SOME EFFECTS OF HYDRAULIC DREDGING AND COASTAL DEVELOPMENT IN BOCA CIEGA BAY, FLORIDA [1]

BY JOHN L. TAYLOR AND CARL H. SALOMAN, *Fishery Biologists*
BUREAU OF COMMERCIAL FISHERIES BIOLOGICAL LABORATORY
ST. PETERSBURG BEACH, FLA. 33706

ABSTRACT

Filling of 1,400 hectares (3,500 acres) of bay by hydraulic dredging has reduced the area of Boca Ciega Bay, Fla., by about 20 percent since 1950. An estimate of the annual standing crop destroyed is 1,133 metric tons (798 kg. per hectare, dry whole weight) of sea grass and about 1,812 metric tons (1,277 kg. per hectare, dry weight) of associated infauna. In terms of annual production, the loss of biological resources is far greater—minimum estimates are 25,841 metric tons of sea grass, 73 metric tons of fishery products, and 1,091 metric tons of infauna exclusive of meiofauna. Natural areas remaining in the Bay support local and offshore fisheries and are of value for recreation, public utilities, commerce, and industry. At an estimated value of $988 per hectare per year, worth of the estuarine area already eliminated is $1.4 million annually. In addition, inestimable secondary losses occur, principally from sedimentation, turbidity, and domestic sewage.

Boca Ciega Bay is a part of Tampa Bay, Fla., where coastal development and progressive deterioration of water quality have adversely influenced plant and animal production. This report describes some biological and physical changes that followed alteration of the bay and compares estuarine conditions in dredged areas with those in relatively undisturbed areas.

Hydraulic dredging became an accepted means of creating coastal upland in Florida about 1920, and has since proved an efficient means of providing waterfront real estate of premium value. Dredging was not a serious threat to coastal resources until after 1950 when coastal construction started on a large scale, especially along the lower east coast and the low-energy strand of the west coast from Tampa Bay southward. Profit and permissive attitudes toward the sale of submerged land contributed to rapid disposal of vast public holdings along much of Florida's 14,400 km. (9,000 statute miles) of tidal coastline. Bay filling has been little regulated, and in most situations biological and recreational resources of estuarine waters have been disregarded by coastal developers and governing authorities (Davis, 1956; Brunn and De Grove, 1959; Kidd, 1963).

Legislation to control dredge-fill projects in Florida appeared first in 1957 (Section 253.122 Florida Statutes, 1957), and the following year all such projects became subject to Federal review (Fish and Wildlife Coordination Act, P.L. 85–624). Unfortunately, under these laws the sale and development of submerged land remained largely arbitrary and most efforts to stop landfills in estuaries have been unsuccessful (Arnold, 1967).

Guidelines for appraisal of estuarine areas were proposed by Thompson (1961), and more positive measures are now being taken to conserve marine resources and provide for their rational use in Florida as well as in other parts of the country and abroad (Florida Statutes, chapter 67–393; Gilmour, 1965; Hutton, 1964; Tukey, 1965; Cain, 1966; Caldwell, 1966). Encouraging, too, is the

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fact that developers of bayfill projects have recently demonstrated a willingness to preserve some natural features on development sites (Gresham, 1967; Sykes, 1967).

In Florida and other States bordering the Gulf of Mexico, dredging and other forms of estuarine destruction damage fisheries because most of the species taken in sport and commercial fisheries live in estuaries during part or all of their life cycle (Skud and Wilson, 1960; Sykes and Finucane, 1966). Premium estuarine habitats that support the fisheries are vegetated, littoral biotopes containing populous, stable, and highly productive communities (Humm, 1956; Odum and Hoskin, 1958; Pomeroy, 1959; Odum, 1961; Margalef, 1963; Moore, 1963; Livingstone, 1965; Stephens, 1966; O'Gower and Wacasey, 1967).

Commercial fisheries in the Gulf of Mexico account for one-third of the Nation's marine landings and are worth about $114 million annually (Lyles, 1966). The landings could probably be increased two to five times through greater fishing effort, and use of species not now fished would raise these figures even higher (Schaefer, 1965; Pirie, 1967). In addition, production in some estuaries will certainly increase when methods are developed for culture of certain fishes, crustaceans, mollusks, and marine plants (Allen, 1963; Loosanoff and Davis, 1963; Shelbourne, 1964; Boney, 1965). Thus, perhaps the most timely argument against further destruction of estuarine habitats is the present and potential value of these areas for production of food (Tressler and Lemon, 1951; Hornig, 1966). Other nondestructive uses of estuaries, such as recreation, are compatible with fisheries and greatly add to the cash value of estuarine acreage, particularly in resort areas like Boca Ciega Bay.

DESCRIPTION OF AREA

Boca Ciega Bay lies within Tampa Bay, midway along the west coast of peninsular Florida. Separated from the Gulf of Mexico by a chain of barrier islands, Boca Ciega Bay merges with Tampa Bay on the south and extends 25.6 km. (16 miles) north as a narrow coastal lagoon (fig. 1). Water area is about 70 km.^{2} (27 square miles) and water depth over nearly 80 percent of the area is 1.8 m. or less (Olson, 1953; Olson and Morrill, 1955).

Bayfills occupy about 1,400 hectares (3,500 acres) and have reduced the water area by nearly 20 percent (Saloman, 1965). Aerial photographs taken before and after major dredging illustrate how coastal development has reshaped Boca Ciega Bay in less than a generation (figs. 2–9).

In areas that remain relatively undisturbed, sediments are a firm mixture of shell and sand (Goodell and Gorsline, 1961). They support luxuriant beds of sea grass except in deep depressions and channels where light is inadequate. Turtle grass (*Thalassia testudinum* König) is the most common species, but in many places any of three other species may be present (Phillips, 1960a, 1962).

The first comprehensive study of Boca Ciega Bay began in 1955 as a joint project of the Florida Board of Conservation and the Fish and Wildlife Service (Hutton, Eldred, Woodburn, and Ingle, 1956). The objectives were to determine commercial and recreational assets of the lagoon and focus attention on undesirable consequences of past and pending dredge-fill operations. Although the report did not impede bayfill construction, it described many biological and physical features of the bay. Subsequent work on the biology of Boca Ciega Bay included that of Springer and Woodburn (1960), Phillips (1960b), Dragovich and Kelly (1964), Saloman (1965), Sykes and Finucane (1966), and Bullock and Boss.[2]

PROCEDURE

Sampling began in September 1963 at 31 stations. Ten of these (BC series) had been previously sampled by biologists of the Florida State Board of Conservation (Hutton et al., 1956). The other 21 (D and PB series) were in natural areas, deeply dredged canals, and a variety of habitats influenced to some degree by dredging. On the basis of an evaluation of initial collections at all stations, we selected six (PB series) to represent conditions at dredged and undredged locations. Sampling at these stations began in November 1963 and continued at 3-month intervals for 9 months (February, May, and August 1964). Four stations (PB 1, 3, 5, and 6) were in undredged areas, and two (PB 2 and 4) were in dredged access canals be-

[2] Bullock, Bob, and Chuck Boss. The ecological distribution of the marine mollusks in Boca Ciega Bay—1962. On file at Department of Biology, Florida Presbyterian College, St. Petersburg, Fla. 33711.

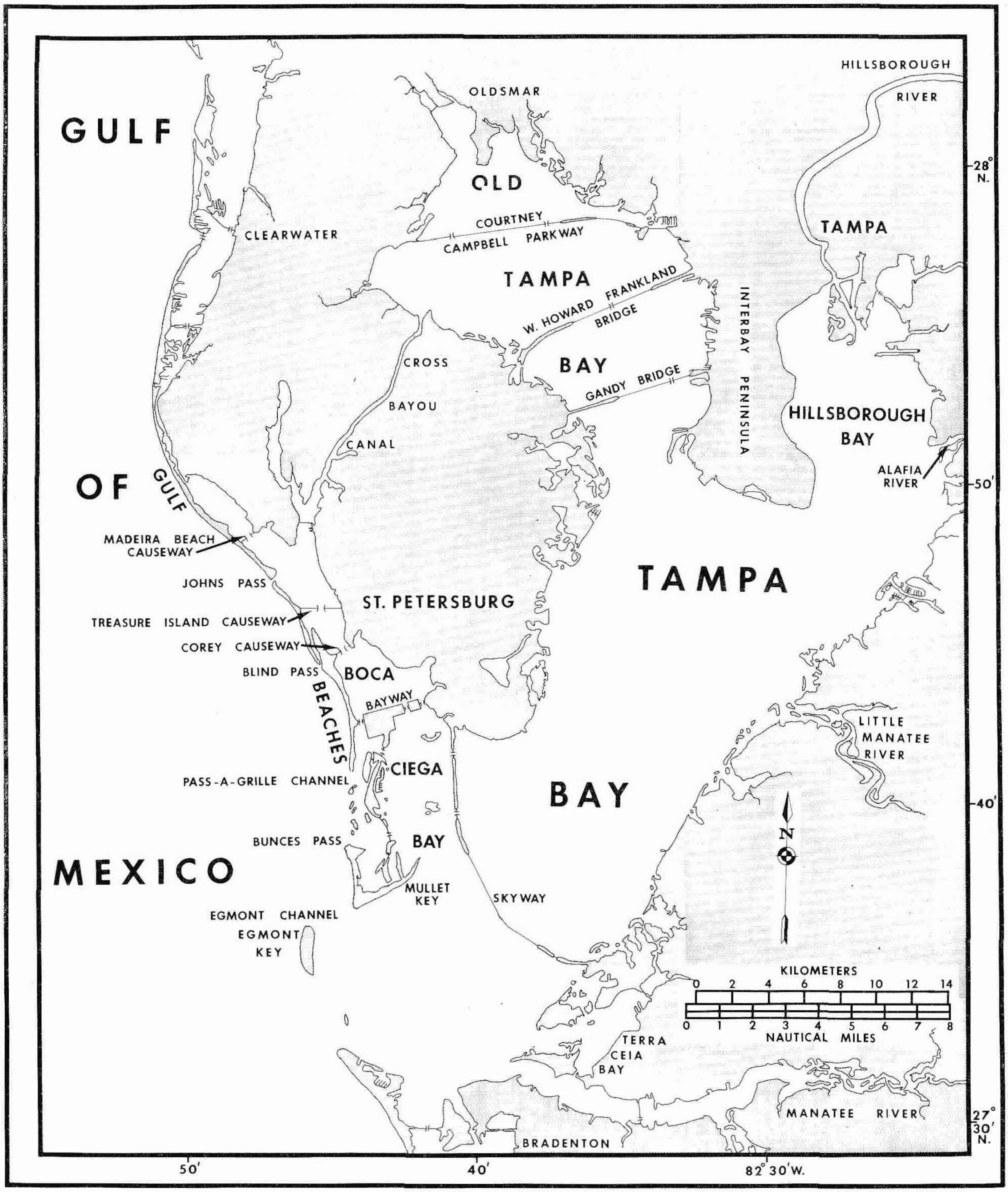

FIGURE 1.—Boca Ciega Bay and Tampa Bay, Fla.

FIGURE 2.—Southern Boca Ciega Bay in 1953 before major bayfill construction (photograph courtesy of Airflite, St. Petersburg, Fla.).

tween bayfills. In addition, four areas of the bay (A, B, C, and D) were sampled in August 1964 to estimate the biomass of turtle grass and infauna (figs. 10 and 11). At all sampling stations, water was collected at surface and bottom for physical and chemical analyses, sediment samples were obtained for textural and chemical analyses, and biological collections were made for benthic invertebrates, plants, and fishes.

Measurements were made of water temperature, salinity, pH, total phosphorus, dissolved oxygen, secchi disc depth, chlorophyll *a*, and primary production following methods described by Saloman, Finucane, and Kelly (1964)—see table 1. Supplemental data on water quality were used to show long-term hydrological changes that have occurred throughout Tampa Bay as a result of coastal development (tables 2–5). The supplementary data are from the following published reports and unpublished data of the Bureau of Commercial Fisheries Biological Laboratory, St. Petersburg Beach, Fla.: Odum (1953), Hutton et al. (1956), Marshall (1956), Finucane and Dragovich (1959, 1966), Pomeroy (1960), Dragovich, Finucane, and May (1961), Saloman et al. (1964), Dragovich, Kelly, and Finucane (1966), Saloman and Taylor (1968), May and Johnson (unpublished data on

FIGURE 3.—Southern Boca Ciega Bay in 1963 showing Pinellas County Bayway and other bayfill areas (photograph courtesy of Airflite, St. Petersburg, Fla.

chlorophyll *a* and primary productivity),[3] and the U.S. Weather Bureau (unpublished water temperature data for Egmont Key).[4]

Sediments and infauna were collected with a shovel in water as deep as 1 m. and with a bucket dredge at greater depths (Taylor, 1965). A subsample of about 500 cc. was withdrawn from each bottom sample for sediment analysis. Each subsample was sealed in a moist condition and later analyzed at Florida State University.[5] Particles of sand size and larger were separated from silt and clay by wet sieving through a screen of 62-micron mesh. Material remaining on the sieve was dried and subdivided by use of a series of nested screens mounted on a mechanical shaker. The fine fraction that passed the 62-micron mesh was sized electronically in a Coulter counter.[6] Clay minerals were examined by X-ray diffraction, and chemical analyses were made for carbonates, organic carbon, and organic nitrogen. Statistical calculations were made by computer and included mean

[3] May, B. Z., and Lucius Johnson. On file at Bureau of Commercial Fisheries Biological Laboratory, St. Petersburg Beach, Fla. 33706.

[4] On file at U.S. Weather Bureau, Tampa International Airport, Tampa, Fla. 33614.

[5] Sediment analyses were under the direction of H. Grant Goodell, Sedimentological Laboratory, Florida State University, Tallahassee, Fla. 32306.

[6] References to trade names in this publication do not imply endorsement of commercial products.

FIGURE 4.—Central Boca Ciega Bay near Corey Causeway in 1949 before major bayfill construction (photograph courtesy of Airflite, St. Petersburg, Fla.

grain size, standard deviation (sorting), skewness, and kurtosis.

In addition to the collection of bottom organisms taken by shovel and dredge, the epibenthos was sampled at all stations by a bottom drag fitted with fine netting (Taylor, 1965). Infauna was removed from sediments in a Tyler No. 24 screen of 30-cm. diameter and 0.701-mm. mesh. To distinguish small specimens from debris, rose bengal dye was added to material concentrated by screening (Jones, 1961). Ten percent sea-water Formalin used to fix specimens was replaced later by 70 percent isopropanol.

Fishes were collected at each station with either a 4.8-m. semi-balloon trawl or a 21-m. beach seine. The trawl was hung with a 3.75-cm. stretch mesh body fitted with a 1.25-cm. bag liner. The seine had a stretch mesh of 1.25 cm. in the end sections and 0.08 cm. in the bag. In addition, a 7.5-cm. stretch mesh trammel net, 90 m. x 1.8 m., was fished each sampling period at the entrance of access canals where stations were located. Fishes, invertebrates, and plants taken in nets and by bottom samplers were sorted, enumerated, and identified. Animals in each group are not treated in detail in the present report, although some are mentioned because of their prominence in bayfill canals.

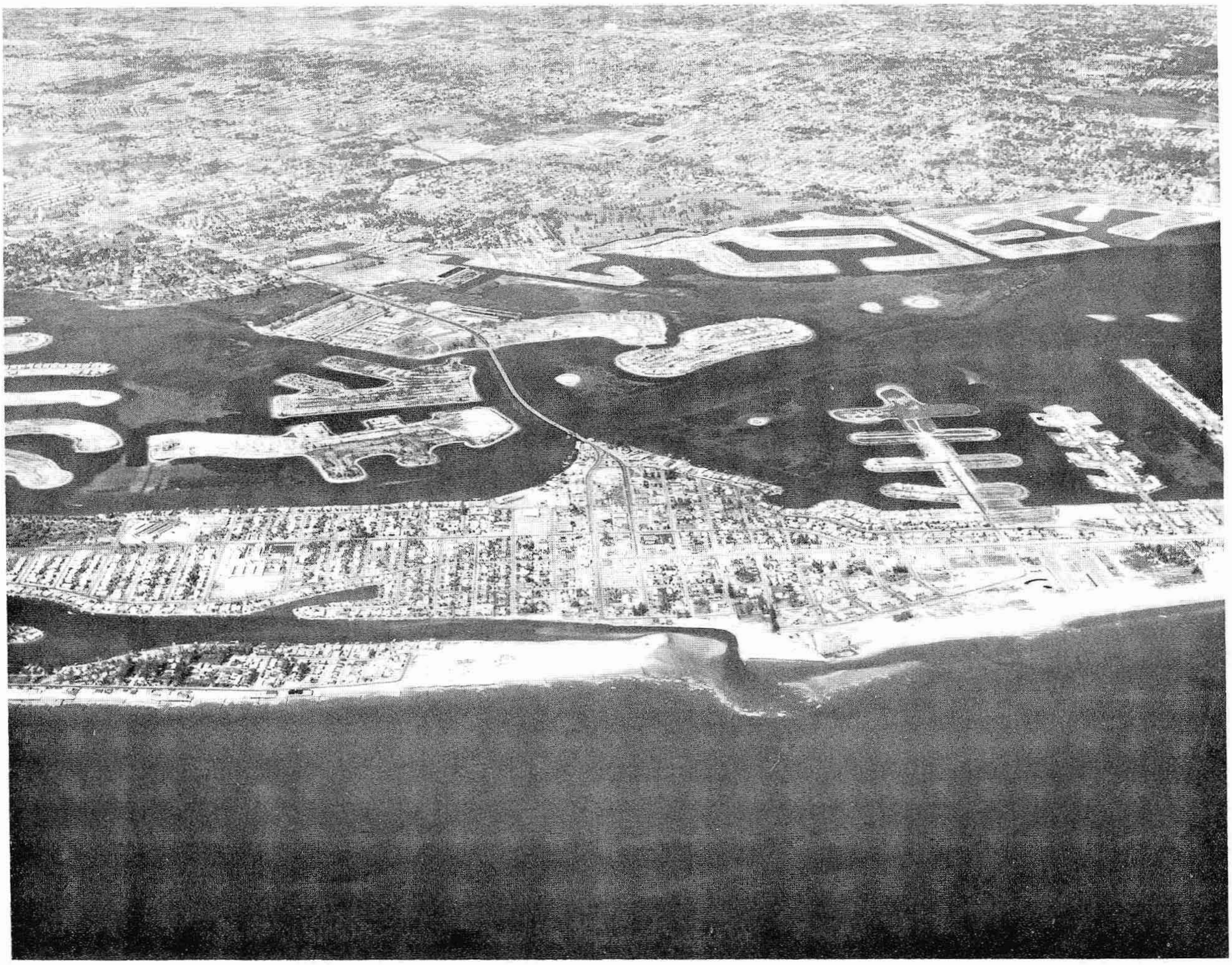

FIGURE 5.—Central Boca Ciega Bay near Corey Causeway in 1963 showing bayfill areas (photograph courtesy of Airflite, St. Petersburg, Fla.).

Quantitative samples for estimates of biomass were taken in August 1964 with a 0.25 m.[2] plug sampler that extracts sediments to a depth of 22.5 cm. (fig. 12). In operation, the sampler is pushed into the sediment and then dug out with a shovel which covers the bottom of the sampler and retains the sediment plug. Total weights of plants and infauna from grass beds were determined from sets of triplicate samples taken in representative stands of turtle grass in lower, central, and upper Boca Ciega Bay (areas A, B, and C, fig. 10). Infaunal biomass from unvegetated bottom was determined from a single set of three samples in the central part of the bay shoreward of station D–5 in area D (fig. 11). Wet and oven-dried plants and wet whole animals were weighed on a Mettler K–7 balance. Dry whole weight of animals was arbitrarily calculated at 15 percent of wet whole weight because most of the animals in all samples were polychaete worms, small crustaceans, and small mollusks (Sanders, 1956; Thorson, 1957). Large mollusks and crustaceans that appeared sporadically in bottom samples were disregarded in calculations of standing crop because of the bias they would have introduced. Consequently, figures for dry whole weight of animals are conservative, particularly in lower Boca Ciega Bay (area A), where the southern hard-shell clam (*Mercenaria*

FIGURE 6.—Central Boca Ciega Bay near Treasure Island Causeway in 1949 before major bayfill construction (photograph courtesy of Airflite, St. Petersburg, Fla.

campechiensis) and pink shrimp (*Penaeus duorarum*) are abundant (Saloman, 1965; Taylor and Saloman, 1967). Biomass estimates of turtle grass are also minimal because the sampler did not collect roots and rhizomes that penetrate sediments beyond 22.5 cm. (9 inches).

TEMPERATURE, SALINITY, AND pH

Temperature, salinity, and pH of Boca Ciega Bay are similar to those in water near the mouth of Tampa Bay because land drainage is not appreciable and four passes lead directly to the Gulf of Mexico. Furthermore, there is little or no stratification of water masses in unprotected parts of the bay because of shallow depths and tidal and wind-driven circulation (table 1).

The most detailed record of water temperature for lower Tampa Bay comes from daily observations over 18 years by the U.S. Coast Guard at Egmont Key. The monthly means correspond closely to means of our water temperature data for 1963–64 and to means of other records from Boca Ciega Bay between 1961 and 1965 (tables 1 and 2). The range of water temperature over shallow flats, however, is considerably greater than the range of monthly means. For example, Phillips (1960b) recorded 36.9° C. from water standing over turtle grass in July 1958, and a low of 4.8° C.

FIGURE 7.—Central Boca Ciega Bay near Treasure Island Causeway in 1963 showing bayfill areas (photograph courtesy of Airflite, St. Petersburg, Fla.).

was recorded near shore at Mullet Key on January 31, 1966 (Saloman and Taylor, 1968).

Water temperature is usually the same in the open bay and in bayfill canals, except in winter when periodic cold fronts create a temporary thermocline in deep water. At such times, bottom water may be 4 to 5° C. warmer than surface water and serves as a refuge for polythermal fishes (Kinne, 1963). If cold weather persists for more than a few days, however, bottom water becomes cold and sequestered fishes may die. During prolonged cold in February 1966, John H. Finucane (unpublished data)[7] observed mass mortality among snook, *Centropomus undecimalis* (Block), in bayfill canals of Boca Ciega Bay.

Average salinity in Boca Ciega Bay (32 p.p.t.) approaches that of the nearshore Gulf and is at least 10 p.p.t. higher than water in northern reaches of Old Tampa Bay and Hillsborough Bay (table 3). Even though the major portion of annual rainfall (127 cm.) comes in the summer and fall, seasonal fluctuations of salinity in the lagoon are slight. Appreciable changes occur only in surface water directly south of Lake Seminole Dam

[7] Unpublished data (quarterly report) on file, Bureau of Commercial Fisheries Biological Laboratory, St. Petersburg Beach, Fla. 33706.

FIGURE 8.—Northern Boca Ciega Bay near Johns Pass in 1952 showing first bayfill areas (photograph courtesy of Airflite, St. Petersburg, Fla.).

at station PB–1 (fig. 10 and table 1). Stable and relatively high salinity in Boca Ciega Bay and the temperate or subtropical water temperature favor the occurrence of a large number and diversity of marine plants and animals (Gunter, 1961; Kinne, 1964).

In the sea, pH is generally near 8 and remains stable unless affected by abnormally high photosynthetic activity, rapid temperature change, or anoxic conditions on the sea floor (Skirrow, 1965). In Boca Ciega Bay the observed pH range of 7.2 to 8.5 is normal for water of nearly oceanic salinity (Park, Hood, and Odum, 1958; Reid, 1961). Within any single sampling period pH on the surface and bottom at each station varied no more than one unit.

OXYGEN

Daytime concentrations of oxygen on the surface and bottom of dredged and undredged stations were at least 3.5 ml./l. in all seasons (table 1). In more recent work, however, less than 2 ml./l. was recorded in June and August from bottom water at a dredged location in the central part of Boca Ciega Bay near station PB–4 (Dragovich et al., 1966). These recent data show that oxygen is re-

FIGURE 9.—Northern Boca Ciega Bay near Johns Pass in 1963 showing bayfill areas (photograph courtesy of Airflite. St. Petersburg, Fla.).

duced in summer over the soft sediments of access canals. Tidal movements in the bay probably make some oxygen available throughout the water column at most times, but occasional reductions limit some marine animals (Emery and Stevenson, 1957; Reish, 1959).

Elsewhere in Tampa Bay, marked oxygen reduction near the bottom has been recorded only in Hillsborough Bay (Saloman et al., 1964), where pollution from sewage is heavy, summer water temperature is high, and water circulation is poor. Additional bayfill development in Boca Ciega Bay would increase sewage volume, impede water circulation, and further reduce dissolved oxygen.

PHOSPHORUS AND NITROGEN

Phosphorus concentration was high in surface and bottom water at dredged and undredged locations. At dredged locations, bottom concentration was generally higher than surface concentration. At undredged locations, however, concentration did not vary consistently with water depth (table 6). Phosphorus was probably reduced in calm, surface water between finger-fills by deposition of sorbed phosphates bound to particles of silt and clay (Pomeroy, Smith, and Grant, 1965).

Nitrogen was not measured in this study, but other data show that it is plentiful in Boca Ciega Bay (table 4).

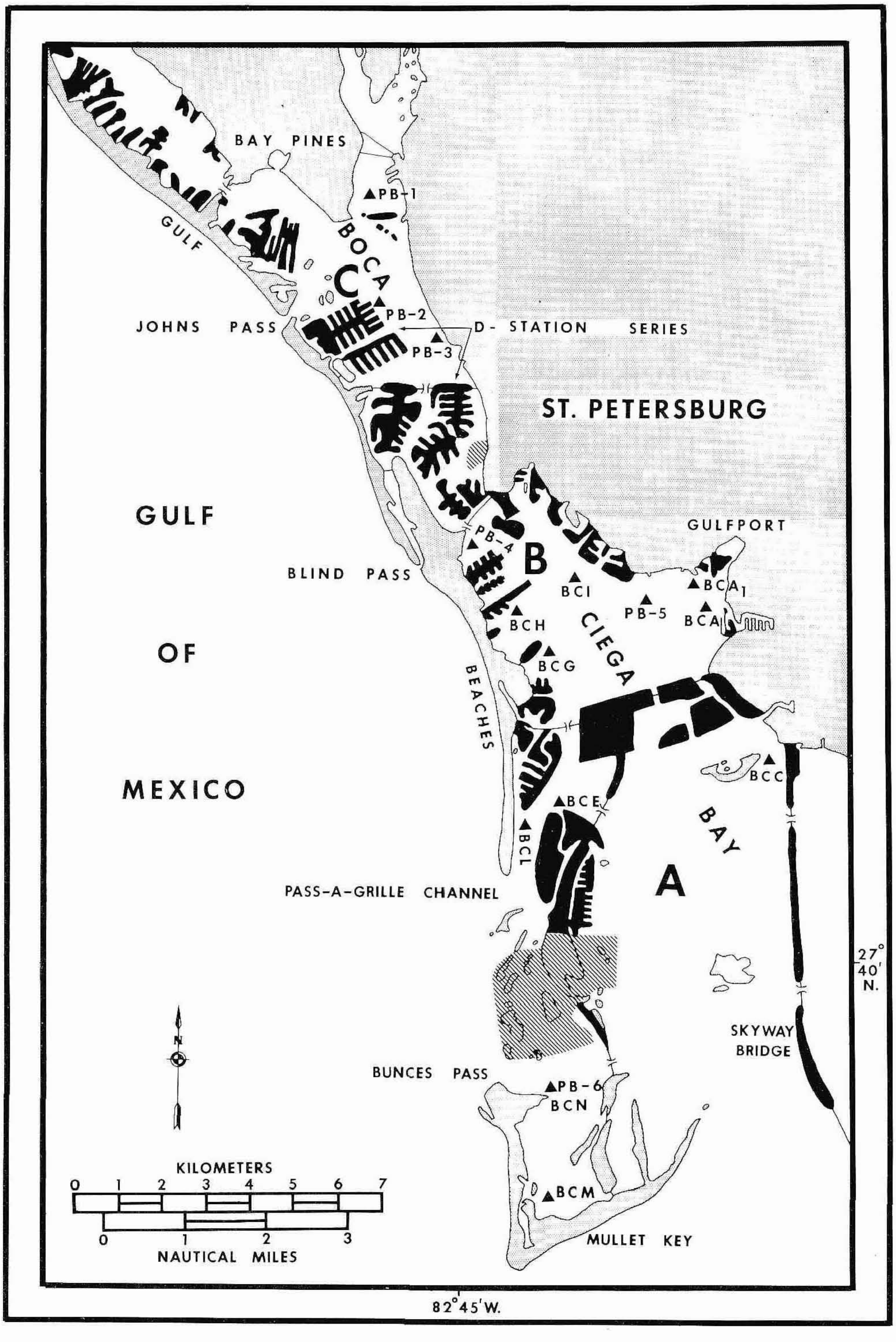

FIGURE 10.—Boca Ciega Bay showing station locations (BC and PB series, and biomass stations A, B, and C), bayfill areas (black), and proposed bayfill areas (shaded).

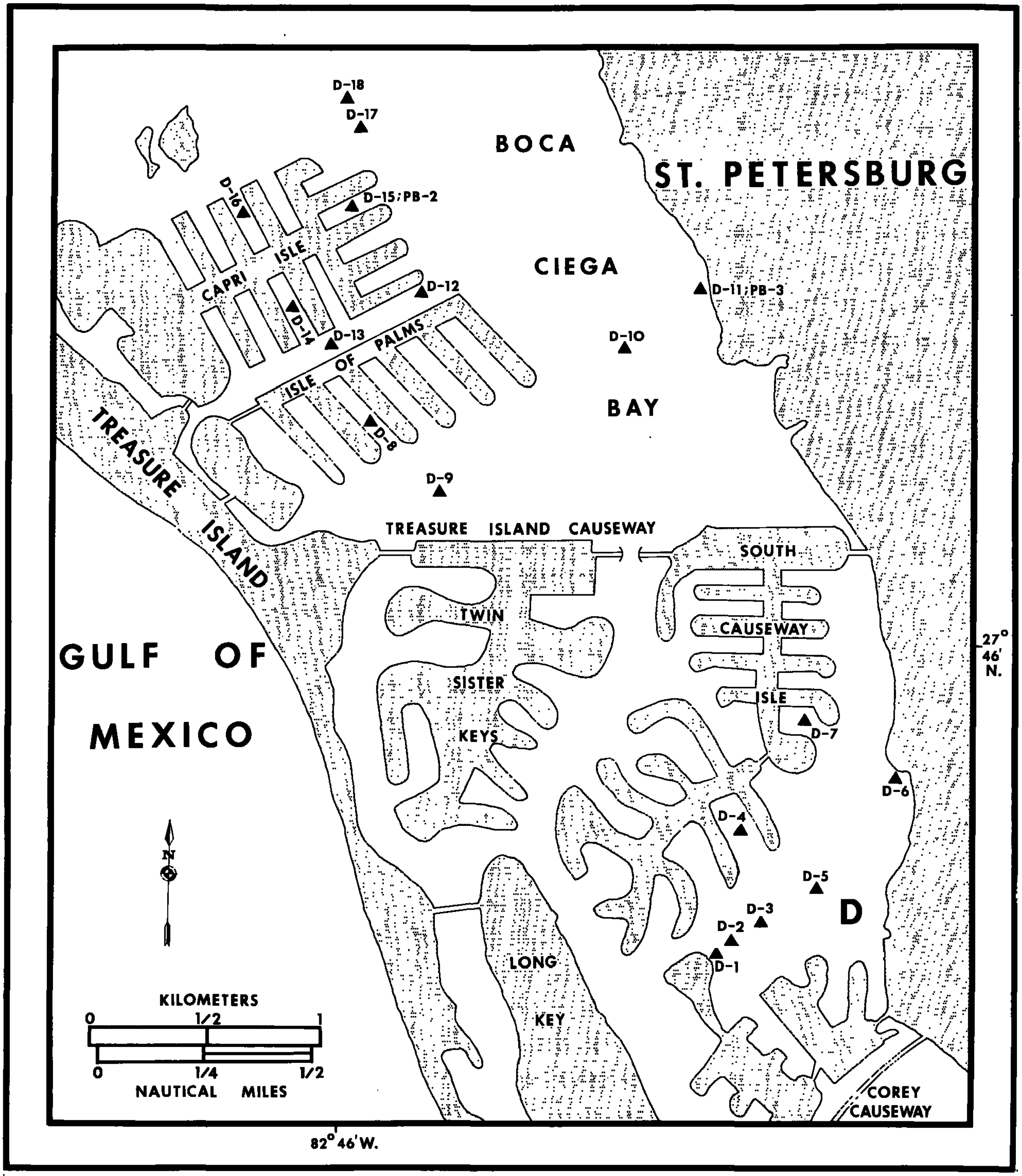

FIGURE 11.—Boca Ciega Bay north of Corey Causeway showing station locations (D–1 through D–18, and biomass station D).

TABLE 1.—*Hydrological measurements from surface and bottom water at sampling stations in undredged and dredged areas of Boca Ciega Bay, Fla., 1963–64*

Date and stations	Depth	Temperature	Salinity	pH	Dissolved oxygen	Total phosphorus	Secchi disc depth	Chlorophyll a	Primary production
NOVEMBER 1963									
Undredged stations:									
PB-1	M.	°C.	P.p.t.		Ml./l.	µg.at./l.	Cm.	Mg./m.³	G.C/m²/day
Surface	0	20.9	29.6	8.0	4.6	16.6	105.0	13.1	0.52
Bottom	2	20.6	30.3	8.2	5.2	5.0			
PB-3									
Surface	0	19.8	31.9	8.2	4.7	22.1	100.0	11.1	.48
Bottom	2	19.4	31.9	8.2	5.5	21.4			
PB-5									
Surface	0	20.0	31.8	7.9	4.9	15.6	92.5	9.5	.44
Bottom	3	20.0	31.9	8.1	4.9	14.1			
PB-6									
Surface	0	20.5	32.5	8.1	5.3	1.1	240.0	1.5	.17
Bottom	4	20.4	32.8	8.0	5.2	17.3			
Mean surface value		20.3	31.5	8.1	4.9	13.9	134.4	8.8	.40
Mean bottom value		20.1	31.7	8.1	5.2	14.5			
Dredged stations:									
PB-2									
Surface	0	18.4	32.4	8.1	4.5	5.9	105.0	9.5	.37
Bottom	4	18.5	32.0	8.2	4.1	18.6			
PB-4									
Surface	0	19.8	31.7	8.0	4.4	4.7	130.0	12.9	.81
Bottom	4	19.7	31.7	8.0	4.0	1.1			
Mean surface value		19.1	32.1	8.1	4.5	5.3	118.0	11.2	.59
Mean bottom value		19.1	31.9	8.1	4.1	9.9			
FEBRUARY 1964									
Undredged stations:									
PB-1									
Surface	0	13.8	20.3	8.1	5.3	8.8	80.0	13.0	.44
Bottom	2	14.7	29.2	7.9	5.6	5.0			
PB-3									
Surface	0	15.2	29.7	8.5	7.8	3.8	92.5	4.6	.16
Bottom	2	13.9	31.0	7.8	6.1	3.9			
PB-5									
Surface	0	15.2	29.0	8.4	5.9	6.7	88.5	17.0	.25
Bottom	3	15.2	29.0	8.1	5.9	7.4			
PB-6									
Surface	0	14.7	31.6	8.1	5.4	6.4	112.5	13.3	.24
Bottom	4	14.6	31.7	7.2	5.4	7.1			
Mean surface value		14.7	27.7	8.3	6.1	6.4	93.1	12.0	.27
Mean bottom value		14.6	30.3	7.8	5.8	5.9			
Dredged stations:									
PB-2									
Surface	0	13.8	29.7	8.1	6.6	3.2	82.5	7.7	.27
Bottom	4	13.8	30.2	8.0	5.8	2.8			
PB-4									
Surface	0	14.7	28.2		5.9	5.4	82.5	18.9	.07
Bottom	4	14.5	28.8	8.1	5.3	5.4			
Mean surface value		14.3	29.0	8.1	6.3	4.3	82.5	13.3	.17
Mean bottom value		14.2	29.5	8.1	5.6	4.1			

TABLE 1.—*Hydrological measurements from surface and bottom water at sampling stations in undredged and dredged areas af Boca Ciega Bay, Fla., 1963–64*—Continued

Date and stations	Depth	Temperature	Salinity	pH	Dissolved oxygen	Total phosphorus	Secchi disc depth	Chlorophyll a	Primary production
MAY 1964	*M.*	*°C.*	*P.p.t.*		*Ml./l.*	*μg.at./l.*	*Cm.*	*Mg./m.³*	*G.C/m.²/day*
Undredged stations:									
PB-1									
Surface	0	27.0	33.6	7.8	3.6	6.1	87.5	9.9	.55
Bottom	2	26.8	33.4	8.0	3.8	6.2			
PB-3									
Surface	0	28.0	33.8	7.9	5.0	4.3	110.0	7.1	.48
Bottom	2	27.0	33.8	8.1	4.9	4.8			
PB-5									
Surface	0	27.9	32.9	7.9	4.1	12.4	115.0	3.5	.25
Bottom	3	27.7	32.9	7.9	3.9	10.9			
PB-6									
Surface	0	28.5	34.7		4.9	7.5	150.0	2.2	.19
Bottom	4	28.5	34.5	8.2	5.0	5.4			
Mean surface value		27.9	33.8	7.9	4.4	7.6	115.6	5.7	.37
Mean bottom value		27.5	33.7	8.1	4.4	6.8			
Dredged stations:									
PB-2									
Surface	0	27.3	34.0	8.0	4.5	4.1	142.5	6.6	.59
Bottom	4	26.6	34.1	8.3	4.0	4.9			
PB-4									
Surface	0	27.3	33.6		4.0	6.3	130.0		
Bottom	4	27.2	33.6		3.6	10.8			
Mean surface value		27.3	33.8	8.0	4.3	5.2	136.3	6.6	.59
Mean bottom value		26.9	33.9	8.3	3.8	7.9			
AUGUST 1964									
Undredged stations:									
PB-1									
Surface	0	29.8	27.7	7.8	4.5	15.8	45.0	28.2	.67
Bottom	2	27.7	31.8	7.9	3.8	11.8			
PB-3									
Surface	0	30.1	33.9	8.1	6.3	9.5	100.0	6.4	.33
Bottom	2	29.8	33.8	8.1	4.9	8.6			
PB-5									
Surface	0	30.5	33.3	7.4	4.8	12.9	125.0	4.5	.32
Bottom	3	30.0	33.3	8.4	4.8	13.3			
PB-6									
Surface	0	31.1	34.0	8.1	5.6	13.6	147.5	6.7	.59
Bottom	4	30.1	33.9	8.2	4.4	15.5			
Mean surface value		30.4	32.2	7.9	5.3	13.0	104.4	11.5	.48
Mean bottom value		29.4	33.2	8.2	4.5	12.3			
Dredged stations:									
PB-2									
Surface	0	30.7	34.3	7.9	5.2	7.1	105.0	10.6	.59
Bottom	4	29.8	34.4	7.9	3.5	7.2			
PB-4									
Surface	0	29.7	33.6	8.0	4.4		125.0	3.9	.28
Bottom	4	29.5	33.8	8.2	3.4	12.4			
Mean surface value		30.2	34.0	8.0	4.8	7.1	115.0	7.3	.44
Mean bottom value		29.7	34.1	8.1	3.5	10.8			

TABLE 2.—*Mean monthly surface water temperature (°C.) from observations (daily at 0700 hours) near Tampa Bay entrance (Egmont Key) 1948–65,[1] and Boca Ciega Bay (near station PB–4) 1961–65[2]*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Egmont Key, Fla.:												
Mean low	13.9	12.7	16.3	20.0	25.1	27.5	27.9	28.5	27.0	24.0	19.4	14.6
Mean high	20.2	20.8	23.0	24.4	26.8	29.4	30.5	30.6	29.7	27.1	23.7	21.1
Mean	16.3	17.3	19.7	22.3	25.9	28.5	29.6	29.8	28.6	25.5	21.1	17.5
Boca Ciega Bay, Fla.:												
Mean	14.2	16.5	19.3	23.6	25.5	29.8	29.3	30.2	28.7	25.3	21.8	16.9

1 U.S. Weather Bureau, Tampa International Airport, Tampa, Fla. 33614.

2 Saloman et al., 1964; Dragovich et al., 1966; Finucane and Dragovich, 1966.

TABLE 3.—*Mean monthly surface water salinity (p.p.t.) for areas of Tampa Bay and adjacent Gulf of Mexico, 1954–65[1]*

Areas	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Yearly mean
Old Tampa Bay:													
Upper	20.0	18.6	21.1	23.5	22.8	26.4	22.5	22.6	18.3	21.4	21.4	23.1	21.8
Middle	23.4	21.8	22.3	23.8	24.9	26.5	25.8	22.3	21.6	21.4	22.4	23.7	23.3
Lower	25.8	25.8	25.3	25.8	26.9	27.6	26.9	24.6	22.6	23.8	23.7	24.7	25.3
Hillsborough Bay:													
Upper	19.7	22.2	19.3	22.8	19.8	23.6	19.3	19.1	16.6	21.3	22.3	23.0	20.8
Lower	21.3	21.2	21.4	22.3	21.3	25.9	23.6	20.4	22.0	22.9	25.2	25.6	22.8
Tampa Bay:													
Upper	25.6	24.6	22.7	23.0	25.9	27.5	26.5	22.0	21.2	22.7	24.8	25.8	24.4
Middle	27.5	26.8	25.0	25.0	28.1	29.0	29.0	23.4	24.3	25.8	26.5	27.5	26.5
Lower	30.5	29.3	28.5	30.6	31.4	31.8	32.2	30.3	29.1	29.8	30.5	30.7	30.4
Terra Ceia Bay	27.6	25.5	27.6	30.2	31.1	31.6	29.9	24.4	25.4	28.4	30.0	30.2	28.5
Egmont Key	31.9	31.9	31.5	31.5	33.1	34.1	34.3	32.4	30.7	31.0	31.7	31.8	32.2
Boca Ciega Bay	31.7	32.0	30.7	31.8	33.2	34.0	33.4	31.3	31.2	31.9	32.5	32.1	32.1
Gulf of Mexico	33.4	33.7	33.4	34.0	34.6	35.1	35.0	34.1	34.0	33.9	33.7	33.7	34.1

1 Finucane and Dragovich, 1959; Dragovich et al., 1961; Saloman et al., 1964; Finucane and Dragovich, 1966; Dragovich et al., 1966.

TABLE 4.—*Surface values of total phosphorus, 1952–66, total nitrogen, 1961–66,[1] and nitrogen-phosphorus ratio (N/P)[2] for areas of Tampa Bay, Fla.*

Area	1952–53	1954	1955	1956	1957	1958	1959	1960	1961		1962		1963		1964		1965		1966	
	P	P	P	P	P	P	P	P	N	P	N	P	N	P	N	P	N	P	N	P
	µg.at./l																			
Area I—Old Tampa Bay:																				
January											44.5	20.6	31.2	29.9	33.7		37.6	23.6	26.1	24.6
February											24.2	23.7	35.8	22.3	33.7	29.1			15.7	27.6
March											42.6	14.6	43.0	18.5	49.6	28.2			55.8	18.7
April	7.7										47.0	18.5	63.5	32.5	39.1	22.3			62.4	20.7
May											54.4	23.9	36.4	25.9	27.6	24.9			40.7	28.7
June											50.2	28.0	31.7	19.6	27.6				62.8	30.1
July											47.7	21.5	74.1	19.4	25.4				36.4	11.9
August											46.6	21.4	42.8	25.5	69.4	24.2	83.1	25.5	46.3	14.0
September	8.1								57.0	21.6	58.4	21.2	52.4	26.6	46.4	23.7	61.7	25.1	58.8	25.5
October									41.7	26.2	35.4	29.8	36.0	5.6	43.3		66.6	28.2	64.3	19.3
November									38.9	18.5	27.2	30.9			33.6	24.6	47.9	22.1	48.4	18.3
December									39.4	22.3	62.2	23.2	31.8	18.5	28.0	21.6	46.1	22.1	47.5	19.3
Yearly mean	7.9								44.3	22.2	45.0	23.1	43.5	22.2	38.1	24.8	57.2	24.4	47.1	21.6
N/P									.9		.9		.9		.6		1.3		1.0	
Area II—Hillsborough Bay:																				
January													37.9	36.1	48.1					
February													55.3	25.5	50.7					
March													57.0	23.5	47.4					
April	18.7													27.9	60.7					

See footnotes at end of table.

TABLE 4.—*Surface values of total phosphorus, 1952–66, total nitrogen, 1961–66,*[1] *and nitrogen-phosphorus ratio (N/P)* [2] *for areas of Tampa Bay, Fla.*—Continued

Area	1952–53	1954	1955	1956	1957	1958	1959	1960	1961		1962		1963		1964		1965		1966	
	P	P	P	P	P	P	P	P	N	P	N	P	N	P	N	P	N	P	N	P
Area II—Hillsborough Bay—Continued																				
May													41.0	42.7	45.4					28.6
June													38.3	23.2	30.7					25.4
July													77.4	22.7	43.6					10.1
August													60.9	29.5	73.9				69.6	11.2
September	23.9										59.2	23.3	55.7	26.0	50.1				90.7	23.0
October											50.5	31.4	49.7	16.9	44.1				95.5	18.7
November											75.3	32.6			67.4				73.3	19.9
December											41.4	16.4	60.7	22.1	47.6				71.8	18.2
Yearly mean	21.3										56.6	25.9	53.4	26.9	50.8				80.2	19.4
N/P											1.0		.9						1.8	
Area III—Tampa Bay:																				
January								22.8		24.5	21.0	23.2	35.6	33.3					26.8	22.4
February								23.6		23.0			28.5	22.5					31.3	8.8
March								28.3			46.8	19.5	44.1	26.0	33.0				58.3	19.7
April	3.5							23.7			31.3	31.0	54.0	9.6	59.3				76.6	11.4
May								22.6				24.9	31.4	25.2	37.6				37.0	31.7
June								22.7		24.2	37.7	24.3	30.0	22.0					45.0	20.8
July								20.9		26.9	40.6	20.7	32.1	18.4	28.7				44.8	10.1
August								21.1			42.1	20.5	34.0	25.0	26.0		79.3	20.2	50.1	10.7
September	9.2							27.9	50.7	32.5	29.0	18.8		27.0	20.7		71.4	19.1	56.5	28.5
October									36.7	24.5	33.4	29.1	37.9	19.0	28.7		49.4	24.6	61.9	17.5
November								21.1	34.3	19.5	42.2	31.4			27.4		42.0	21.0	51.1	17.9
December								23.5	25.1	18.0	48.2	14.5	38.6	10.4	20.0		44.7	20.5	46.7	18.1
Yearly mean	6.4							23.5	36.7	24.1	37.2	23.4	36.6	22.6	31.3		57.4	21.1	48.8	18.1
N/P									.7		.7		.7				1.1		1.2	
Area IV—Tampa Bay Entrance:																				
January								2.1	26.9	7.7	33.3	10.9			26.1				14.7	6.2
February				13.6				3.9	18.1	4.7			22.0	10.6	21.2				13.0	5.5
March				9.7				8.4		3.9	45.4	3.0	20.5		19.4				44.0	15.2
April				4.9				3.9			31.2	8.6	29.4	8.6	12.8				42.0	13.7
May				1.7				3.6	19.6	5.2	36.7	4.5	23.6	7.1	28.7				34.0	8.6
June				9.8				4.9	47.3	5.1	26.8	7.7	27.1	8.8	11.7				47.6	13.9
July				5.4				4.6	34.2	2.8	24.9	8.2	32.6	9.6	39.0				37.8	10.4
August								4.4			36.3	12.5	22.0	10.6	23.1		32.7	11.4	39.4	10.3
September	4.2		21.6	15.9				6.4	39.0	5.7	23.2	9.2	33.7	14.4	22.8		62.6	11.3	51.6	17.4
October			18.3	9.5				10.5	46.4	16.2			28.0	11.6	17.6		37.9	10.6	62.3	17.3
November				12.7				6.3	36.2	13.4	28.0	14.3			21.0		53.1	5.6	44.8	15.0
December			4.0					3.6	25.3	13.6	34.4	7.0	28.6	7.9	13.7		32.7	5.8	47.7	12.0
Yearly mean	4.2		14.6	9.2				5.2	32.6	7.8	32.0	8.6	26.8	9.9	21.4		43.8	8.9	39.9	12.2
N/P									2.5		1.3		1.3				2.0		1.5	
Area V—Boca Ciega Bay:																				
January							1.4				27.6	3.3			23.3		42.1	3.9	25.1	6.7
February							4.1				22.8	3.3	36.8	4.7	26.7	1.5			39.1	4.4
March						2.2	3.9				37.2	3.2	29.7	11.8	26.4	7.9			60.7	9.1
April		2.4				2.2	4.4				28.7	4.9		13.2	14.7				50.1	6.0
May						2.5	4.1				47.4	2.0	26.1	4.4	50.3	11.4			36.4	15.1
June						3.7	5.8				39.4	10.6	33.3	10.1		11.2			64.8	10.2
July						2.6	5.3				40.7	7.8	32.6	13.4		16.0			31.4	11.2
August						2.8	5.4				32.8	9.7	25.7	11.4	63.9		51.9	15.4	48.1	11.4
September						3.7	7.0		57.4	8.6	38.6	14.4		9.0	29.9	13.4	42.1	10.1	47.2	15.3
October						1.5	5.9		39.0	11.3			39.4	18.1			55.1	14.3	49.6	14.2
November	.8					2.3	2.5		30.3	6.9	25.2	12.8	29.0	4.3		9.0	42.4	6.7	41.3	8.9
December						1.1	3.1		43.2	5.3	35.3	4.0	31.8	3.1		6.5	38.6	4.2	47.6	7.5
Yearly mean	.8	2.4				2.5	4.4		42.5	8.0	34.2	7.0	32.6	9.4	33.6	9.6	45.4	9.1	45.1	10.0
N/P									3.0		2.5		1.7		1.7		2.0		2.0	

[1] Odum, 1953; Hutton et al., 1956; Finucane and Dragovich, 1959, 1966; Dragovich et al., 1961; Saloman et al., 1964; Dragovich et al., 1966; Saloman and Taylor, 1968.

[2] To calculate the nitrogen-phosphorus ratio, μg.at./l. values for nitrogen and phosphorus have been converted to parts per million (p.p.m.) by multiplying by 0.014 (nitrogen) and 0.031 (phosphorus).

TABLE 5.—*Surface values of chlorophyll* a *(mg./m.*^{3}*), 1952–66, and primary production (G. C/m.*^{2}*/day), 1962–66, for areas of Tampa Bay, Fla.*[1]

Area	1952–53		1958		1962		1963		1964		1965		1966	
	Chlor. *a*	Primary prod.	Chlor. *a*	Primary prod.	Chlor. *a*	Primary prod.	Chlor. *a*	Primary prod.	Chlor. *a*	Primary prod.	Chlor. *a*	Primary prod.	Chlor. *a*	Primary prod.
Area I—Old Tampa Bay:														
January	2.0						3.3	0.32			1.6	0.44	8.1	0.22
February							1.7	.11					3.5	.14
March							6.8	.72	4.0	0.34	2.4	.29	3.6	.16
April	3.1						9.4	.61	6.3	1.34	7.1	.81	5.0	.24
May	3.1						3.9	.54	3.7	.61	2.1	.35	9.8	.37
June							10.4	1.26	1.8	.29			5.0	.28
July							20.0	.90	5.3	.48			5.1	.22
August							8.9	.96	3.9	.32	26.6	1.26	7.7	.43
September	9.9				10.9		15.2	.56	2.6	.32	9.1	.52	5.0	.28
October					15.2	0.97	5.9	.51			8.9	.41	6.5	.46
November					5.0	.39			5.1	.45	11.8	.56	3.1	.17
December					6.4	.41			12.6	1.13	8.1	.30	5.2	.25
Yearly mean	4.5				9.4	.59	8.6	.65	5.0	.59	8.6	.55	5.6	.27
Area II—Hillsborough Bay:														
January	4.6						25.9	1.79			5.5			
February							9.3	.71				.77		
March							25.7	.57	8.3	.51	7.1			
April	4.6						4.7	.23	27.5	1.41	3.6	.79		
May	7.9						16.1	1.26	.8	.33	6.0	.43		
June							4.9	.25	1.6	.13		.99		
July							27.1	1.66	13.7	2.08				
August							35.4	1.49	26.5	1.43				
September	13.3				18.8		29.0	.79	16.2	.70				
October					10.2	.19	11.3	.77						
November					14.7	.95			4.9	.23				
December					16.0	.61			8.2	.62				
Yearly mean	7.6				14.9	.58	18.9	.95	12.0	.83	5.6	.75		
Area III—Tampa Bay:														
January							2.2	.53			1.0	.14	7.6	.26
February							10.4	.82					6.4	.26
March							5.7	.64	4.7	.54	5.5	.65	5.6	.26
April	6.9						11.5	.64	13.4	.62	5.4	.37	6.3	.31
May							4.4	.42	4.1	.43	3.1		4.1	.16
June							3.6	.21	.6	.30			5.3	.30
July							3.0	.19	10.6	.77			8.4	.36
August							3.9	.43	4.3	.37	10.8	.52	12.7	.65
September	9.3				7.5		9.2	.56	8.7	.50	22.4	.74		
October					5.0	0.57	5.1	.22			4.8	.22		
November					11.0	.73			3.7	.21	10.5	.52		
December					3.0	.31	7.6	.59	2.6	.10	10.7	.44		
Yearly mean	8.1				6.6	.53	6.1	.48	5.9	.43	8.3	.45	7.1	.32
Area IV—Tampa Bay Entrance:														
January	1.7										2.2	.30	1.2	.04
February							2.8	.32					3.3	.14
March							1.6	.21	1.7	.38	3.9	.66	2.3	.10
April							1.9	.27	3.0	.54	2.4	.36	1.4	.07
May	3.1						6.1	.69	.7	.23	1.2	.10	2.5	.11
June							9.3	.54	.4	.07			2.6	.10
July							3.3	.47	2.9	.14			8.4	.40
August							2.8	.28	3.1	.31			6.9	.35
September	10.0				1.6		6.0	.75	5.3	.79	9.9	.52	8.2	.46
October					8.2	.57	1.9	.25			8.9	.37	21.1	.95
November					5.0	.49			11.4	.57	3.2	.15	5.9	.22
December					5.7	.41	3.8	.16	.7	.12	6.4	.26		
Yearly mean	4.9				5.1	.49	4.0	.39	3.2	.35	4.8	.34	5.8	.27

See footnote at end of table

TABLE 5.—*Surface values of chlorophyll a (mg./m.³), 1952–66, and primary production (G.C/m.²/day), 1962–66, for areas of Tampa Bay, Fla.*[1]—Continued

Area	1952–53 Chlor. *a*	1952–53 Primary prod.	1958 Chlor. *a*	1958 Primary prod.	1962 Chlor. *a*	1962 Primary prod.	1963 Chlor. *a*	1963 Primary prod.	1964 Chlor. *a*	1964 Primary prod.	1965 Chlor. *a*	1965 Primary prod.	1966 Chlor. *a*	1966 Primary prod.
Area V—Boca Ciega Bay:														
January							7.5	.30	11.1	.47			9.1	.30
February							7.9	.27	7.4	.32			1.8	.07
March							6.2	.30	7.9	.41			19.3	.89
April	5.1						3.8	.28	4.5	.30			13.8	.67
May	3.4						5.0	.34	3.4	.22			4.7	.18
June					9.0	.71	6.5	.37	3.9	.25			15.8	.89
July			3.5		8.3	.51	7.6	.43					10.6	.45
August					8.7	.44	6.2	.36					9.2	.53
September					9.0	.44	10.0	.46			5.1	.26	8.1	.47
October					8.8	.47	5.0	.27			10.1	.41	11.6	.61
November	3.1				9.2	.40	6.7	.31			9.0	.41	5.5	.31
December					7.4	.32	9.5	.40			15.0	.59	7.1	.41
Yearly mean	3.9		3.5		8.6	.47	6.8	.34	6.4	.33	9.8	.42	9.7	.48

[1] Marshall, 1956; Pomeroy, 1960; May and Johnson, unpublished data, on file at Bureau of Commercial Fisheries Biological Laboratory, St. Petersburg Beach, Fla.; Saloman et al., 1964; Finucane and Dragovich, 1966; Dragovich et al., 1966; Saloman and Taylor, 1968.

Compared with average concentrations of phosphorus and nitrogen in surface sea water, Boca Ciega Bay has about five times more phosphorus and four times as much nitrogen (Sverdrup, Johnson, and Fleming, 1942; Armstrong, 1965; Vaccaro, 1965). Even when compared with other estuarine systems of the Atlantic and Gulf Coasts, Boca Ciega Bay and the other areas of Tampa Bay rank high in these elements (Newcombe and Brust, 1940; Williams, 1954; Riley and Conover, 1956; NcNulty, Reynolds, and Miller, 1959; Lackey, 1963; Mackenthun, 1965; Saville, 1966).

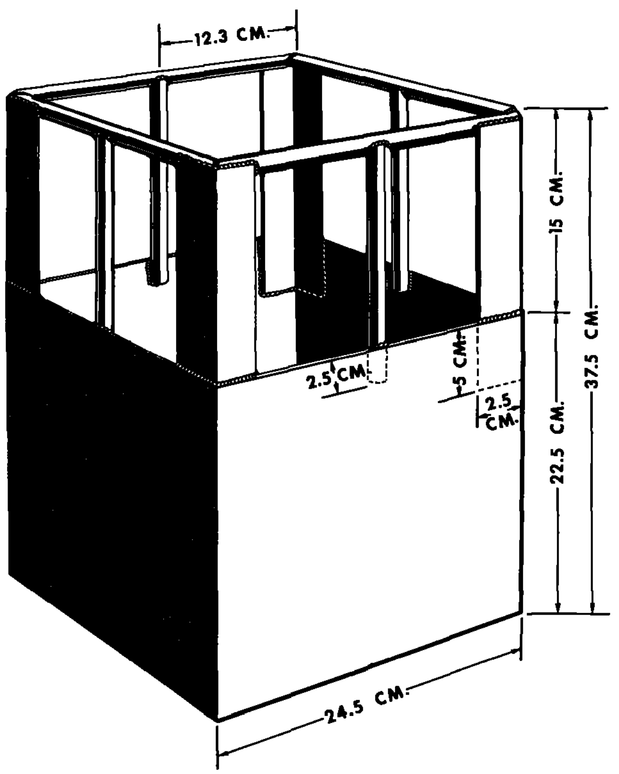

FIGURE 12.—Bottom sampler of stainless steel (0.25 m.²) used for sampling vegetation and infauna.

Under natural conditions, phosphorus and nitrogen enter Tampa Bay mainly through discharge from rivers and springs (Dragovich and May, 1962; Dragovich, Kelly, and Goodell, 1968). The major contribution of phosphorus enters Hillsborough Bay through the Alafia River from mining operations in extensive phosphatic deposits east of Tampa. On the basis of water analyses made in the early 1950's phosphorus in Hillsborough

TABLE 6.—*Mean total phosphorus from surface and bottom water of undredged and dredged sampling stations in Boca Ciega Bay, Fla., 1963–64*

	Undredged Surface	Undredged Bottom	Dredged Surface	Dredged Bottom
	µg.at./l.			
1963				
November	13.9	14.5	5.3	9.9
1964				
February	6.4	5.9	4.3	4.1
May	7.6	6.8	5.2	7.9
August	13.0	12.3	7.1	10.8
Mean	10.2	9.9	5.5	8.2

Bay has remained at about its present level since 1952 or before (Odum, 1953)—see table 4. In areas of the estuary less affected by mining runoff, high concentrations of phosphorus and nitrogen recorded since the early 1960's are due to an increase in industrial and domestic sewage. Population in the area around Tampa Bay was less than one-half million in 1950, rose to about three-fourths million by 1960, and is now near 1 million. As population rose, the method of sewage disposal was converted from septic tanks to treatment plant in the late 1950's and early 1960's. This change introduced treated sewage directly into all areas of the estuary. In Boca Ciega Bay, the mean annual concentration of total phosphorus rose from 2.5 μg.a./l. in 1954–58 to 4.4 in 1959, and 8 by 1961. At present, total phosphorus averages 10 μg.a./l. and total nitrogen 45.1 μg.a./l., and sewage volume is about 17 million gallons per day (secondary treatment) from outfalls located throughout the lagoon. Along with progressive eutrophication of Boca Ciega Bay, counts of coliform bacteria have risen so high that shellfishing has been prohibited near all outfalls and in all waters of the bay north of Pinellas County Bayway (fig. 13)—Pinellas County Health Department, personal communication.

Relative as well as total concentration of nitrogen and phosphorus influences the occurrence and abundance of marine life (Raymont, 1963). Within limiting values, studies of marine plankton indicate that growth and reproduction of marine phytoplankton are greatest when the ratio of nitrogen to phosphorus is 10 or higher (Odum, Lackey, Hynes, and Marshal, 1955; Lackey, 1963). In Boca Ciega Bay the observed N/P is about 2. The disproportionately high level of phosphorus may limit kinds and numbers of phytoplankton in the lagoon and perhaps explains why plankton blooms are infrequent and planktonic primary production is not extremely high (Dragovich, Kelly, and Kelly, 1965; Rounsefell and Dragovich, 1966; Dragovich and Johnson, 1966).

Attached algae and sea grasses also respond to eutrophy. McNulty (1961) noted an abundance of *Gracilaria blodgettii* Harvey, other red algae, and the green alga *Ulva lactuca* Linnaeus in Biscayne Bay, Fla., before pollution abatement. Wilkinson (1964) found a direct relation between eutrophication of a New Zealand estuary and marked increase of two green algae, *Ulva* sp. and *Enteromorpha* sp. He wrote that foul odor of hydrogen sulphide was emitted from decay of algal mats and that white paint was turned black on homes nearby. Production of hydrogen sulphide by *Enteromorpha* has also been studied by Baas Becking and Mackay (1956).

Species of *Gracilaria* have been implicated in reports of offensive odors arising from Hillsborough Bay (Florida State Board of Health, 1964). The Federal Water Pollution Control Administration is now investigating this matter. In Boca Ciega Bay, *Gracilaria* is present, as are *Ulva* and *Enteromorpha*. We observed windrows of *Ulva lactuca* in bayfill access canals after residents reported objectionable odors in the central part of the bay in the spring of 1965. Further nutrification of Boca Ciega Bay would increase growth of these and perhaps other filamentous algae that become fetid as they decompose.

TURBIDITY

Data from 1963–64 show that secchi discs were visible to depths greater than 150 cm. only in southern Boca Ciega Bay (PB–6), well away from bayfill developments (table 1). Here, average light transmission through the water column is 53 percent of incident radiation at about 40 cm. beneath the surface (Saloman et al., 1964). In contrast, water in the open bay nearer bayfills is turbid. Within protected waters of access canals, however, transparency approaches that of the lower bay. For example, average monthly light transmission in one canal was 45 percent at 40 cm. (Saloman et al., 1964). Even so, canal bottoms are far too deep to receive light required for the growth of sea grass.

Much of the silt and clay raised by dredging will eventually be removed from circulation in the lagoon by biological fixation and tidal transport (Dapples, 1942; Ginsburg and Lowenstam, 1958; Van Stratten and Kuenen, 1958; Phillips, 1960a; Lyntz, 1966). Until water is clarified by these processes, turbidity will continue to limit biological production in central and northern parts of Boca Ciega Bay.

CHLOROPHYLL *A* AND PRIMARY PRODUCTION

Neither chlorophyll *a* nor rate of planktonic primary production differed consistently in

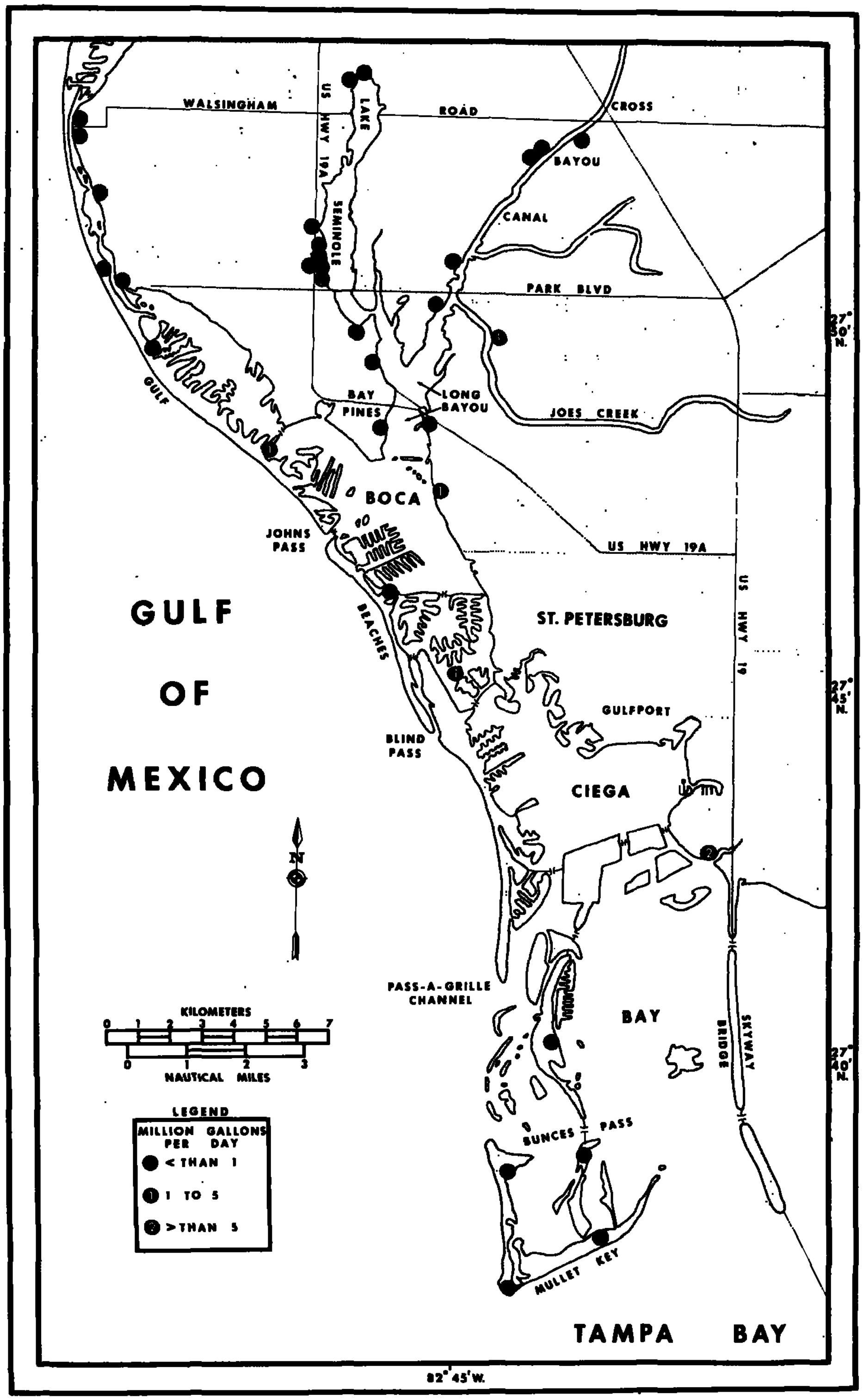

FIGURE 13.—Approximate sewer outfall locations and discharge volumes (secondary treatment) in Boca Ciega Bay, Fla. 1966.

dredged and undredged locations. Chlorophyll *a* did not fluctuate seasonally. Low primary production noted in February may be due to turbid conditions rather than lack of nutrients or limitation by another factor, such as temperature (table 1). Except for higher values in extremely eutrophic Hillsborough Bay, pigment and production figures (table 5) are both similar to those recorded for other areas of the estuary as well as other estuarine waters of the southeast (Ragotzkie, 1959; Odum and Wilson, 1962; Williams, Murdock, and Thomas, 1966; Saville, 1966; Dragovich and Johnson, 1966).

In 1962–66, mean chlorophyll *a* in Boca Ciega Bay was 8.6 mg./m.^{3} and mean primary production by phytoplankton was 0.40 G.C/m.^{2}/day. The most extensive data for chlorophyll *a* and primary production in Boca Ciega Bay are from daily observations by May and Johnson [8] between June 1962 and June 1964 (table 5). These figures show a slightly lower mean annual value for chlorophyll *a* (7.3 mg./m.^{3}) but the same value for mean annual production (0.40 G.C/m.^{2}/day). Earlier data indicate about a twofold rise in chlorophyll *a* since 1952, following nutrification of the lagoon by sewage (table 5).

Actually, the productivity figures given above for Boca Ciega Bay are misleading and far too low because sea grasses and unicellular and filamentous benthic algae add to the production that was recorded only for phytoplankton. Pomeroy (1960), who considered photosynthetic contributions by all hydrophytes in his study of primary production in lower Boca Ciega Bay, concluded that an average value is about 5 G.0_2/m.^{2}/day. Odum and Hoskin (1958) gave a value of about 5 grams of dry organic material per day. On the basis of an allowance of 0.5 G. of C for each gram of organic matter produced (May, 1966), this is equivalent to about 2.5 G.C/m.^{2}/day or nearly six times the estimates of daily production in the lagoon by phytoplankton alone. The main point to be made is that under natural conditions primary production from a variety of photosynthetic taxa far exceeds production in turbid waters where photosynthetic activity of benthic flora has been reduced or eliminated (Blinks, 1955; Odum, McConnell, and Abbott, 1958; Pomeroy, 1959).

[8] See footnote 3.

SEDIMENTS

Sediments of Tampa Bay are mainly a firm mixture of sand and shell containing little silt or clay (Goodell and Gorsline, 1961). Soft deposits are localized in upper reaches of Old Tampa Bay, Hillsborough Bay, natural depressions, and dredged bottom of bayfill access canals, where the weight percentage of silts and clays may exceed 90 percent. In Boca Ciega Bay the sediments in undredged areas averaged 94 percent sand and shell whereas the sediments in dredged canals averaged 92 percent silt and clay (table 7).

The ooze measured in two dredged pockets between bayfill fingers extended downward to a depth of about 3.6 m. The upper 30 cm. was dark, semifluid, and sulphurous; below was an unconsolidated horizon of gray clay. The predominantly organic upper layer consists of decomposing detritus that accumulates in the canals. The origin of the underlying clay has not been determined, but it seems likely that a thick stratum of clay was uncovered in the dredging which extended some distance below a bay floor veneer of sand and shell. To judge from the uniformity of the viscous clay layer, this material was redeposited after dredging ceased and now lies too deep to be reworked by normal water movements. Clay settles out of suspension slowly and may form deposits to 364 m. or more beyond dredging sites (Phillips, 1960a; Mackin, 1961; Hellier and Kornicker, 1962; Odum, 1963; Woodburn, 1965). Thus, resident benthos far from fill and borrow areas may be suffocated by sedimentation from dredging operations.

MACROBIOTA

Analysis of biological samples in Boca Ciega Bay supplements earlier studies in undredged areas and contrasts these findings with a scarcity of macrobiota found in bayfill canals.

DIVERSITY AND ABUNDANCE

In the first comprehensive survey of Boca Ciega Bay, Hutton et al. (1956) recorded nearly 200 plant and animal species from marine and tidewater communities and presented fishery statistics that attest to the importance of commercial and sport species. Later a notable addition was made to the list of algal species by Phillips (1960b); Springer and Woodburn (1960) brought the list of fishes from Tampa Bay up to 108; and unpublished work by Bullock and Boss[9] increased the recorded number of mollusks in Boca Ciega Bay from 30 to 175. Nearly 700 species of marine plants and animals have been identified from our sampling in 1963–64 and from other work in the area. Among the major taxa are about 180 species of mollusks, 120 polychaete worms, 60 decapod crustaceans, 20 echinoderms, 110 fishes, and 200 plants.

Comparative records show that stations inside deeply dredged canals contain less than 20 percent of the species we recorded for the bay. If fishes are excluded from the species total, nearly 100 percent of the organisms recorded come from collections made outside dredged areas. Invertebrates collected in bayfill canals consisted of only a few polychaete worms, mollusks, blue crabs, and pink shrimp. We conclude, therefore, that soft deposits in the canals are in some way unsuitable for most bottom invertebrates found in other areas of the bay. Thorson (1957) and others have demonstrated that larvae of many benthic forms are sensitive to sediment composition and will not metamorphose from a planktonic stage until contact is made with suitable bottom. In 10 years, recolonization of canal sediments has been negligible and it appears doubtful that soft sediments of bayfill canals will

[9] See footnote 2.

TABLE 7.—*Comparison of sediments at undredged and dredged stations in Boca Ciega Bay, Fla. (1963–64), showing depth, mean grain size, percentage of shell and sand by weight (particle size $<4\ \phi$), percentage of silt and clay by weight (particle size $>4\ \phi$), and percentage of total carbon by weight*

Station	Depth	Mean grain size	Percentage of shell and sand by weight	Percentage of silt and clay by weight	Percentage of total carbon by weight
Undredged:	*Meters*	*Phi units (φ)* [1]	*Percent*	*Percent*	*Percent*
BCA	2	3.5	81	19	1.7
BCH	2	2.5	95	5	.5
BCC	1	2.5	96	4	.7
BCE	7	2.6	99	1	.2
BCG	1	2.3	97	3	.6
BCI	3	3.4	87	13	1.3
BCL	1	1.9	98	2	.6
BCM	2	3.0	95	5	.7
PB-6; BCN	3	1.4	98	2	.4
D-1	3	2.8	98	2	.4
D-2	1	2.5	98	2	.4
D-3	1	2.5	88	12	1.4
D-5	2	2.6	97	3	.8
D-6	1	2.8	96	4	.8
D-9	2	2.8	96	4	.5
D-10	2	3.0	89	11	1.0
PB-3; D-11	1	2.9	92	8	.4
D-17	2	2.8	96	4	.5
D-18	1	3.4	85	15	1.3
PB-1	2	2.6	99	1	.3
PB-5	3	2.5	98	2	.4
Means	2	2.7	94.2	5.8	.7
Dredged:					
BCH	3	7.1	12	88	4.6
D-4	4	6.5	6	94	.6
D-7	4	6.3	5	95	8.9
D-8 [2]	2	4.6	60	40	6.6
D-12 [2]	1	.8	99	1	.2
D-13 [3]	4	4.0	83	17	.9
D-14	4	7.0	7	93	3.8
PB-2; D-15	4	7.0	6	94	1.3
D-16	4	6.3	14	86	1.3
PB-4	4	----------	----------	----------	----------
Means	3.9	6.7	8.3	91.7	3.4

[1] The phi unit is a logarithmic transformation of the Wentworth grade scale of particle size (Krumbein and Pettijohn, 1938).
[2] Berm of canal not included in calculation of mean.
[3] Transitional bottom not included in calculation of mean.

ever support a rich or diverse infauna. The existence of soft sediments does not necessarily preclude the presence of a diverse and abundant bottom fauna (Barnard and Hartman, 1959; Sanders, 1960), but where sediments are highly organic, deposition rapid, and dissolved oxygen low, the benthos is likely to be impoverished (Pratt, 1953; Bader, 1954; Reish, 1959; McNulty, Work, and Moore, 1962; McNulty, 1966).

Forty-nine species of fishes were caught at stations in dredged canals. None were demersal, and the absence of this type of fish in the catch may be due to lack of food organisms on and in bottom deposits. In contrast, 80 species of fish were collected at stations outside bayfill canals. Even though waters in the open bay accounted for a greater number of fish species, 30 percent more fish were netted within dredged canals. One species, the bay anchovy, *Anchoa mitchilli* (Valenciennes), was most common in the canal catch but the Cuban anchovy, *Anchoa cubana* (Poey), and the scaled sardine, *Harengula pensacolae* (Goode & Bean), were also abundant.

BIOMASS AND PRODUCTION

The major benthic habitats in Boca Ciega Bay are turtle grass beds, unvegetated bottom, and oyster reefs. All contain large numbers of species, but the grass bed community is outstanding because it is widespread and highly productive.

Extensive beds of turtle grass now exist only south and east of the Pinellas County Bayway (fig. 1). Poorer stands are located in central and northern parts of the bay, but only in very shallow water. Representative beds were sampled to compare standing crop in the relatively undisturbed southern section of the bay (area A) with that in extensively dredged central (area B) and northern (area C) sections (fig. 10). Dry whole weight of turtle grass in areas A, B, and C averaged 1,198, 1,008, and 320 g./m.^{2}, respectively. The figure for area C agrees with other biomass estimates of turtle grass in the Gulf of Mexico, but values from areas A and B are two to three times greater (Phillips, 1960a; Odum, 1963). Maximum development of turtle grass probably occurs in the Caribbean where Burkholder, Burkholder, and Rivero (1959) have observed stands having a biomass of 2,800 g./m.^{2} dry weight.

Pomeroy (1960) reported an average biomass of about 81 g./m.^{2} for turtle grass sampled randomly along a transect across lower Boca Ciega Bay. This figure seems low, but no doubt includes values from samples in some sparsely vegetated areas. Since bayfills cover bare and vegetated bottom, 80 g./m.^{2} is probably a reasonable factor for calculating total biomass of turtle grass that has been covered by bayfills in Boca Ciega Bay. Using 1,400 hectares (3,500 acres) as the filled area of the bay, we compute that standing crop of turtle grass buried by filling is at least 1,133 metric tons. If the area of bayfill canals and other borrow areas were included in this calculation, the figure would be nearly doubled.

Our estimate of total primary production in Boca Ciega Bay is based on work by Pomeroy (1960) and studies in vegetated Texas bays by Hellier (1962) and Odum and Wilson (1962). An average production figure would be about 5 G.O_2/m.^{2}/day (ca. 2.5 G.C/m.^{2}/day) which is roughly equivalent to 18,206 kg./ha./yr. (16,243 lbs./acre/yr.) of dry organic material or an annual loss of about 25,841 metric tons (28,425 tons) for the 1,400 hectares (3,500 acres) of the bay now filled.

No quantitative study has been made of biomass of animals living among blades of turtle grass, although Moore (1963) and Stephens (1966) estimated the abundance of small invertebrates, and drop-net samples in Texas bays gave data on some larger invertebrates and fishes (Hellier, 1958, 1962; Jones, Ogletree, Thompson, and Klenniken, 1963). The drop-net studies gave a mean annual standing crop of about 15 g./m.^{2} wet weight (3 g./m.^{2} dry weight—20 percent of wet weight) (Vinogradov, 1953). Annual fish production is also about 3 g./m.^{2} in Texas bays or about 30 kg./ha./yr. (27 lbs./acre/yr.) (Hellier, 1962). This figure is below an estimate by Sykes (1963) for fishery production in Gulf estuaries (52 kg./ha./yr., or 46 lbs./acre/yr.). Using Sykes' estimate, we calculate that filling of 1,400 hectares (3,500 acres) has reduced fishery production in Boca Ciega Bay by 73 metric tons (80 tons) per year.

Biomass of invertebrate infauna living among roots and rhizomes of turtle grass was calculated from wet whole weight of animals recovered by sieving 0.25 m.^{2} plug samples collected in areas A, B, and C. At area D, the infauna biomass was determined in the same manner for unvegetated bottom (fig. 10). Mean wet weights of infauna in areas A, B, C, and D were 912, 560, 128, and 80 g./m.², respectively. Thus, the density of sea grass and abundance of infauna were positively correlated. If 85 percent of wet whole weight is weight of contained water and inert structures, dry weight of infauna from luxuriant beds of turtle grass in the lower bay was about 137 g./m.² This figure is high in comparison with other biomass figures for estuarine waters (Sanders, Goudsmit, Mills, and Hampson, 1962). Bayfills in Boca Ceiga Bay have reduced the standing crop of bottom invertebrates by about 1,812 metric tons (1,993 tons)—calculated from relatively low infaunal biomass of area C.

Figures for the annual production of infauna are much higher. Sanders (1956) estimated infaunal production at two to five times the standing crop and indicated that the larger factor very likely applied in tropical situations. We arbitrarily selected four as a multiplier, and calculated infaunal production in the best stands of turtle grass at about 548 g./m.²/yr. (5,466 kg./ha./yr., or 4,877 lbs./acre/yr. dry weight). Even in poor grass beds at area C infaunal production would be about 768 kg./ha./yr. or 685 lbs./acre/yr. This figure multiplied by the 1,400 hectares (3,500 acres) now in bayfills puts the loss of infaunal production at about 1,091 metric tons (1,200 tons/yr.). If more refined collecting had been done (screening at less than 0.701-mm. mesh), the addition of biomas from meiobenthos would have added considerably to the figures reported for macrobenthos alone, and the annual production of meiobenthos would very likely be equivalent or somewhat greater than the estimate for macrobenthos (Weiser, 1960; McIntyre, 1964).

ESTUARINE EVALUATION

Products and other values provided by the Nation's tidewaters are so numerous and diverse that their true worth is difficult to compute. Nonetheless, a number of attempts have been made to estimate the cash value of estuarine acreage. In the northeast, notable contributions were made by Shuster (1959); Fogg (1964); Jerome, Chesmore, Anderson, and Grice (1965); Jerome, Chesmore, and Anderson (1966); and Cain (1966). Pertinent details of estuarine evaluations along the Gulf of Mexico were abstracted and annotated by Woodburn (1965).

On the basis of these estimates, we conclude that fishery production alone in Tampa Bay estuary has an annual value of about $741/ha. ($300/acre). In addition, these waters are used by public utilities, industry, and commerce and serve recreational requirements of nearly a million residents [10] and 1½ million annual vacationers.[11] Hence, total worth of each water acre in the estuary can be conservatively estimated at $988/ha. ($400/acre) per year. At this rate, the 1,400 hectares (3,500 acres) covered by bayfills in Boca Ciega Bay represent an annual loss of about $1.40 million, which if capitalized at 6 percent would total a natural investment of $23.3 million. This accounting is not complete because the undesirable aspects of coastal development extend well beyond bulkheads and outfalls.

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[10] Tampa data, Greater Tampa Chamber of Commerce, Tampa. Fla.

[11] St. Petersburg Times, July 19, 1966.

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