				
Dry season	45	50	50	65
Wet season	70	70	75	80
POINT SOURCES[c]				
Dry season	30	15	35	30
Wet season	15	10	15	20

[a] Urban runoff represents pollution loads from the adjacent urban areas.
[b] River flows represent pollution loads from the Hillsborough, Alafia, and Palm Rivers.
[c] Point sources represent those discharging directly to Hillsborough Bay.

Table 26. Concentrations (μmol) of nutrient nitrogen in Tampa Bay and other estuaries (adapted from Fanning and Bell 1985).

Area	$(NO_3^-)+(NO_2^-)$	(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, Netherlands	9-19	6-8	0.3-0.4
Caminada Bay, Louisiana	0-9	1-6	0.4-1
Barataria Bay, Louisiana	2-19	2-5	0.2-0.5
Narragansett Bay, Rhode Island	0-15	0-15	0.5
Rhode Island coastal lagoons	0-9	0-4	0.31
Bahia de Mochima and Laguna Grande, Venezuela	1.7	2.5	0.60

the bay, nitrogen concentrations in the water column have remained high.

Windsor (1985) examined existing water quality data for 28 coastal areas of Florida and found only three in which nutrient enrichment was indicated and definite problems of dissolved oxygen depletion were observed: Perdido Bay, Tampa/Hillsborough Bay, and Biscayne Bay.

Lewis et al. (1985a) noted that eutrophication leading to microalgal and macroalgal blooms may have contributed to the decline in seagrasses in the bay due to reduction in downwelling light through competition and epiphytic algae loading on seagrass blades. Direct experimental evidence of this phenomenon has been provided by Twilley et al. (1985) where artifical nutrient loading led to light attenuation by microalgae, epiphytic algae loading on leaves of macrophytes and significant decreases in biomass of submerged macrophytes. Orth and Moore (1983) hypothesized that the significant loss of submerged aquatic vegetation in Chesapeake Bay may be due, in part, to similar nutrient enrichment.

Fanning and Bell (1985) recommended that four areas of research be pursued to further clarify the problem of eutrophication in Tampa Bay:

(1) long-range coordinated nutrient sampling of the bay to accurately characterize conditions and detect changes;
(2) sampling to determine pathways and rates of nutrient transformation;

(3) a study of interactions and exchanges of nutrients in the bay with the Gulf of Mexico; and

(4) clarification of the role of sediments as sinks or sources of nutrients under varying conditions.

5.2.5 Other Management Considerations

Tampa Bay is an aesthetic resource for the large, growing population which surrounds it. The bay is a buffer and refuge from the assaults of urban life. For all but the affluent, the bay is the only accessible coastal resource where comparative isolation and wilderness can be experienced. Management of the bay somehow must work to preserve the key elements of this experience which, for examples, include silence, long vistas, darkness at night, encounters with wildlife, and the feeling of solitude.

The value of special places in the bay area, such as Cockroach Bay or Double Branch Creek, rests as much with their scientifically documented productivity as with their possession of intangible wilderness opportunities. Proposals to develop shorelines near such sensitive areas may meet or even exceed specific regulatory requirements which protect resource quantities or quality, but still destroy the intangible and increasingly rare character of the site.

5.3 CONCLUSION

When sewage treatment is inadequate we have depended on Tampa Bay to assimilate and disinfect the effluents. When more potable water is needed, we have dammed rivers first and considered the effects later. When a ship channel is in need of deepening we have simply dumped the spoil on nearby wetlands. And when a convenient and free place is needed to dump toxic wastes, we have constructed pipes and ditches flowing to the bay.

Tampa Bay is a billion dollar resource (Table 27). It has satisfied the agendas of all social and economic interests in the region, free of charge and with no management for 100 years. It cannot continue to do so, because natural threshholds are being approached beyond which ecosystems fail. Fisheries will continue to decline because fish stocks cannot simultaneously adapt to large habitat losses, anoxic waters, mortality from power plant entrainment, unlimited sport and commercial fishing pressure, and toxic materials.

Consideration should be given to holistic management of Tampa Bay. Responsibility for management of resources in the bay is fragmented along artificial lines and no ecosystem level management exists. One state agency regulates effluents and power plants; several agencies participate in wetland regulation; another agency protects freshwater species. The situation is analagous to one highway department being in charge of north-south roads, another in charge of east-west roads, and still another responsible for intersections and traffic signals.

Joseph L. Simon stated in his 1974 synopsis of Tampa Bay:

> To speak of management or mismanagement of the Tampa Bay Estuarine System prior to the late 1960s is inappropriate -- up to that time, there was simply development. Management implies control over a system. Mismanagement implies improper control. Only in the past few years has the public demanded management practices be applied to Tampa Bay. It is too soon to make the judgement whether these practices are going in the right direction (i.e., proper management) or whether governmental bodies are simply paying lip-service to the problems (i.e., mismanagement). The lack of willingness to slow growth until plans can be implemented to solve old and lingering problems would seem to imply we are headed towards mismanagement. Tampa Bay cannot wait much longer for advanced sewage treatment, nor can it tolerate more dredging without further degradation of its waters and bottoms. Hopefully, an irate citizenry will awaken policy making bodies to adopt sound management practices and will not accept mismanagement as an alternative.

Table 27. Known economic benefits for selected aspects of Tampa Bay, by county (MacAulay 1986).

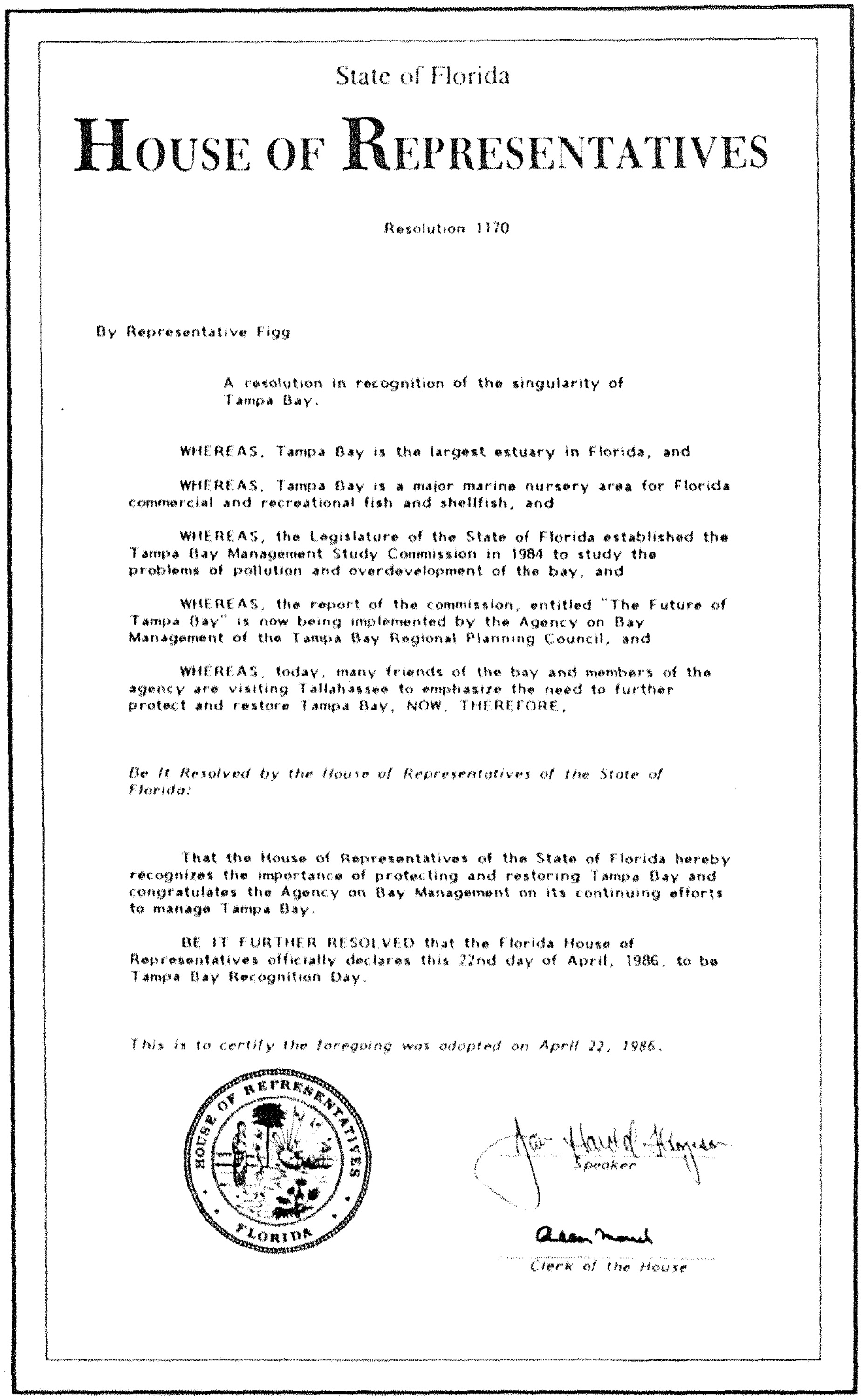
	Direct benefits by county (millions of dollars)			
Item	Hillsborough	Manatee	Pinellas	Total
Shipping	$281.0	Not studied	Not studied	$281.0
Waste disposal				
Sanitary	$137.0[a]	Not studied	$ 41.0[b]	$178.0
Cooling	40.5	Not studied	41.0	81.5
Fishing				
Commercial	$ 3.0	$ 3.3	$ 13.0	$ 19.3
Recreational	--	--	--	197.0
Recreation				
Boat sales	--	--	--	$184.0
Beaches/Ramps	--	--	--	23.0
Real estate	----------------Studied, no estimate----------------------			
Total				$963.8

[a] Employs least expensive alternative to selected plan of expanding Hookers Point Plant.

[b] North Pinellas County only.

[Editor's note: Progress has been made toward implementing and funding a Tampa Bay management program. In 1986, the Legislature passed a resolution recognizing the singularity of Tampa Bay (Figure 85). The 1987 legislative session passed a funding program as part of the new Surface Water Improvement and Management (SWIM) program. A total of $7.74 million dollars is proposed for the first three years of funding this program.]

We hope our efforts to bring together this information about the bay will encourage real bay management to begin.



State of Florida

HOUSE OF REPRESENTATIVES

Resolution 1170

By Representative Figg

A resolution in recognition of the singularity of Tampa Bay.

WHEREAS, Tampa Bay is the largest estuary in Florida, and

WHEREAS, Tampa Bay is a major marine nursery area for Florida commercial and recreational fish and shellfish, and

WHEREAS, the Legislature of the State of Florida established the Tampa Bay Management Study Commission in 1984 to study the problems of pollution and overdevelopment of the bay, and

WHEREAS, the report of the commission, entitled "The Future of Tampa Bay" is now being implemented by the Agency on Bay Management of the Tampa Bay Regional Planning Council, and

WHEREAS, today, many friends of the bay and members of the agency are visiting Tallahassee to emphasize the need to further protect and restore Tampa Bay, NOW, THEREFORE,

Be It Resolved by the House of Representatives of the State of Florida:

That the House of Representatives of the State of Florida hereby recognizes the importance of protecting and restoring Tampa Bay and congratulates the Agency on Bay Management on its continuing efforts to manage Tampa Bay.

BE IT FURTHER RESOLVED that the Florida House of Representatives officially declares this 22nd day of April, 1986, to be Tampa Bay Recognition Day.

This is to certify the foregoing was adopted on April 22, 1986.

Speaker

Clerk of the House

Figure 85. Florida House of Representatives Resolution 1170 recognizing the importance of Tampa Bay.

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Tampa Bay is Florida's largest open-water estuary and one of the most highly urbanized. This report summarizes and synthesizes many years of scientific investigation into Tampa Bay's geology, hydrology and hydrography, water chemistry, and biotic components. The estuary is a phytoplankton-based system, with mangroves being the second most important primary producer. Benthic organisms are abundant and diverse, although in parts of the bay the benthos consists of a relatively few opportunistic and pollution indicator species. The estuary provides habitat for the juveniles and adults of a number of commercial and recreational fishery species. Significant changes occurring as a result of urbanization and industrialization include significant declines in intertidal wetlands and seagrass meadows, changes in circulation and flushing, and degradation of water quality. Important management issues include dredge and fill operations, restoration of fisheries, increasing freshwater flow to the bay, and eutrophication.

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