AN ECOLOGICAL SURVEY OF THE SUBTROPICAL INSHORE WATERS ADJACENT TO MIAMI [1]

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A considerable amount of investigation has been carried out into the general ecology of the shallow water life of temperate seas, particularly with regard to the sedentary organisms, the literature of which is summarized by McDougal ('43), Scheer ('45) and Smith ('46). The food cycles, breeding seasons, succession and growth under various conditions have principally been studied. A relatively small amount of attention has been devoted to the quantitative relationships existing between the dissolved inorganic and organic nutrients, the plankton and the animal and plant communities, and much of this has been restricted to special interests such as the shell fish industry. Considerably more fundamental study has been given to such relationships and to the associated problems of organic production in fresh water and even in the less accessible open ocean. It is also true that, compared to temperate regions, the tropical waters have been greatly neglected in these respects. The outstanding exception to this generalization is the careful and painstaking work of the Great Barrier Reef Expedition, which dealt, however, with a somewhat specialized situation.

The general paucity of quantitative information regarding the chemical, physical and biological conditions in the Miami area, in addition to the considerations mentioned above, prompted the investigations which form the subject of the present report. They were designed rather to outline the range of general conditions and their interrelations in subtropical shallow waters than to provide detailed information on any specific circumscribed problem.

In carrying out the work a considerable amount of data was accumulated. It would be impracticable to present this except in summarized form. It is hoped, however, that more detailed presentations may be offered elsewhere as investigations are carried out into more specific problems arising out of the present survey.

The observations were made at a series of stations covering a wide range of environmental conditions. Chemical and physical observations and plankton samples were made at intervals of approximately one month during 1945 and 1946. A wooden float, containing racks for glass collecting panels, was anchored at each station for the purpose of recording breeding seasons, attachment density, growth rate and succession of sessile organisms.

In the sometimes difficult task of making observations and of replacing floats lost during storms the authors were assisted at various times by Albert Schwartz, C. E. Dawson and J. Q. Tierney. Chemical determinations were made by Robert H. Williams, and plankton examination was carried out by Charles C. Davis. Credit should also be given to Mrs. Dorothy Clum Morse who originally began the plankton studies. Examination of the glass collecting panels was carried out by F. G. Walton Smith.

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Location of the Stations

Ten of the stations were located in Biscayne Bay, which is at the southeast

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end of the Florida peninsula between 25° 23′ and 25° 55′ North latitude and between 80° 08′ and 80° 21′ West longitude. It is elliptical in shape, 32 nautical miles long and up to 8.6 nautical miles wide. As shown in the map (fig. 1) it is bordered on the west by the mainland from Miami southward. The northern part of the bay is bounded to the eastward by a chain of keys starting with Miami Beach. The central part of the bay is separated from the Atlantic Ocean by broad coral banks covered with sand, shell and mud which continue south of the line of keys and which are only partly exposed at low tide. They are known as the Safety Valve. The small island of Soldier Key is the only land raised above these sand flats at high tide. The southern part of the bay is separated from the ocean by Elliot Key and from the rest of the bay by an east-west shoal, Featherbed Bank.

The bay is very shallow, mostly from eight to eleven feet deep; the maximum depth is fifteen feet; much of the northern and western portion of the bay is less than six feet deep.

The tide flows rapidly in and out of the bay between the keys and through several deeper channels in the central flats. The flooding tide flows southward over Featherbed Bank. Currents elsewhere in the bay have not been charted. Between the line of keys and flats on the one hand and the outer coral reefs such as Fowey Rocks and Triumph Reef on the other is a southward flowing counter current in the lagoon channel. The northward flowing Florida Current or Gulf Stream is farther east beyond the outer coral reefs.

The eleven stations where the samples were collected over a period of a year, as shown on the map (fig. 1), were chosen to represent ecologically distinct habitats. The Beach Boat Slips station (No. 1) was considered representative of the northern bay where moderate amounts of sewage were present. The N. E. 18th Street, Miami, station (No. 2) was located within 100 feet of the end of a large city sewer from which raw sewage entered the bay. These stations were the only ones immediately adjacent to the built-up dock and city areas. Sea walls, offering good attachment for sedentary organisms, extend for several miles north and south of these places and are absent at the locations which were selected for the remaining stations. On both east and west sides of the northern bay the tidal currents run strongly north and south.

The station north of Hurricane Harbor on Biscayne Key (No. 3) was chosen to compare with the station in Hurricane Harbor (No. 4), a dredged harbor fifteen to twenty-five feet deep, almost completely land locked, but without any sewage inflow.

The Biscayne Channel (No. 5) and Soldier Key (No. 10) stations are similar in that both are located in deep channels between bay and ocean, through which strong tidal currents run. The former differs by proximity to the land mass of Biscayne Key. The Chicken Key station (No. 11) is close to the mainland and to the mouth of artificial drainage channels, but without the sewage which enters the northern part of the bay. It is more exposed to wind and wave action than most of the other stations in the bay. Featherbed Bank (No. 6) was chosen as in intermediate situation between the isolated water to the west of Elliot Key (No. 7) and the rapidly circulating tidal waters at Soldier Key (No. 10). It lies at the entrance to a dredged channel through Featherbed Bank, connecting the central and southern parts of the Bay.

East Elliot Key (No. 8) was chosen to represent the shoreline of the ocean bathed by the southward drift. The shore here is sandy with low rocky exposures and very little mangrove. The western shore of Elliot Key (No. 7) is partly fringed with mangroves. Both of these stations are in about three feet of water at low tide, over a sandy bottom.

Triumph Reef (No. 9) on the line of

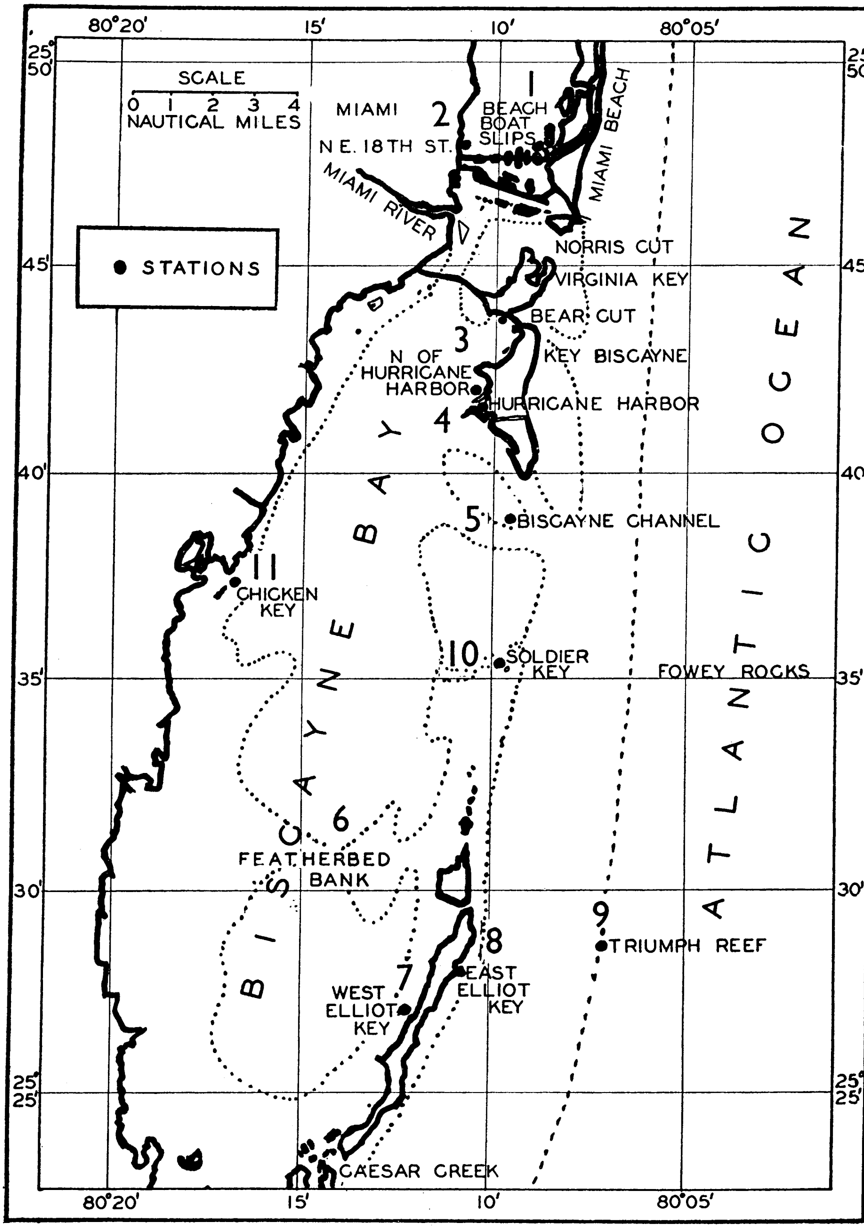

FIG. 1. Map of Biscayne Bay and vicinity. Numbers refer to stations. . . . . 1 fathom and 50 fathom contours.

reefs near the margin of the Florida Current is in about twenty feet of water. The prevailing onshore winds from the southeast bring a drift of surface ocean water across the reef.

Physical and Chemical Conditions

Chemical and physical observations were chosen which would be most useful in correlating with the distribution of the plankton and attached organisms, and which could be determined accurately with the limited equipment and facilities available. These were: temperature, a factor influencing all biological activity; salinity; dissolved oxygen, an indicator of the photosynthesis-respiration balance; phosphate-phosphorus, an essential mineral which is often a limiting factor for plant growth in the sea; and nitrite-nitrogen, intermediate between ammonia and nitrate in the nitrogen cycle in the sea.

Analytical methods used were those described in mimeographed "Methods of Oceanographic Chemistry," prepared by Rex J. Robinson and Thomas G. Thompson, Oceanographic Laboratories, University of Washington. Salinities were calculated from the results of silver nitrate titrations. Dissolved oxygen was determined by the standard Winkler method. The methods for phosphate and nitrite have since been published (Robinson and Thompson, '48a, '48b).

Data obtained from the analyses of surface samples at the eleven stations between July 1945 and June 1946 are summarized in tables I to VI. The seasonal variations in sea temperature (table I) show the expected correlation with air temperatures and total hours of sunshine, as reported by the U. S. Weather Bureau. The sea temperature reached its lowest point at all stations in December and then increased rapidly in the spring. All stations except Triumph Reef showed similar seasonal variation in temperature, varying from the extremes of 18.25° C

TABLE I. *Sea water temperatures at the surface*
Degrees Centigrade

Date	Stations										
	1 Beach Boat Slips	2 N. E. 18th Street, Miami	3 N. of Hurricane Harbor	4 In Hurricane Harbor	5 Biscayne Channel	6 Featherbed Bank	7 West Elliot Key	8 East Elliot Key	9 Triumph Reef	10 Soldier Key	11 Chicken Key
7–7–45	30.2	31.2	31.3	32.0	31.3	32.0	32.0	32.3	29.4	31.7	—
8–4–45	29.7	29.8	29.7	30.7	30.1	30.5	30.5	30.5	29.8	30.5	30.5
10–27–45	24.62	24.88	24.93	25.30	25.00	26.87	27.90	27.68	26.68	24.70	26.80
12–2–45	20.55	21.93	20.20	19.93	21.50	18.25	19.06	19.15	24.35	19.58	18.35
1–6–46	21.80	22.00	21.18	21.10	21.70	21.30	21.30	—	—	21.79	22.47
2–3–46	22.70	22.70	21.93	22.70	22.45	23.15	22.85	22.78	25.00	23.23	24.08
4–28–46	26.12	27.00	24.68	25.28	25.60	24.67	24.91	24.12	25.25	25.15	28.57
6–6–46	28.58	27.82	28.28	29.35	28.00	29.12	28.90	29.05	27.60	28.13	29.78

TABLE II. *Sea water salinities at the surface*
Grams per kilogram

Date	Stations										
	1 Beach Boat Slips	2 N. E. 18th Street, Miami	3 N. of Hurricane Harbor	4 In Hurricane Harbor	5 Biscayne Channel	6 Featherbed Bank	7 West Elliot Key	8 East Elliot Key	9 Triumph Reef	10 Soldier Key	11 Chicken Key
7–7–45	37.35	37.52	38.04	38.69	37.35	39.09	38.97	37.40	36.36	37.11	—
8–4–45	36.38	36.24	37.71	37.83	36.97	38.08	39.26	36.82	35.62	36.67	35.47
10–27–45	29.67	27.36	30.95	30.99	32.41	35.61	35.19	35.52	35.25	33.06	29.85
12–2–45	32.41	27.01	31.69	31.11	34.41	33.71	34.09	34.43	36.04	33.91	29.34
1–6–46	29.33	24.92	34.67	33.13	35.14	35.41	35.37	—	—	36.22	28.97
2–3–46	34.25	28.66	34.63	34.47	35.59	36.58	36.56	36.65	36.02	36.26	33.19
4–28–46	36.80	35.63	38.24	38.26	36.96	38.32	38.06	37.25	36.50	36.86	38.22
6–6–46	34.29	30.17	35.10	35.23	35.50	37.39	36.36	36.22	36.08	35.70	32.14

TABLE III. *Dissolved oxygen in sea water at the surface*
Milligram atoms per liter

Date	Stations										
	1 Beach Boat Slips	2 N. E. 18th Street, Miami	3 N. of Hurricane Harbor	4 In Hurricane Harbor	5 Biscayne Channel	6 Featherbed Bank	7 West Elliot Key	8 East Elliot Key	9 Triumph Reef	10 Soldier Key	11 Chicken Key
7–7–45	.349	.355	.380	.351	.394	.441	.297	.377	.375	.408	—
8–4–45	.313	.386	.350	.288	.380	.445	.342	.405	.430	.451	.403
10–27–45	.342	.312	.351	.397	.426	.394	.401	.488	.416	.453	.347
12–2–45	.428	.401	.467	.421	.453	.465	.493	.525	.434	.436	.428
1–6–46	.383	.386	.438	.354	.258	.443	.438	—	—	.416	.410
2–3–46	.384	.287	.432	.356	.363	.456	.448	.480	.424	.492	.445
4–28–46	.416	.381	.448	.456	.458	.492	.446	.491	.447	.478	.517
6–6–46	.307	.178	.369	.336	.394	.431	.374	.393	.408	.400	.452

TABLE IV. *Dissolved oxygen in sea water at the surface*
Per cent of saturation

Date	Stations										
	1 Beach Boat Slips	2 N. E. 18th Street, Miami	3 N. of Hurricane Harbor	4 In Hurricane Harbor	5 Biscayne Channel	6 Featherbed Bank	7 West Elliot Key	8 East Elliot Key	9 Triumph Reef	10 Soldier Key	11 Chicken Key
7–7–45	88.5	91.7	98.6	92.3	101.6	116.5	78.3	98.6	93.3	105.8	—
8–4–45	78.3	96.6	88.6	74.2	96.0	111.6	88.7	103.0	106.7	114.7	101.5
10–27–45	74.7	67.5	77.7	88.5	95.3	93.2	96.3	117.0	97.5	101.1	78.6
12–2–45	89.0	82.2	96.0	85.7	96.9	93.6	101.0	107.9	98.5	89.9	84.0
1–6–46	79.6	78.4	93.1	74.5	55.6	95.1	93.9	—	—	90.5	86.1
2–3–46	83.4	60.2	92.9	77.5	79.6	101.8	100.0	106.6	97.5	109.8	98.5
4–28–46	98.3	90.3	104.6	107.9	105.0	115.2	104.6	112.4	103.4	112.1	128.8
6–6–46	74.2	41.2	89.2	82.9	95.0	107.6	92.1	97.1	98.3	96.7	109.7

in winter to 32.2° C in summer, with a range of 14° C.

This is a greater seasonal variation than that found by Orr ('33a) in the Great Barrier Reef lagoon in Australia, where the extreme range was 8.6° C. This difference is partly to be explained by the fact that the lagoon was considerably deeper (to 40 meters) than Biscayne Bay. Dole ('14) reported temperature determinations at some of these Florida stations on June 23, 1913, which averaged 1.4° C cooler than those on June 6, 1946. This difference is probably the result of weather variations.

Triumph Reef water was cooler in summer and warmer in winter than water at any other station; it varies from 24.35° to 29.8° C. This small range is characteristic of oceanic conditions and is probably due to the water at Triumph Reef mixing with water from deeper parts of the Florida Current.

Salinities (table II) at all stations except Triumph Reef show the expected correlation with rainfall. Lowest salinities were found at the station at N. E. 18th Street, Miami, where fresh water from sewer and drainage outlets further diluted the sea water. The ocean at Triumph Reef showed the least changes in salinity, probably because vertical and horizontal exchange with ocean water nearby distributed the rain water quickly.

Dole ('14) reported chlorinity determinations on water at some of these stations June 23, 1913, which were less than 0.7°/₀₀ above or below those on June 6,

TABLE V. *Phosphate-phosphorus in sea water at the surface*
Microgram atoms per liter

Date	Stations										
	1 Beach Boat Slips	2 N. E. 18th Street, Miami	3 N. of Hurricane Harbor	4 In Hurricane Harbor	5 Biscayne Channel	6 Featherbed Bank	7 West Elliot Key	8 East Elliot Key	9 Triumph Reef	10 Soldier Key	11 Chicken Key
7-7-45	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	—
8-4-45	<.03	.03	<.03	<.03	.00	.00	.00	.00	.00	.00	.00
10-27-45	<.03	.12	.00	.00	.00	.00	<.03	<.03	.00	<.03	.00
12-2-45	.00	1.20	.00	.00	.03	.00	.00	<.03	.10	.00	.00
1-6-46	.00	.00	.00	<.03	<.03	.00	.00	—	—	.00	.00
2-3-46	.00	1.5	.00	.00	.00	<.03	<.03	.00	.00	.00	<.03
4-28-46	.03	.72	.00	.00	<.03	.03	.06	<.03	.00	.00	.00
6-6-46	.06	2.4	.03	.03	<.03	.00	<.03	<.03	.00	<.03	<.03

1946. The water in the lagoon behind the Great Barrier Reef of Australia (Orr, '33a) had an average salinity of about $33.4^{0}/_{00}$ and annual range of $4.2^{0}/_{00}$. Average of the mean of seasonal ranges of all stations in south Florida is $34.7^{0}/_{00}$ and the average annual range is $6.2^{0}/_{00}$.

The dissolved oxygen content (tables III and IV) was near saturation at all stations away from pollution. The lowest oxygen content was found after five and one-half hours of ebbing tide at the N. E. 18th Street station on June 6, 1946. The sewage here would contain much unsaturated material which reacts with the iodine liberated by Winkler's method and thus the results probably indicated a lower oxygen content that actually exists in the water. However, the abundant bacteria in such water probably reduce the oxygen considerably.

McClendon ('18) reported that the sea water in the shallow areas of the Dry Tortugas, Florida, was generally slightly supersaturated with oxygen during the day and undersaturated at night. Orr ('33a) reported that the sea water in the lagoon behind the Great Barrier Reef was usually 90 to 100% saturated, only once supersaturated, and only for a short period below 90% saturated. A wider range of oxygen concentration, 55 to 120% of saturation, was reported by Orr ('33b) for another station inside the Great Barrier Reef. Riley ('39) reported 99% saturation in a sample of water taken at one meter depth at his station 3492, fifteen nautical miles south of Triumph Reef. At this station, on May 16, 1939, he found that water contained more oxygen at a depth of 48 meters than at the surface. In the latitude of 15° South in the Atlantic Ocean, Wattenberg ('29) reported that the high oxygen content at the surface extends downward to about fifty meters, then decreases rapidly.

For purposes of correlation with plankton and fouling organism distribution, the phosphate and nitrate data are probably the most significant. The method used for phosphate determination measures as little as 0.03 microgram atom per liter. Samples which showed distinguishable color but less than the most dilute standard were recorded as "less than (<) 0.03 μg. atom/L." If no color formed at all, they were recorded as "0.00."

The only significant phosphate (table V) was found at the 18th Street station near the outlet of the city sewer. This phosphate is probably derived from bacterial decomposition of phosphoproteins and other organic phosphorus compounds in the sewage.

The apparent almost complete absence of phosphate at most of the stations may be the result of phytoplankton growth using up phosphate in the surface layers and failure of replenishment from phosphate-rich deeper waters of the ocean, where Riley ('39) found up to 1.82 milligram atoms of phosphate per cubic meter of water at a depth of 184 meters at his station 3942 which is outside the reef and fifteen miles south of Triumph Reef. His sample at that station from a depth of one meter on May 16, 1939, contained 0.06 mg. atom per cubic meter (equals 0.06 microgram atom per liter). Our samples taken down to 15 meters outside Triumph Reef usually contained no measurable phosphate.

The phosphate content of south Florida inshore waters is much lower than that in the lagoon behind the Great Barrier Reef, reported by Orr ('33a), which averaged about 5 mg. phosphate-phorphorus per cubic meter (0.16 μg. atom per liter). Seasonal changes in phosphate and dissolved oxygen are negligible in both areas. Low phosphate values are characteristic of surface waters of tropical seas in general (Atkins, '26; Hentschel and Wattenberg, '30; Rakestraw and Smith, '37).

Nitrite is more abundant than phosphate. Measurable quantities of nitrite (table VI) were found at most stations (except Triumph Reef) throughout the year except in December, which is the month of the lowest temperatures. The seasonal maximum at most stations occurred in February. The high nitrite values (to 2.0 microgram atoms per liter) were found at the Miami and Beach Boat Slips stations. This nitrite is probably the product of bacterial oxidation of ammonia from nitrogenous compounds pouring out of the sewers nearby. Further oxidation would be expected to produce nitrate which would stimulate phytoplankton growth. The organic material in the sewage would be expected to stimulate growth of certain marine animals which can use it for food.

The absence or near-absence of nitrite in the ocean water at Triumph Reef most of the year suggests that in the ocean most of the nitrogen has been oxidized to nitrate and used by the phytoplankton. In the shallow water of the bay, decay of organic matter on the bottom probably renews the nitrite content. It is possible that the sharp decrease in temperature in December slowed these bacterial oxidations in the unpolluted water, so that the phytoplankton might entirely remove the diminished supply of inorganic nitrogen.

Such variations in nitrite are to be expected under the variable conditions of these stations (Rakestraw, '36).

PLANKTON

Methods

All samples were obtained from near the surface by means of a Clarke-Bumpus net of No. 20 mesh. In each case the net was towed for a standard period of ten minutes at a constant engine speed in order that the volumes of the samples

TABLE VI. *Nitrite-nitrogen in sea water at the surface*
Microgram atoms per liter

Date	Stations										
	1 Beach Boat Slips	2 N. E. 18th Street, Miami	3 N. of Hurricane Harbor	4 In Hurricane Harbor	5 Biscayne Channel	6 Featherbed Bank	7 West Elliot Key	8 East Elliot Key	9 Triumph Reef	10 Soldier Key	11 Chicken Key
7-7-45	0.1	0.3	0.1	0.15	0.1	0.1	0.1	<0.1	0.0	0.1	—
8-4-45	.2	.25	.1	.1	.05	.1	.1	.0	.0	.0	.1
10-27-45	.8	1.6	.3	.25	.3	.15	<.1	.0	.0	.15	.2
12-2-45	.15	.8	.15	.1	.0	.0	.0	.0	.0	.0	.0
1-6-46	.8	1.0	.2	.1	.1	.1	.2	—	—	.2	.1
2-3-46	.4	2.0	.4	.4	.4	.1	.2	1.6	.2	.2	.4
4-28-46	.2	.2	.15	.2	<.1	<.1	.1	<.1	<.1	.1	<.1
6-6-46	.6	1.0	.15	.2	.2	.15	.15	.1	<.1	.1	.25

TABLE VII. *Plankton volumes in milliliters*

Date	Stations										
	1 Beach Boat Slips	2 N. E. 18th Street, Miami	3 N. of Hurricane Harbor	4 In Hurricane Harbor	5 Biscayne Channel	6 Featherbed Bank	7 West Elliot Key	8 East Elliot Key	9 Triumph Reef	10 Soldier Key	11 Chicken Key
7–7–45	12.8	22.9	11.0	21.1	6.4	2.8	<1.0	<1.0	<0.5	0.5	—
8–4–45	2.0	3.0	0.5	0.5	<0.5	0.5	2.0	0.5	1.0	1.0	<0.5
10–27–45	1.0	<1.0	3.5	5.5	0.5	trash	3.0	4.0	4.5	5.0	5.0
12–2–45	<0.5	2.5	15.0	7.5	2.0	2.5	<0.5	2.5	2.5	2.5	5.5
1–6–46	13.0	5.0	2.0	2.0	1.0	—	—	—	—	—	—
2–3–46	1.0	2.0	5.0	4.0	2.0	0.75	0.5	0.5	0.5	0.5	1.5
4–28–46	0.75	1.0	1.0	1.0	0.5	0.5	1.5	0.5	1.0	0.5	1.0
6–6–46	10.0	4.5	1.0	0.5	0.5	0.75	0.25	0.5	0.25	1.0	1.0

might be comparable. Defective action of the counter on the net prevented the determination of the exact volume of water passed at each station.

In the laboratory, a small portion of the thoroughly mixed sample was examined microscopically. The first 200 organisms encountered were listed in order to obtain an idea of the composition of the plankton, its dominant species and their relative abundance. In the case of chain-forming diatoms, each chain encountered was considered to be a single organism. This method has the obvious disadvantage of neglecting size differences between the several organisms.

The volume of each sample was obtained after microscopical analysis by a water displacement method. The volume of the plankton plus the suspending water was obtained after which the sample was filtered through standard smooth-surface chemical filter paper, which had previously been wet with tap water. A measurement of the volume of the filtrate then made possible the calculation of the plankton volume.

Volume

The volumes of samples obtained in Biscayne Bay and vicinity by the above method varied from 0.25 ml. at several localities to a maximum of 22.5 ml. at Station 2 in July, 1945 (table VII). In general, the largest volumes were found at Stations 1, 2, 3, and 4, the first two in polluted regions, the other two in unpolluted, but protected locations in the northern portion of the bay. Lowest average volumes were found at Stations 6 and 7, in the southern part of the bay. Maximal volumes were always associated with a high percentage of diatoms.

Stations in the northern portion of the bay (Nos. 1, 2, 3, 4 and 5) show two maxima, one in July 1945, and a smaller maximum in December–January. The remaining stations, all located in the southern portion of Biscayne Bay, or in the ocean outside Elliot Key, which delimits the southern portion, show only one maximum, in October 1945. One exception to this statement is Featherbed Bank (No. 6), which shows a small maximum in July 1945, and a second in December, as in the northern stations. However, the July maximum is very small, and volume was not measured for the October sample because of the presence of considerable trash consisting largely of broken turtle grass and other detritus. In addition to the above, Stations 1 and 2 show a third maximum in June 1946, apparently corresponding to the maximum of the previous July. This does not appear markedly at any of the other stations.

Diatoms

Diatoms were important in nearly every sample in the present study, at times constituting as much as 99.5 per cent of the total organisms. However, in the southern part of the bay (Nos. 6, 7), they were relatively unimportant.

In the northern portion of the bay and in Biscayne Channel, the diatoms were always the most important ingredient of the plankton, with the exception of outside Hurricane Harbor (No. 3) during April and June, when they were exceeded by the dinoflagellates. These stations were characterized by the dominance especially of species of *Chaetoceros, Rhizosolenia,* and to a lesser degree, *Bacteriastrum. Thalassiothrix nitschioides* was relatively abundant in all but one of these northern stations in December, but not at any other time of the year.

In the remaining stations, located in the southern portion of the Bay, or outside of Elliot Key, which bounds the southern portion, the abundance of the diatoms was more variable. At Soldier Key (No. 10) they were always the most important ingredient, but at all the other stations they were a minor, though still important portion of the plankton in one or more of the observations. Featherbed Bank (No. 6) and west of Elliot Key (No. 7), especially, were characterized by having a plankton population poor in diatoms for the whole year. At West Elliot Key the diatoms at no time constituted the major portion of the plankton.

The diatom population of the southern stations, with the partial exception of Soldier Key (No. 10), was very different from that of the northern stations (Table VIII). In the place of *Chaetoceros, Rhizosolenia* and *Bacteriatrum,* the predominant diatoms, when any individual group of diatoms was dominant in the plankton, were the naviculoids, *Striatella unipunctata* and occasionally other forms. In October, December and June, Soldier Key had characteristics similar to the northern stations. At other times it was similar to the southern stations. Also, in December, all but West Elliot Key of the southern stations and all the northern stations had species of *Chaetoceros* as dominant forms.

TABLE VIII. *Genera of dominant diatoms*

Station	July	Aug.	Oct.	Dec.	Jan.	Feb.	Apr.	June
1	Chaetoceros	Rhizosole nia	Chaetoceros–Skeletonema	Chaetoceros Thalassiothrix	Chaetoceros	Chaetoceros Nitzschia Rhizosolenia	Chaetoceros Nitzschia	Chaetoceros Nitzschia Rhizosolenia
2	Chaetoceros Rhizosolenia	Rhizosolenia	Chaetoceros	Chaetoceros Thalassiothrix	Chaetoceros	Chaetoceros Rhizosolenia	Chaetoceros	Rhizosolenia
3	Chaetoceros	Chaetoceros	Bacteriastrum Chaetoceros	Chaetoceros	Chaetoceros	Chaetoceros	Naviculoids	Chaetoceros
4	Chaetoceros	Chaetoceros	Bacteriastrum Chaetoceros	Chaetoceros Thalassiothrix	Chaetoceros	Bacteriastrum Chaetoceros	Chaetoceros	Bacteriastrum Chaetoceros
5	Chaetoceros	Chaetoceros	Bacteriastrum Chaetoceros	Asterionella Chaetoceros Thalassiothrix	Nitzschia	Chaetoceros Naviculoids	Naviculoids	Chaetoceros
6	?	?	Bacillaris	Chaetoceros	—	None	Naviculoids	None
7	?	?	None	None	—	None	Naviculoids	None
8	?	?	None	Chaetoceros Melosira	—	None	Naviculoids	None
9	?	?	None	Chaetoceros	—	? Licmophora	Naviculoids	Asterionella
10	?	?	Chaetoceros Nitschia	Chaetoceros	—	Naviculoids Striatella	Naviculoids	Naviculoids Rhizosolenia
11	—	Strictella Rhabdonema	None	Chaetoceros	—	Naviculoids	Naviculoids	Naviculoids

Dinoflagellates

The dinoflagellates were usually subordinate to the diatoms in abundance in the plankton of Biscayne Bay and vicinity, but there were some important exceptions, mostly in the southern part of the region. Outside Hurricane Harbor (No. 3) in the northern portion of the bay, however, the dinoflagellates constituted the major ingredient of the plankton on the April and June 1946 cruises, amounting to 31 per cent and 60.5 per cent of the total organisms respectively. This was due in the former case to the abundance of *Ceratium furca,* and in the latter case to a flowering of a species of *Gonyaulax.*

Among the southern stations, the dinoflagellates were especially important at Featherbed Bank (No. 6) and West Elliot Key (No. 7), a region that seems somewhat exceptional in many respects. At Featherbed Bank (No. 6) the dinoflagellates were important ingredients of the plankton in every sample and in February and June respectively they constituted 80.5 per cent and 52.0 per cent of the total plankton. At West Elliot Key (No. 7), and the other southern stations, the dinoflagellates were usually of considerable importance, especially during February.

Of the various dinoflagellata occurring in the region, it was found that *Ceratium furca* and species of *Gonyaulax* are the most likely to be dominant, and of these *C. furca,* even when not dominant, is almost universally present.

Animals

The use of a fine meshed net alone did not lead to an accurate picture of the total animal population, particularly the larger forms, such as copepods. Nevertheless, some of the results are of interest, both in regard to the smaller forms and to the larger forms.

The samples collected during April show, in general, the largest percentages of animals. This was a month of uniformly low plankton volumes at all the stations (table VII). Further studies will be necessary to ascertain whether these results indicate a greater *number* of animals per unit volume of seawater, or simply that the animal population is more conspicuous because of the absence of a masking bloom of plant life. From the present samples it is possible to estimate roughly that the animals are actually present in smaller numbers per unit volume of seawater, as would be expected when their natural food is sparse.

Considering the copepods, copepod nauplii and tintinnids alone as the most important and regular members of the plankton population it can be seen that during the year studied none of these forms was ever dominant at stations in the upper bay (Nos. 1, 2, 4) and that, at the other extreme, one or more of these forms were dominant in every observation except that for July 1945 at Stations 7 and 8, located in the southern part of the territory (Nos. 7, 8) (table IX). Stations 6, 9 and 11 also had one or more of these forms dominant on three of the visits, while Stations 3, 5 and 10 had one or more of the forms dominant only on one inspection. Thus, as was the case with the diatoms and the dinoflagellates, there is again a differentiation between northern and southern stations. This is not a differentiation between inside and outside stations, such as the preliminary results indicated might be the fact, since at Triumph Reef (No. 9), near the edge of the Gulf Stream, the copepoda, copepod nauplii or tintinnids were dominant on only three of the visits (October, April and June), whereas West Elliot Key (No. 7) in the bay had one or more of of these forms dominant at all times except July 1945.

The highest percentage of tintinnids occurred west of Elliot Key in June 1946 (38.5 per cent) but Triumph Reef ran a close second with 37.5 per cent in April. On the other hand, to the east of Elliot Key (No. 8), in the ocean, but protected by the outside reefs, tintinnids

TABLE IX. *Copepoda, copepod nauplii and tintinnids, by station number and date*

Station	1	2	3	4	5	6	7	8	9	10	11
July, 1945											
Copepoda	—	p	p	—	p	—	—	—	p	p	?
Copepod nauplius	p	p	p	p	?	p	—	—	—	p	?
Tintinnids	p	p	p	p	p	—	—	p	—	p	?
August, 1945											
Copepoda	p	—	—	—	—	p	—	—	p	p	p
Copepod nauplius	p	p	p	p	p	p	*dom*	p	p	—	p
Tintinnids	—	p	p	p	p	p	p	*dom*	p	p	p
October, 1945											
Copepoda	.5	p	—	—	p	*12*	8	5	*17*	4.5	*48.5*
Copepod nauplius	—	p	.5	p	—	*10*	21.5	19.5	6.5	7	4.5
Tintinnids	.5	—	p	.5	p	.5	6.5	4	.5	.5	2
December, 1945											
Copepoda	1	—	—	—	—	—	—	—	—	—	—
Copepod nauplius	3	p	—	.5	—	8.5	*19.5*	*13*	1.5	1	.5
Tintinnids	.5	—	—	—	—	—	3	.5	—	—	—
January, 1946											
Copepoda	—	.5	—	.5	—						
Copepod nauplius	p	3	2	p	2						
Tintinnids	—	—	1.5	—	3.5						
February, 1946											
Copepoda	.5	p	p	p	—	1	1.2	2.5	2.5	2.5	4.5
Copepod nauplius	p	.5	.5	p	.5	4	*11.3*	*12*	5	5	5.5
Tintinnids	p	p	p	—	1	3.5	.6	*14*	4.5	7.6	2.5
April, 1946											
Copepoda	2.4	1	*10.5*	3.5	5	6	*11.8*	4	1.5	2	1
Copepod nauplius	8.3	2.5	*15*	2.5	*13.5*	*21.5*	*19*	7.5	6	20	*17.5*
Tintinnids	2.6	.5	1.5	3.5	*15.5*	7	*12.2*	*17*	*37.5*	4	2.5
June, 1946											
Copepoda	p	—	1.5	2.5	2	2.5	1.5	5	*11.5*	p	*16.5*
Copepod nauplius	p	p	6	1.5	8	*13.5*	*13.5*	*11*	*12*	1.5	6.5
Tintinnids	p	.5	4.5	p	9	*20.5*	*38.5*	*32.5*	3	1.5	9

(p) The organism was observed and present in the sample.
(—) The organism was not observed.
(*dom*) The organism was dominant, though the percentage was not determined.
Numbers indicate percentage of total organisms.

were a dominant form on four observations. This was less often the case at any of the inside stations, or at Triumph Reef, which is located farther out in the ocean.

Copopod nauplii were more widely distributed than the tintinnids, though even the latter were seldom completely absent from any of the samples. Copepod nauplii were usually one of the dominant forms at Stations 7 and 8, but were also dominant and even more abundant at times in some of the other stations, mostly in the southern portion of the area studied.

The copepoda (both immature copepodid stages and adults) were seldom a very considerable percentage of the total organisms, but their relatively large size made them more important than the percentages would indicate. Most of the copepoda found, however, were of relatively small species. The highest percentages were obtained twice at the same station at widely different dates, namely at Chicken Key (No. 11), near the mainland in the southern portion of the bay. In October 1945, 48.5 per cent of the total organisms were copepoda, and in June 1946, 16.5 per cent of the total organisms were copepoda. In the latter instance, over one-third were adult copepods, belonging to all three sub-orders, the Calanoida, Cyclopoida and Harpacticoida. Copepoda were also a very large percentage of the plankton on two separate occasions at West Elliot Key.

General composition of the samples

It is frequently stated that the plankton of tropical waters, as distinguished from that of temperate and frigid waters, is sparse, but contains many species. The present investigation tends to bear out the sparseness of the plankton population at most times of the year. However, at times of diatoms maximum in Stations 1, 2, 3 and 4 in the northern portion of the bay, the volume of the plankton was considerable, considering the small type of net used.

On the other hand, there was little to distinguish the samples from those from temperate seas as far as number of species involved was concerned. In temperate seas plankton samples usually contain as many species (though frequently different forms are involved, of course) as were found in the Biscayne Bay area. Conversely, some of the Biscayne Bay samples were sparse in the number of species involved. In the upper bay (Nos. 1, 3, 4, 5) in July 1945, 95 to 99 per cent of the total organisms were species of *Chaetoceros*. In August a species of *Rhizosolenia* constituted 95 to 99 per cent of the total organisms at Station 1, and over 90 per cent at Station 2. In January, two species of *Chaetoceros* constituted 91 per cent of the total organisms. Finally, in June 1946 a species of *Rhizosolenia* constituted 90 per cent of the total organisms at Station 2. It is true that all these stations are in the northern portion of the area studied and that this may be an unusual situation for tropical waters, but comparable samples obtained in connection with Bird Island studies in the Gulf of Mexico showed 86.5 per cent *Ceratium furca* at the station located at Green Key, Tampa Bay and 85.5 per cent *Skeletonema costatum* at the station located in the N. W. Terra Ceia Bay.

Data on fouling organisms

Very little direct evidence was obtained on the prevalence of fouling organisms (table X). The larvae of barnacles of bryozoa and of the tunicates very seldom occurred in any numbers, nor did they tend to occur more frequently in those areas where fouling was more intense.

TABLE X. *Distribution of larvae of certain fouling organisms*

(Numbers indicate station numbers)

Month	Barnacle nauplii	Barnacle cyprids	Bryozoa	Tunicates
July	none	none	none	9?
August	1	1, 2, 6, 7, 9	none	4?, 5?
October	6, 7, 8	4, 5, 7, 8, 10	none	10?, 11?
December	none	none	none	none
January	2, 3	5	none	none
February	none	7, 11	4, 10	none
April	1, 2, 11	10, 11	none	4
June	none	11	none	11

Two probable reasons for the rare occurrence of the larval forms of fouling organisms are (1) A probably very short pelagic life for the organisms and (2) The tendency of these forms to swarm in large numbers, so that they are picked up by the net only by accident if it happens to pass through a swarm. In the future, more adequate means of studying the occurrence of the larval forms of fouling organisms in their pelagic environment should be devised.

Effect of pollution

Station 1, and especially Station 2, were located in a highly polluted area, close to the cities of Miami Beach and Miami, respectively. It was expected that the sewage pollution at these stations would have a marked effect on the plankton by enriching the water with nitrates and phosphates. Chemical conditions show that the phosphate content of the water is decidedly higher at Station 2 than elsewhere in the area and that nitrite nitrogen is higher at both Stations 1 and 2.

The highest plankton volume of any obtained in this investigation was found at Station 2 in July 1945, but the average plankton volume over the year at Stations 1 and 2 was only very slightly higher than that at Stations 3 and 4, which are located at some distance from polluted areas and which show typically low amounts of nitrite and phosphate. Stations 1, 2, 3, and 4 have much higher volumes than those obtained in any of the other stations. All these stations are in the upper bay.

With the data at hand, it is difficult to state the reason for the high plankton volumes at Stations 3 and 4, outside of the polluted area. It is necessary to keep in mind that the bay water is not static, but is constantly moving. Increased plankton growth, stimulated by the influx of phosphorus-rich and nitrogen-rich sewage from the metropolitan area, might be carried by the currents down the bay. Subsequently, as the initial growth of plankton died, decay would liberate nutrient salts, which would immediately be used by other phytoplankton organisms. On the other hand, the evidence from this investigation shows that the winter plankton maximum in the two unpolluted stations occurred a month earlier (December) than it did in the two highly polluted stations (January). Also, the average plankton volume outside Hurricane Harbor (No. 3) in the open Bay, and hence subject to the influence of up-bay water, was somewhat lower than that inside the nearly land-locked harbor, which is thus cut off from outside influences to a greater extent. The mangrove swamps in this vicinity may possibly have contributed nutrient materials.

During most of the year these stations had essentially the same dominant species of diatoms as the northern stations (Nos. 1, 2) but during April outside Hurricane Harbor was similar to the southern stations. Inside the harbor, however, the plankton was still characterized by *Bacteriastrum* and *Chaetoceros* as dominants. This seems to indicate a northward movement of southern water in April, cutting off Hurricane Harbor.

Effect of low nitrite and low phosphate

Nitrites and phosphates, as indicators of essential inorganic nutrient materials, were uniformly very low or even apparently absent in the area studied. This seems to be usual in tropical waters. It is discussed in relation to the Great Barrier Reef by Marshall ('33, p. 124). It is not possible to distinguish in the present study the effect of variation of nutrient salts on the plankton growth, with the exception of the area of pollution discussed above.

Most of the species of diatoms, both during periods of great abundance and periods of scarcity, were rather uniformly small in size compared to those of nitrite-rich and phosphate-rich areas, such as, for example, Puget Sound. It would be desirable to make detailed comparisons of the relative sizes of identical species (e.g. *Skeletonema costatum, Rhizosolenia alata,* or *Chaetoceros* spp.) as well as abundance with the concentration of nutrient salts. On the other hand, the small size might be due to the relatively high temperatures of Biscayne Bay and vicinity, or to other factors.

An area of stagnation

The results show that Featherbed Bank (No. 6) and West Elliot Key (No. 7), both located in the southern portion of the Bay, differ from all other stations, in certain important respects. The volume of plankton is uniformly lowest at these stations, the diatom population is of lesser importance, and the dinoflagellate population is of greater importance. Chemical and physical observations show that these two stations tend to be colder in winter and hotter in the summer than the others. In addition, there is a tendency for higher

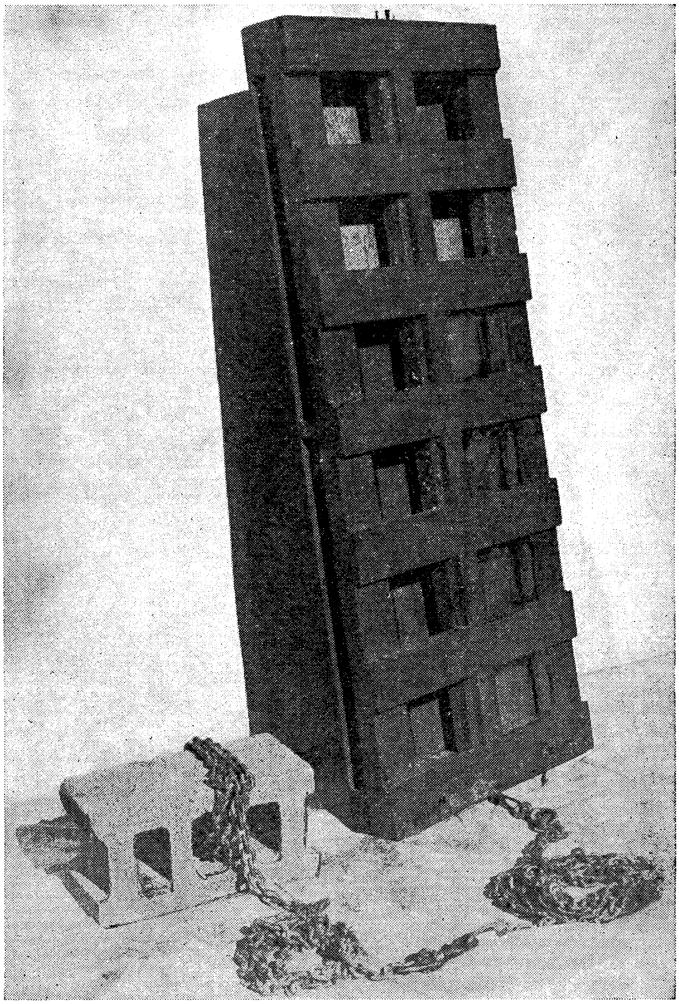

FIG. 2. Raft with slots for glass collecting panels, viewed from beneath. Mooring chain and cement anchor block attached.

salinities, both winter and summer, than at the other stations. On the nautical charts of the area, it may be observed that lower Biscayne Bay, in which these stations lie, is connected directly with the sea only by very narrow and shallow channels, and that it is also cut off to a considerable extent from the more northern reaches of the bay by shallow Featherbed Bank. Thus the water of this portion of the bay suffers a minimum of mixing with any fresh supply of seawater or of water from the upper portions of the bay.

FOULING ORGANISMS

Observations were made at each station upon floating rafts. The rafts were solidly constructed of wood and each one bore on its lower surface twelve slots arranged in two rows (fig. 2). The slots were designed to take horizontal, rectangular glass panels, each 6×8 inches in size.

Experience showed the need for strong ground tackle and the rafts were accordingly anchored by means of $\frac{3}{16}''$ chains provided with swivels and about three times as long as the depth of the water. The anchor consisted of two heavy concrete, hollow building blocks to which the chain was shackled. In spite of the rugged nature of the anchors, rafts were lost on several occasions, partly by storm damage. It is believed, however, that some of these were stolen, since anchor chains were very scarce during the period of the survey.

When first set out, each raft was provided with one glass panel. At approximately monthly intervals, a new panel was added and the lower surfaces of all the previously inserted panels were examined. In this way, not only was the initial attachment and growth during each month observed, but also the progressive changes in the sessile communities from month to month.

In addition to identification of as many of the species as possible, the number of barnacles and the greatest diameter of the largest barnacle were recorded. The area of the glass panel covered by attached forms was recorded as tenths of the total area. The greatest dimensions of solitary ascidians and branching Bryozoa were also measured. Attempts to obtain the wet weight of each panel were abandoned since it was found impractical to use even a spring balance in a small boat under the weather conditions frequently encountered.

Organisms

Since observations were confined to one type of collector, the organisms encountered were not fully representative of the region, and do not admit of detailed comparison with those of other regions. It was noticed, however, that the forms collected are generally typical of the West Indies, although a few are also encountered at stations as far north as Beaufort, North Carolina. They agree with the list given by Weiss ('48) for the northern part of the bay. The principal organisms appearing on the floats are shown in table XI, which represents the month by month attachments to the panels of each raft.

Slime film, although present on all the rafts, was obscured in many cases by the heavy attachment of macro-organisms and no indication was given in the present series of observations that it is a necessary preliminary to the attachment of the larger forms. On those rafts in the lower bay, which had relatively little fouling, slime was present at all times of the year. Composition of the slime was not subjected to detailed investigation, but in most cases it was brown in color due to diatoms. The thickness of the film varied, and during periods of heavy weather a considerable amount of silt was often present. The silt consisted usually of the fine calcium carbonate or marl, characteristic of this region. It was particularly noticed at the stations in the lower bay and outside Hurricane Harbor. It was never heavy at Trimuph Reef.

Algae were particularly evident in the lower part of the bay and were usually absent to the north, where animals were plentiful. The only exception was a fairly heavy growth of *Enteromorpha* sp. at Station 1 during November. At other stations, *Enteromorpha* was never found. *Acetabularia* and *Batophora* were frequently in evidence. Less common genera were *Dasya, Polysiphonia, Chondria* and *Laurencia.* Algae were found at most times of the year, but were less noticeable during November and December.

Coelenterates were never very plentiful at any of the stations. *Tubularia* was found during December to March, mostly in the lower bay. Other hydroids, unidentified, were noted only on rare occasions.

Bryozoa were represented by *Bugula neritina* and by the encrusting form *Watersipora cucullata. Zoobotryon pellucidum,* which sometimes forms dense, heavy branching masses on piling, was surprisingly rare on the panels. *Bugula* was plentiful, and more marked in the northern part of the bay during November to March. A smaller peak was evident during May, and again in August. The only noticeable exception to this distribution was a single occurrence at Triumph Reef in April. *Watersipora* was heaviest in the northern part of the bay during December to March, and again in May. It was also fairly frequent in the stations of the lower bay and Triumph Reef, but never in large quantities. The peak periods were from December to March and in May.

Polychaets were never abundant. The calcareous tubes of serpulids were occasionally noticed during April to July. Like other small organisms, they appeared to be unable to compete with the larger forms in the upper part of the bay, but were present in small numbers at the other stations. An interesting form found inside Hurricane Harbor during July was *Dasychone* sp., forming a colony of small parchment tubes.

Mollusca were poorly represented. *Anomia* sp. was occasionally found on the surface of panels when the growth of other organisms was not heavy. It was found much more frequently, however, on other parts of the raft and on the upper surface of the glass panels which did not otherwise appear to encourage larger organisms.

Ostrea virginica occasionally appeared on the rafts, but never on the exposed surface of the panels.

Crustacea were principally represented by *Balanus amphitrite* and *B. improvisus.* These occurred at all times of the year, but principally during November to March, and from May to July. Attachments were much greater in stations of the upper bay, although large attachments occurred at the eastern Elliot Key station during November, and at Chicken Key from November to March. *Balanus eburneus* was freqently found but the remaining balanomorph barnacles of this region, *Tetraclita squamosa* and *Cthamalus stellata,* were almost absent from all stations. *Lepas anatifera* was found at Triumph Reef and in Biscayne Channel in small numbers during May and June, and again in February on the eastern shore of Elliot Key.

The tube living amphipod, *Erichthonius* sp., was found in fair quantity, but only in the stations of the upper bay. It appeared during April to July and again in November. It was not only found on the exposed surface of the panels but frequently in large numbers on the upper sheltered surface as well.

Ascidians were probably the most successful colonizers of panels in the upper bay, but rarely present elsewhere, except at the western side of Elliot Key. They were represented by the large, knobbly, white *Styela plicata* and to somewhat lesser extent by *Ascidia hygomiana, Ascidia nigra* and *Ecteinascidia turbinata.* Attachments took place during all the months of the year, but reached a peak from May to July, and a much smaller peak during March. Colonial tunicates were represented by various brightly colored botryllids, the white encrustation of *Didemnum candidum* and occasionally by mottled growths of *Symplegma viride.* Heavy collections of fouling organisms were sometimes covered by a thin greenish network of *Perophora viridis.*

Colonial tunicates, like the solitary forms, attached throughout the year, peaks occurring during May to July and to a lesser extend during December. Attachments were heaviest in the upper enclosed parts of the bay.

In addition to the organisms listed above, there were occasionally found free living animals which made their homes among the attached growth, although they cannot properly be classified as sedentary organisms. These include numerous crabs, shrimp, young spiny lobsters, amphipods, caprellids and small fishes. Fish eggs which were not identified, and occasionally the eggs of mollusks, were also found attached to the panels. Frequently, on the upper surface of the glass panel, or on the raft itself, there appeared organisms which were not observed on the collecting surface. Most commonly occurring in this category was *Anomia* sp.

Sponges were not found during the survey.

Initial fouling

The organisms observed on each panel at the end of the first month of exposure are listed in table XI. The results of observations are also shown in summarized form in figure 3.

The greatest amount of attachment was observed in the upper bay (Nos. 1, 2). A comparable amount of attachment was also found in the land locked harbor of Biscayne Key (No. 4). Station 3, near to Station 4, but in the open water of the bay, showed distinctly less accumulation of fouling except during the months of February and March. The remaining stations acquired markedly less fouling throughout the year. During the month of May, Triumph Reef (No. 9) showed a greater accumulation than other stations in the southern part of the survey area. East of Elliot Key (No. 8) and at Chicken Key (No. 11), respectively, higher attachments appeared during November and December.

In general the peak of attachments at the northern stations occurred during May and June, with a smaller one in November. Owing to a loss of rafts there is insufficient information about a mid-

TABLE XI. *Summary of initial fouling accumulation*

0–10 Coverage of plate
B *Balanus*
A Solitary Ascidians
Lep. *Lepas*
Bug. *Bugula*
EB Encrusting Bryozoans
Alg. Algae
T. Colonial Tunicates
S. Serpulids
D. *Dasychone*
H. Hydroids
Amp. Amphipod tubes

Balanus and *Lepas* by numbers, others by coverage

Station	1	2	3	4	5	6	7	8	9	10	11
April 1945	—	—	1 B:1 EB:1	—	0	—	0–1 T	0	3 B:9 Bug:2 EB:1	0–1 B:2	0–1 EB
May	10 B:400 Bug:1 EB:2 T:6 Amp.	10 B:400 A:10 T:1	1 Alg. S	10 B:20 T:9 A:1	0–1 B:3 Alg.	—	1 T:1 Alg.	1 EB S	1 A Lep. Alg.	1 EB:1	1 B EB
June	10 B:100 T:9 Amp.	10 A:10 B T:2	1 B:20 A:1 T, S	10 B:20 A:1 T:10	0–1 Alg.	—	0–1 T,S	1 Alg.	1 Lep.	1 EB,T	—
July	10 B:50 T:9 S	10 A:10 B T:1	1 T Amp. D	7 B:65 T:4 D:1	0–1 Alg.	—	0–1 Alg.	1 Alg. S	—	0–1 Alg.	—
August	4 B T	—	2 T:2	5 B:70 A:1 Bug:2 T:1 D:2	—	—	—	1 Alg.	—	—	—
Sept. to Oct.	—	—	—	2 A:1 T:1 D:2	7 B:500	—	—	—	—	—	1 B:14 Alg,H

TABLE XI—*Continued*

Station	1	2	3	4	5	6	7	8	9	10	11
Nov.	5 B:2 Bug:5 EB:1 T:2	—	—	7 B:500	1 B:16 EB:1	0–1 B:6	1 B:25 Alg.	7 B:400 EB:1	—	0–1 B:1	9 B:500
Dec.	8 A:1 Bug:3 T:4 H:1	4 B:200 A:1 Bug:2	2 B:200	2 B:250 Bug:1	1 B:15 Lep:2	2 B Alg. EB	2 H Alg.	—	—	0–1 B:3	2 B:150
Jan. 1946	4 B:200 Bug:2 EB:2	—	5 Bug:1 H:4	7 B Bug:7	—	2 Alg. H EB	1 A,T	—	—	3 B:3 Alg. H	0–1 B:35
Feb.	5 B:10 Bug:1 EB:3	—	9 B:500 Bug:1 Amp:1	7 B Bug:3 T:4	0–1 B:4	0–1 Alg.	2 A:1 T:1	1 Lep:1 Alg.	—	1 Alg.	0–1 B H,Alg.
March	6 B:40 Bug:1 EB:3 S	—	2 B:75 Alg:2	10 B A:5 T:4 Bug:4	0–1 B:6	1 Alg.	1 B:10 A:1	1 Alg.	3 EB:1 Alg:3 S	1 Alg.	1 B:250 H,Alg.
April	7 A:2 Bug:1 T:7 Amp.	—	1 B	7 B A:3 Bug:1 T:4 D	2 B:2 Alg:2	1 Alg.	1 T,A	1 Alg.	2 EB,S Alg:2	1 Alg.	0–1 Alg.
May	—	—	1 B:10 Alg.	10 A:1 T:9 Amp. D	1 B:10 Alg:1	1 Alg.	1 Alg. A	1 Alg.	2 Alg:2	1 Alg.	2 B:10 Alg. H:2

winter peak at Station 2, although heavy fouling occurred during May and June. The pattern of mid-summer and mid-winter peaks may be seen in Hurricane Harbor. Station 3, outside the harbor, shows a peak in February and March alone. Of the remaining stations, only Triumph Reef shows a peak during May. Stations 6, 8 and 11 show the mid-winter peak.

The considerable seasonal variations in attachments with major peaks roughly occurring in mid-winter and early summer are substantiated by the observations of Weiss ('48) which were limited however to the upper bay.

Growth rates

Growth rates during the first month following attachment are shown in tables XII and XIII. It was not possible to obtain comparable growth rate determinations of all organisms throughout the year principally owing to the intense competition existing at certain times and to the absence of organisms at others. Further gaps in observations are due to loss of the rafts by storm and human agencies.

With the foregoing reservations in mind, it may be stated that in general the greatest amount of growth following attachment took place during the months be-

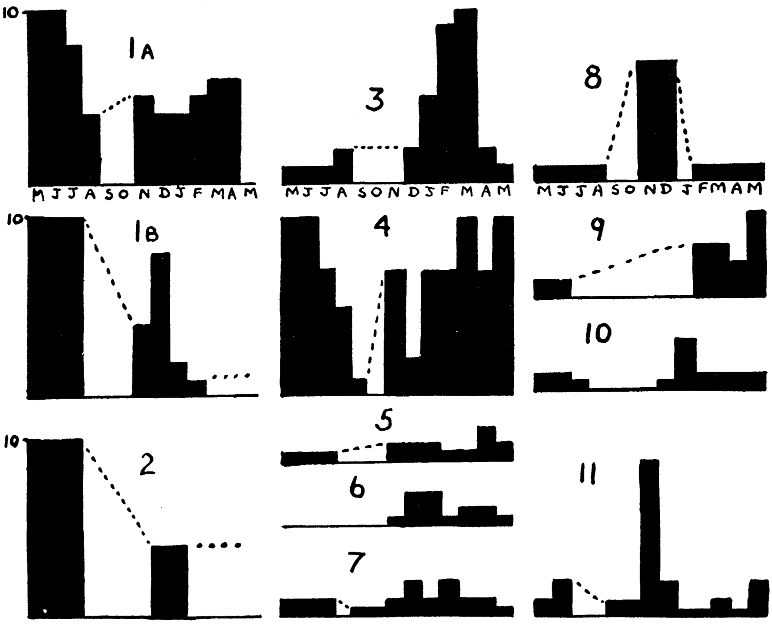

FIG. 3. Monthly fouling accumulations expressed in tenths of panel covered after one month of exposure. Station 1B is in the same locality as station 1A but is inside covered boat slip.

tween April and July. In spite of the fact that during December the lowest sea temperatures were observed, there was also a slight increase in growth rate during mid-winter. Thus, the periods of maximum growth coincide generally with the periods of greatest attachment.

Greatest growth was observed at the stations in the upper bay (Nos. 1, 2, 3, 4). Even during the summer peak, growth at

TABLE XII. *Season of maximum growth*

Figures indicate greatest growth in any direction recorded at each station during the month of attachment, measured in millimeters

Organism	Station											
	1A	1B	2	3	4	5	6	7	8	9	10	11
Balanus sp.	*20* May	8 Dec.	14 May	12 April	*20* May	8 Nov.	4 Dec.	10 April	7 Nov.	10 May	9 Dec.	10 June
Lepas anatifera						*23* Dec.			7 Nov.			
Bugula neritina	5 Dec.	10 Nov.	8 Dec.	25 Feb.	*50* Jan.							
Encrusting Bryozoons	10 Dec.	10 Dec.		*50* Feb.			10 Jan.					
Ascidia nigra	*20* May							18 May				
Styela plicata	20 Apr.		25 June	28 May	*60* Apr.			13 Jan.				

TABLE XIII. *Growth rate of* Balanus amphitrite

Figures indicate greatest increase in diameter recorded during the month of attachment, measured in millimeters

	Station											
	1	2	3	4	5	6	7	8	9	10	11	Max.
April, 1945	—	—	12	—	—	—	10	—	5	2	—	12
May	20	14	—	20	3	—	—	—	10	5	—	20
June	—	—	—	—	—	—	—	3	—	—	10	10
July	—	—	8	10	—	—	—	2	—	—	—	10
August	—	—	—	7	—	—	—	—	—	—	7	7
September	—	—	—	7	—	—	—	—	—	—	7	7
October	—	—	—	10	—	—	—	—	—	—	—	10
November	10	—	—	10	8	4	2	7	—	3	9	10
December	7	2	4	3	3	4	—	—	—	9	2	9
January, 1946	9	—	7	—	—	—	3	—	—	—	4	9
February	5	—	10	—	—	—	—	—	—	4	—	10
March	5	—	—	—	—	4	—	—	—	—	—	5
April	12	—	—	—	—	4	5	—	—	—	—	12
May	—	—	10	—	—	—	10	—	—	4	—	10
Maximum	20	14	12	20	8	4	10	7	10	9	10	20

Stations 5, 9 and 10 was considerably lower than at the others.

The amount of growth recorded for individual species was generally much greater than observed by Edmondson and Ingram ('39) in Kaneohe Bay, Oahu. It was also decidedly greater than at Beaufort, according to the data supplied by McDougall ('43).

Balanus amphitrite during May 1945 showed a maximum increase of diameter of 20 mm. This is considerably in excess of the 15 mm reported by Edmondson and Ingram for a period of forty to sixty days. McDougall records a growth of 12 mm for a four week period.

Bugula neritina attained a maximum length of 50 mm during a four week period in January, 1946. This is more than twice the amount recorded by McDougall. The greatest growth for this species in Hawaii was 25 mm in approximately two weeks.

No direct comparisons are available for encrusting bryozoa. The species *Watersipora cucullata* attained a maximum diameter of 50 mm during the month of February at Station 3. This species was not observed in Hawaii or at Beaufort, but *Schizoporella* grew 30 mm and 45 mm during the same period in these two localities respectively.

Styela plicata at Station 4 attained a maximum length of 60 mm during April This is twice the growth observed at Beaufort and more than four times the rate observed at Kaneohe Bay. Edmondson ('44), however, reports the growth of an unknown species of solitary ascidian at Pearl Harbor. This grew to 50 mm in length during sixty days.

Succession

The organisms initially appearing upon the panels varied with the time of the year and the station as already described. There did not appear to be any regular order of succession. Supplementary observations on microscope slides exposed during March when barnacle attachments were heavy showed that settling would take place in less than two hours after immersion of the glass surface. The presence of a slime film does not, therefore, seem to be necessary for settlement by barnacles. Further observations over the past few years of a similar nature have shown this to be equally true for encrusting bryozoa and colonial tunicates.

The growth on panels subsequent to

their first month of exposure appeared to depend upon the intensity of periodic sets of the various organisms and their ability to survive competition. At the stations where attachments were poor and growth slow, the monthly changes in fouling on the continuously exposed panels were generally in the nature of additions which corresponded to the attachments on initially exposed panels. To some extent the organisms already present tended to die or lose attachment, possibly due to lack of food.

Heavier setting and more vigorous growth produced different effects at stations in the upper bay. Thus, a heavy growth of barnacles during January at Station 1 was gradually overgrown by subsequent sets of encrusting bryozoa and *Bugula*. While this covered the shells of the barnacles, it did not prevent their continued growth. In March and April, however, colonial tunicates developed and, while at first ineffective, these, by the end of April, had greatly reduced the number of barnacles that remained alive. A similar sequence was observed at Station 4. Barnacles were able to survive following attachment of *Bugula*. A heavy growth of solitary ascidians during May, however, finally resulted in the death of all the barnacles, which were completely overgrown.

Encrusting bryozoa were the first to attach during December at Station 1. These were not affected by subsequent growth of barnacles which did not settle upon them in large numbers. By the end of March, however, they had been largely smothered by growth of *Bugula*. By the end of May, solitary ascidians had largely replaced all other forms.

Colonial tunicates which attached during May and June at Station 4 were partially superseded by barnacles and later by solitary ascidians. At this station it was observed that the presence of heavy growths of solitary ascidians prevented further attachment of barnacles, although colonial tunicates and, to some extent, *Bugula* were able to attach. Colonial tunicates, at various times and places, were frequently lost, apparently by mechanical action as a result of poor adhesion. Other organisms prevalent at the time were then able to attach. The solitary ascidians remained for a longer period but eventually were lost in clumps as their weight became excessive and the area exposed to wave action increased. Other organisms then became attached.

Thus there was no regular succession, since all organisms attached at some period of the year during the initial month of exposure, depending upon the intensity of breeding, and were not greatly dependent upon the presence of previously attached organisms. Seasonal succession was present only where earlier arrivals had not taken complete possession or where the later arrivals were able to attach and to exert a smothering effect upon the earlier attachments by virtue of numbers. Breeding appeared to take place to a limited extent at all seasons and the species attaching at any one time and place depended mostly upon the relative breeding intensities at that time and place. Solitary ascidians appeared to be most capable of supplanting others and of resisting further attachments. To this extent they may be regarded as a climax, although even they would sometimes be lost and leave a clear space for others as they open in size. The order in which the remaining organisms were able to supplant each other depended to a considerable extent upon the relative amount of already attached growth and of the intensity of new attachments.

In the case of many of the organisms, breeding, as shown by attachments, continued throughout the year to a varying extent. Similar observations were made by Scheer ('45) at Newport Harbor, California, where the range is very small, 14° C in February to 19° C in July. At Beaufort where the range is from 5° C in February to 28° C in July, McDougall ('43) observed that organisms were decidedly seasonal in their breeding habits. Perhaps as a result of this there ap-

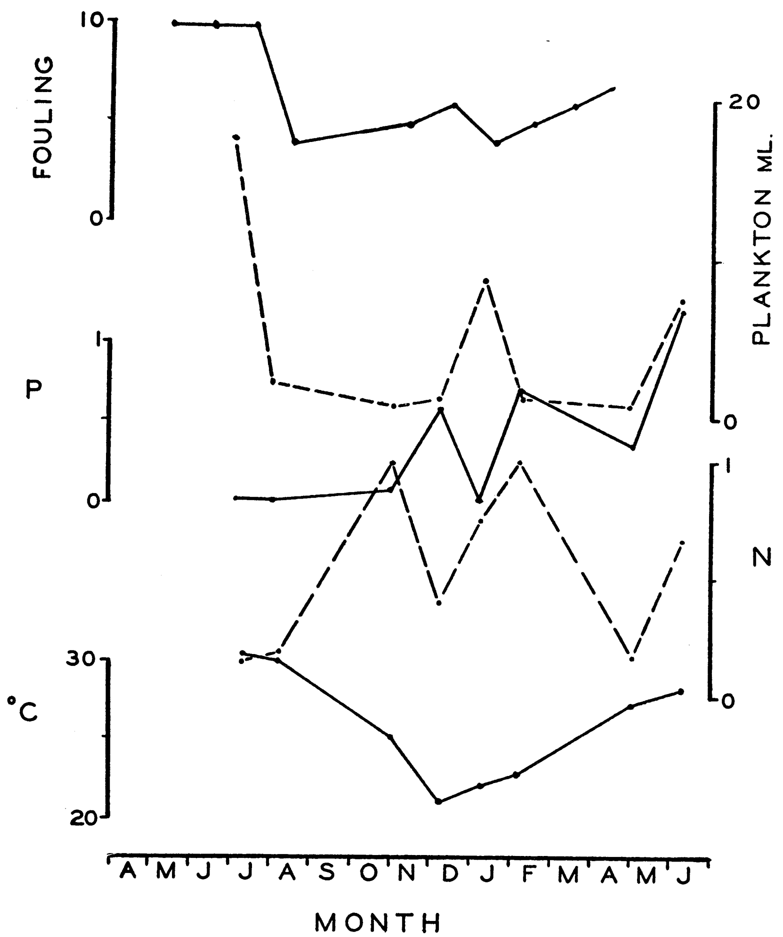

FIG. 4. Average of quantitative observations at stations 1 and 2 in the northern part of Biscayne Bay. N: nitrite nitrogen, P: phosphate phosphorus both expressed in microgram atoms per liter. Fouling expressed in tenths of panel covered after one month of exposure. Plankton expressed in milliliters per standard sample.

peared to be a seasonal progression at Beaufort, whereas at Newport this was greatly overshadowed by an ecological succession. At Miami the temperature range was from 16° C in December to 32° C in July and, although fouling tended to occur at all months of the year, there were decided peaks in intensity. This may be the reason for the lack of any definite ecological succession. On the other hand, succession was not truly seasonal. This may possibly be an indirect result of higher temperatures which would bring about the much greater growth rate of organisms. Thus competition would favor earlier attachments to the extent that organisms in season would not necessarily replace those out of season. Furthermore, there appeared to be considerable variation in the life of attached organisms, some of which only disappeared as a result of mechanical difficulties. The changes in a community of fouling organisms may therefore be regarded as being due to two series of antagonistic factors. The fact of previous attachment, vigorous growth, degree of coverage of surface, and mechanical advantages such as the bulk and slimy surface of solitary ascidians and length of life are factors favoring the continued attachment of organisms. Intense concentrations of larvae, favorable conditions of food and temperature for rapid growth following attachment, greater efficiency in competition for food and oxygen, such as the smothering of barnacles by a heavy growth of solitary ascidians and the dying out of previous attachments, are factors favoring new attachments. Where physical conditions favor short breeding seasons and relatively brief life and where attachments are light, seasonal progression would be more noticeable. Where breeding is year around as at Newport Harbor, an ecological succession would be observed. At Miami the long breeding seasons and the variability in intensity of attachment and growth rates result in a condition intermediate between a seasonal progression and an ecological succession characterized by considerable variation in the order of succession, but without pronounced seasonal tendencies.

A study of the relative intensity of fouling at the different stations reveals a fairly sharp distinction between those of the relatively enclosed northern part of

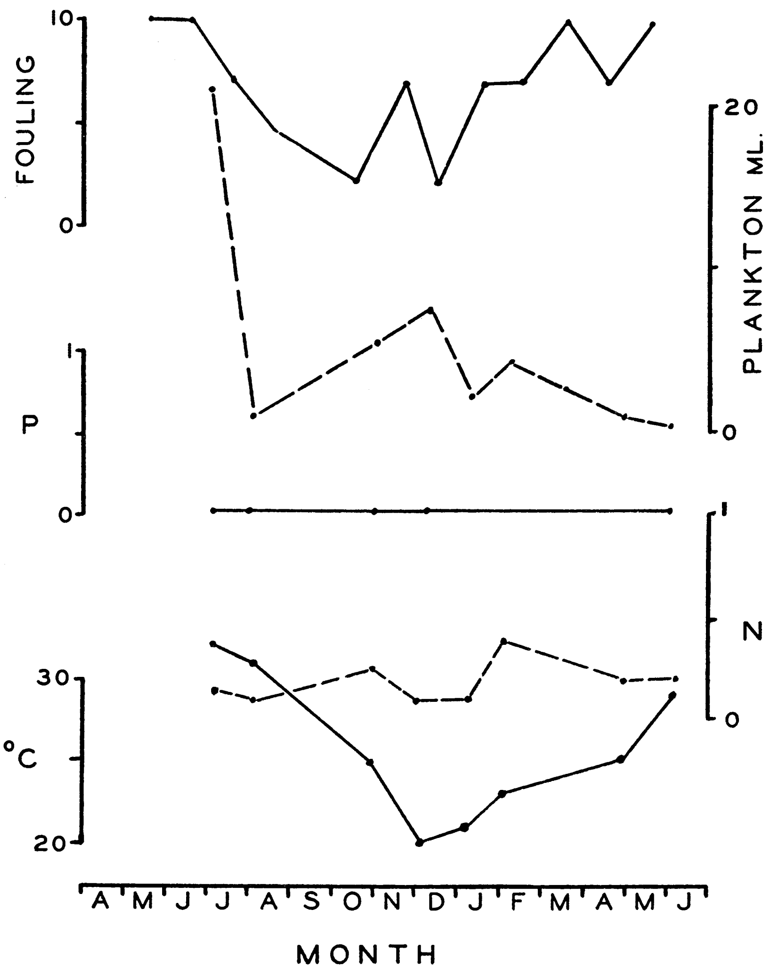

FIG. 5. Quantitative observations at station 4 in Hurricane Harbor. Units as in figure 4.

the bay and the remaining stations. Heavy fouling in the upper part of the bay cannot be associated with ordinary land drainage and factors of enclosure alone, since similarly enclosed stations in the southern part of the bay collected very few organisms. The northern part of the bay, however, is rimmed by seawalls and piers which offer a large area for fouling attachment, thereby insuring a plantiful supply of larvae. This is not true in the lower part of the bay where suitable surfaces for attachment are virtually non-existent, since the shores consist, for the most part, of mangroves. The tidal run of water in the upper bay runs north and south and little mixing taken place. Thus the larvae liberated from the seawalls are not dissipated but remain to bring about re-infection. The upper part of the bay is also heavily polluted with city sewage, resulting in increased nutrient content and plankton growth. These two factors would serve to explain on the one hand the higher intensity of attachment, and on the other hand the higher growth rate characteristic of the upper part of the bay.

Stations 3 and 4, in some respects intermediate in topographical situation, more nearly approximate the northern

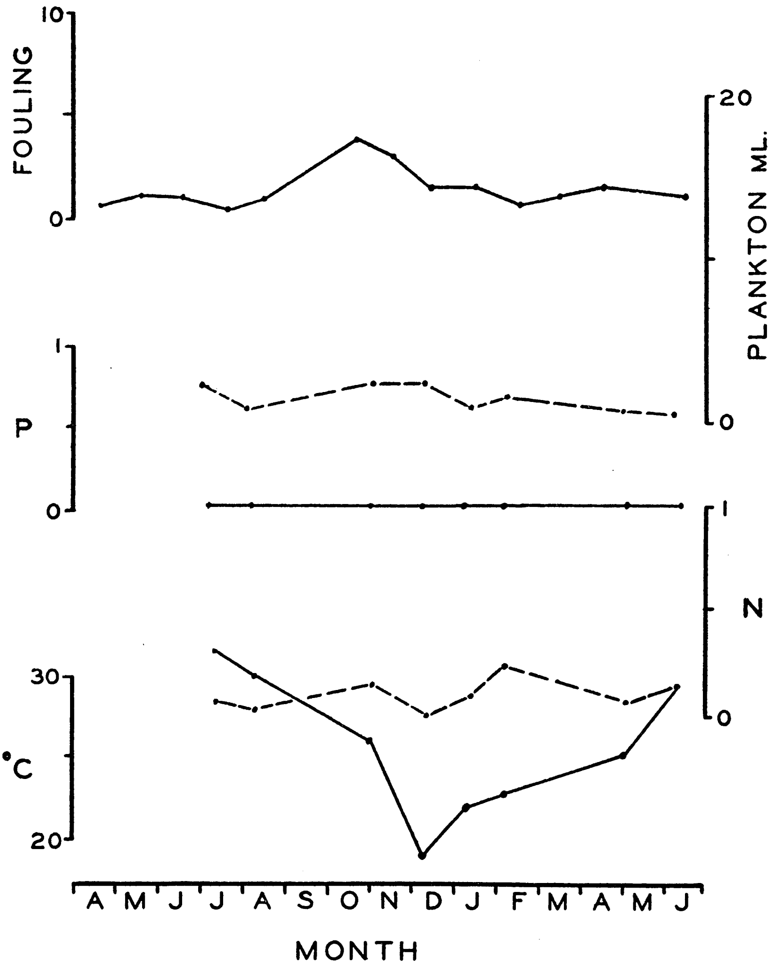

Fig. 6. Average of quantitative observations at stations 5, 6, 7, 10 and 11 in the central and southern part of bay. Units as in figure 4.

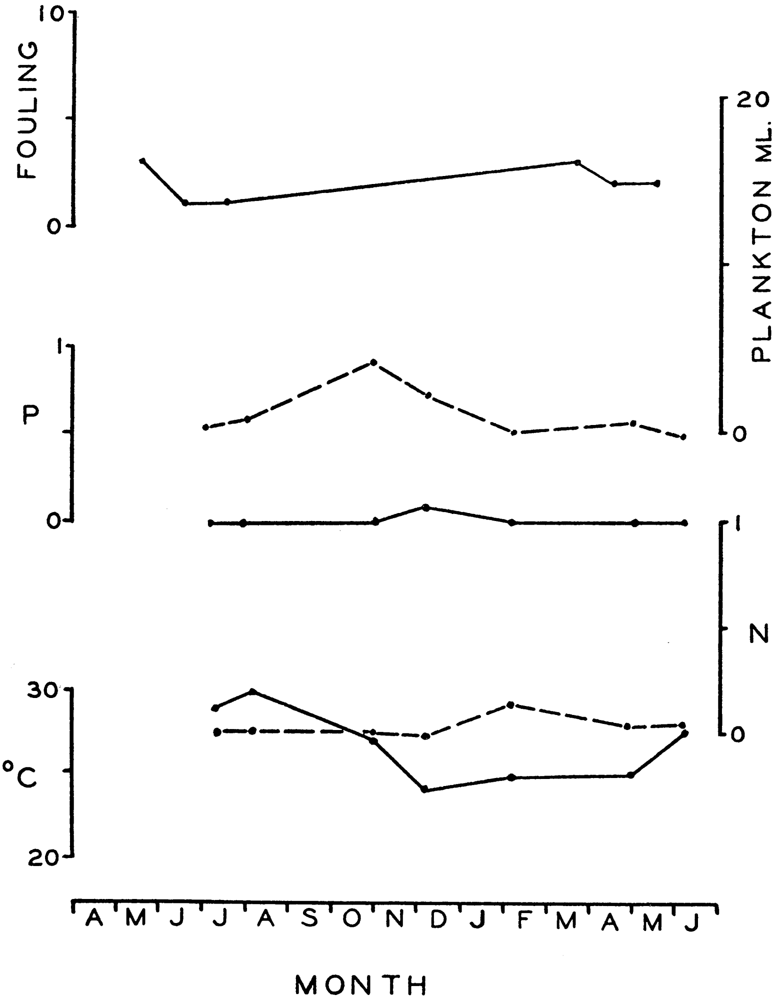

FIG. 7. Quantitative observations at station 9 on Triumph Reef. Units as in figure 4.

stations in their fouling characteristics. Station 3, outside Hurricane Harbor, is noticeably poorer in this respect than the nearby station within Hurricane Harbor. Apparently, the enclosed nature of Hurricane Harbor favors heavy fouling. The lack of mixing with outside water here would also tend to keep larvae in high concentration.

Other stations were uniformly low in fouling intensity. Triumph Reef and East Elliot Key, nearer to the open ocean and Chicken Key, on the inner shore of the middle part of the bay, showed slightly greater fouling than the remainder. These differences and their distribution do not appear to admit of any correlation with the situation of the stations with respect to water currents, land drainage or communication with the open ocean. Stations within and without the bay show no consistent difference.

Summary and Conclusions

In contrast to oceanic conditions which in the tropics are usually rather uniform and which show only slight annual variation, the conditions in Biscayne Bay exhibited a wide range. Water temperatures ranged 18° C to 32° C in the inshore stations. By contrast, the reef station showed a range of 24° C to 29° C only. Seasonal changes followed, in a general way, the changes in mean air temperature and the total daily hours of sunshine. Variations in salinity were, as might be expected, much greater inshore than offshore. The effects of rainfall and the evaporation of shallow waters during dry summer weather sufficiently account for these ranges.

Dissolved mineral nutrients were extremely low or undetectable at all stations throughout the year, except at a station in the northern part of the Bay where sewage was abundant. It appeared that, in the case of phosphate-phosphorus at least, the plankton growth and nutrient demand were always in excess of the rate of replacement. Unfortunately, it was not feasible to undertake total phosphorus determinations during the survey, but it also appears from the plankton studies that the total phosphorus might also be very low. Nitrite-nitrogen content showed a peak value in February but otherwise followed the pattern of phosphate-phosphorus. The significantly higher nutrient content at the northern inshore stations could well be explained on the basis of bacterial decomposition of sewage components. The greatest plankton concentrations were obtained from sewage polluted stations in the northern part of the bay and in the almost enclosed lake on Biscayne Key. Elsewhere there was little difference between the inshore and offshore stations. Two volume maxima appeared, in July and in December–January. At some of the stations a single peak appeared in October.

While the plankton was generally sparse compared to that of temperature latitudes, the number of species was by no means larger. The higher volumes in the Biscayne Key lake might be attributed to land drainage although this did not appear to be effective on the mangrove fringed shores of the mainland. Inshore areas were quite different in species constitution to the offshore areas.

The generally low phytoplankton volumes are in accordance with the findings of Russell and Coleman ('33) and of Marshall ('34) for the Low Isles areas of the Great Barrier Reef, where it is suggested that the higher metabolic rate of the zooplankton brings about a high grazing rate, thus preventing the phytoplankton from developing any excess of production over utilization.

The organisms attaching to the glass panels suspended beneath rafts were predominantly barnacles, colonial tunicates, solitary ascidians, encrusting bryozoans and *Bugula*. Some organisms of each group attached during every month of the year, but the peak of attachment density occurred during mid-winter and mid-summer. Under the more truly tropical conditions of the Great Barrier Reef, Stephenson ('34) found a similar situation with a slight majority of organisms exhibiting a summer breeding peak only. Growth rates were much higher than previously recorded for the same or similar species, with maximum growth occurring in mid-winter or early summer.

The stations where greatest amount of initial attachment and greatest subsequent growth occurred were in the northern part of Biscayne Bay. This high rate of attachment may be due to conditions favorable to larval growth and development, arising from sewage products, to the continuous harbor works covered with fouling organisms which provide a considerable supply of larvae, and to the relative isolation of the water. Enhanced growth in this area is almost certainly correlated with sewage and enhanced plankton production. Similar conditions of growth and attachment were found in the landlocked harbor on Biscayne Key. The remaining areas, however, showed very poor fouling characteristics. This might be partly due to lack of larvae, resulting from the absence of rocky shores or harbor works which might support breeding organisms but it is certainly partly accounted for by the lack of nutrients and plankton. No significant difference appeared between offshore and inshore stations in this respect.

The nature of changes in the fouling communities subsequent to the initial month of exposure showed that neither a true ecological succession nor a definite seasonal progression is present. The changes appear to depend upon the relative potency of such factors as concentration of larvae, growth rate, length of life and length of breeding season. The interaction of these factors may reverse the succession more commonly present and may also greatly modify seasonal progression. It was noticeable that solitary ascidians with a high growth rate and large bulk, once established, tended to survive longer than other organisms, yet if attaching in large enough numbers colonial tunicates might completely invest the ascidians and kill them off, leaving the plate once more free for barnacles or bryozoans to colonize. While *Lepas* was more obvious at the reef station it was no less prevalent in initial attachments at the inshore stations. Its presence was obscured by the greater growth of other organisms.

In general, the results indicate the great part played by land drainage and sewage in the growth of plankton and of sedentary organisms, the otherwise low nutrient and plankton content of inshore waters, and the presence of a winter as well as a summer peak in breeding and growth. They also indicate a year around plankton growth limited by the rate of phosphate production and a grazing rate limited by phytoplankton formation.

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