HYDROLOGICAL AND BIOLOGICAL CHARACTERISTICS OF FLORIDA'S WEST COAST TRIBUTARIES[1]

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ABSTRACT

Data are given for 10 stations in the Hillsborough, Alafia, Little Manatee, Manatee, Myakka, Peace, and Caloosahatchee Rivers, which flow into west Florida bays. Variations in temperature, salinity, chlorophyll "a," dissolved oxygen, total phosphorus, inorganic phosphate-phosphorus, copper, and iron were recorded over a 13-month period. The variations are discussed in terms of differences in precipitation, river discharges, and general geological properties of river basins. Certain hydrological conditions of the tributaries are compared with the conditions of the adjacent neritic waters of the Gulf of Mexico.

Thermal differences between surface and bottom were negligible. The temporal distribution of salinity was influenced by precipitation. Distribution of total phosphorus and inorganic phosphate-phosphorus was related to the underlying phosphatic formations of the various river basins. Maximum values of total dissolved oxygen occurred in winter and minimum in summer; no anaerobic conditions were encountered. Concentrations of chlorophyll "a," copper, and iron were higher in the rivers than in the adjacent sea.

The quantity of nutrients contributed by rivers to the sea is determined largely by the volume of river flow, not by the actual concentrations of the nutrients. The possible relation between the mean input of various materials by the tributaries, and the presence of the Florida red-tide organism, *Gymnodinium breve* Davis, was tested. A correlation between iron and *G. breve* was significant at the 80-percent level.

Ecological studies were made of the waters of Tampa Bay, Charlotte Harbor, and the adjacent Gulf of Mexico as part of an investigation of the Florida red-tide organism, *Gymnodinium breve*. Red tide in waters along the southwest Florida coast is associated with dense concentrations of *G. breve*, discolored water, and fish kills.

Red tides throughout the world occur primarily in coastal areas and usually in periods of heavy rainfall and increased river discharge. The presence and growth of phytoplankton in coastal waters depend largely on the quantity and quality of inorganic and organic nutrients, particularly trace metals and external metabolites (Provasoli, 1958).

Rivers make annual additions of nutrients to the sea. In evaluating the effects of Florida west coast tributaries on red-tide outbreaks and estuarine productivity, a thorough knowledge of the hydrology of the tributaries may be helpful. Because published information on the hydrology of these streams is limited, a survey was undertaken to assess hydrological characteristics of seven major rivers that flow into Gulf estuaries. Dragovich and May (1962) listed publications concerned with the hydrology of streams of the west coast of Florida.

We studied monthly variations in certain hydrological and biological properties of the Myakka, Peace, and Caloosahatchee Rivers which enter the Charlotte Harbor estuarine system. These streams were selected because of their importance to red-tide problems and coastal oceanography. The Hillsborough, Alafia, Little Manatee, and Manatee Rivers, which are tributaries of Tampa Bay, were included because new ecological factors were added to those measured

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in previous studies (Dragovich and May, 1962).

Temperature, salinity, chlorophyll "a," oxygen, total phosphorus, inorganic phosphate-phosphorus, copper, and iron were measured.

Copper was included in our past studies and in the present one because its high toxicity to laboratory cultures of *G. breve* suggested that it might be a limiting factor in the physiology of this species in natural waters. It was determined only in the Myakka, Peace, and Caloosahatchee Rivers because earlier studies in Tampa Bay tributaries revealed that the concentrations there were nontoxic to *G. breve* (Dragovich and May, 1962).

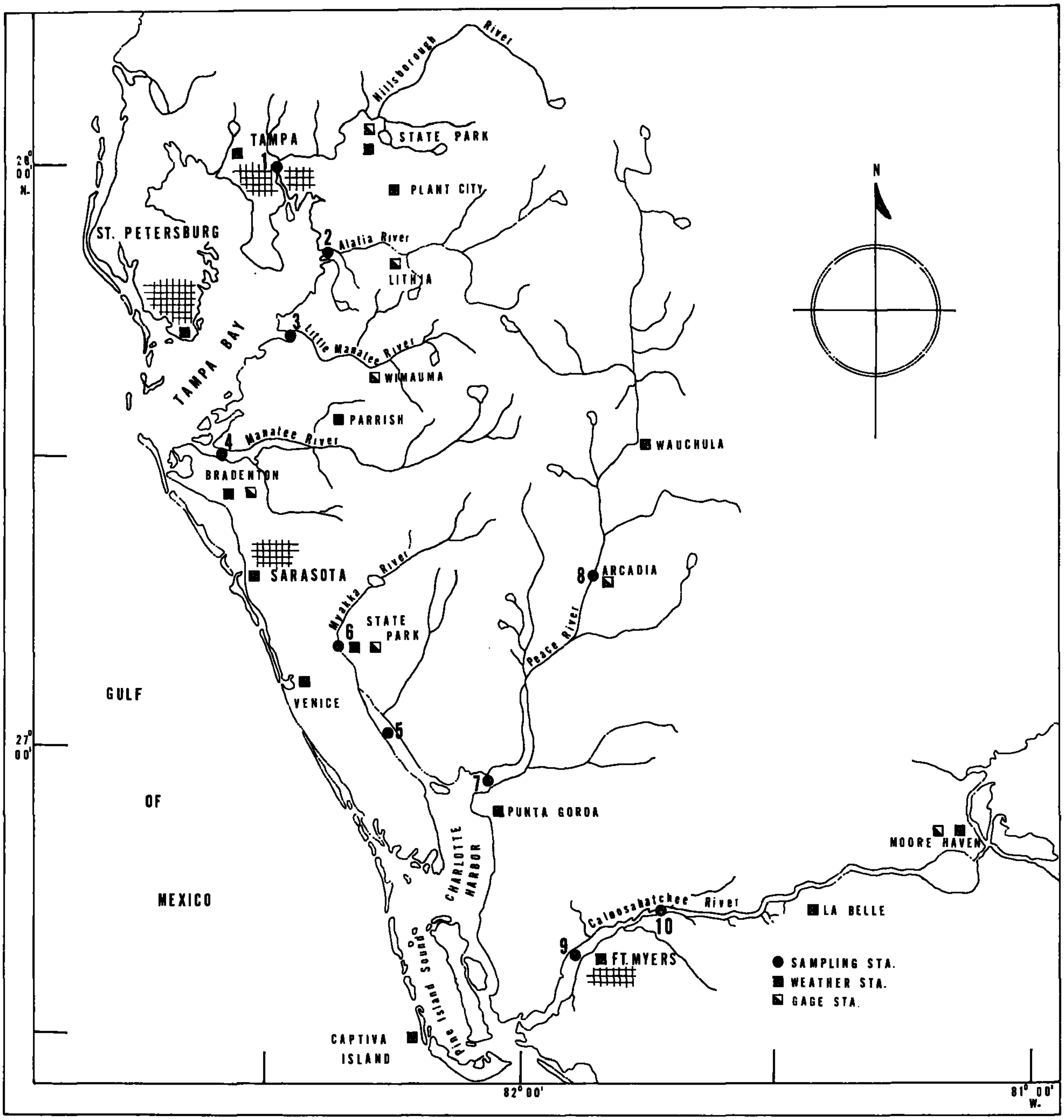

FIGURE 1.—West coast of Florida showing rivers, sampling locations, and weather and gage stations.

SAMPLING PROCEDURES AND LABORATORY TECHNIQUES

The study began in January 1964 and continued through January 1965. The sampling consisted of monthly collections of water samples near the surface and bottom at 10 stations (fig. 1). Station depths ranged from 1.8 to 4.6 m. Water samples at all stations were collected with a modified Van Dorn sampler (Van Dorn, 1957). Samples for total phosphorus and inorganic phosphate-phosphorus were immediately put into 200-mm. culture vials capped with polyethylene-lined screw-caps, and quick-frozen. Samples for the determination of copper and oxygen were transferred into 250-ml. glass-stoppered bottles, and for salinity into 113-ml. prescription bottles. Water samples for the determination of iron and chlorophyll were placed in polyethylene containers and sterile 500-ml. Erlenmeyer flasks.

The following physical and chemical methods of analysis were employed:

Water temperature—mercury thermometer calibrated to the nearest 0.1° C.

Salinity—Mohr-Knudsen method (Knudsen, 1901).

Inorganic phosphate-phosphorus—Robinson and Thompson (1948) method.

Total phosphorus—Harvey (1948) method.

Total dissolved copper—Hoste, Eeckhout, and Gillis (1953) method.

Total iron—Armstrong (1957) method.

Dissolved oxygen—Winkler method (Jacobsen, Robinson, and Thompson, 1950).

Chlorophyll "a"—Richards and Thompson (1952) method.

Samples for copper analysis were filtered, but not those for total phosphorus and iron. The iron and total phosphorus values represent the respective elements in true solution and particulate form combined.

DISTRIBUTION OF METEOROLOGICAL, HYDROLOGICAL, AND BIOLOGICAL PROPERTIES

PRECIPITATION

Data on precipitation are from the Annual Summary of Climatological Data, 1964, prepared by the Environmental Science Services Administration, U.S. Department of Commerce. Stations used were: Tampa, Hillsborough River State Park, and Plant City for the Hillsborough and Alafia Rivers; St. Petersburg, Parrish, and Bradenton for the Little Manatee and Manatee Rivers; Sarasota, Venice, and Myakka for the Myakka River; Wauchula and Punta Gorda for the Peace River; and Captiva Island, Fort Myers, La Belle, and Moore Haven for the Caloosahatchee River (fig. 1).

From January 1964 to January 1965 the mean annual precipitation was 135.1 cm. for Tampa Bay and 108.2 cm. for the Charlotte Harbor-Pine Island Sound area. The period July through September contributed 54 percent and February 10.5 percent of the total precipitation. Minimum and maximum mean monthly precipitation values were 6.6 cm. and 267.5 cm. in the area of the Hillsborough and Alafia Rivers.

RIVER DISCHARGE

The office of the U.S. Geological Survey, Branch of Surface Water, Ocala, Fla., supplied information on river discharges at seven stations (fig. 1). These stations gave a combined flow of 2,566,-729,830 m.[3] from all rivers from January 1964 through January 1965 (grand total discharged). Volumes of water were highest in the Hillsborough and Peace Rivers (figs. 2, 8, and 9). River flow was highest in periods of heavy rainfall (figs. 2–11).

SALINITY

Only two stations (6 and 8) possessed limnetic characteristics throughout the period of study. Salinities at the remaining stations ranged from 0.12 p.p.t. (parts per thousand) at stations 9 and 1 during the rainy season to 28.93 p.p.t. at station 4 in May just before the onset of the rainy season.

The true temporal and vertical distribution of salinity cannot be assessed from these observations because the samples were collected without regard to tidal stage. Nevertheless, the rainfall-river discharges and salinity showed a close inverse relation (figs. 2, 4, 6, and 11). At a few stations (1, 5, and 10) salinity reached 0.12 p.p.t. during, or immediately following, periods of heavy rainfall.

The difference in salinity between the surface and bottom at all stations varied from 0 to 13.11 p.p.t. Vertical mixing was relatively good at stations 4, 5, 7, 9, and 10. The most pronounced vertical differences of salinity were at stations 1, 2, and 3, near the mouths of the Hillsborough, Alafia, and Little Manatee Rivers.

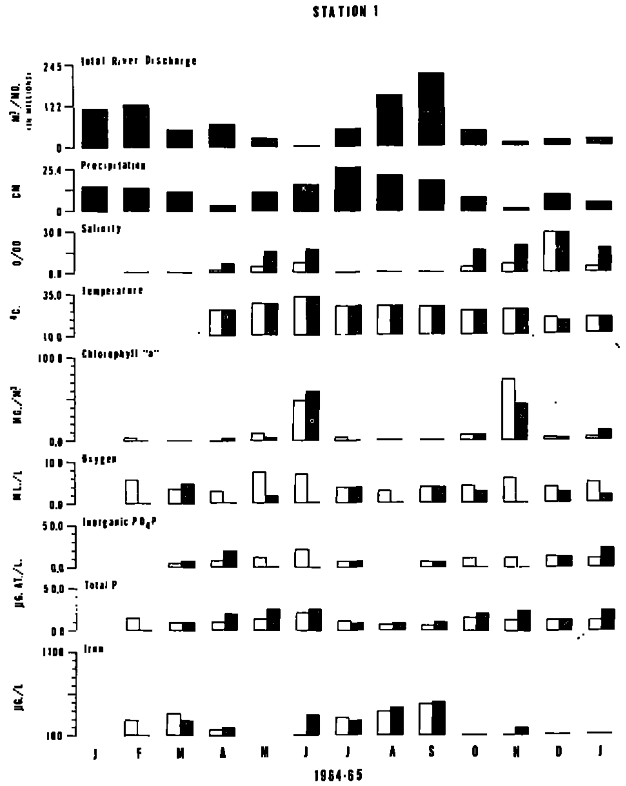

Figure 2.—River discharge, precipitation, and hydrological properties at station 1, Hillsborough River, Fla., January 1964 to January 1965. (Open bars=surface; solid bars=bottom.)

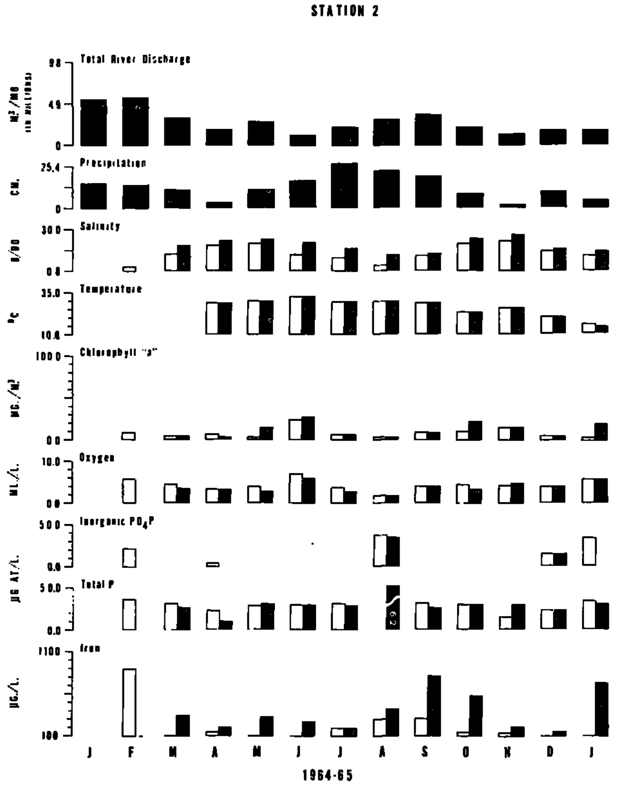

Figure 3.—River discharge, precipitation, and hydrological properties at station 2, Alafia River, Fla., January 1964 to January 1965. (Open bars=surface; solid bars=bottom.)

Salinity is a limiting factor in the distribution of many marine and estuarine organisms, but reliable data on the relation of estuarine organisms to salinity are scarce (Gunter, 1961). The unstable salinity at most stations was an ecological barrier to stenohaline and to some euryhaline organisms. Conditions were suitable only to forms that can exist over the entire salinity range from fresh water to sea water.

Since the favorable salinity range for the growth of *Gymnodinium breve* lies between 21 and 37 p.p.t. (Rounsefell and Dragovich, 1966), salinities at the river stations were seldom favorable for its growth.

TEMPERATURE

The annual temperature ranges during this study were the observed tolerance ranges for fishes (Springer and Woodburn, 1960) and invertebrates (Dragovich and Kelly, 1964) in Tampa Bay and for resident biota in Florida Bay (Tabb and Manning, 1961).

The water temperature varied from 12.8° to 32.4° C.; monthly changes in all rivers and stations were similar (figs. 2–11). Temperatures were high from April through September (highest in June and July 1964), and low in December, January, and February (lowest in January 1965).

Temperature differences between surface and bottom were less than 0.5° C. in about 92 percent of the observations; twice they exceeded 1° C. Temperatures at the stations with brackish water were affected by displacement of water masses during tidal oscillations.

CHLOROPHYLL "a"

Concentrations of chlorophyll "a" varied from 1.3 to 245.5 mg. per cubic meter. The highest individual and mean values for the entire period were at station 8 in the Peace River (fig. 9), where mean surface and bottom concentrations were 82.3 and 49.2 mg. per cubic meter. At other stations, corresponding values varied from 3.9 to

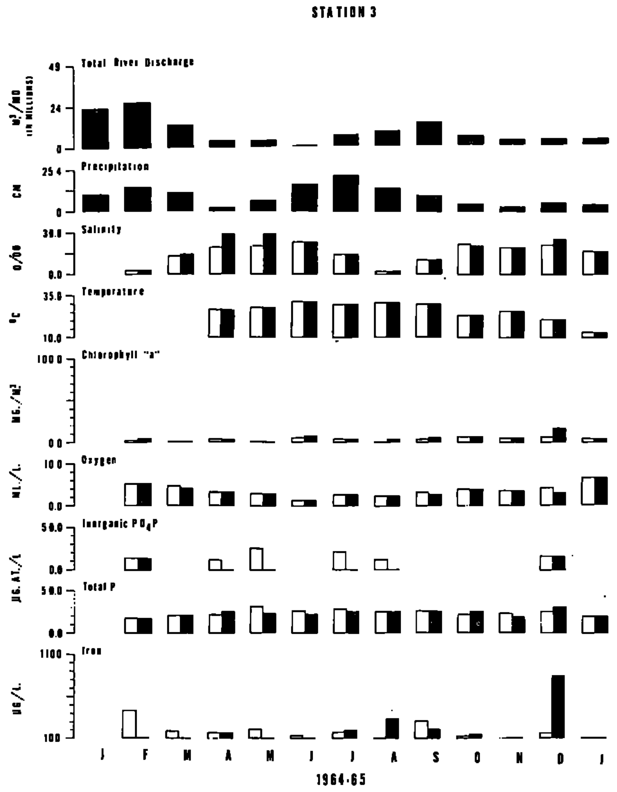

Figure 4.—River discharge, precipitation, and hydrological properties at station 3, Little Manatee River, Fla., January 1964 to January 1965. (Open bars=surface; solid bars=bottom.)

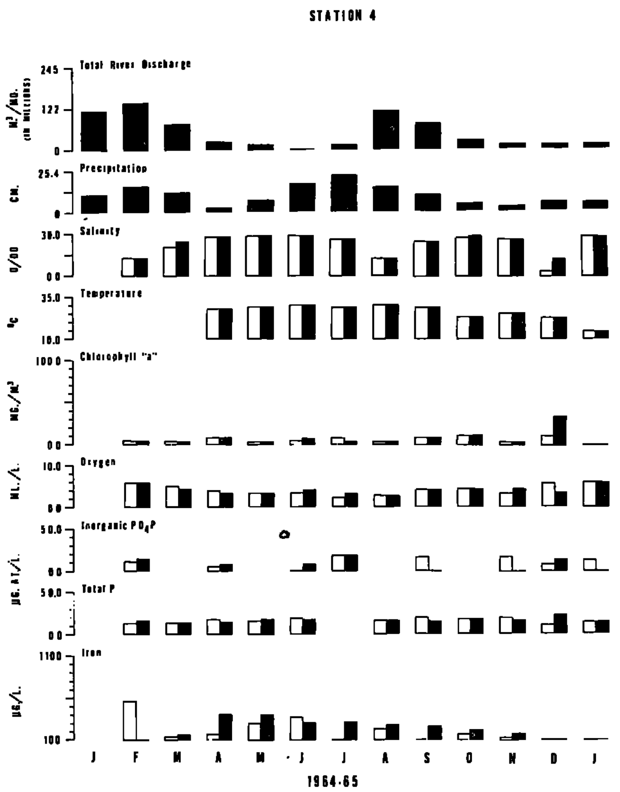

Figure 5.—River discharge, precipitation, and hydrological properties at station 4, Manatee River, Fla., January 1964 to January 1965. (Open bars=surface; solid bars=bottom.)

17.9 mg. per cubic meter; in 74 percent of the observations they were below 10 mg. per cubic meter.

The temporal distribution of chlorophyll "a" was dissimilar between stations (figs. 2–11). The expected peaks during phytoplankton blooms in the spring or fall did not appear at all stations. The production was lowest in February, March, May, July, and August 1964 and in January 1965.

Concentrations of chlorophyll "a" at all river stations were higher than the corresponding values in the adjacent Gulf of Mexico (table 1). The extremely high means for surface and bottom at the upstream station in the Peace River were 30.2 and 17.8 times greater than the corresponding values from the upper section of Charlotte Harbor. The mean surface concentration of chlorophyll "a" at this river station was comparable to the maximum reported from East Lagoon, Galveston, Tex., and higher than the mean values reported from Alligator Harbor and the Dry Tortugas, Fla. (table 2).

The mean values of chlorophyll "a" in Tampa Bay tributaries were highest in the Hillsborough and Alafia Rivers (table 1). Except for the Hillsborough River, the mean chlorophyll "a" values in Tampa Bay tributaries were similar to those in upper Tampa Bay but lower than those from East Lagoon, Tex., and Alligator Harbor, Fla. (table 2).

The dissimilarity among stations in production of chlorophyll "a" may have been caused by a combination of factors. Zein-Eldin (1961) attributed the vertical gradient of chlorophyll "a" in East Lagoon to tidal oscillations and turbulence. The fact that mean concentrations were lower at the river mouths of the Hillsborough, Alafia, and Little Manatee Rivers than in Hillsborough Bay favors this view.

PRODUCTION OF ORGANIC MATTER

The rate of organic production in tributaries was estimated from the following equation (Ryther and Yentsch, 1957):

$$P=\frac{R}{K}\times C\times 3.7$$

TABLE 1.—*Mean concentrations of chlorophyll "a," iron, and inorganic phosphate-phosphorus in Florida west coast tributaries and adjacent bays and neritic waters of the Gulf of Mexico, January 1964 to January 1965*

[S=surface; B=bottom]

Location	Chlorophyll "a"		Iron		PO_4-P	
	S	B	S	B	S	B
Tampa Bay area	$mg./m.^3$	$mg./m.^3$	$\mu g./l.$	$\mu g./l.$	$\mu g.\ at./l.$	$\mu g.\ at./l.$
Rivers:						
Hillsborough	12.41	12.03	202.4	235.0	9.6	19.1
Alafia	8.13	12.04	216.6	381.0	33.6	29.1
Little Manatee	3.92	5.05	187.5	219.0	22.2	24.8
Manatee	5.44	7.68	217.0	251.6	15.1	16.6
Bays:						
Old Tampa Bay	5.56	9.40	115.0	......	23.2	25.8
Hillsborough Bay	30.22	19.47	147.8	......	24.4	24.0
Upper Tampa Bay	6.78	7.37	74.1	......	22.2	24.0
Lower Tampa Bay	3.14	3.37	40.6	......	14.5	16.4
Gulf:						
9.3 km. off Tampa Bay	1.17	1.03	16.3	19.4	2.6	3.2
18.5 km. off Tampa Bay	3.78	0.95	......	......	1.4	0.9
27.8 km. off Tampa Bay	0.50	.54	......	......	0.6	1.8
37.1 km. off Tampa Bay	.36	.58	6.0	5.3	.4	.6
Charlotte Harbor area						
Rivers:						
Myakka:						
Station 6	7.18	6.76	622.9	683.0	9.6	7.1
Station 5	5.25	5.79	299.2	434.3	6.3	7.2
Peace:						
Station 8	82.28	49.93	460.6	490.4	32.6	30.7
Station 7	8.74	9.89	329.7	305.9	18.6	18.4
Caloosahatchee:						
Station 10	10.65	13.53	265.8	535.5	2.4	4.4
Station 9	12.13	17.94	320.9	414.3	6.2	6.4
Bays:						
Upper Charlotte Harbor	2.73	2.80	111.9	111.6	11.5	9.3
Lower Charlotte Harbor	2.37	2.28	93.3	76.4	10.4	5.8
Gulf:						
9.3 km. off Boca Grande	1.86	1.28	26.0	20.3	1.6	1.1
18.5 km. off Boca Grande	.95	.53	......	......	.7	1.0
27.8 km. off Boca Grande	.54	.42	......	......	1.0	.7
37.1 km. off Boca Grande	.28	.29	16.5	4.6	.7	.6

TABLE 2.—*Reported concentrations of chlorophyll "a" in coastal and marine areas of the Atlantic Ocean and the Gulf of Mexico*

Location	Concentration		Reference
	Mean	Maximum	
	$mg./m.^3$	$mg./m.^3$	
East Lagoon, Galveston, Tex	17.6	84.6	Zein-Eldin (1961).
Alligator Harbor, Fla	4.3	14.0	Marshall (1956).
Florida coastal waters [1]	--------	30.7	Marshall (1956).
Dry Tortugas, Fla	0.3	----------	Riley (1938).
North Atlantic	--------	2.5–3.6	Riley (1939).

[1] This value was observed in the midst of bloom of *Gymnodinium breve*.

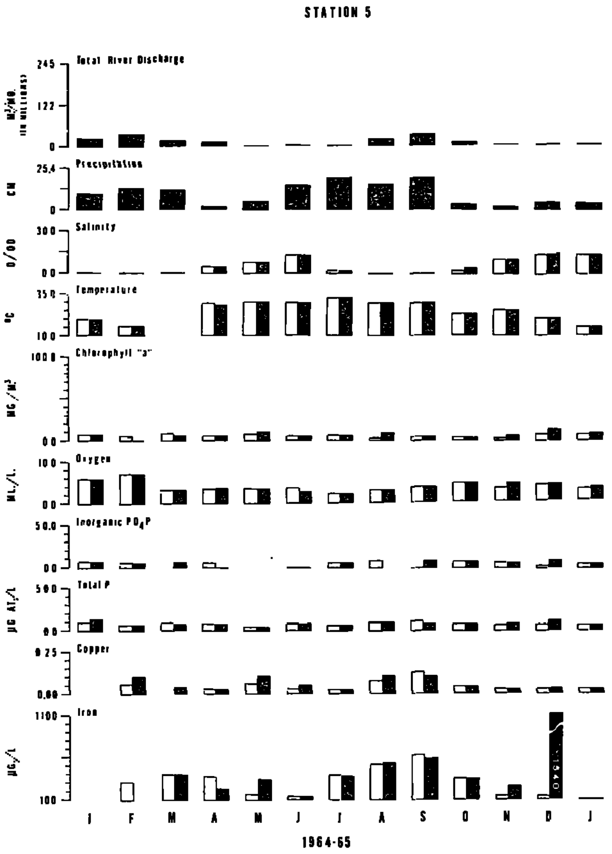

FIGURE 6.—River discharge, precipitation, and hydrological properties at station 5, Myakka River, Fla., January 1964 to January 1965. (Open bars=surface; solid bars=bottom.)

where P is the productivity rate in grams of carbon per square meter per day, R is the radiation factor found from the graphs of Ryther and Yentsch (1957), K is the extinction coefficient of the water, and C is grams of chlorophyll "a" per cubic meter. Because the derived carbon quantities are based primarily on chlorophyll values, their relative values and temporal and areal distribution resemble those of chlorophyll "a." The mean approximations of organic production exceed the analogous values (0.27 g. per square meter per day) from East Lagoon, Tex. (table 2).

The rivers contributed a substantial quantity of organic matter to the adjacent sea (table 3). Included are endocrine products liberated in the process of chlorophyll synthesis (Provasoli, 1958). The fate of these metabolites is not known, but they may have a bearing on the genesis of phytoplankton blooms and particularly of Florida red tide, if only a fraction reaches the bays and the adjacent sea. From the chlorophyll data and the river discharges, it may be deduced that quantitatively more metabolites reach the bays and adjacent sea during heavy rainfall than in periods of light rainfall.

TABLE 3.—*Mean estimates of primary productivity (g. C/m.^{2}/day) in west Florida rivers*

River	1964												1965	Average
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	
Hillsborough:														
Station 1	------	0.23	0.38	0.42	1.25	9.70	0.32	0.19	0.29	0.87	7.97	0.39	1.05	1.92
Alafia:														
Station 2	------	.16	1.45	1.44	2.95	9.53	1.63	1.15	2.69	4.13	3.24	.67	2.61	2.63
Little Manatee:														
Station 3	------	.49	.59	.83	0.44	1.10	.68	.38	.69	.91	0.67	1.40	0.39	0.71
Manatee:														
Station 4	------	.22	.45	.95	.38	0.69	.62	.48	.97	1.10	.39	1.92	.12	.69
Myakka:														
Station 5	0.90	.57	1.19	1.05	1.58	.64	.74	.93	.46	.46	.55	1.18	1.18	.87
Station 6	.39	.84	.51	2.00	1.03	1.81	1.10	1.41	.33	.59	.66	.37	.27	.87
Peace:														
Station 7	1.49	2.33	.79	1.54	1.21	1.34	1.54	2.91	.56	1.12	1.42	1.89	.64	1.44
Station 8	8.36	4.29	3.25	2.84	3.26	3.57	2.42	4.13	1.30	25.14	24.58	8.26	4.77	7.39
Caloosahatchee:														
Station 9	2.42	8.40	3.40	1.02	1.27	1.04	1.26	1.95	1.08	4.67	.97	1.55	.98	2.28
Station 10	1.95	1.32	2.74	2.37	.68	1.22	1.67	1.49	.71	4.79	1.29	3.06	1.31	1.89

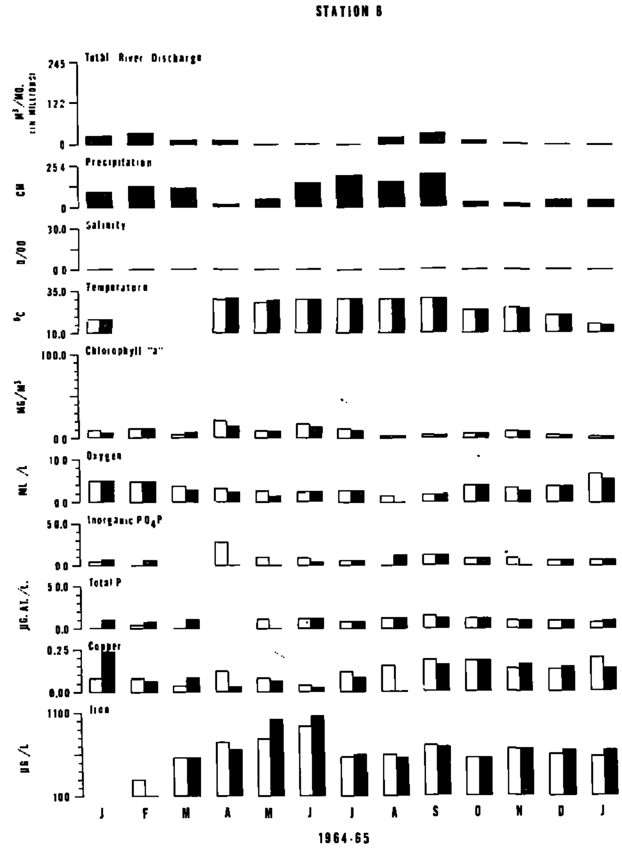

FIGURE 7.—River discharge, precipitation, and hydrological properties at station 6, Myakka River, Fla., January 1964 to January 1965. (Open bars=surface; solid bars=bottom.)

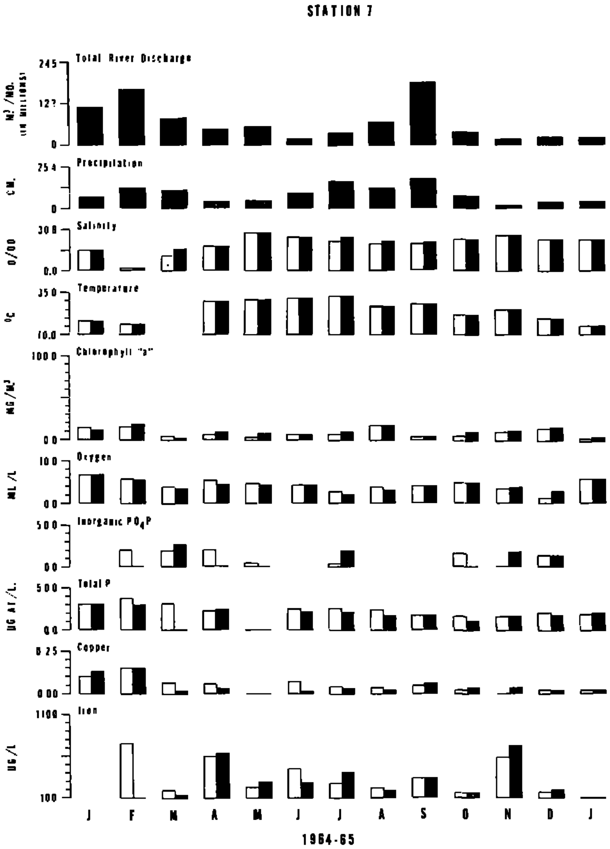

FIGURE 8.—River discharge, precipitation, and hydrological properties at station 7, Peace River, Fla., January 1964 to January 1965. (Open bars=surface; solid bars=bottom.)

DISSOLVED OXYGEN

Concentrations of dissolved oxygen at the river stations varied from 0.44 to 7.56 ml. per liter. Values were highest at most stations in winter and lowest in June and July (figs. 4–8). Oxygen values occasionally reached 100 to 142 percent saturation during every season. Most of the high values (stations 1, 2, 7, and 8) coincided with high concentrations of chlorophyll "a."

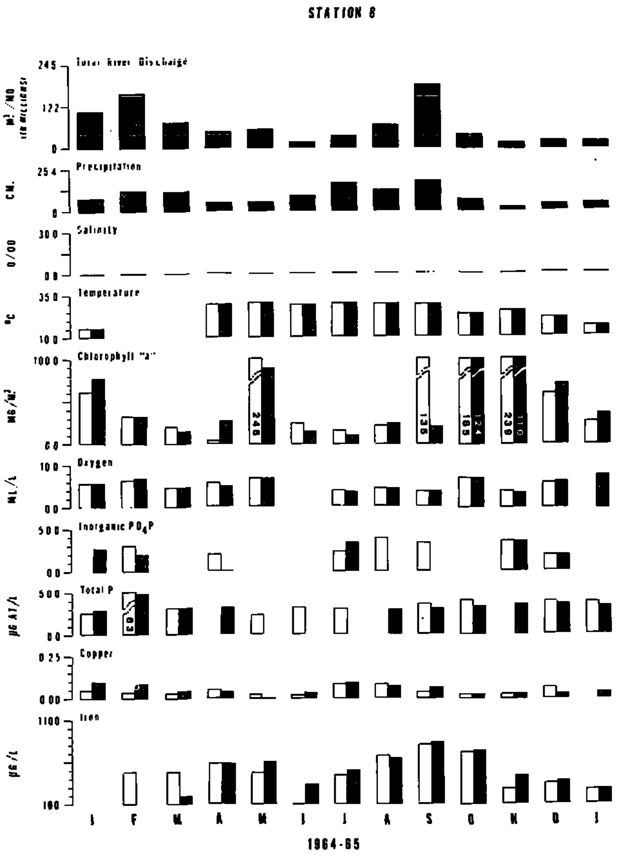

FIGURE 9.—River discharge, precipitation, and hydrological properties at station 8, Peace River, Fla., January 1964 to January 1965. (Open bars=surface; solid bars=bottom.)

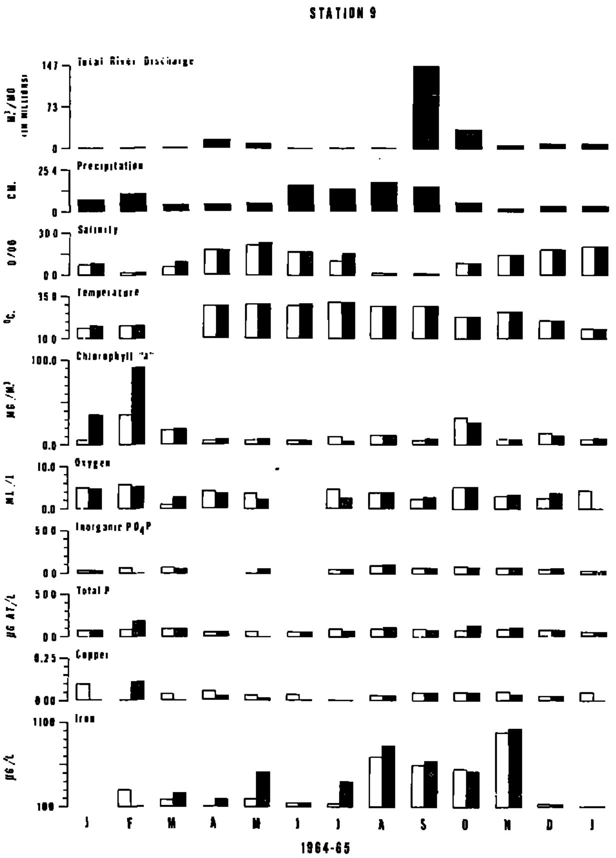

FIGURE 10.—River discharge, precipitation, and hydrological properties at station 9, Caloosahatchee River, Fla., January 1964 to January 1965. (Open bars=surface; solid bars=bottom.)

Even though anaerobic conditions were approached several times, no complete deoxygenation was detected. In 80 percent of the observations, oxygen saturation exceeded 50 percent. Values below 50 percent in one-fifth of the observations indicated that oxygen depletion occurred in the rivers. The occurrence of 75 percent of these values from April through September suggests that the depletion was seasonal.

Differences between surface and bottom values of oxygen were less than 1 ml. per liter in 84 percent of the observations. The similarity for most of the sets of observations reflects the capacity of the river system to maintain relatively high subsurface oxygen concentrations.

Irregularities in the vertical distribution of oxygen in periods of water stratification were associated with the presence of hydrogen sulfide near the bottom. Oxygen was almost exhausted near the bottom in the Hillsborough River (station 1) in April, June, August, and November (fig. 2).

TOTAL PHOSPHORUS

Concentrations of total phosphorus increased from downstream to upstream stations in the tributaries of Charlotte Harbor; Tampa Bay tributaries were sampled only at the mouths of rivers.

Quantities of total phosphorus were highest in the Peace River (station 8) and second highest in the Alafia River. Mean values at the surface and bottom in the Peace River (station 8) were 35.1 and 33.3 µg.at. per liter, and in the Alafia River (station 2) 27.5 µg.at. per liter, and 28.7 µg.at. per liter. At the remaining stations, the values for surface and bottom ranged from 4.2 to 23.5 µg.at. per liter. Values were lowest at the upstream station (10) in the Caloosahatchee River.

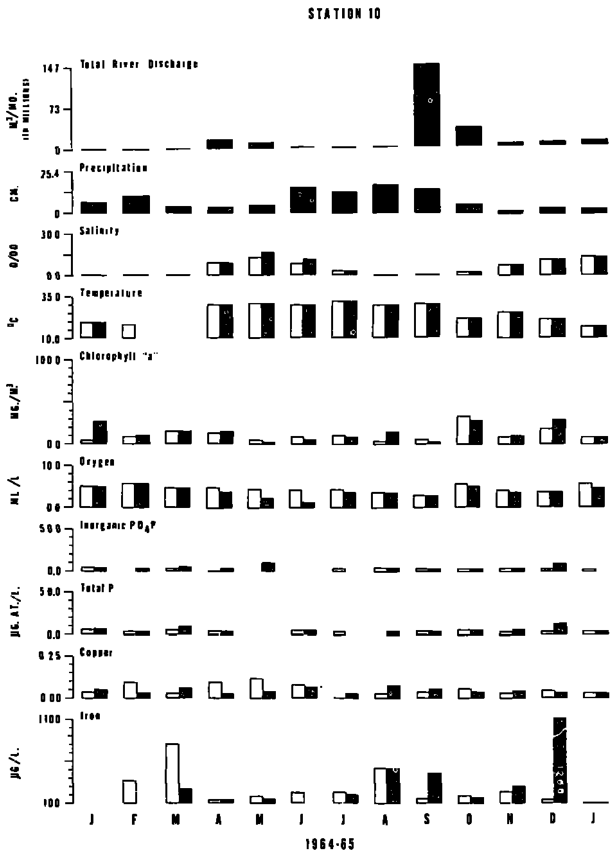

FIGURE 11.—River discharge, precipitation, and hydrological properties at station 10, Caloosahatchee River, Fla., January 1964 to January 1965. (Open bars=surface; solid bars=bottom.)

Concentrations of total phosphorus in individual samples for all stations ranged from 3.1 µg.at. per liter in the Caloosahatchee River (station 10) to 62.9 µg.at. per liter in the Peace River (station 8).

The differences between surface and bottom values of total phosphorus varied from 0.0 to 15.4 µg.at. per liter. In the Hillsborough River (station 1) values were higher near the bottom than at the surface due to upstream intrusion of Hillsborough Bay water, in which phosphorus concentrations exceeded those in Hillsborough Bay (fig. 2, table 2). Salinity differences at surface and bottom substantiate the conclusion. This observation agrees with previous studies (Dragovich and May, 1962; Odum, 1953).

Vertical differences in salinity in the Alafia River (station 2) were not reflected in a pronounced vertical stratification of phosphorus (fig. 3). Concentrations of phosphorus in the river markedly exceed those in Hillsborough Bay (table 1). The discharge waters of the Alafia River are the chief source of phosphorus for Hillsborough Bay (Dragovich and May, 1962).

The Little Manatee River empties into the upper portion of Tampa Bay, and the Manatee River into the lower portion. Phosphorus concentrations in the upper and lower bays were similar to those in the Little Manatee and Manatee Rivers (table 1). Thus, the vertical stratification of phosphorus in these two rivers was usually moderate (figs. 4 and 5).

Phosphorus values generally were higher at the surface at stations 7 and 8. Differences between surface and bottom at stations 5 and 6 were slight. Values were higher at the bottom occasionally at both stations in the Caloosahatchee River. This situation may arise from the bottom sediment which enters the lower portion of the water column during periods of turbulence.

Monthly variations in total phosphorus showed no trend. Mean concentrations of total phosphorus at each river were multiplied by flow to estimate changes in the total monthly quantity of phosphorus. Combined calculations for all rivers showed maximum quantities in February, March, August, and September—the months with maximum runoff; values were low during the minimum runoff in June and November (table 4). It appears, therefore, that the quantity of phosphorus added to the bays and the adjacent sea depends more on volume of river flow than on concentrations of phosphorus in the streams. An exception was the Alafia River—the total quantity of phosphorus was much higher than in the Hillsborough River despite greater flow rate in the latter.

Geological formations influence the phosphorus content of the river water (fig. 12). The high phosphorus values are directly attributable to drainage areas that are highest in $CaPO_4$. Quantities were highest in the Peace and Alafia Rivers which flow primarily through Hawthorne phosphatic formations. Relatively high phosphorus concentrations in the Manatee, Myakka, and Peace Rivers may be explained by the fact that they flow through phosphorus-bearing formations (Bone Valley and Hawthorne). Higher values at the Hillsborough River station result from mixing of relatively phosphorus-rich bay water with river water. Concentrations were lowest in the Caloosahatchee River, only part of which drains

TABLE 4.—*Quantities of iron, total phosphorus, and copper discharged by Florida west coast tributaries*

[Metric tons]

River	1964												1965	Total
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	
	Iron													
Hillsborough	------	33.6	15.6	12.6	1.4	0.7	15.3	56.4	100.0	4.5	1.4	1.6	1.5	244.6
Alafia	------	49.9	6.7	3.2	6.3	1.9	4.3	10.6	19.4	7.4	2.0	2.1	6.8	120.6
Little Manatee	------	10.8	2.0	0.8	0.6	.1	1.3	2.6	3.6	0.6	0.2	1.6	0.2	24.4
Manatee	------	7.4	1.3	.7	.6	.2	0.4	2.9	1.3	.5	.2	0.1	.1	15.7
Myakka	------	8.9	6.6	5.6	.6	.1	1.0	10.3	18.8	1.7	.1	.2	.3	54.2
Peace	------	96.2	18.0	27.6	20.9	4.0	14.1	28.1	102.1	16.8	8.1	5.8	3.1	344.8
Caloosahatchee	------	0.2	0.6	1.6	2.3	.1	.2	0.5	64.6	11.3	2.5	3.1	.5	87.5
Total	------	207.0	50.8	52.1	32.7	7.1	36.6	111.4	309.8	42.8	14.5	14.5	12.5	891.8
	Total phosphorus													
Hillsborough	------	49.2	15.0	29.7	14.4	2.6	16.2	35.6	55.1	22.7	6.6	7.3	10.2	264.6
Alafia	------	61.3	26.0	9.0	26.1	9.0	18.9	56.2	30.6	18.2	8.2	12.4	16.2	292.1
Little Manatee	------	12.6	7.7	3.0	3.6	0.8	5.0	5.0	8.7	3.1	1.0	2.8	1.6	54.9
Manatee	------	6.0	3.0	1.1	0.8	.3	------	5.3	3.7	1.3	0.5	0.6	0.5	23.1
Myakka	6.8	6.1	3.6	2.6	.2	.1	0.5	6.8	10.9	1.1	.1	.1	.2	39.1
Peace	90.8	216.7	72.8	38.5	36.2	12.3	27.8	48.4	137.6	30.1	11.2	18.3	15.6	756.3
Caloosahatchee	0.1	0.2	0.4	1.8	1.6	.1	.1	0.2	27.9	8.2	.9	1.6	1.0	44.1
Total	97.7	352.1	128.5	85.7	82.9	25.2	68.5	157.5	274.5	84.7	28.5	43.1	45.3	1474.2
	Copper [1]													
Myakka	0.2	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	0.2	<0.1	<0.1	<0.1	<0.1	0.8
Peace	.6	1.0	.2	.1	<.1	<.1	.1	.2	.6	<.1	<.1	<.1	<.1	3.1
Caloosahatchee	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	.4	<.1	<.1	<.1	<.1	.6
Total	.8	1.2	.2	.2	.1	.03	.2	.4	1.2	.2	.02	.05	.04	4.5

[1] All values of <0.1 in computation toward the total were not used; instead, actual values were used.

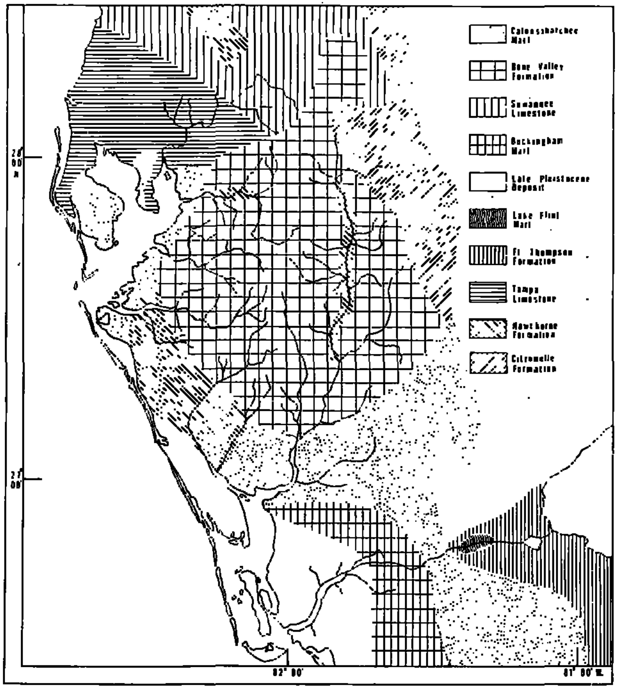

FIGURE 12.—Surface phosphate-bearing formations of the west coast of Florida (after Cooke, 1945). See table 5 for explanation of legend.

TABLE 5.—*Explanation of the legend for figure 12*

Geological formation	Composition
Caloosahatchee marl	Predominantly sand and shell marl.
Bone Valley formation	Phosphatic, sandy clay and gravel. Composition: 55–79% bone phosphate.
Suwannee limestone	Hard and resonant. Composition: 91–98% $CaCO_3$; chief impurity, silica.
Buckingham marl	Impermeable calcareous clay containing small grains of phosphatic material.
Lake Pleistocene deposits	Marine and estuarine deposits less than 30.5 meters above sea level.
Lake Flint marl	Calcareous fresh-water marl.
Ft. Thompson formation	Marine shell marl and fresh-water limestone.
Tampa limestone	Fairly hard and dense. Contains a large portion of very fine sand and phosphate. Composition: 74% calcium carbonate; <24% silica; trace magnesium carbonate.
Hawthorne formation	Sandy, phosphatic limestone, and green phosphatic clays.
Citronelle formation	Sand, gravel, and clay. The clay is kaolin when mixed with sand or gravel and is commonly iron stained.

through Buckingham marl formation (mainly impermeable calcareous clay containing only small grains of phosphatic material).

INORGANIC PHOSPHATE-PHOSPHORUS

The monthly changes and areal distribution of inorganic phosphate-phosphorus in all rivers were similar to those of total phosphorus (figs. 2–11). In 85 percent of the observations, inorganic phosphate-phosphorus exceeded organic and was responsible for the greater portion of total phosphorus. The quantities of phosphate-phosphorus always exceeded the minimum necessary for the growth of phytoplankters in vitro (Ketchum, 1939).

IRON

The study of the distribution of iron in Florida's west coast tributaries was undertaken for the first time in connection with the Florida red-tide studies. Thus, a few introductory remarks in regard to the importance of iron in the growth of phytoplankton seem to be appropriate. Iron occurs in many different physical and chemical forms in sea water (Ryther and Kramer, 1961). It may be present in generally unstable organic compounds that are slowly hydrolyzed in sea water (Harvey, 1937). The quantity of iron in true solution is extremely small because of the insolubility of ferric hydroxide.

The importance of iron in the physiology of phytoplankton has been stressed repeatedly (Harvey, 1957; Sverdrup, Johnson, and Fleming, 1942). Algae are able to use particulate iron as their major source of this element through ingestion by the protoplasm of particles of ferric hydroxide (Goldberg, 1952). Gran (1933) and Menzel and Ryther (1961) demonstrated the physiological dependence of phytoplankton on iron. Ryther and Kramer (1961) studied the relative iron requirements of some coastal and offshore planktonic algae. The consistency of their results demonstrates the importance of iron in determining the distribution of phytoplankton in the sea. Iron is beneficial in the culture of *Gymnodinium breve* (W. Wilson, personal communication). Even though the physiological importance of iron is known, no reliable techniques exist for determining the form in which it is available to phytoplankton (Harvey, 1937).

The concentration of iron in the sea is very small—from 0 to 10 μg. per liter (Ryther and Kramer, 1961). Quantities of this metal are much higher in drainage waters than in adjacent seas (Harvey, 1937).

The individual concentrations of iron in our study varied from 24.2 μg. per liter (at the surface in May at station 1, Hillsborough River) to 1540.4 μg. per liter (at the bottom in December at station 5, Peace River). The mean values for the entire period varied from 187.5 μg. per liter (at the surface of Little Manatee River) to 683.0 μg. per liter (at the bottom of Myakka River, station 6). Individual values were highest at the fresh-water stations in the Myakka and Peace Rivers and lowest in the Hillsborough River (figs. 2, 7, and 9). In 83 percent of all observations, iron values were from 50 to 599.0 μg. per liter; in 63 percent the concentrations were higher near the bottom than near the surface. The monthly changes in iron were very irregular at all stations (figs. 2–11) throughout the observation period.

Concentrations of iron in the rivers were several times higher than those in the adjacent sea and declined progressively in the seaward direction (table 1). River waters contribute iron to bay waters, but this influence is negligible offshore.

The highest concentrations of iron in the major rivers were in the area of limestone formation where the surface rock beneath the thin veneer of Pleistocene sands was either Miocene or Oligocene limestone. Iron values were intermediate in the major river (Myakka), which flows through Miocene phosphatic clays, and the difference was considerable between upriver values (station 5, fig. 6) and downriver values (station 6, fig. 7). This change can be directly attributed to the change from Pleistocene to Miocene deposits downstream. The lowest values were in the Alafia and Peace Rivers which flow through Pleistocene shelly sands of the Buckingham marl. The limestone areas are highly soluble to carbonated rain waters and carry the iron into solution with the $CaCO_3$. As long as iron is in the Fe^{+2} state, it moves readily; but when it is oxidized, it is precipitated as insoluble $Fe(OH)_3$. An occasional association between the increased rainfall and river discharge and higher iron concentrations was probably due to the oxidation of the iron in the limestone soils, and subsequent fixation. In times of high rainfall, iron moves into the rivers before oxidation can take place.

The total quantity of iron contributed to Gulf of Mexico waters by the rivers was estimated by multiplying average concentrations by flow. Even though monthly changes of iron concentrations at individual stations lacked a trend, combined data for all rivers showed that the contribution of iron by the rivers to the Gulf was greatest during maximum discharge (table 4).

COPPER

Concentrations of total dissolved copper at all stations varied from 0.00 to 0.23 µg.at. per liter. The levels were highest at fresh-water station 6 (Myakka River) and lowest at station 9 (Caloosahatchee River). In 82.5 percent of the observations, copper values were below 0.09 µg.at. per liter; 76 percent of the values that exceeded 0.09 µg.at. per liter were in the Myakka River. Although the highest values of copper came in January (0.08 µg.at. per liter), February (0.07 µg.at. per liter), and September (0.08 µg.at. per liter), at periods of high river discharge, the contribution of copper to the sea by the rivers was determined to a large extent by volume of river water, not by actual concentration.The largest total quantity of copper was contributed by the Peace River, and the lowest by the Caloosahatchee River (table 4).

Concentrations of copper were greater than those in Tampa Bay and adjacent waters of the Gulf of Mexico. The mean values for the Myakka River at station 6 exceeded those from Tampa Bay tributaries; values in the Peace and Caloosahatchee Rivers and at station 5 of the Myakka River were similar to the mean values for the Hillsborough, Alafia, and Manatee Rivers. Mean concentrations of copper were higher than those from San Juan Channel, Wash. (Chow and Thompson, 1952), but the mean concentrations at stations 5, 7, 8, and 9 are comparable with those reported by Chow and Thompson (1952) for the lower Mississippi River (table 6).

In general, changes in copper follow those of iron. This agreement results from the chemical scavenging of the colloidal $Fe(OH)_3$ for copper, which is absorbed to the surface of the particles.

Copper plays an important part in biological processes of higher aquatic organisms (Vinogradov, 1953; Galtsoff, 1964; Dragovich and May, 1962); it is adsorbed by phytoplankton (Atkins, 1953) and is selectively toxic to barnacles, algae, and mollusks. The dose of copper lethal to *Gymnodinium breve* under laboratory conditions is about 0.5 µg.at. per liter (W. Wilson, personal communication). None of the values observed in this study approached that level.

TABLE 6.—*Concentrations of total dissolved copper in Florida west coast rivers, Tampa Bay, and the adjacent Gulf of Mexico waters and in the Mississippi River and the San Juan Channel, Wash.*

Locality	Concentrations of copper			Reference
	Minimum	Maximum	Mean	
Hillsborough River:	*µg.at./l.*	*µg.at./l.*	*µg.at./l.*	
Station 29:				Dragovich and May, 1962.
Surface	0.02	0.07	0.04	
Bottom	.02	.09	.04	
Station 30:				
Surface	.02	.09	.05	
Bottom	.02	.08	.04	
Alafia River:				Do.
Station 31:				
Surface	.02	.16	.06	
Bottom	.03	.22	.06	
Station 32:				
Surface	.02	.08	.05	
Bottom	.01	.08	.04	
Little Manatee River:				Do.
Station 33:				
Surface	.03	.13	.07	
Bottom	.02	.12	.06	
Station 34:				
Surface	.02	.12	.08	
Bottom	.02	.13	.08	
Manatee River:				Do.
Station 35:				
Surface	.02	.11	.06	
Bottom	.02	.15	.06	
Station 36:				
Surface	.00	.16	.05	
Bottom	.01	.13	.04	
Myakka River:				Present study.
Station 5:				
Surface	.02	.12	.04	
Bottom	.02	.11	.05	
Station 6:				
Surface	.03	.17	.10	
Bottom	.02	.23	.10	
Peace River:				Do.
Station 7:				
Surface	.00	.16	.05	
Bottom	.00	.15	.04	
Station 8:				
Surface	.02	.08	.04	
Bottom	.01	.09	.04	
Caloosahatchee River:				Do.
Station 9:				
Surface	.00	.09	.03	
Bottom	.00	.11	.02	
Station 10:				
Surface	.00	.11	.04	
Bottom	.02	.11	.03	
Tampa Bay, Fla.	.00	.09	.03	Dragovich, Finucane, and May, 1961.
Gulf of Mexico adjacent to Tampa Bay.	.00	.10	.03	Do.
Mississippi River	--------	--------	.04	Chow and Thompson, 1952.
San Juan Channel, Wash.	.012	.06	.023	Do.

RELATION OF THE INPUT OF FLORIDA WEST COAST TRIBUTARIES TO THE ABUNDANCE OF *GYMNODINIUM BREVE*

Water samples for analysis of *G. breve* were collected each month from 22 stations in Tampa Bay, Charlotte Harbor, and the adjacent offshore waters (Dragovich and Kelly, 1966). *G. breve* was absent in samples from Tampa Bay and present only twice in samples from Charlotte Harbor. In Gulf waters adjacent to Tampa Bay, Charlotte Harbor, and Pine Island Sound, *G. breve* was collected every month. Regression analysis was used to explore the relation between the mean monthly concentrations of *G. breve* and the weighted average input by the tributaries of Tampa Bay and Charlotte Harbor-Pine Island Sound. Weighted monthly inputs of iron, copper, phosphorus, and chlorophyll "a" for the tributaries were calculated by the formula:

$\overline{X}_{\%} = \overline{X}_{I} (I_{\%}) + \overline{X}_{II} (II_{\%}) + \overline{X}_{III} (III_{\%})$ . . . . etc.
where $\overline{X}$ is the average value of the variable, I, II, . . . at the station or river, and $I_{\%}, II_{\%}$, . . ., the percentage of the total monthly river discharge for a particular river.

Regression analysis was chosen because its requirements are not as strict as those for correlation, in which a normally distributed population is prerequisite. Two relationships were tested—polynomial and linear multivariate regression.

In the polynomial regression, each variable (total phosphorus, copper, iron, and chlorophyll "a") was taken as the independent variable, and *G. breve* as the dependent one. The linear, quadratic, and cubic regression relationships were calculated, and each tested for significance by analysis of variance. Relationships were insignificant at the 95-percent level. At the 80-percent level, the linear regression relationship between *G. breve* and iron was significant off both Tampa Bay and Charlotte Harbor. One reason for the weakness of this relationship may be that the independent variables were not measured at the places where *G. breve* was collected.

SUMMARY

A hydrological survey of Hillsborough, Alafia, Little Manatee, Manatee, Myakka, Peace, and Caloosahatchee Rivers, west Florida, was made from January 1963 to February 1964. Monthly changes in temperature, salinity, chlorophyll "a," dissolved oxygen, inorganic phosphate-phosphorus, total phosphorus, copper, and iron were determined. Data on precipitation and river discharges and general geomorphological features of the area are also given.

The water temperature data for all rivers varied from 12.8° C. (January 1965) to 32.4° C. (June and July 1964). Temperatures were low during December, January, and February and variably high from April through September. The vertical differences of temperature were insignificant.

Oligohaline (0.5 p.p.t. to 5 p.p.t.), mesohaline (5 p.p.t. to 18 p.p.t.), and polyhaline (18 p.p.t. to 30 p.p.t.) salinities were encountered at all but two fresh-water stations. Salinity was reduced in months of high rainfall and high river discharge.

The levels of chlorophyll "a" varied from 1.3 to 245.5 mg. per cubic meter and did not show the expected seasonal cycle of spring and autumn maximums and summer and winter minimums. The highest concentrations were in the Peace River at the fresh-water station.

No serious depletion of dissolved oxygen was indicated. In 80 percent of the observations, oxygen saturation exceeded 50 percent. Maximum values came in winter and minimums in summer. Some supersaturation was detected in every season.

Concentrations of inorganic phosphate-phosphorus and total phosphorus were high in all rivers; levels were exceptionally high in the Peace and Alafia Rivers which flow directly through an area rich in phosphatic formations. Inorganic phosphate-phosphorus was responsible for most of the phosphorus.

Copper values varied from 0.00 to 0.23 µg.at. per liter and were higher than those in the adjacent Gulf of Mexico. They were markedly below the lethal dose for *Gymnodinium breve.*

The concentrations of iron were several times higher in the rivers than in the adjacent Gulf of Mexico waters. Values were highest at the fresh-water stations in the Myakka and Peace Rivers and lowest in the Hillsborough River. Temporal changes in iron lacked a distinct trend.

Variation in rate of flow has a marked effect on the total quantities of the materials in the rivers.

The polynomial regression between total phosphorus, copper, iron, chlorophyll "a" as the independent variable and abundance of *G. breve* as the dependent variable revealed no relationships significant at the 95-percent level; iron and *G. breve* were directly related at the 80-percent level of significance in coastal waters off Tampa Bay and Charlotte Harbor.

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