PRNC - 196

PUERTO RICO NUCLEAR CENTER

AGUIRRE ENVIRONMENTAL STUDIES

JOBOS BAY, PUERTO RICO

FINAL REPORT

June 1975

VOLUME I

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FOREWORD

The Aguirre Environmental Studies, Jobos Bay, Puerto Rico, Final Report is the last of a series of reports and published papers on the research of the Aguirre Power Project Environmental Study.

In 1970, an impact study was planned for a proposed nuclear power plant to be located at Aguirre, Jobos Bay, on the south coast of Puerto Rico. A cooperative effort of the U.S. Atomic Energy Commission, the Puerto Rico Nuclear Center, and the Puerto Rico Water Resources Authority was initiated. As the study progressed, the Puerto Rico Water Resources Authority and the Puerto Rico Nuclear Center continued the research in what came to be known as the "Jobos Bay Project."

The first two years of the Jobos Bay Project emphasized the assembling of a research team and library, gathering of baseline data, and monitoring of the area. Basic background data was reported, and the main environmental study begun. The research investigations over the five years of this study have resulted in a wealth of scientific information on an area where little or no scientific investigation had been done before. This new knowledge and information is valuable and useful not only to the government and people of Puerto Rico but also to all scientists who are interested in further researching the Caribbean area.

Many persons have contributed to the success of the Jobos Bay Project, and many studies were initiated through the good offices of Dr. Carlos Jimenez, Director of the Puerto Rico Environmental Quality Board, formerly with the Puerto Rico Water Resources Authority. Dr. Frank G. Lowman, Associate Director for Environmental Sciences, Puerto Rico Nuclear Center, directed the project in its early years. Later, Dr. Michael J. Canoy, PRNC scientist, assumed leadership.

The PRNC scientists and staff who have contributed to earlier reports are named in those reports. The staff most directly concerned with the final year of the project and the Jobos Bay Annual Environmental Report 1974, issued in March, 1975, and this report are: James W. Parrish and Eugene Johnson (oceanography); Marsh J. Youngbluth and Gary P. Owen (zooplankton), with Juan M. Muñoz, Eladio Rodriguez, Oscar Menendez Ortiz, Carmen Cintron; Vance P. Vicente (sea grass bed communities) and Paul M. Yoshioka (mangrove root communities), with Nelson Acosta, Beverly Buchanan, Roberto Castro, Irene Justiniano, José Rivera and Alice Vega; K. W. Watters (fish egg entrainment estimates) and F. Douglas Martin (diversity, seasonal distribution and feeding ecology of fishes), with James Patus and Diane Mathews; and George A. Seiglie (holocene changes of foraminiferal assemblages).

Other staff included Master and Captain D. Greene of the MRV R.F. Palumbo, and Jose Montalvo; Byron Smith, John Kovarna, Lynn Blickenstaff and Peter Schroeder, Computer Programming, with Rosa Asencio, Keypuncher; Cathy Patus, Administrative Assistant, Jean Dietsch, PRWRA Projects Manager; Dolores Quellar and Domenica De Caro, Budget Coordinators; and Carole Serth, Project Secretary. Photographs are by Tom Smoyer and Vance P. Vicente.

This report, and the Jobos Bay Annual Environmental Report 1975, were edited by Mary Kimmel. The Technical Editor for this report is Ferne Galantai.

SUMMARY OF SAMPLING OF SURFACE TEMPERATURES AT JOBOS BAY 1974-1975

by

Eugene Johnson

Surface temperatures at 17 selected and representative stations have been monitored weekly at Jobos Bay since October 1973. The results of these observations have been submitted monthly to the Puerto Rico Water Resources Authority since that time. Beginning in February 1974, other parameters (salinity, dissolved oxygen, and turbidity in depth profiles) at these stations were added to the study and included in the above mentioned observations. Figure 1 shows a map with these stations located for reference.

Figure 2 is a graph of surface temperatures of selected stations within the series. These stations reflect surface temperatures at Station I (intake), Station II (discharge), Station VII (channel) and Station X (inland channel). The X-axis represents days and dates of the year and the Y-axis measures in degrees centigrade. Data are reported on this graph from January 1974 to February 1975. From February 1974 to February 1975 a cycle of partial operation of the power plant located at Jobos Bay is represented. It should be pointed out that during this period plant operation was sporadic and not operating at full power.

With reference to temperatures sampled at Station II, maximum temperatures were observed on May 31, 1974 with temperatures of 35.89°C. This reflects only weekly sampling, not constant monitoring. January 4, 1974 shows surface temperature of 24.95°C and one year later, 25.40°C. The months from December to February show the coolest recordings. The factors contributing to this could be seasonal and due to the lack of plant operation, also. Temperature differences between Stations I and II varied from 0.3°C on August 31 to 6°C on November 16. The solid acute angled lines on the graph represent Station II, the interrupted lines represent Station I, and the solid curvilinear line represents a mean between Stations VII and X.

SURFACE TEMPERATURES

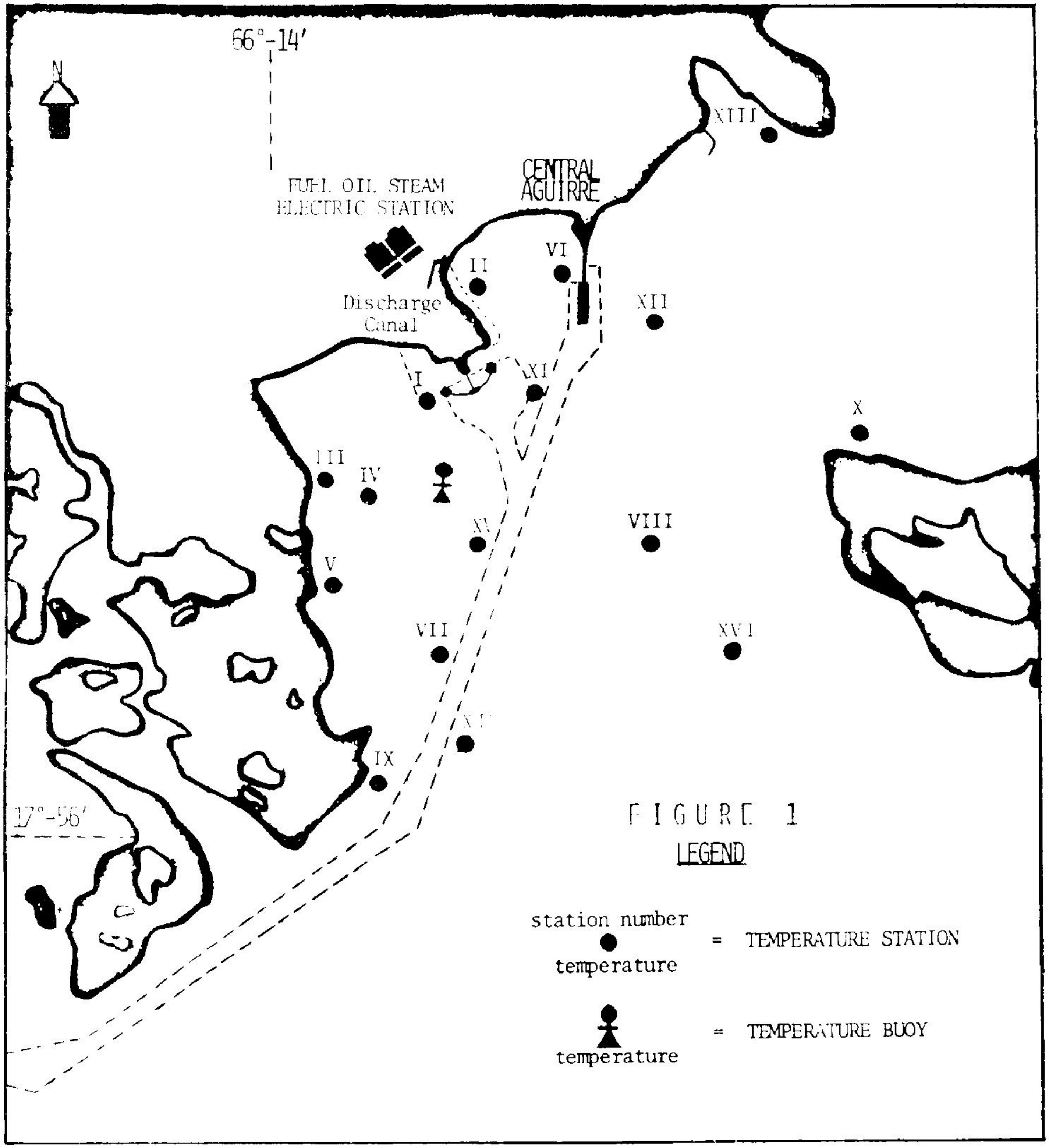
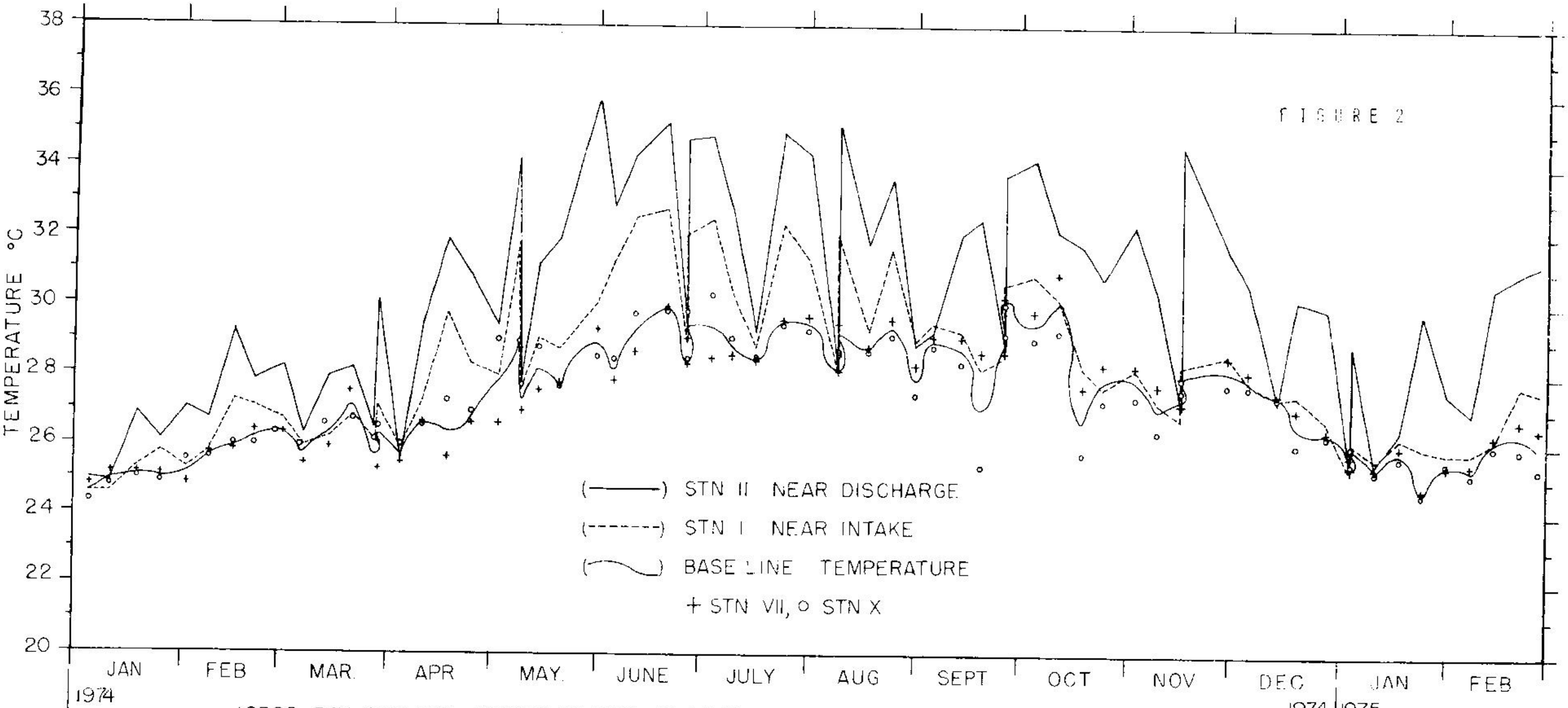


FIGURE 1

FIGURE 2



JOBOS BAY SURFACE TEMPERATURES AT STATIONS I, II, VII & X - JANUARY, 1974 - FEBRUARY, 1975

SEASONAL CHANGES IN THE MICROZOOPLANKTON OFF THE AGUIRRE POWER COMPLEX, JOBOS BAY 1973

by

Gary P. Owen

INTRODUCTION

Environmental studies at Jobos Bay were initiated to assess the impact that construction and operation of an electric generating complex would have on marine communities. In February 1973 a microzooplankton monitoring program was added to the general study. Collections were made from February 1973 to March 1974 at five sites within the bay. Those animal plankters which passed through 202 μ mesh netting, but were retained by 64 μ mesh, and preserved in a recognizable condition were examined. A preliminary report by Owen (1974) identifies some of the major microzooplankton components and speculates on their importance relative to the macrozooplankton. This paper provides more detailed information on microzooplankton community structure and describes their seasonal fluctuations in the waters near the Aguirre Power Station during 1973.

While some type of predictive study on the effects of thermal pollution on marine plankton is needed, this generally is not possible. Plankton communities are extremely complex units and the methodology necessary to predict the effect of any particular pollutant is either undeveloped or the efforts required to obtain the necessary information are prohibitive. An alternative approach is to obtain enough base line information on community structure and stability to make a post hoc judgment on the effects of thermal disturbance and deal with any harmful situation as it develops. This is the general philosophy on which the microzooplankton study in Jobos Bay was based.

Description of the Study Area

Jobos Bay, located on the south coast of Puerto Rico, is a small, narrow, "S" shaped bay covering nearly eight square miles, not including mangrove swamp areas. The bay can be divided into three major zones: an outer bay, limited on the seaward side by Cayos de Pajaros, Cayos de Barca, and Cayos de Caribes, a central area which the Aguirre power complex faces, and a long, shallow, back bay lying between Punta Pozuelo and the mainland (see Figure 3). Depths in the back bay range from less than one meter to eight meters, with an average depth of two meters. The central bay ranges from two to ten meters. Outer bay depths average eight meters with a maximum depth of twelve meters.

No rivers or major streams enter Jobos Bay. Average rainfall is 97 cm per year, approximately half of Puerto Rico's mean rainfall. Most of the bay's water comes in from the open coast entering at the surface through gaps between the cayos and along the bottom through the outer bay during flood tides. Prevailing southeasterly winds flush the surface waters out of the back bay and central bays, probably promoting extensive upwelling in the back bay during the day. Mean residence time for a water mass in the back and central bay is approximately 5.5 days (PRWRA 1972). Tides within the bay are predominantly diurnal ranging up to 30 cm. The average excursion of a water particle during a half-tide cycle is 574 m for the back bay and 667 m for the central bay.

Mangroves and turtlegrass border the study area. Numerous drift lines appeared at the site throughout the study, indicating the region is subject to extensive downwelling via Langmuir circulation. No major discharge from thermal electric plant sources occurred during the sampling period covered by this report, but the area did receive heated and organic effluent from the Central Aguirre (sugar mill) located nearby.

Samples were collected from a station established approximately 500 meters off the Aguire power plant's dock over a mud-clay bottom. Average depth at the station was 5.7 meters.

MATERIALS AND METHODS

Field Procedures

Microzooplankton were collected biweekly between February 7 and December 19. A single tow with a half-meter 64 μ mesh net of cylinder-cone design (Smith et al. 1968) was taken from a 17 foot skiff. The net was towed in a circular path and allowed to oscillate through the upper two meters of water while the skiff maintained a speed between two and three knots. A digital flowmeter mounted eccentrically within the mouth of the net measured the volume of water filtered. Tows made before October 11 were of five minute duration. After this date, a two and a half minute tow was used. The shorter tow collected adequate material for examination with less clogging.

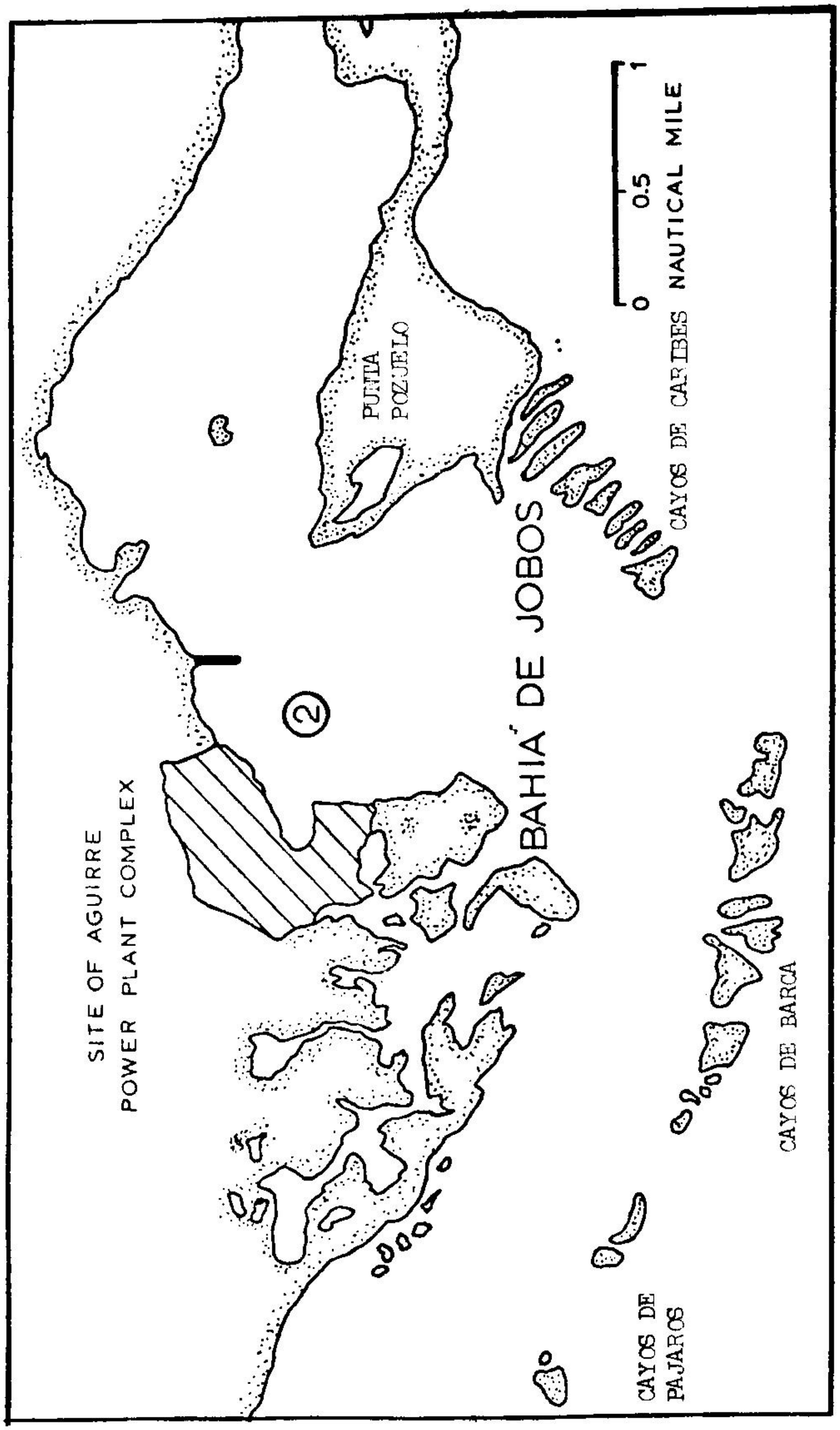


Fig. 3. Jobos Bay zooplankton study site.

After each tow, the net was thoroughly washed with sea water provided by a small portable pump (Jabsco water puppy) before removal of the cod end. Collected material was preserved in 4% formalin buffered to a pH near 7.6. The pH of the sample was checked within 24 hours of collection and hydrochloric acid or sodium tetraborate added as needed.

Surface water samples for salinity and surface temperatures were taken before each tow. A sounding was taken and water transparency estimated with a 30 cm secchi disc.

Laboratory Procedures

Before counting, samples were washed through 202 μ and 64 μ mesh netting to remove macroplankton and those microplankton elements smaller than 64 μ. For subsampling, a sample was brought to a volume between 1000 and 2000 ml and the contents mixed by a series of stirring and bubbling operations. A 2.0 ml pipette cut off square at the tip was used to draw the subsamples. Aliquots were placed in settling chambers and counted at 200x magnification using the inverted microscope method of Utermohl (1936). Volumes of the subsamples were chosen to allow total counts of at least 200 animals.

The presence of numerous larval and juvenile forms that were unidentifiable to genus or species made it necessary to use a group rather than a species designation for most organisms. Nine major taxonomic groupings were considered: total microzooplankton, total protozoans, tintinnids, nonloricate ciliates, foraminiferans, radiolarians and acantharians, total metazoa, copepods, and other metazoans. Tintinnids were classified to species.

Biomass was estimated by using a shape simulation method for copepods, tintinnids, and the numerically dominant "other metazoans" (Beers and Stewart 1970). Median volumes of copepod nauplii and post-nauplii were determined using twenty animals from both groups in each of six samples, (Feb. 7, Apr. 4, Apr. 26, Jul. 13, Sept. 20, and Dec. 19). A grand median determined using these values was used to calculate copepod volumes for other samples. The same method was employed to estimate total volumes for other metazoans and tintinnids. Total microzooplankton volumes were determined for each sample by combining the volumes of the copepods, tintinnids, and the four numerically dominant "other metazoan" groups.

RESULTS

Surface Temperature and Salinities

Table 1 shows the fluctuations in surface temperatures and salinities at the site through 1973. Maximum and minimum values were within 4°C (26.2°C to 30.°C) and 3 °/oo (33.6°/oo to 36.3°/oo) for temperature and salinity, respectively. Generally temperature-salinity patterns at Jobos Bay oppose one another. High salinities occur with low temperatures during the dry winter months while the opposite situation prevails in the wet summer (PRNC 1972).

Low temperatures and high salinities were noted in February and March. By May, surface temperatures had reached their summer levels. High surface salinity conditions continued into April but by the latter part of month the salinities had dropped below 34°/oo. The wet summer pattern held from April through October. In November, surface temperature dropped and salinities began to climb to the winter levels.

TABLE 1. Temperature, salinity, transparency (S.D.R.), depth (Z), wind directions and wind velocity .

Date	Temperature (°C)	Salinity (°/oo)	S.D.R. (m)	Depth Z (m)	Wind Direction	Wind Velocity (mi/hr)
7 Feb	27.2	35.44	5.0	7.5	90°	4
7 Mar	26.8	36.19	3.0	10.0	120°	13
21 Mar	28.0	35.74	2.0	9.0	140°	10
4 April	27.3	36.29	3.0	10.0	140°	14
26 April	29.0	36.20	3.5	7.0	130°	15
16 May	29.0	35.84	2.0	5.0	140°	12
31 May	30.0	35.94	3.0	8.0	170°	8
13 June	29.2	36.31	2.0	9.0	180°	5
27 June	29.5	35.89	1.5	8.0	130°	8
13 July	30.0	36.15	4.0	9.0	80°	8
24 July	29.5	35.66	4.0	9.0	140°	13
24 Aug	29.4	33.62	3.0	10.0	140°	10
7 Sept	29.6	34.61	3.0	9.0	130°	10
20 Sept	30.0	34.58	3.0	9.0	120°	10
11 Oct	29.5	33.91	2.0	8.0	90°	10
25 Oct	29.8	33.92	3.0	8.0	150°	7
7 Nov	28.8	34.48	3.0	9.0	150°	7
22 Nov	27.5	34.78	2.0	8.0	150°	7
5 Dec	26.2	35.15	2.5	7.0	150°	10
19 Dec	27.0	35.04	3.0	7.0	60°	15

Water Clarity

Little seasonal pattern was noted in water clarity. Secchi depth readings ranged from 1.6 to 5.0 meters with maximums in February and June and minimums in July, late November and early December. The mean value was 2.9 meters, one third the average depth of the water column.

Wind

A daily pattern of low velocity northeast wind in the early morning, giving way as the day progressed to southeast winds with increased velocities prevailed throughout the year. Sampling was customarily carried out after the southeast shift had started and wind velocities increased. Wind speeds and directions taken at the Ponce Airport concurrently with sampling periods at Jobos Bay are shown in Table 1. (See also Wood, 1975). These data agree well with field estimates of wind speed and direction made at Jobos Bay.

Total Microzooplankton

The biweekly abundance and biomass of the microzooplankters are summarized in Figure 4 and Appendix A, Tables 2 and 3. Total microzooplankton densities ranged from 8.2 x 10^4 to 6.5 x $10^5/m^3$, averaging 2.2 x $10^5/m^3$. Major increases in abundances occurred in March and April while a smaller peak was observed in August. The March and April peaks resulted from increases within all principal groups and occurred during the transitional period between the dry and wet seasons.

Total biomass fluctuations were associated with abundance changes in the three dominant metazoan groups, copepods, larvaceans, and molluscan veligers. The high densities of protozoans seen in the samples contributed little to the total biomass estimate because of their relatively small individual volumes. Biomass estimates ranged from 29 to 254 mm^3/m^3 with maximum of 174, 254, and 136 mm^3/m^3 corresponding to the March, April and August density peaks, respectively. Seven taxonomic groups formed over 90 percent of the microzooplankters collected. Listed in order of numerical abundance they are: copepods, tintinnids, larvaceans, mollusc veligers, rotifers, and polychaetes.

Tintinnida

Seventeen species were identified (Table 2). Eight occurred regularly throughout the year. All eight dominant species are common tropical neritic forms and, with the exception of Metacylis cf. jorgensenii, have been reported previously for Puerto Rico (Duran 1957).

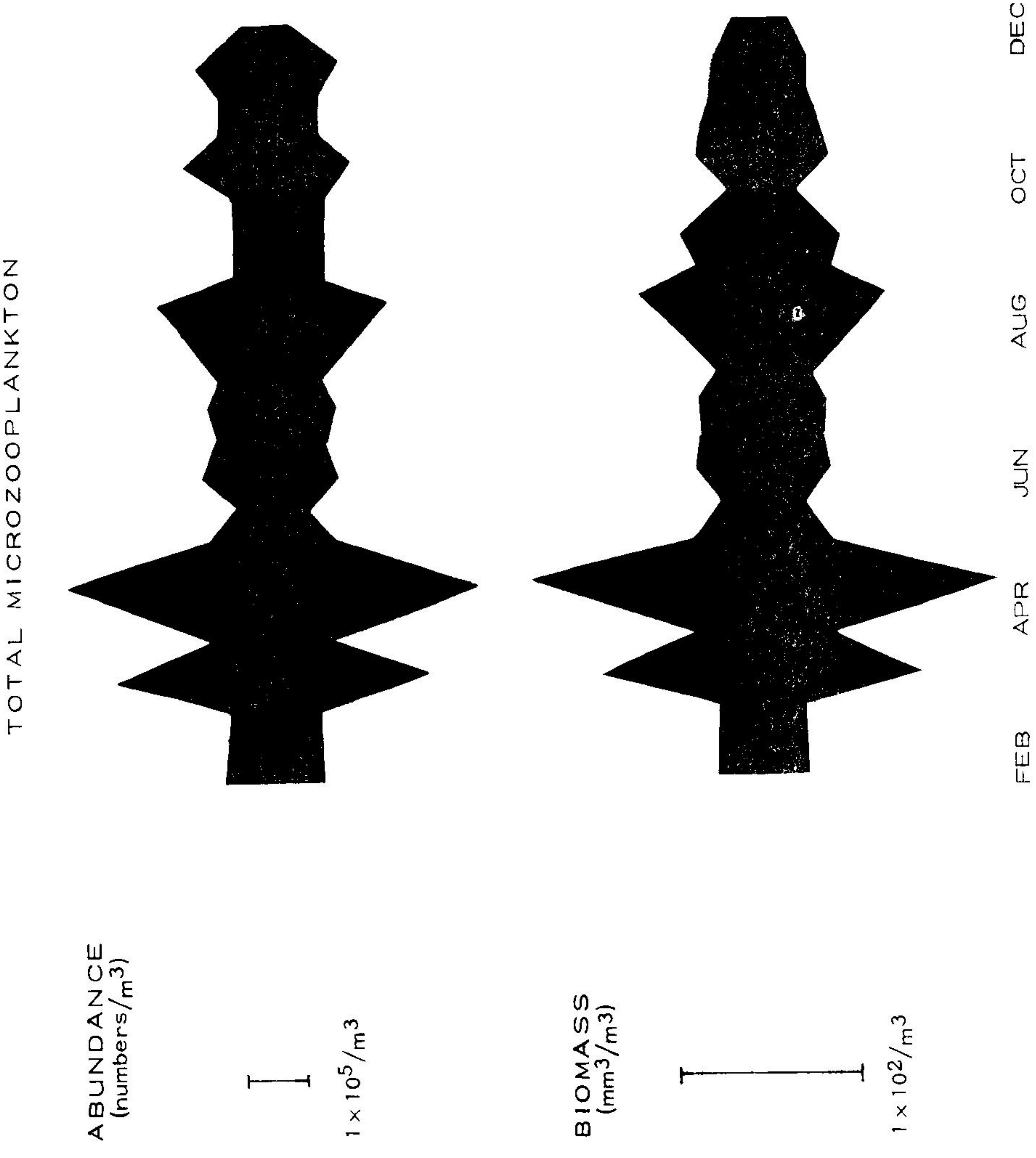


Fig. 4. Biweekly microzooplankton abundance and biomass.
Note: See, also, Appendix A, Tables 2 and 3.

TABLE 2. Tintinnid species presence and absence.

	7 Feb	7 Mar	21 Mar	4 Apr	26 Apr	16 May	31 May	13 Jun	27 Jun	13 Jul
Amphorellopsis acuta	+	+			+		+	+	+	+
Codonaria cf. fimbria	+	+	+	+	+					
Codonellopsis morchella										
Coxiella cf. ampla	+						+			
C. bolivardi	+									
C. longa										
Eutintinnus lusus-undae	+									
Favella panamensis	+	+	+		+	+	+	+	+	+
Leprotintinnus nordquisti	+		+	+	+	+		+	+	+
Metacylis cf. jorgensenii	+		+	+	+		+	+	+	+
Tintinnopsis beroidea		+			+					
T. butschii	+	+		+	+	+	+	+	+	+
T. dadayi	+	+	+	+	+	+	+	+	+	+
T. glans			+							
T. tocantinensis	+		+		+	+	+	+	+	+
T. cf. tubulosa										
T. cylindrica					+					

TABLE 2. Tintinnid species presence and absence. (cont.)

	24 Jul	24 Aug	7 Sep	20 Sep	11 Oct	25 Oct	7 Nov	22 Nov	5 Dec	19 Dec
Amphorellopsis acuta		+			+		+		+	+
Codonaria cf. *fimbria*									+	
Codonellopsis morchella					+			+	+	+
Coxiella cf. *ampla*										
C. bolivardi	+									
C. longa						+				
Eutintinnus lusus-undae					+		+			
Favella panamensis	+	+	+	+	+	+	+		+	+
Leprotintinnus nordquisti		+	+	+	+	+	+			+
Metacylis cf. *jorgensenii*	+	+								+
Tintinnopsis beroidea										
T. butschii	+	+	+	+	+	+	+	+	+	+
T. dadayi	+	+	+	+	+	+	+	+	+	
T. glans										
T. tocantinensis			+		+	+	+	+	+	
T. cf. *tubulosa*					+					
T. cylindrica										

The Tintinnida, except for an extremely low percentage of Radiolaria and Foraminifera, composed the total protozoan fraction. Density averaged 4.6 x $10^4/m^3$, approximately 20% of the total microzooplankton abundance, but was highly variable from one sampling period to the next. Maximum abundances occurred in April, October, and December resulting from individual species blooms in excess of 1 x $10^4/m^3$ for *Tintinnopis butschii*, *T. dadayi*, and *Leprotintinnus norquisti*; *Favella panamensis* and *T. butschii*; and *T. butschii* and *T. tocantinensis*. Biomass estimates for the group ranged from 0.1 to 6.7 mm^3/m^3. At no time did the tintinnid biomass make up more than 3% of the total microzooplankton.

The tintinnid fluctuations observed were probably as much the product of net mesh selection as population abundance changes as most tintinnid species noted in Table 2 are of a size that cannot be quantitatively sampled with a 64 μ mesh net.

Copepoda

Copepod species were dominant at the site throughout the year. They comprised, on the average, 59 percent of the total abundance and 72 percent of the biomass (see Appendix A, Tables 1 and 3). Naupliar stages were twice as numerous as post-naupliar copepods but formed a smaller portion of the total biomass.

Major increases in copepod abundance occurred in late March, late April, and late August. Nauplii dominated during the March increase. Both naupliar and post-naupliar stages were abundant in April and August. Fluctuations in nauplii and post-nauplii generally were closely coupled.

Acartia tonsa nauplii and *Oithona* sp. post-nauplii were abundant at the site at all times. The harpacticoid *Euterpina acutifrons* occurred both in naupliar and post-naupliar stages on a regular basis but at lower densities than the two preceding groups.

Other Metazoans

The non-copepod metazoans made up 18 percent of the total abundance and 26 percent of the total biomass (Appendix A, Tables 1 and 3). The fraction was composed of holoplankton and meroplankton species, each with similar standing stock numbers and biomass. Among the meroplankton the larvae of molluscs and polychaetes were common. Cyphonautes larvae, cirripede nauplii, ascidian larvae, and echinopluteus were occasionally observed. Larvaceans and pelagic rotifers were the most numerous holoplankters. Chaetognaths occurred infrequently and in low numbers. Larvaceans, rotifers, mollusc veligers and polychaete larvae comprised, on the average, 96 percent of this fraction.

Absolute abundances were highest during the initial period of sampling, declining after April. Late March and late April peaks were observed in all four major groups. Large abundances relative to the other microzooplankters occurred in February, early March, and late December when the numbers and biomass of the "other metazoans" equalled or exceeded that of the tintinnids and copepods.

DISCUSSION

Structure

The microzooplankton off the Aguirre Power Station is an embayment assemblage typical of the more protected bays along the south coast of Puerto Rico (Coker and Gonzalez 1960, Duran 1957). Tintinnids, larvaceans, and mollusc veligers are numerous, and copepods clearly dominate. Jobos Bay microzooplankton differ from microzooplankton associations in open coastal areas around Puerto Rico in species composition, diversity and standing stock. In Jobos Bay they show a lower diversity and maintain density levels an order of magnitude higher than off the coast (Table 3).

There are a few long term studies of microzooplankton in the nearshore environment which can be compared with Jobos Bay data. Beers et al. (1970) followed weekly coastal microzooplankton fluctuations off southern California through the summer of 1967.

TABLE 3. Abundance estimates for microzooplankton in coastal waters of Puerto Rico, no./m^3

	North Coast		South Coast	
Site	Tortuguero	Islote	Punta Verraco	
Date	29 Jan '73	6 Aug '73	21 Feb '73	22 May '73*
Total Microzooplankton	3.1×10^4	1.0×10^4	1.9×10^4	1.3×10^4
Total Protozoans	772	2.7×10^3	133	1.6×10^3
Total Metazoans	2.4×10^3	7.3×10^3	1.9×10^4	1.2×10^4
Copepods	1.8×10^3	5.8×10^3	1.2×10^4	8.3×10^3
Other metazoans	493	1.5×10^3	7.9×10^3	3.6×10^3

*Offshore sample

Reeve and his associates monitored microzooplankton in the Biscayne Bay complex in southern Florida through several years (Reeve 1970, Reeve and Casper 1973). Jobos Bay abundances and biomass levels are generally higher than those reported by either of these studies. Group and species composition in Jobos Bay show many affinities to the Biscayne Bay area. A major difference between the two systems is the frequent occurrence of high densities of larvaceans at the Jobos Bay site.

Persistence of larvaceans at the density levels seen in Jobos Bay has generally not been noted in similar areas elsewhere (Bary 1970, Beers 1970, Reeve 1964 and 1970, Essenberg 1922). Larvaceans are one of the few important adult forms in the Bay's microzooplankton, ranking third in abundance and biomass. They have received recent interest because of their importance as a food source for early larval fish stages (Shelborn 1962) and their unique feeding mechanism (Alldredge 1972). The elaborate filtering structures ("houses") produced by these forms serve as collecting sites for small phytoplankters and when abandoned can be utilized as a food source by other herbivores. At heavy phytoplankton concentrations these pelagic tunicates can produce a new "house" every two to five hours (Galt 1972). Much of the phytoplankton is of marginal size for efficient grazing by copepods and other herbivores (Anraku and Omori 1963). The larvacean "houses" provide one pathway by which the smaller phytoplankters are made directly available to the larger zooplankton. The importance of such a pathway in Jobos Bay with its high densities of larvaceans can easily be understood when one considers that the great majority of primary productivity in the tropics is produced by the smaller phytoplankton (Raymont 1966).

Temporal Change

The major microzooplankton groups, with the possible exception of the tintinnids, showed greater seasonal stability than macrozooplankton from the same site (Youngbluth 1974). Fluctuations, as is typical of tropical areas, were of short duration (Raymont 1966). Highest abundances occurred for all seven dominant groups in March and April during the period of increasing surface temperatures. Such synchronous fluctuations were rare in the holoplanktonic forms but among the major meroplankton groups (mollusc veligers and polychaete larvae) fluctuations were highly correlated (Spearman Rank coefficient +0.83; significant at ± 5% alpha error). Youngbluth (1974) reported highest meroplankton densities occurring at an inner bay station and speculated that this part of the bay is an important nursery for benthic invertebrates. If this is the case, the synchronized meroplankton fluctuations at the Aguirre Power Station site could be associated with movement of water masses from the back bay, with their higher meroplankton levels, into the sample site.

A multiple linear regression test was used to analyze seasonal fluctuations of the six dominant metazoan groups with regard to water transparency levels, water mass movement, surface salinity and surface temperature. The square of the average wind speed during the three hours preceding sampling was used to estimate wind induced water mass movement (Hsu 1975). To test for possible predation effects, the variability in the microzooplankton were compared with macrocopepod and macrocirripede variability at the site. The macrozooplankton data were obtained from Youngbluth's 1974 study.

None of the factors analyzed showed significant correlation with any group at the 5% alpha error level. At a 10% alpha error level a significant negative correlation was noted between mollusc veliger abundances and surface salinities. This suggests the possibility that mollusc reproductive activity within the bay may be correlated to periods of increased rainfall and runoff.

Food Chain Considerations

Microzooplankton and macrozooplankton biomass and abundances at the site are shown in Table 4 (Youngbluth 1974). The two sets of data are not directly comparable. The larger zooplankton volumes were derived using a "wet" volume displacement method (Ahlstrom and Thraikill 1963) and a relatively large percentage of interstitial water is included in the "wet" volume estimate. Corrections for this error could reduce the macrozooplankton volumes by as much as one third.

TABLE 4. Macrozooplankton and microzooplankton abundance and standing stock biomass.

Date	Macrozooplankton no/m3 (mm3/m3)	Microzooplankton no/m3 (mm3/m3)
7 Feb 74	303 (36)	1.6×10^5 (49)
7 Mar 74	335 (21)	1.3×10^5 (49)
21 Mar 74	627 (20)	5.1×10^5 (174)
4 Apr 74	1366 (80)	2.0×10^5 (71)
26 Apr 74	155 (41)	6.9×10^5 (254)
16 May 74	686 (37)	2.0×10^5 (75)
32 May 74	476 (36)	1.2×10^5 (44)
12 Jun 74	827 (41)	2.3×10^5 (72)
27 Jun 74	1000 (46)	1.8×10^5 (67)
13 Jul 74	447 (34)	2.0×10^5 (71)
24 Jul 74	360 (48)	1.7×10^5 (51)
24 Aug 74	2165 (106)	3.7×10^5 (136)
7 Sep 74	570 (56)	1.2×10^5 (71)
20 Sep 74	869 (67)	1.2×10^5 (89)
11 Oct 74	881 (47)	1.2×10^5 (36)
25 Oct 74	1686 (60)	2.7×10^5 (72)
7 Nov 74	276 (23)	1.7×10^5 (61)
22 Nov 74	889 (51)	1.7×10^5 (61)
Mean	773 (47)	2.2×10^5 (79)
Range	155-2165 (20-106)	1.2×10^5-6.9×10^5 (36-254)

Macrozooplankton biomass ratios ranged from 0.8:1 to 8.7:1, averaging 1.7:1. The higher physiological activity exhibited by the smaller forms (Zeuten 1947, Johannes 1964, Fenchel 1968, Millin and Brooks 1967) and their generally higher standing stock biomass could be perceived as a demand that most of the primary productivity passing into the animal portion of the planktonic food web enter initially through the microzooplankton.

The importance of the small zooplankters to the overall trophodynamic picture in Jobos Bav can be realized when one remembers the present study treats only the larger microzooplankters. Not included in the results are the majority of the protozoan components and a substantial part of the copepod fraction (Beers and Stewart 1969, Margalef 1963). Reeve (Reeve and Casper 1973) working in Card Sound in southern Florida, an area similar to Jobos Bay in many aspects, found that half the total microzooplankton standing stock biomass was maintained by forms capable of passing through 64 mμ mesh nets. The relative importance of the smaller microzooplankters was also noted by Margalef (1963) in his observations of coastal regions of the western Mediterranean. He estimated that the standing stock biomass of small ciliate forms, 10 - 30 mμ, was 22% of the total net zooplankton and their daily production of new carbon exceeded that of the larger zooplankters. It appears quite possible that the total microzooplankton biomass estimates for the sample site would be doubled with the addition of the animal plankton which passed the 64 mμ mesh cloth.

SUMMARY

Of the total microzooplankton at the site copepods formed, on the average, 59 percent of the standing stock numbers and 72 percent of the biomass. Six groups accounted for most of the remaining abundance and biomass. These are in order of numerical dominance: tintinnids, larvaceans, mollusc veligers, pelagic rotifers and polychaete larvae. Together with the copepods they constituted more than 90% of the microzooplankton.

The majority of the groups and species encountered during the study were embayment forms. The microzooplankton assemblage they formed differed from Puerto Rico coastal plankton associations in species composition, diversity, and abundances, the former having a lower diversity and maintaining standing stocks an order of magnitude higher.

The smaller zooplankton populations in Jobos Bay showed many affinities in structure to microzooplankton in other similar areas. Two exceptions are notable. Abundances and biomass levels are higher than would be predicted from the literature, and the persistence of larvaceans at the high densities observed at the site has not been noted elsewhere.

Microzooplankton fluctuations at the site were of short duration. Maximum densities were seen in late March and late April when abundances exceeded 5.0 x $10^5/m^3$. All seven major groups showed increases during these periods. Synchronized fluctuations were rare among the holoplanktonic groups, but occurred regularly between the mollusc veligers and polychaete larvae. Generally, microzooplankton populations showed greater seasonal stability than the macrozooplankton at the site.

The volumes of the microzooplankton averaged 1.7 times that of the larger zooplankton during the study.

ZOOPLANKTON SURVEY IN JOBOS BAY, 1973-1974

by

Marsh Youngbluth

INTRODUCTION

The abundance and diversity of zooplankton in the surface waters of Jobos Bay during the period February 1973 to December 1974 are broadly summarized in this report. A more detailed discussion of the information contained in the graphs and tables presented in this paper will be completed in the future since these data represent one of the few long term studies of zooplankton in a tropical embayment.

MATERIALS AND METHODS

The field and laboratory methods used were described in the 1974 Jobos Bay Annual Report. Samples were collected during the day from the upper two meters in ten areas of the bay nearly every two weeks (Figures 5 and 6). Beginning in September 1973 at Station 2 and in April or June 1974 in other regions, zooplankton were also gathered at night.

RESULTS

A total of 571 samples was taken during the two year period. Of this number, 374 were collected in 1974. These data, grouped into descriptive and taxonomic categories, are tabulated in Appendix B, Table 1 through 39. All the information on major groups of zooplankton is illustrated in the figures of Appendix B and the figures of Appendix C.

Temperature and Salinities

Fluctuations of surface temperatures and salinity in Jobos Bay were small, ranging from 25 to 30°C and 30 to 37 °/oo, respectively. Although 1974 was a somewhat cooler and wetter year than 1973, the cycles of temperature and salinity were typical for the region (PRWRA, 1972). The patterns at each station are illustrated in Appendix D. Temperatures plateau during the period from May to October, decline slowly from October until January or February, and then begin to rise again toward a stable level reached by May. In 1974, surface water temperatures near the outfall from the power plant (Station 9) were as much as 5°C higher than elsewhere in the bay. At the intake (Station 8) temperatures tended to be 1 to 30°C higher than ambient suggesting that re-entrainment of plume water probably occurs.

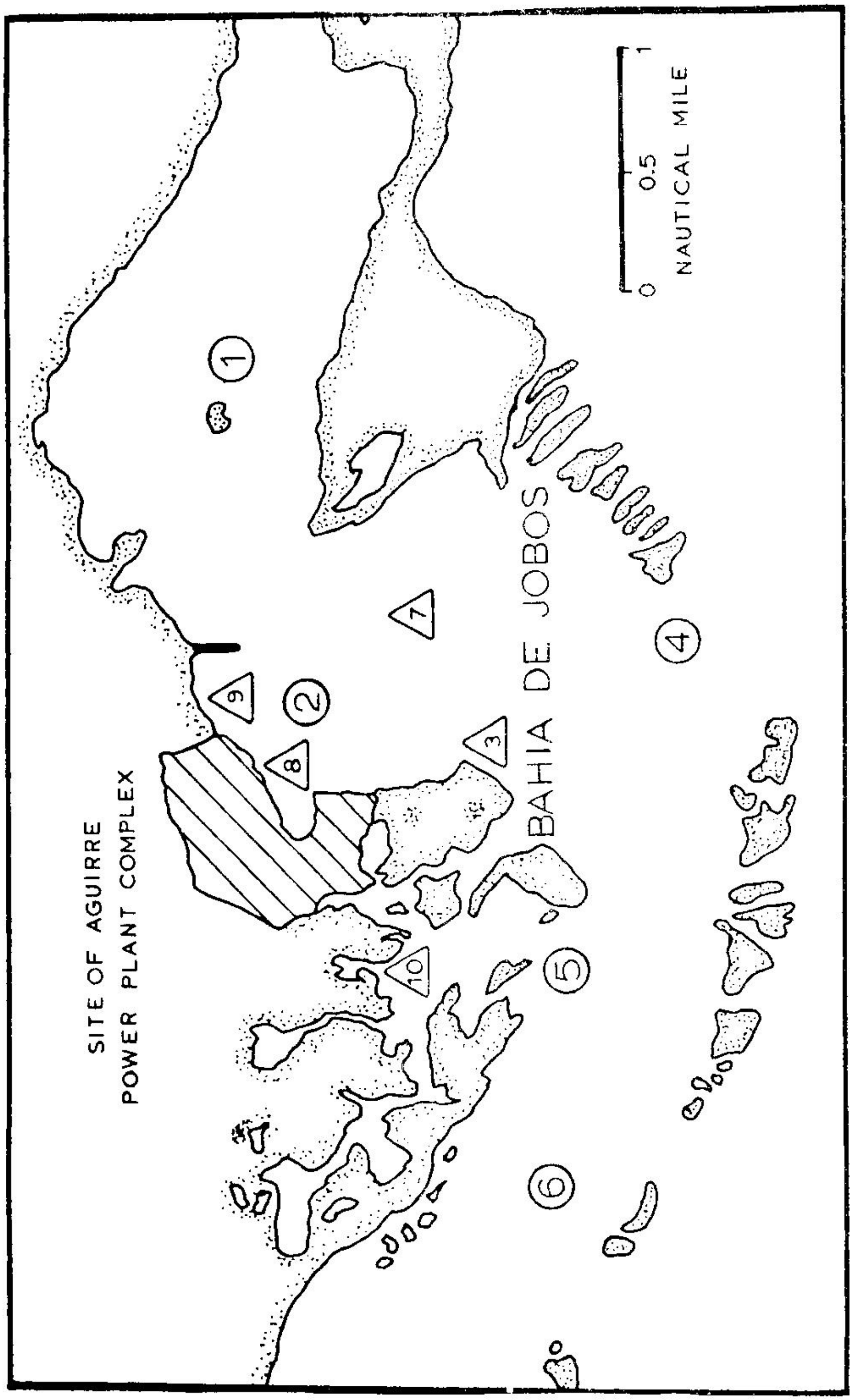


Fig. 5. Zooplankton collection stations. Numbers in circles: 1973 sampling stations; in triangles: Sept.-Dec. 1973 and/or 1974 collection stations.

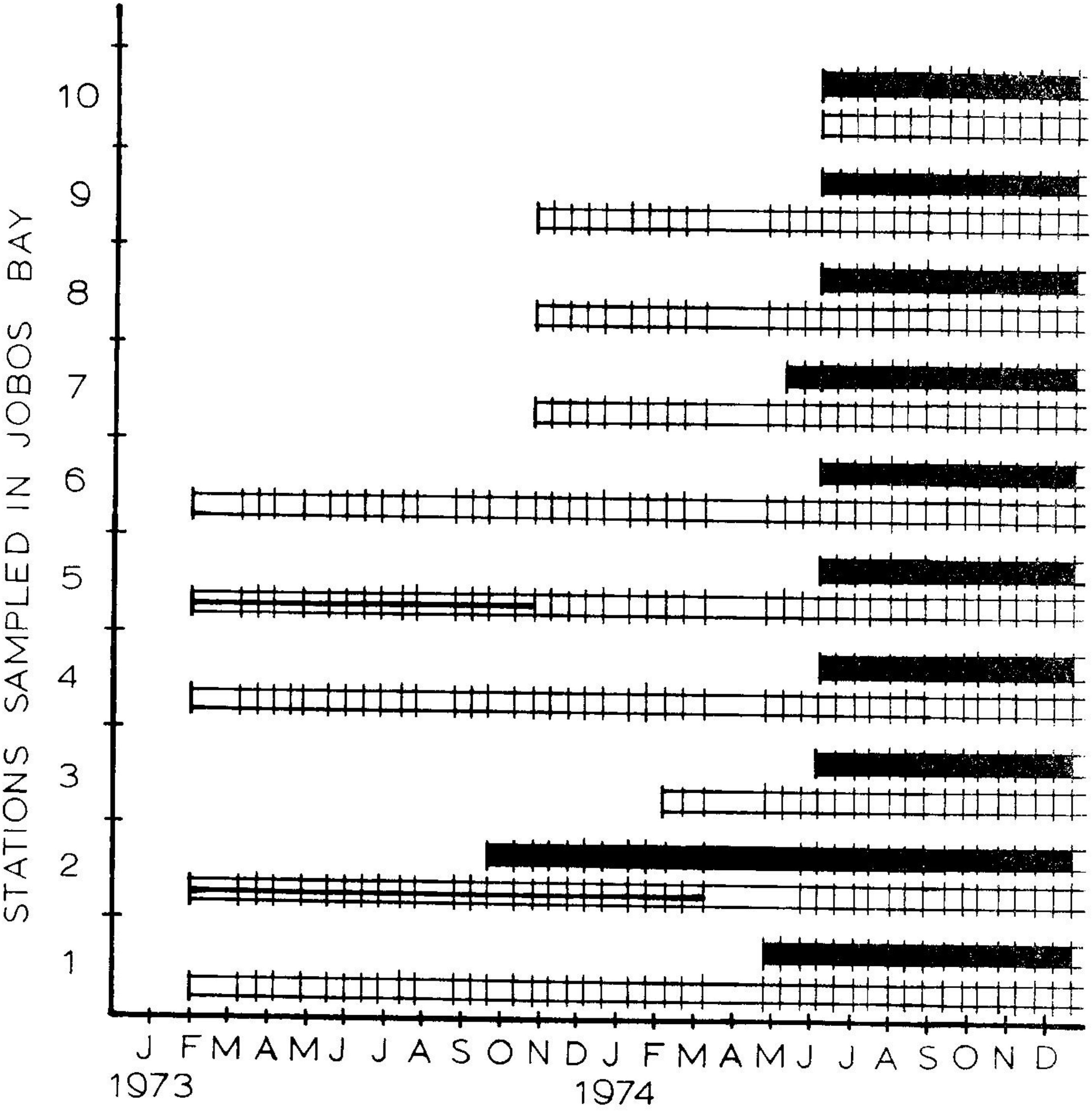


Fig. 6. Zooplankton sampling frequencies.

Salinity changes in Jobos Bay are produced by the seasonal cycle of rainfall which is usually highest during June through November and lowest from December to May. During the rainy season drainage along the shoreline, particularly within the inner bay, accounts for the freshwater input from land since no large streams or rivers empty into the bay. The annual rainfall from year to year is quite variable, for instance, 60 cm may be recorded in one year and 120 cm in the next. The total amounts of rainfall observed in 1973 and 1974 were similar, 95 to 110 cm, respectively. The cycles of salinity change were, however, somewhat different. From March to August values were highest and rather consistent. Less rainfall in 1974 during this time resulted in higher salinities. Between August and November seasonally heavy rains caused the salinity values to fall rapidly. The lower salinities observed in this period during 1974 correlated with the much greater amount of precipitation, that is, 56% of the total rainfall occurred during the rainy season in 1973 and 85% in the same months of 1974. The lowest values observed in November are representative of levels found in the upper meter a day or so after a rain squall. Vertical profiles indicate that below this depth salinities were rarely less than 32^{o}/oo.

Variability Between Samples

The variances between samples, replicated in regions where waters may be influenced by future power plant operations, were used as a basis for distinguishing statistically different abundances between hauls in regard to regions and times. From these calculations it appears that, on the average, a difference of 30% in the total zooplankton density can be detected with three tows and a difference of 50% is revealed with a single tow.(Table 5). This range of variability is similar to observations in other coastal regions around Puerto Rico (Youngbluth 1974b).

Diurnal Fluctuations

Generally, the density and diversity of zooplankton were larger at night. The mean ratio of night/day density for all sets (n = 161) was 3.4. The median was 2.4. The largest differences, 17.5 and 18.1, were observed at Stations 7 and 10, respectively. Copepods were most often the principal component of the pelagic community day and night. Older stages tended to be more abundant at night. Certain species, e.g., *Calanopia americana*, *Euterpina acutifrons*, and *Pseudodiaptomus cokeri*, were more numerous in the night tows. The juveniles of stomatopods and carideans as well as the adults of polychaetes and especially isopods (*Excorallana* spp.) were always found in larger densities in the night samples. Fish larvae were often an order of magnitude more abundant in the night collections. Barnacle larvae and fish eggs were not consistently more numerous day or night. However, fish eggs, oblong in shape, tended to be more abundant during the day and large, spherical, opaque eggs were more numerous at night. These fluctuations in density and diversity are related to behavioral responses, such as endogenous and exogenous vertical movements toward the surface, perception of environmental gradients, probably light, and avoidance of sampling gear.

TABLE 5. Total zooplankton ($\log_{10}$ transformed) from 6 randomly selected sets of replicate tows.

DATE STATION	26 Apr 5	16 May 5	13 Jun 2	20 Sep 5	25 Oct 2	22 Jan 2
	2.50786	3.12024	2.81425	2.94101	3.03302	2.45179
	2.63749	3.31513	2.99211	2.93247	3.35755	2.54283
	2.48714	3.03463	2.92686	3.11461	3.23070	2.59660
5%	49	152	60	78	198	40
10%	12	38	15	20	49	10
20%	3	10	4	5	12	3
30%	1	4	2	2	6	1
50%	1	2	1	1	2	1

The number of replicate tows (n*) needed to detect a ±5-50% difference in density is indicated.

$*n = \frac{t^2 \times s^2}{d^2}$ where t is Student's (t) for the 95% confidence level (d.f.=2), s^2 is the sample variance based on replicate tows, and d is the half-width of the confidence level desired.

Seasonal Cycles and Regional Differences

The major pulses of total zooplankton density during each year coincided with the onset of periods of reduced salinity in August and September. Presumably nutrients, washed into the bay by heavy rainfall, spike phytoplankton growth and subsequent zooplankton production. Smaller peaks in abundance were observed in April, June, November, and December, but these increases did not recur at the same times each year. These latter bursts of growth suggest that the frequency of sampling was inadequate to record the rapid development of copepods, larvaceans, and chaetognaths, and/or that various combinations of factors act to effect zooplankton productions in different months. The mean ratio of the highest/lowest densities of total zooplankton was 26.6 for day and 11.1 for night samples.

Mean values of zooplankton density during 1973 and 1974 tended to be highest at Stations 1 and 10. In most cases, however, the annual averages at each station were not significantly different from each other since the 95% confidence intervals around the means overlapped (Table 6). Thus total zooplankton densities were generally similar through the bay, ranging between 400-1000/m^3 (day) and 900-3000/m^3 (night).

TABLE 6. Mean, range, and 95% confidence interval of total zooplankton density in several regions of Jobos Bay during 1973 and 1974.

STATIONS

1973 DAY	1	2	3	4	5	6
n*	19	20	-	21	20	20
mean	1080	767	-	903	529	419
range	105-4728	155-1686	-	155-3222	36-1489	53-1266
95% C.L.	598-1562	531-1003	-	596-1210	360-798	267-571
1974 DAY						
n*	23	21	21	23	23	23
mean	864	674	367	504	469	397
range	118-2750	163-2942	39-1667	57-1598	80-1917	83-1990
95% C.L.	563-1165	354-994	177-557	328-680	304-634	198-596
1974 NIGHT						
n*	18	20	15	13	14	14
mean	2850	1369	978	1082	923	1000
range	446-9049	380-3341	226-2082	225-2805	427-2769	358-2891
95% C.L.	1690-4010	898-1840	673-1283	672-1492	578-1268	534-1466

STATIONS

1974 DAY	7	8	9	10
n*	23	23	23	15
mean	539	481	678	996
range	49-1780	120-1247	88-2021	126-2589
95% C.L.	335-743	341-621	480-876	561-1421
1974 NIGHT	17	15	15	14
n*	17	15	15	14
mean	2490	1384	1490	2364
range	367-6946	393-3976	343-3743	935-4977
95% C.L.	1488-3492	833-1835	964-2016	1652-3076

*n = total number of samples

Holoplankton, mostly copepods, dominated the zooplankton community in nearly all regions throughout the year. *Acartia tonsa* was clearly the largest copepod population in bay waters, forming 90% or more of the copepods observed. In regions where bay and coastal waters mixed (Stations 3, 4, 5 and 6), other species, *Temora turbinata*, *Paracalanus parvus*, *P. crassirostris*, *Centropages furcatus*, *Corycaeus subulatus*, and *C. amazonicus*, were also numerous.

During May through July, meroplankton, primarily barnacle larvae, were numerous, accounting for 40 to 60% of all zooplankton at Stations 1, 7, 8 and 9. During May 1974, at Stations 3, 4 and 6, prosobranch veligers reached their largest densities, as high as $478/m^3$. Echinopluteus were quite numerous in late October of 1973 and 1974 at Station 5 ($191/m^3$) and Station 3 ($891/m^3$), and were very abundant at all other areas at that time in 1974 except at Stations 1 and 10. Large densities of caridean and/or brachyuran larvae occurred in August at Station 10 and from September until November at Station 4. Concentrations ranged from 130 to $1200/m^3$.

Hydromedusae appeared at stations in the inner and central portions of the bay each year from June until late November reaching their greatest concentrations of about $13/m^3$ in July and August. Fish eggs tended to be more abundant at most stations during June and July. Densities were somewhat lower at Stations 8, 9, and 10. The average number (14) and range (1-158) of $eggs/m^3$ for the entire bay during 1974 were nearly identical to densities recorded in 1973.

Effects of Power Plant Operation

The impact of an operating fossil-fuel power station on the planktonic community in the central portion of Jobos Bay will be the result of a combination of physical-mechanical, chemical, and thermal stress. The effects of prolonged exposure to such stresses will probably be similar to those observed in Guayanilla Bay (Youngbluth 1975a,b). Community structure will be altered, food webs will be less complex, and species diversity reduced. During the course of this study data were gathered before and after one of the two units constructed began operating. The stations closest to the intake and temporary outfall of the plant were numbers 8 and 9. Fluctuations in density and diversity of zooplankton in these areas during the entire period of study were within the ranges observed in other regions of the bay. These results are not surprising since temperature differences in the region adjacent to the outfall were usually only 1 to 3°C above ambient. This small increase in temperature was also localized because the plant never operated at more than 30% of its capacity (Mr. Raul McClin, pers. comm.). Biocide anticorrosive chemicals were not used during this period. Consequently, mechanical damage from pumps cycling $1.25 \times 10^6 m^3$ per day through the power complex should have been the major factor affecting zooplankton mortality. Since death due to pumped entrainment was not studied before this program was terminated, no assessment of the magnitude of this factor can be mentioned.

The only obvious differences noted in the samples collected near the power plant were in the water quality and the quantity of particulate matter suspended in the water. The color of the water in several samples drawn at Station 8, and especially Station 9, ranged from dirty grey to dark amber. High levels of suspended sediments resulting from increased turbulence at the outfall probably caused the grey hue in these shallow waters. The introduction of chemical effluents, possibly originating from the sugar mill discharge, may have produced the amber coloration. Plant detritus, primarily bits of sea grass and decaying floral fibers of terrestrial origin, as well as ash particles, were more frequently observed and occurred in higher concentrations at these stations.

Limitations of the Data

Samples collected in the surface waters at night indicate the concentration and diversity of zooplankton were in many instances much higher than estimates based on daytime catches. An additional series of tows gathered during the day on three successive biweekly trips indicated that the biomass and density of zooplankton sampled in nets towed along an oblique path from near the bottom to the surface were not significantly different from collections in the upper two meters. These data suggest that during the day there is a pronounced stratification of zooplankton near the bottom of Jobos Bay, e.g., the older stages of *Acartia tonsa*, decapod larvae, *Sagitta tenuis*, and fish larvae. Future investigations of zooplankton in this bay with discrete depth sampling should determine where these organisms reside during the day and if some forms, such as fish larvae, remain near the bottom day and night. These studies will be particularly important since they can provide insight into the interdependence and coupling of planktonic and benthic communities.

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SEA GRASS BED COMMUNITIES OF JOBOS BAY

by

Vance P. Vicente

INTRODUCTION

The term "sea grass" is applied to submerged aquatic vascular plants which form extensive meadows in shallow, sheltered coastal regions. Sea grasses are classified as members of the families Hydrocharitaceae and Potomogetonaceae. In the tropical Atlantic Ocean, Thalassia testudinum König (Hydrocharitaceae), commonly called turtle grass, is the most abundant phanerogam. Syringodium filiform (Kutzing) and Diplanthera wrightii (Ascherson), both from the family Potomogetonaceae, are also common sea grasses in the tropics and initiate the ecological succession which climaxes in the Thalassia bed community (Margalef 1962, Welch 1962).

Sea grass beds serve as feeding, spawning, and nurturing areas for many marine organisms. The queen conch, spiny lobster, green turtle, the manatee, and many species of fish (Randall, 1965, 1966) utilize the sea grass beds throughout different phases of their life cycles.

In Puerto Rico, sea grass beds occur mainly on the south coast where much of the inner coastal waters are protected by fringing coral reefs. Sea grasses do not grow profusely in environments exposed to heavy wave action. For example, at Islote on the north coast, Thalassia testidinum occurs among the dominant red algae at 15 meters and Halophila baillonis forms patches in the deeper sandy substrate at Tortuguero Bay.

The sea grass beds at Jobos Bay are composed principally of Thalassia and can be divided into three main types (see Figure 7). In the outer bay the beds are well iluminated with hard bottoms (Stations 8 and 11 of Figure 7). Beds closer inshore are poorly illuminated with soft, muddy substrate (Stations M, X, IV, VII, 10 and 3 of Figure 7). The mangrove channels feature beds with soft, silty bottoms (Station 12).

Several aspects of the sea grass bed communities were examined. Distribution and zonation of all local grasses were studied, and biomass, root and leaf standing crop, growth rate, epiphytism, and photosynthetic pigment diversity were measured for Thalassia testudinum. A list of the invertebrates with their frequency of occurrence at each station was compiled. The zonation, relative distribution, frequency, and area coverage of the macro-epibenthic invertebrates and the role of the echinoid fauna were studied.

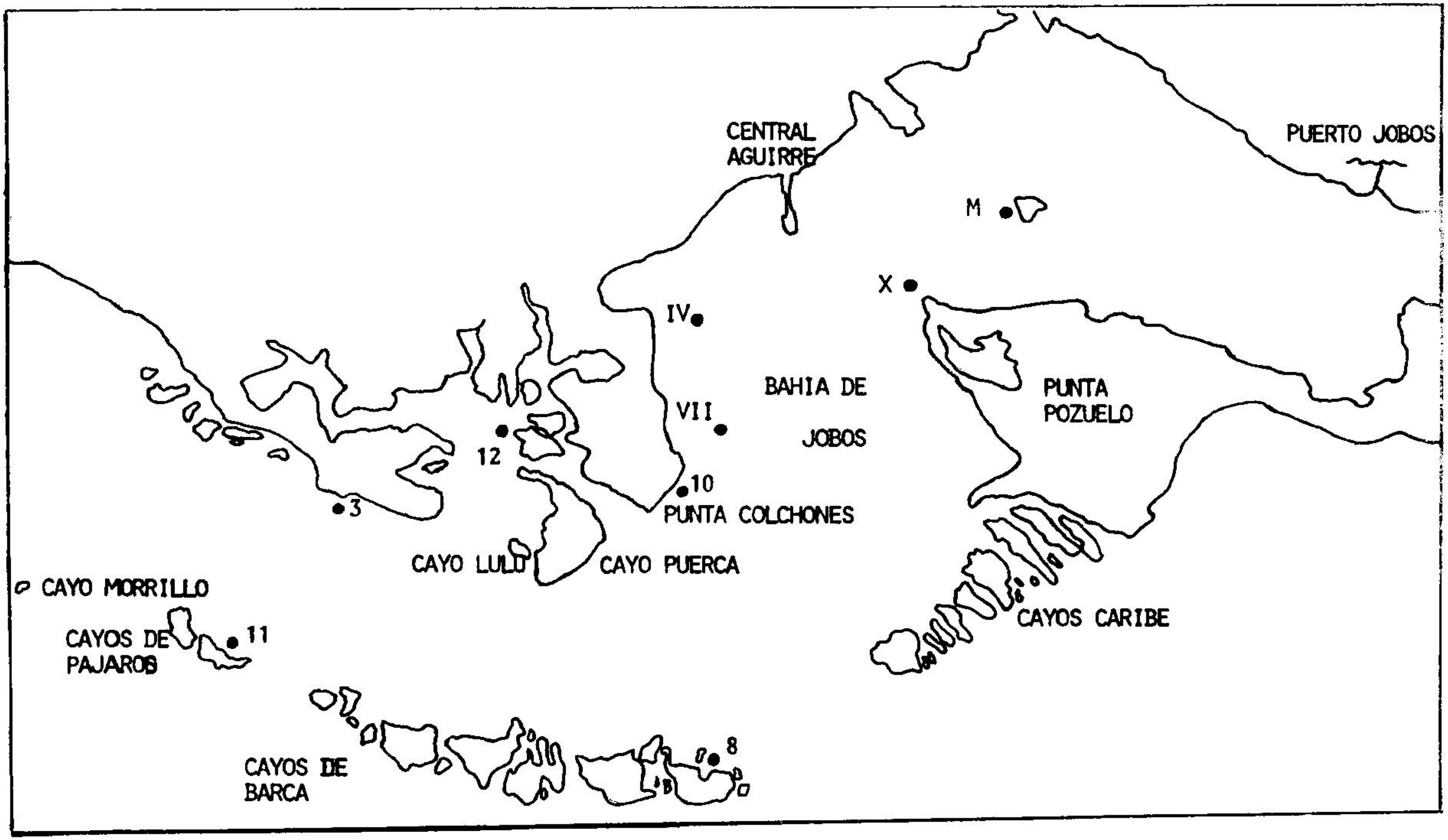


Fig. 7. *Thalassia* bed stations. Stations 8, 11: well-illuminated, hard bottom; M,X,IV,VII,10,3: poorly-illuminated, soft, muddy substrate; 12: mangrove channels, soft, silty bottom.

MATERIALS AND METHODS

Sea Grasses

Transect studies were conducted at each Thalassia station to determine the zonation and distribution of the marine angiosperms. A nylon line (.5cm x 100m) marked at 5 meter intervals was used to delineate the transect. One stake was pounded into the substrate at the greatest depth where Thalassia occurred. The transect line was placed perpendicular to shore. Notes were taken on the dominant vegetation in and around the quadrat at 5 meter intervals. Temperature and depth readings were also taken at 5 meter intervals. Temperature was measured with a centigrade thermometer which was placed on the bottom for three minutes before taking the reading. A carpenter's rule was used to measure the shallower portions of the Thalassia bed. Lines and weights were used to measure the deeper areas.

Records of Thalassia's reproductive structures were kept throughout the sampling period to determine where and when reproduction occurred. Records on the occurrence of macroalgal blooms and deleterious epiphytes growing on Thalassia were kept. Epiphytic species, location, and time of observation were noted.

To determine blade growth, Thalassia blades were cut with scissors as close to the substrate as possible. The cut blades within a ¼m^2 sample at Station M inside the bay, and at Station 11 outside the bay, were permanently marked at the apical end of the straight cut. The growth rate was determined by measuring the distance between the cut apical end and the base of the blade. After 28 days, the marked Thalassia blades were cut at the base and taken to the laboratory for measurement. (For a different method of determining blade growth, see Zieman, 1970).

To ascertain biomas, samples of Thalassia testudinum were obtained with a corer especially designed to prevent loss of contents. The corer samples an area 203 cm^2 and can penetrate 43.2 cm. A more detailed description of the corer is given in Kolehmainen 1972, and Shroeder, 1972. Five core samples were obtained each time a station was visited. Each sample was sorted and washed. Sea grasses were separated from other vegetation and placed in plastic bags. Wet and dry weights were obtained by use of a Mettler top balance. All drying was done in a Precision Thelco Model 6 oven set at 45°C for 48 hours.

Separate values for root and leaf standing crop were obtained in June and July 1974 for all stations, using the corer. The root materials (roots and rhizomes) and foliage materials (new, old, and decomposing blades) were separated, and then weighed in wet and dry weights using the Mettler top balance. Standing crop values obtained were compared to values previously established (Kolehmainen 1972, Shroeder 1972) in order to gain perspective on the relative health of the Thalassia beds in Jobos Bay.

Ten leaves free of necrotic area were gathered at each station. The samples were kept on ice in total darkness until they could be taken to the laboratory. Epiphytes and debris were removed. Three 1 cm^2 sections were cut from each leaf and placed in individual 50ml beakers to which 25mlg of 90% acetone had been added. A Sorvall Omni mixed tissue homogenizer was used to break up the leaf sections for pigment extraction. The solutions were kept under aphrotic conditions by wrapping the flasks with aluminum foil to avoid pigment deterioration. A small amount of magnesium carbonate ($MgCo_3$) was added to each solution as a buffer.

After a 24-hour extraction period, the solutions were centrifuged to precipitate the suspended plant material. The supernatant was decanted into a clean vial. An aliquot of 2ml was withdrawn with a pipette and emptied into a cuvette for spectrophotometric analysis. A Bausch and Lomb spectrophotometer was used and an absorption spectro from 400mm to 700mm was obtained for each sample.

Invertebrates

The core sampler previously mentioned was used to sample invertebrates. Five random core samples were obtained at each station, usually on a monthly basis. The cores were placed in plastic bags tagged with the station number and date. (For a similar sampling procedure, see Zimmerman, 1972).

The samples were sorted in shallow water in the field and placed in a plastic bucket which contained seawater. The compact sample was then diluted to separate plant material and invertebrates from substrate. Samples were poured through 12, 3, and 1mm meshes, one attached to another by wooden frames. Each frame measured 50 x 33 by 8.5 cm. After each sample had sieved through, the specimens trapped in each layer were sorted and transferred to screw-cap plastic vials and fixed with 4% formalin for further identification. Counts were kept on each species, and the biomass of each specimen was obtained with the use of the Mettler balance. (For similar sampling procedures used in Florida, see Zimmerman, 1972).

Transect studies were carried out at each station to determine the zonation and distribution of the epibenthic and some semi-infaunal organisms. The 100 meter transect line used to profile the marine angiosperms also delineated the transect for the invertebrate distribution studies. One sample was collected at each 5 meter interval. All invertebrates enclosed by a ¼m^2 quadrat placed beside the 5 meter mark constituted a sample. Each sample was placed in a plastic bag and then frozen. The specimens were classified to the lowest taxonomic group possible. Records were kept of abundance (number of individuals/.25cm^2) and surface area covered (cm^2/.25m^2) by each species.

Notes on population densities, distribution, and species diversity of the echinoids in Jobos Bay were taken throughout the study. The population density of Lytechinus variegatus was determined by throwing a 1 m^2 frame over each study area ten times and counting the specimens which became enclosed. The frame was divided into ¼m^2 subunits with nylon string. A similar field method was used by McPherson in 1969 to calculate the population density of the tropical urchin Echinometra. In order to compare population densities between stations and times, data were computed for mean, variance, standard deviation and error.

To observe the grazing activity of Lytechinus, all of the Thalassia blades which were growing in a small, caged area were cut close to the bottom. The blades were allowed to grow again. A few specimens of Lytechinus were left inside the cage. Marks found later on the blades were considered to be the result of grazing by Lytechinus.

RESULTS AND DISCUSSION

Four submerged marine vascular plants are found in Jobos Bay. They are: Thalassia testudinum (Kӧnig), Syringodium filiforme (Kutzing), Diplanthera wrightii (Ascherson), and Halophila baillonis (Ascherson). The most abundant sea grass in Jobos Bay is Thalassia testudinum. The manatee grass, Syringodium, is the next most common and is intermixed with Thalassia at some locations. Diplantheria wrightii has been observed in very shallow areas only. Halophila grows in deeper waters.

The general distribution and zonation of the sea grasses with notes on dominant species, depth, temperature, and distance from shore are presented in Appendix E, Tables 1 through 7. In general, Diplanthera inhabits only the shallows, Syringodium intermixes with Thalassia in the shallower portions of the beds, Thalassia occurs in the deeper portions of the beds, and Halophila grows in much deeper areas.

The present zonation pattern of the sea grasses in Jobos Bay is different from other sea grass beds found in the tropics. Zimmerman (1972) reports a pattern of Diplanthera, Thalassia, and then Syringodium in the deeper locations at Anclote Bay, Florida. Although Phillips (1960) states that Syringodium is restricted to submersion, it grows abundantly at Station X in the intertidal zone and disappears with increasing depth. The presence or absence of a sea grass may be largely a matter of succession, according to Welch (1962), and seasonal influences. When the substrate is stable, the presence or absence of phanerogams is by chance (Welch, 1962).

The depth limit of sea grasses has been attributed to hydrostatic pressure (Gessner 1961) but most authors agree that light penetration or water turbidity limits the growth of sea grasses in deeper areas (Phillips 1962, Kolehmainen 1972, Zimmerman 1972). In the turbid areas of Jobos Bay, the Thalassia beds do not extend as far into deeper waters as do beds in the outer bay where the water is clearer (Kolehmainen 1972). Syringodium occurs in the shallows at Stations X, 10, and 8 and decreases with depth. Diplanthera also grows in very shallow water, especially at Station 8 on the sandy substrate, and near Station VII. The only phanerogam found growing in waters deeper than that in which Thalassia is found is Halophila at Stations 3 and 10.

Thalassia testudinum (Kőnig)

Rydberg (1909) first described the flowers and fruits of Thalassia. Philip and Boral (1964) described the anatomy of the seed and germination of this plant and cleared up discrepancies found in earlier descriptions of the fruit and seeds. Orpurt and Boral (1964), working in Florida near Miami, described Thalassia's developing stages. The flowers are pollinated under water (hydrophilous). Fruits from the earliest flowers mature in about 8 weeks. Some fruits float for long distances. When the fruit bursts, the seeds are liberated and sink. They settle with their flat side downward. Root hairs on the flat side of the seed anchor it to the loose substrate. The seed then germinates and becomes an adult plant.

Orpurt and Boral (1964) observed flowers to develop in early April through September. Tomlinson (1969), however, reports that flowering varies from year to year and may not occur in some seasons. At present, there are no publications on the life cycle of Thalassia in Puerto Rico. Fruits and flowers were observed in May, 1974, at Station 11 on the leeward side of Cayo de Pajaros (see Figure 7). The appearance of reproductive structures of Thalassia at each station in Jobos Bay occurred as follows:

Stations	Months
11,10,8	May and June
X	June and July
IX	June
VII	July
3	No reproductive structures observed.

Stages in the life cycle of Thalassia in Jobos Bay are illustrated in the photographs of Figure 8.

Any organism growing on Thalassia blades will have a negative effect on production, because light penetration, which is essential for plant photosynthesis, is reduced or eliminated.

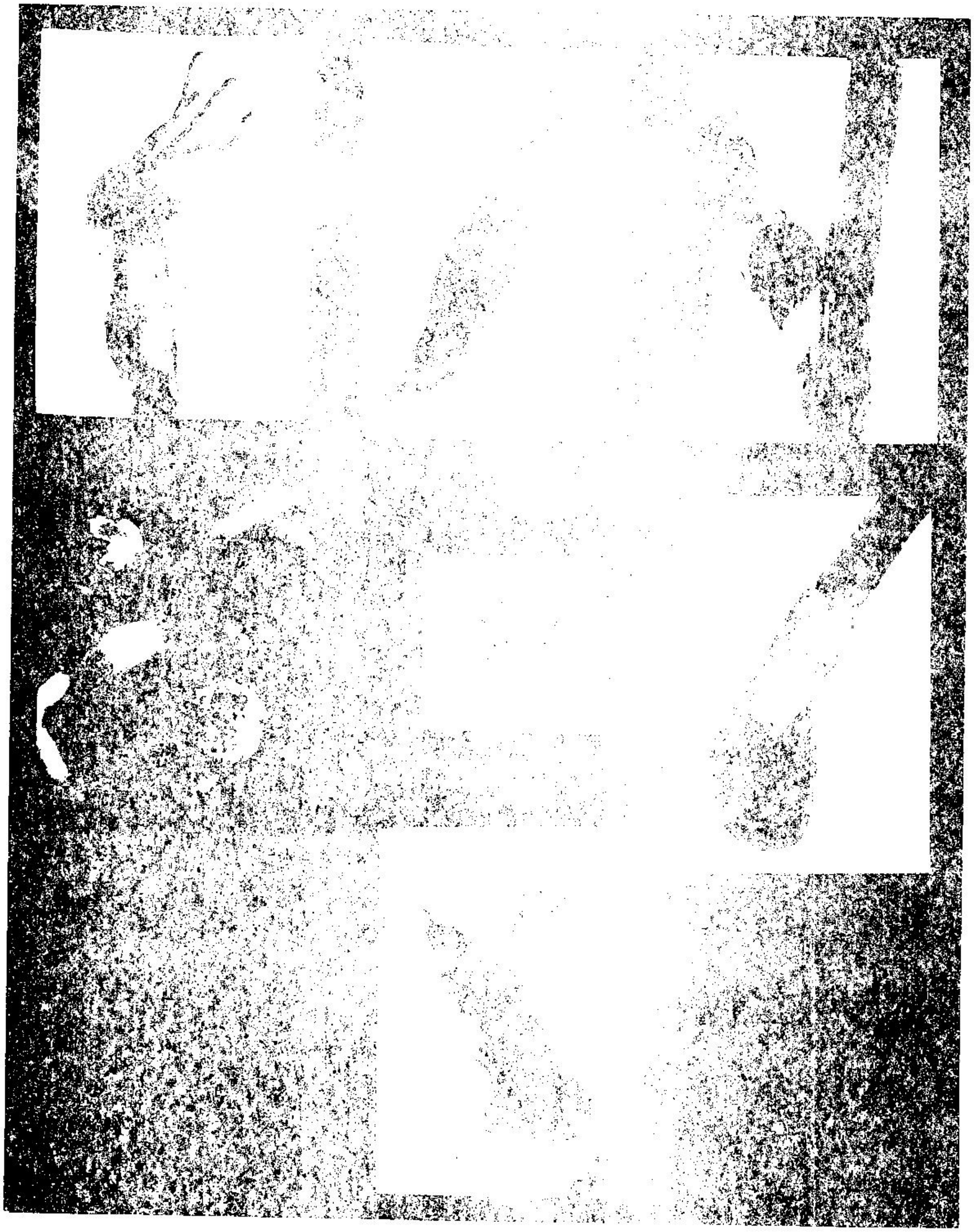


Fig. 8. *Thalassia testudinum* [illegible] stages. Female flower, young [illegible], floating stage of [illegible] seedling developing rhizomes, [illegible] and rhizomes. (Left to right [illegible] to abundant root hairs.

Organisms covering the rhizomes, especially those closest to the surface of the substrate, will eliminate or reduce the production of new leaves originating from the rhizomes. *Thalassia* blades can tolerate large amounts of epiphytic algae and other organisms (Humm 1964, Reyes-Vazques 1965) but a bloom of epiphytes over a prolonged period could prevent *Thalassia* from photosynthesizing enough to keep up with respiratory losses. This could result in the exhaustion of all starch reserves in the rhizomes.

At Jobos Bay, particular attention was given to previously unreported epiphytes and macro-algal blooms. The macro-algae of Jobos Bay have been studied by Almodovar (1964) and Horton (1972). The most conspicuous epiphytic algae on *Thalassia* is the crustose coralline red type (Corallinocene: *Rhodophyta*). It was observed throughout the entire sampling period. This algae forms thin encrustations on the blades and, when dried, appears to be white. The only crustose algae of this type ever reported for Jobos Bay appears in Horton (1972).

Three types of bloom were observed. A blue-green (Cyanophyta) bloom appeared on August 29, 1974 at Station 10 and extended over the *Thalassia* bed from 38.1cm depth at 10 meters from shore to 76.2cm in depth at 40 meters from shore. A similar bloom was observed at Station X on December 20, 1974, over the intertidal zone. A major red-brown algal bloom formed a mat over almost the entire *Thalassia* bed on September 21, 1974 at Station IV, the station closest to the thermal effluent in the bay. The principal components of this bloom were *Hypnea spinella* (Rhodophyta) and *Dictyota linearis* (Phaeophyta). The third type of bloom occurred at Station 3. Virtually all *Thalassia* blades had patches of the brown algae *Ectocarpus* sp. growing on them.

Erthropodium caribaeorum thrives throughout the year in well-illuminated beds (Stations 8 and 11). This encrusting gorgonian grows over *Thalassia* shoots and blades (see Figure 9). *E. caribaorum* has been reported to form sheets over coral rubble, thus stabilizing the substrate (Welch, 1962), but it has not been reported to grow on *Thalassia* itself as it does at Jobos Bay. In the less illuminated beds, the bryozoan *Schizoporella* grows on *Thalassia*. The chicken liver sponge, *Chondrilla nucula*, is also commonly found in Jobos Bay, especially at Station 8 where it grows on Thalassia, Syringodium and Halimeda. The colonial ascidian is an important epiphyte at Stations IV and VII (see Figure 10).

Preliminary studies to determine the growth rate of *Thalassia* blades were conducted from September through November, 1974, at Stations M and 11. The average growth rate is presented on the page following. From 30 randomly selected leaves, the average length of the cut *Thalassia* blades at Station M was calculated to be 14.1 ± 5.2cm. The average growth rate during this period of 26 days was 7.3 ± 3.8cm, or approximately half the average height of blades under normal conditions. Evidently, *Thalassia* blades are able to restore half their normal length in a 26-day period at this station.

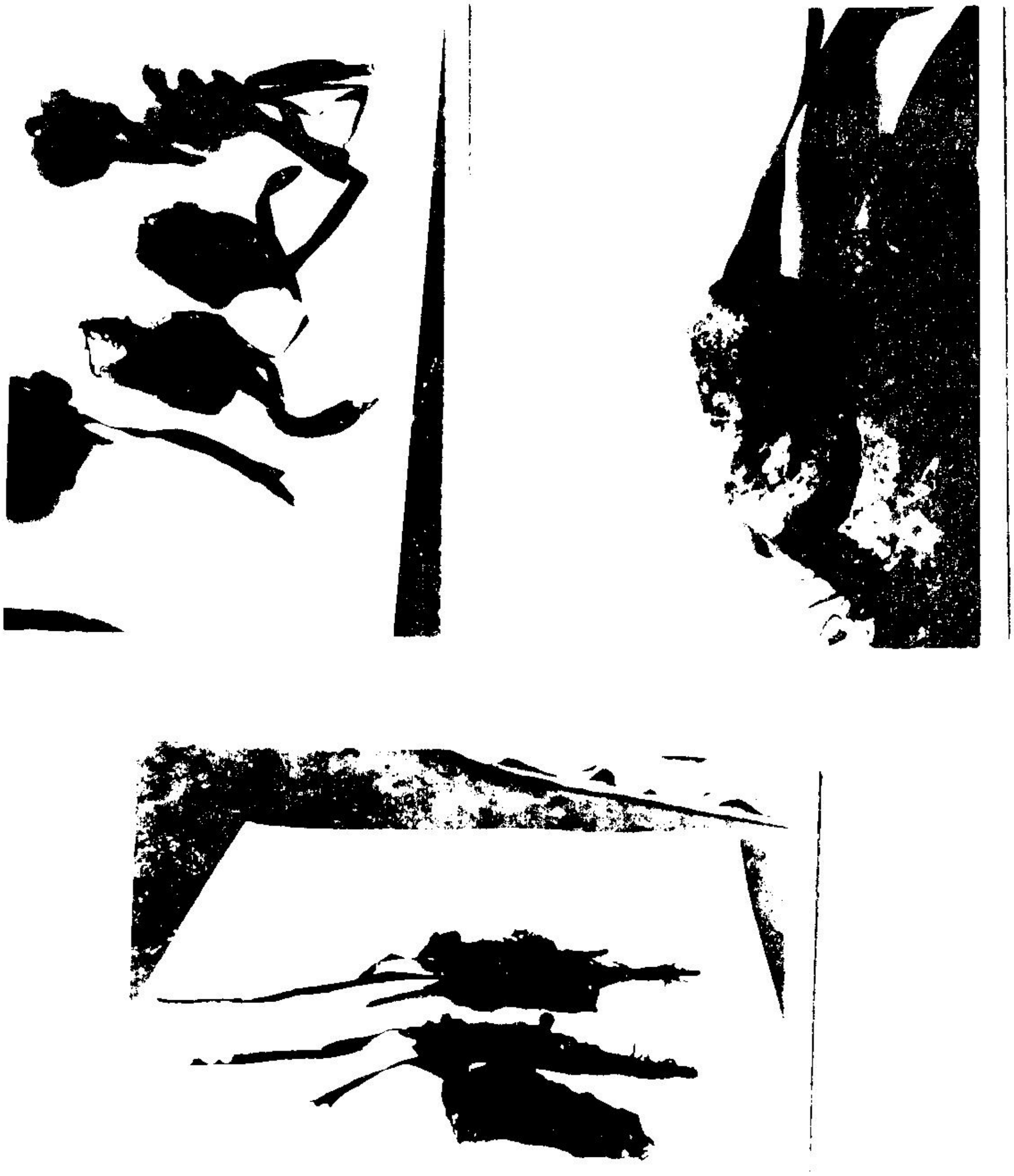


Fig. 9. Encrusting gorgonian *Erythropodium caribaeorum* growing on *Thalassia*; *Bryozoan* *Schizoporella* sp. growing on *Thalassia*.

Fig. 10. *Chondrilla nucula* growing on *Thalassia* rhizomes, on calcareous green algae *Halimeda*, on a blade of *Syringodium*, and a colonial ascidian covering *Thalassia* rhizomes and blades.

Station	Date	Cut Blades (ave)	Emergent Blades (ave)
M	27 Sep-22 Oct	9.9 ± 26cm/ 26 days	7.3 ± 3.8cm/ 26 days
11	17 Oct-16 Nov	5.2 ± 2.0cm/ 30 days	5.4 ± 1.9cm/ 30 days

A comparison between the average standing crop of cut blades at Station M and four other samples taken at that station during the same period shows that Thalassia is able to restore half of its average standing crop of blades in 26 days, also.

1974	$g/.25m^2$ dry weight	(ave)
27 September	30.0	
27 September	28.6	
22 October	47.0	
22 October	36.0	35.2 ± 8.5

Standing crop of cut blades after 26 days ($g/.25m^2$): 18.0

Other authors (Zieman 1970, Moore and McPherson 1965) have obtained growth rate values. More data are needed before growth rates in Jobos Bay can be compared with those of Zieman and More and McPherson.

The biomass values of Thalassia testudinum at the different beds in Jobos Bay are given in Appendix F, Tables 1 through 7. A 2-way ANOVA (Tate and Clelland 1957) determined variations in biomass values between months and stations. Stations 3, 8 and 11 were used for the test because they had been sampled for the longest periods of time. Analysis reveals that biomass values for March were significantly higher ($p = .05$) than the values for November and July. This peak was also evident at Stations X and IV (see Figure 11). The average values at Station 8 were significantly higher ($p = .05$) than at Stations 3 and 11.

TABLE 7. Data used for 2-way ANOVA of biomass values for Stations 3, 11 and 8 ($g/.02m^2$ dry weight)

Station	Nov	Jan-Feb	Mar	Apr	May	Jun	[illegible]	X'
3	33.0	33.0	26.2	32.7	22.5	32.7	25.2	29.3
11	30.2	29.0	56.7	39.4	28.9	40.1	27.6	36.0
8	29.6	61.2	91.1	65.4	50.2	52.2	40.9	55.8
X^2	30.9	41.1	58.0	45.8	33.9	41.7	31.8	

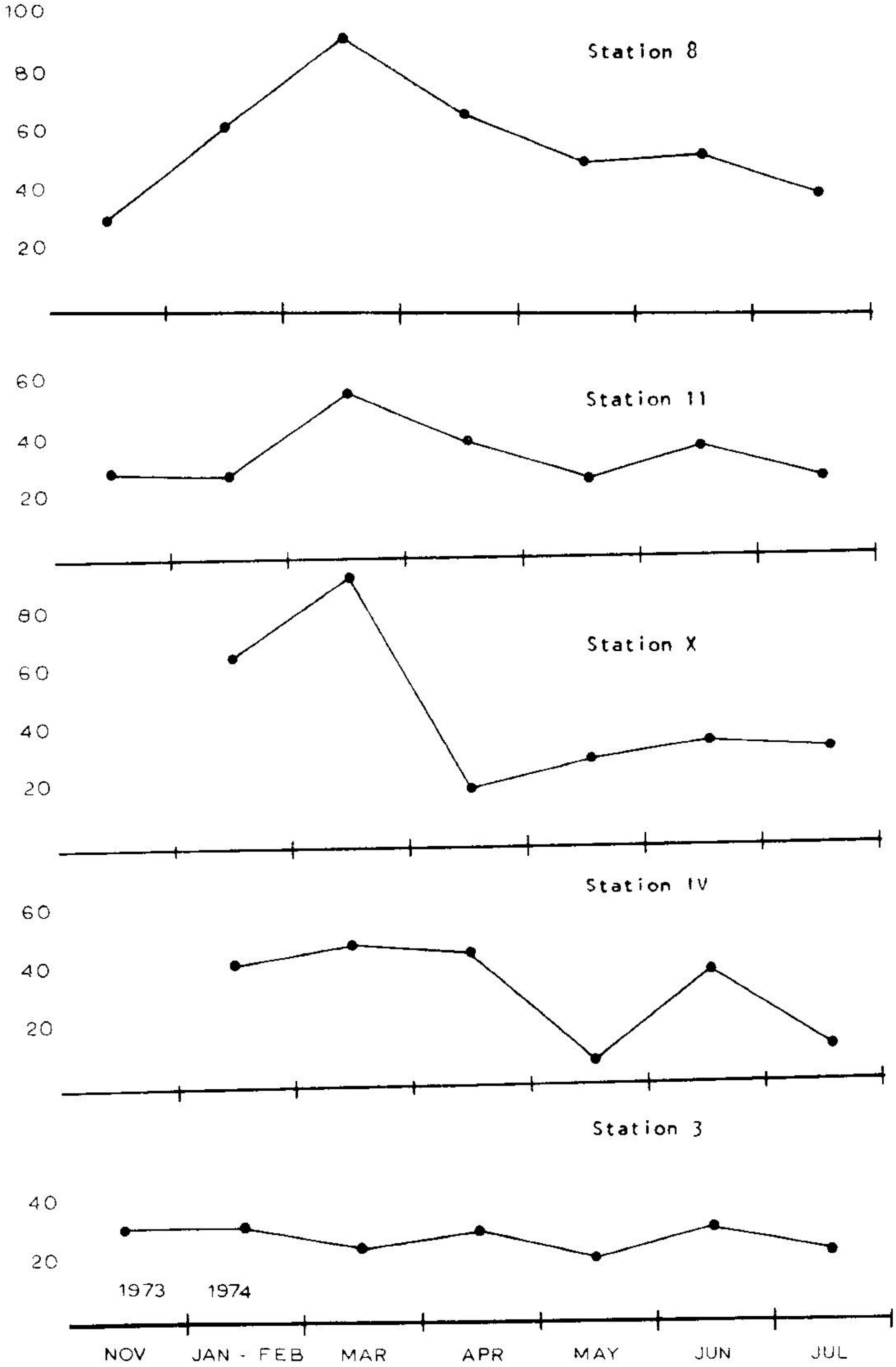


Fig. 11. Average monthly values of Thalassia testudinum biomass g/.o2 m^2 (dry weight)

Biomass values of *Thalassia* are affected by both biological and physical factors. A Tukey Corner Test (Tate and Clelland 1957) was carried out (see Figure 12) comparing the biomass values of *Halimeda* and *Thalassia* from Station 3. Analysis revealed a negative correlation between the biomass values of the two species (p .05-.01). The results suggest competition between the two species, probably for available substrate. Competition may also exist between one sea grass and another (Phillips 1960).

The comparatively low biomass figures for July coincide with the flowering and fruiting season of *Thalassia*. When a plant forms flowers and fruits much of the photosynthetic energy is shunted toward this process away from the production of blades (Zieman 1970) or from the accumulation of starch.

The very low biomass values of *Thalassia* in the mangrove channel (2.0 $g/.02m^2$ dry weight) at Station 12 may be caused by insufficient light (Margalef 1962). The unusually long *Thalassia* blades in this silty environment may indicate the plants' attempts to reach more light. (See Appendix F, Table 8).

In order to determine the average standing crop of *Thalassia* leaves and roots in Jobos Bay, 74 values obtained from all stations during June and July 1974 were analyzed (see Table 8). The average leaf standing crop for Jobos Bay during this period was 5.03 + 3.26 $g/.02m^2$ dry weight, or 250 g/m^2. The average root standing crop was calculated to be 28.11 ± 15.03 $g/.02m^2$ or 1,405.50 g/m^2 dry weight. This value is significantly higher than the leaf standing crop value which indicates that root material makes up most of the total biomass of *Thalassia testudinum* in Jobos Bay.

Thalassia blades appear to be more abundant inside the bay than they were outside the bay. Four .25m^2 samples from Stations M and 11 were compared and the following results obtained:

1974	Station 11	Station M
27 Sep	17.0 g*	30.0 g*
27 Sep	11.5 g	28.0 g
22 Oct	14.0 g	47.0 g
22 Oct	9.0 g	36.0 g
Average:	12.9 ± 3.1	35.2 ± 8.5

* dry weight

The difference in the standing crop of blades between Station 11 on the leeward side of the coral reefs and Station M in the inner bay is probably an effect of grazing pressure. The *Thalassia* beds at Stations 8 and 11 are the only beds where the urchin *Diadema* is found. Under experimental caged conditions, this urchin ate entire *Thalassia* blades. In similar experiments *Lytechinus variegatus* showed a slower rate of consumption and

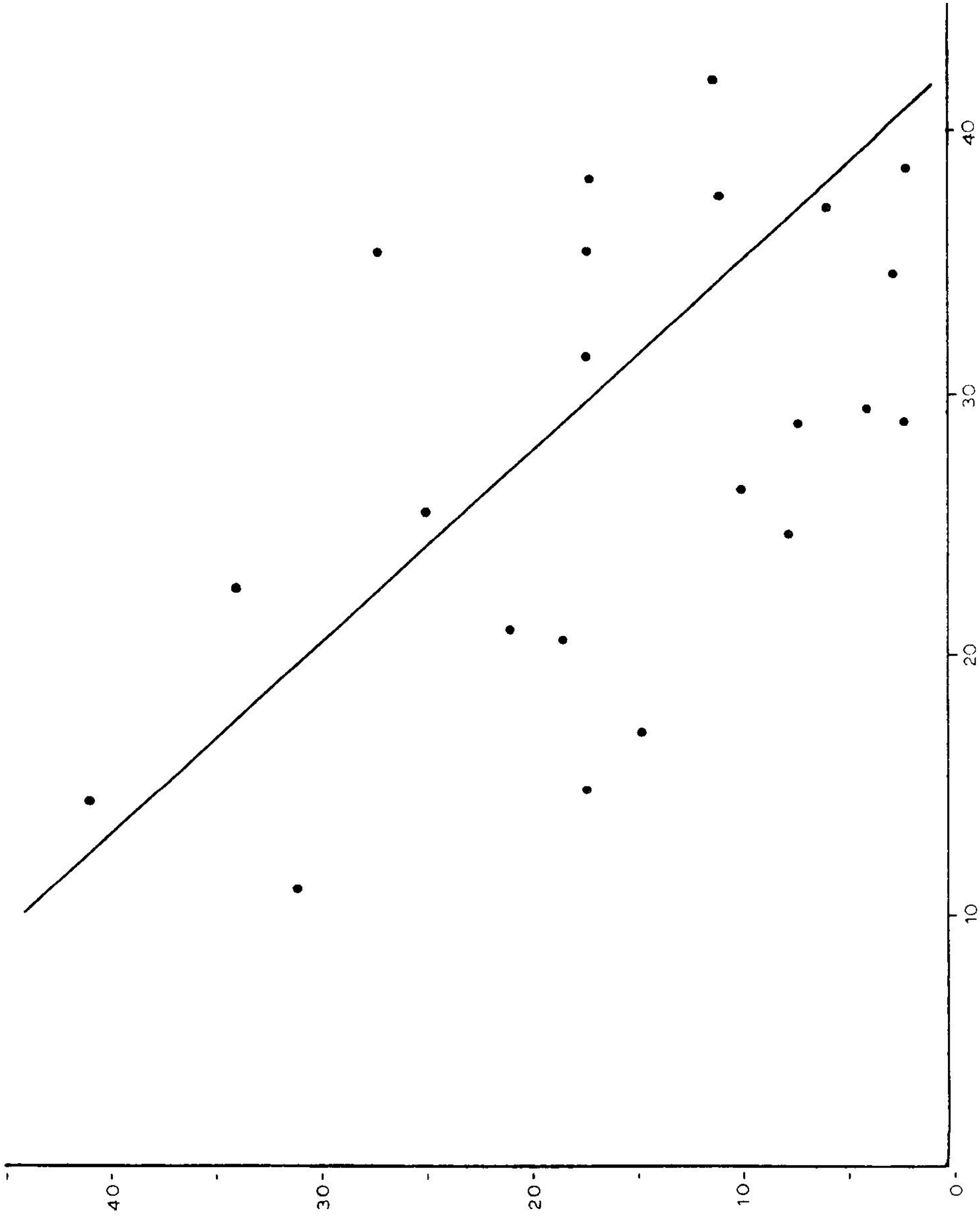


Fig. 12. Correlation between biomass values of <u>Thalassia</u> and <u>Halimeda</u> (Tukey Corner Test)

did not devour entire blades. Ogden (1973) found a negative correlation between the density of Diadema and blade length with blade length being shorter where there was an increase in the population density of Diadema.

TABLE 8. Root and leaf standing crop of Thalassia testudinum June and July, 1974

Station 11		Station VII		Station 8		Station IV	
Leaves	Roots	Leaves	Roots	Leaves	Roots	Leaves	Roots
1.3	39.1	3.5	25.9	4.4	39.2	4.1	58.5
4.0	41.1	2.2	32.7	2.8	50.4	6.7	61.9
1.5	29.0	3.0	26.6	3.6	48.3	3.3	21.0
3.3	27.3	4.2	16.6	4.3	48.0	7.0	49.8
3.6	47.3	1.8	16.2	6.7	33.5	2.8	13.1
2.2	19.3	13.8	26.0	---	----	1.1	17.1
3.7	27.5	5.0	32.2	3.5	61.8	.8	19.0
3.1	33.0	10.2	33.2	4.0	33.0	1.8	8.7
1.7	24.3	9.1	37.1	2.6	23.2	.3	4.3
1.3	21.5	9.8	33.1	1.5	72.0	4.1	16.2

Station X		Station 10		Station 3		Station 12	
Leaves	Roots	Leaves	Roots	Leaves	Roots	Leaves	Roots
3.1	10.1	5.9	27.4	5.9	29.4	.6	1.3
8.8	38.1	9.1	29.0	6.8	30.3	.9	1.9
7.0	49.1	8.8	38.8	3.9	26.5	0	.2
10.1	20.1	9.3	28.6	11.0	20.6	.7	2.5
4.7	36.5	11.2	44.8	5.1	24.2	.2	1.7
7.8	29.6	4.4	29.7	3.3	11.4		
9.5	33.1	4.6	23.1	4.9	16.1		
8.5	25.9	3.8	30.0	9.6	20.7		
10.8	30.8	5.8	30.0	12.4	22.2		
5.5	11.4	2.9	24.8	---	----		

Total average for leaves: 5.03 ± 3.26
Total average for roots: 28.11 ± 15.03

The ratio of yellow to green pigments (D430/D665) has been interpreted by various authors as an index of photosynthetic potential, activity of vegetation, and the maximal power output (Margalef 1962, Burkholder and Burkholder 1959). The D430/D665 coefficients for all stations in different months are given in Appendix G. A 2-way ANOVA was done for all stations in May and June 1974. These data used for analysis are given in Table 9.

There were no significant differences between the two months ($p = .05$). Station X was the only significantly different station, having a relatively high ratio of 1.938 ($p = .05$). The average values for Jobos Bay were high compared to results published by Burkholder and Burkholder (1959) who obtained an average of 1.7 for *Thalassia*. Samples taken during July at Stations X, 12, and 11 showed a drop in the index.

TABLE 9. D430/D665 coefficient values used for analysis of all stations May and June 1974.

Station	May	June	X'
10	1.850	1.813	1.832
8	1.782	1.786	1.784
VII	1.779	1.797	1.788
3	1.819	1.823	1.821
IV	1.956	1.811	1.884
11	1.821	1.899	1.860
X	1.912	1.965	1.938
12	1.852	1.722	1.787

Values are averages of 10 subsamples.

Invertebrate Fauna of Sea Grass Communities

A list of all invertebrate species sampled at each station and their frequencies of occurrence are presented in Appendix H.

There are no references on the zonation of the macro-invertebrate fauna of tropical sea grass communities. An attempt was made to delineate the distribution and zonation pattern of the larger invertebrates by determining the frequency and surface area covered for each species. These data are presented in Appendix I.

At Station 11, the dominant epifaunal invertebrates show a clear zonational pattern (see Figure 12-A) in which the scleractinian coral *Siderastrea* inhabits the shallower portion of the bed and the encrusting gorgonian *Erythropodium caribaeorum* and the sponge *Haliclona erina* dominate the deeper substrate (see Appendix I, Table 6). A graph relating surface area covered ($cm^2/.25m^2$) by each species and depth illustrates spatial interaction between the three dominant species (see Figure 12-B). This figure suggests that an increase in the surface area covered by *Erythropodium* and *Haliclona* results in a decrease of *Siderastrea*, and an increase in *Erythropodium* results in a decrease in *Haliclona*. *Siderastrea*, a scleractinian coral characterized by slow growth, is probably eliminated in the deeper locations by the much faster growing *Erythropodium*.

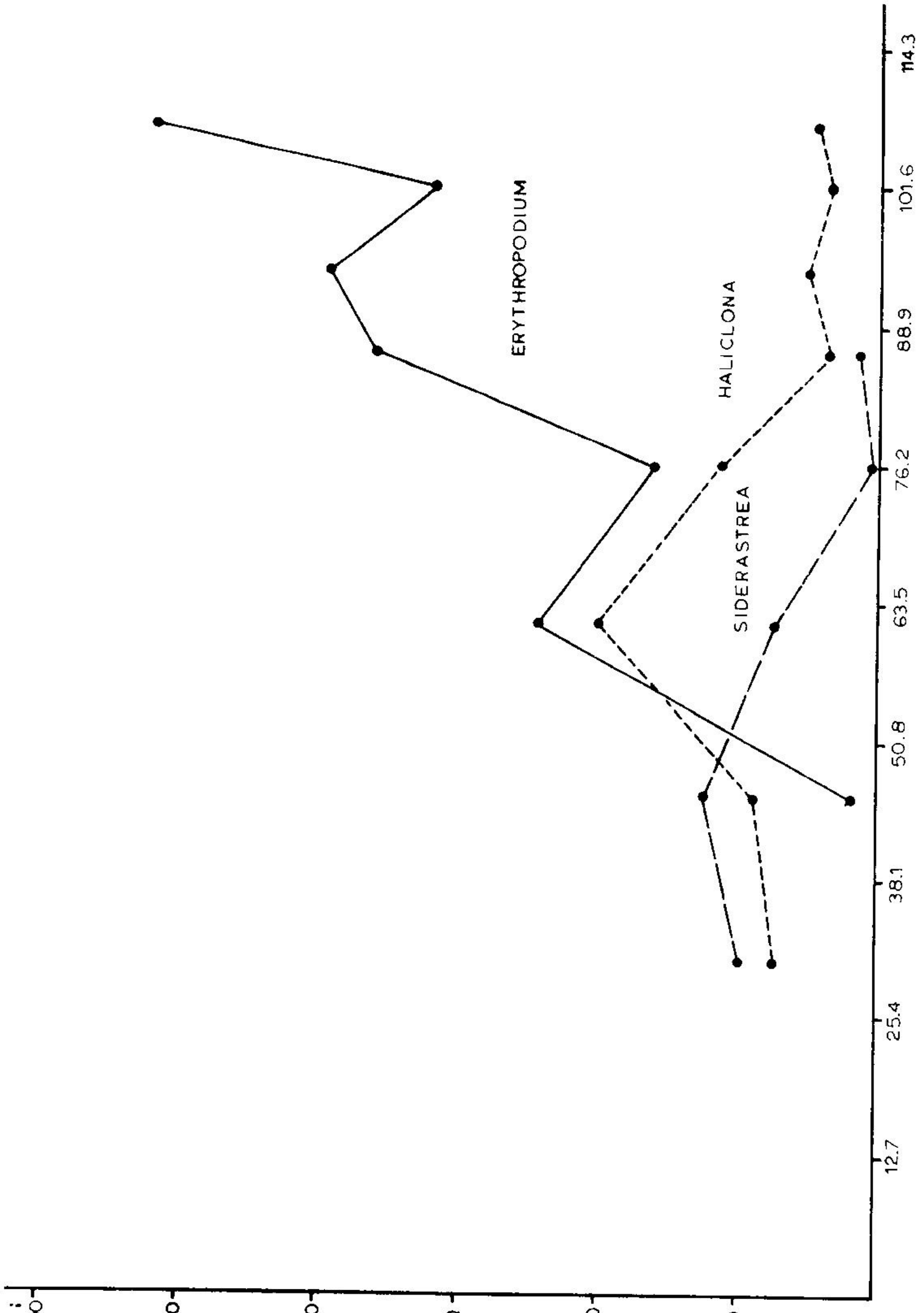


Fig. 12-A. Verticle profile and zonation pattern at Station 11.

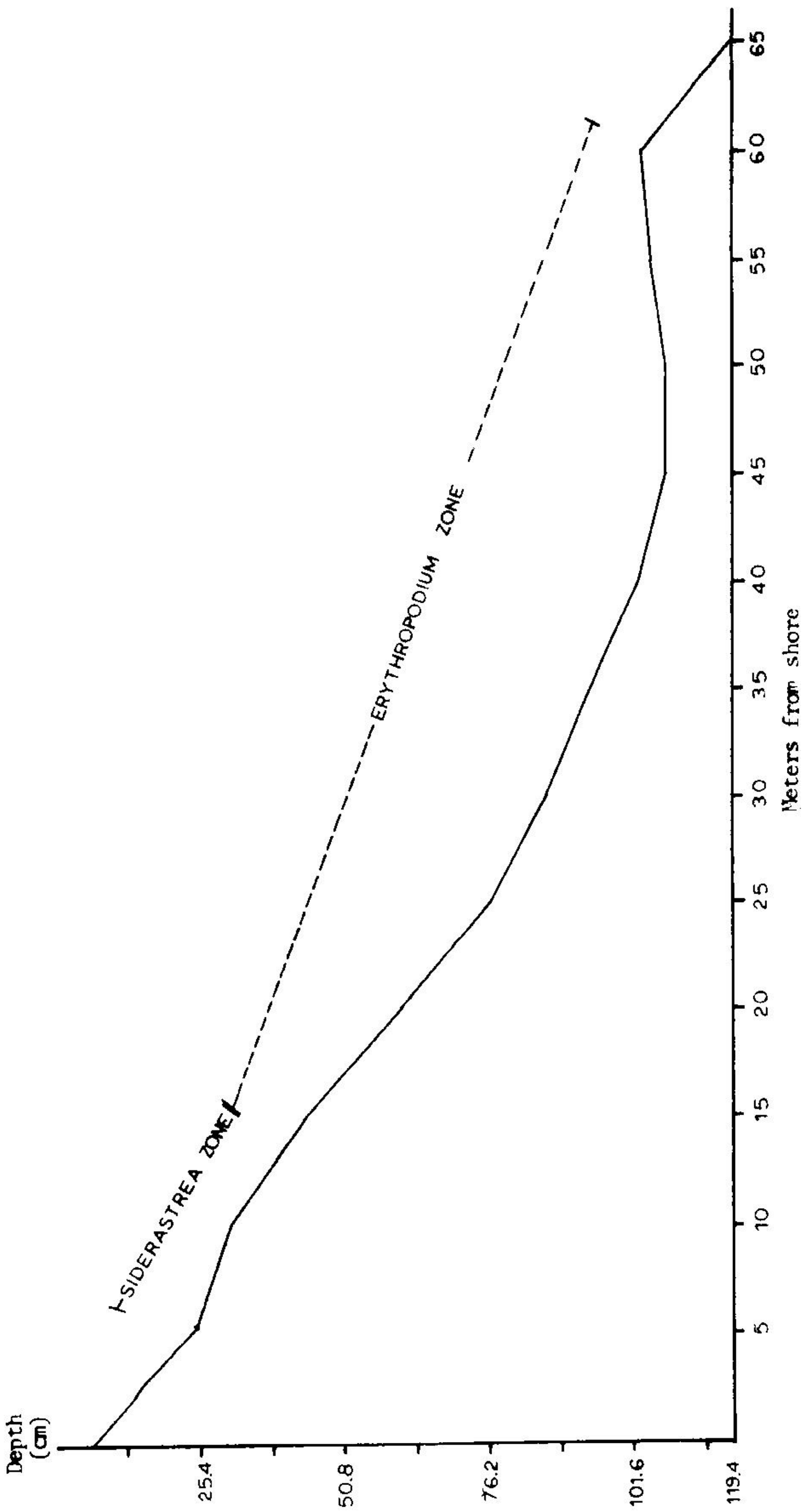


Fig. 12-B. Abundance of Siderastrea, Haliclona and Erythropodium relative to depth at Station 11.

The chicken liver sponge, *Chondrilla nucula*, was observed in the shallow substrate at Stations 8 and 10 but not in the deeper benthos (Figures 13-A and B). At Station 8, the occurrence of this sponge is directly related to the amount of coral rubble, mostly *Porites* (Figure 13-C). The distribution of ascidians within *Thalassia* beds varies with location. Solitary ascidians are principally filter feeders. They were observed in the *Thalassia* beds at Stations IV and 3. No ascidians were observed in those *Thalassia* beds where clear water and good circulation dominate, probably because suspended matter on which they feed was scarce. At Station X (Figure 14) they occur in the deeper parts of the bed, but at Station IV (Figure 15) they inhabit the shallower parts of the beds.

Echinoid Fauna

The dominate invertebrates of the sea grass communities are the echinoids. Sea urchins play a principal role in the trophic structure of a community as primary consumers, principally of vegetation. The most abundant echinoids in Jobos Bay are *Lytechinus variegatus*, *Diadema antillarum*, *Eucidaris tribuloides* and *Echinometra* sp. The echinoid fauna for each station and population densities are shown below. *Lytechinus* was the only urchin found in the inner bay. The outer bay stations (8 and 11) had higher diversities with more than one species per station.

TABLE 10. Population densities of echinoids at Jobos Bay (numbers per meter^2)

Species	Station	Population Density
Lytechinus variegatus	M	29.8 ± 9.8
	X	12.0 ± 3.8
	IV	10.5 ± 3.7
	VII	*
	10	*
	12	*
	3	3.3 ± 4.1
	11	.6 ± .2
	8	1.4 ± 1.6
Tripneustes esculentus	10	*
	3	*
	11	.1 ± 3.0
	8	.3 ± 1.6
Eucidaris Tribuloides	3	*
	8	.6 ± 1.6
Diadema antillarum	11	2.6 ± 1.3
	8	*

* observed

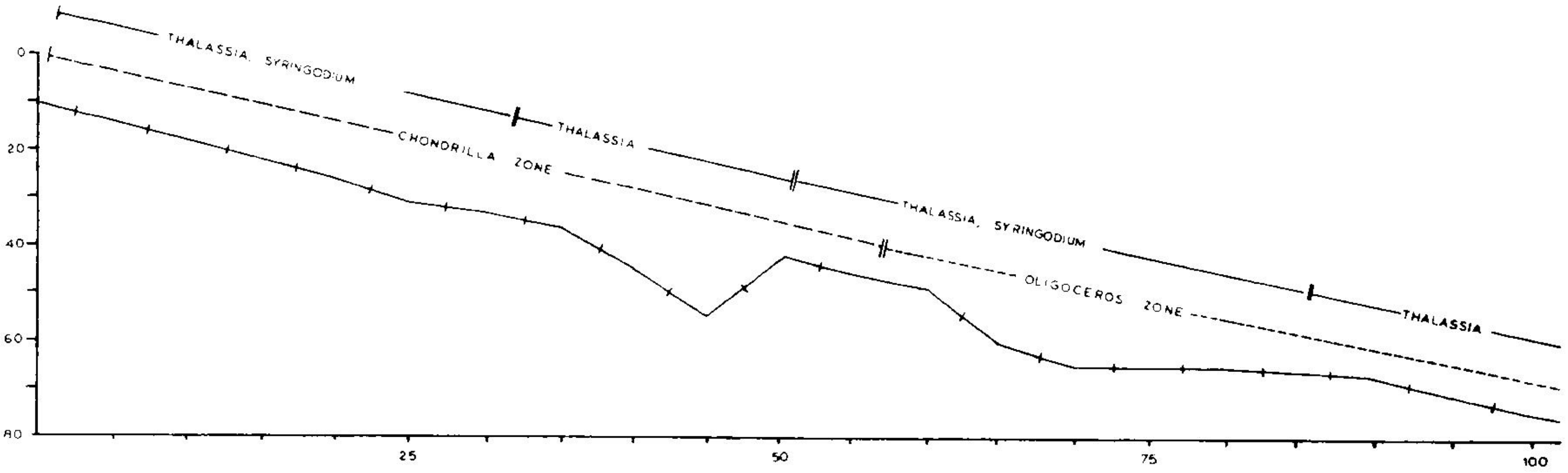


Fig. 13-A. Verticle profile and zonation pattern at Station 8.

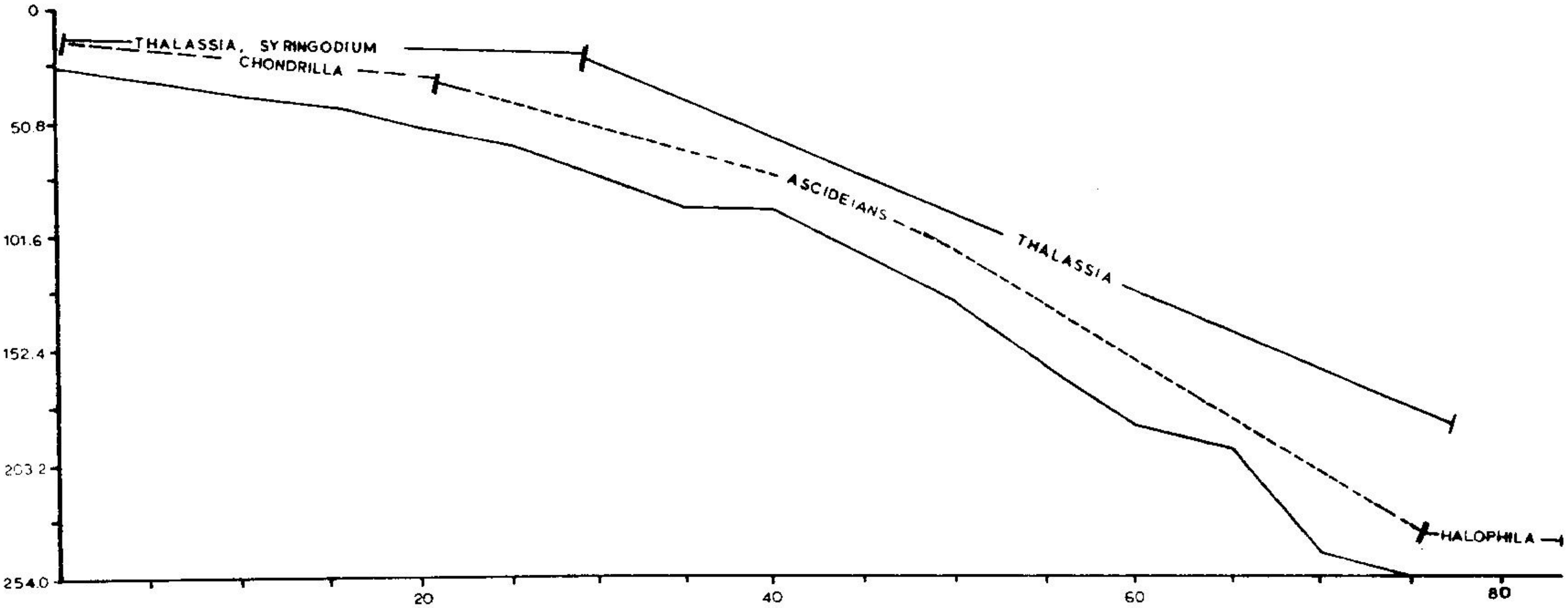


Fig. 13-B. Vertical profile and zonation pattern at Station 10

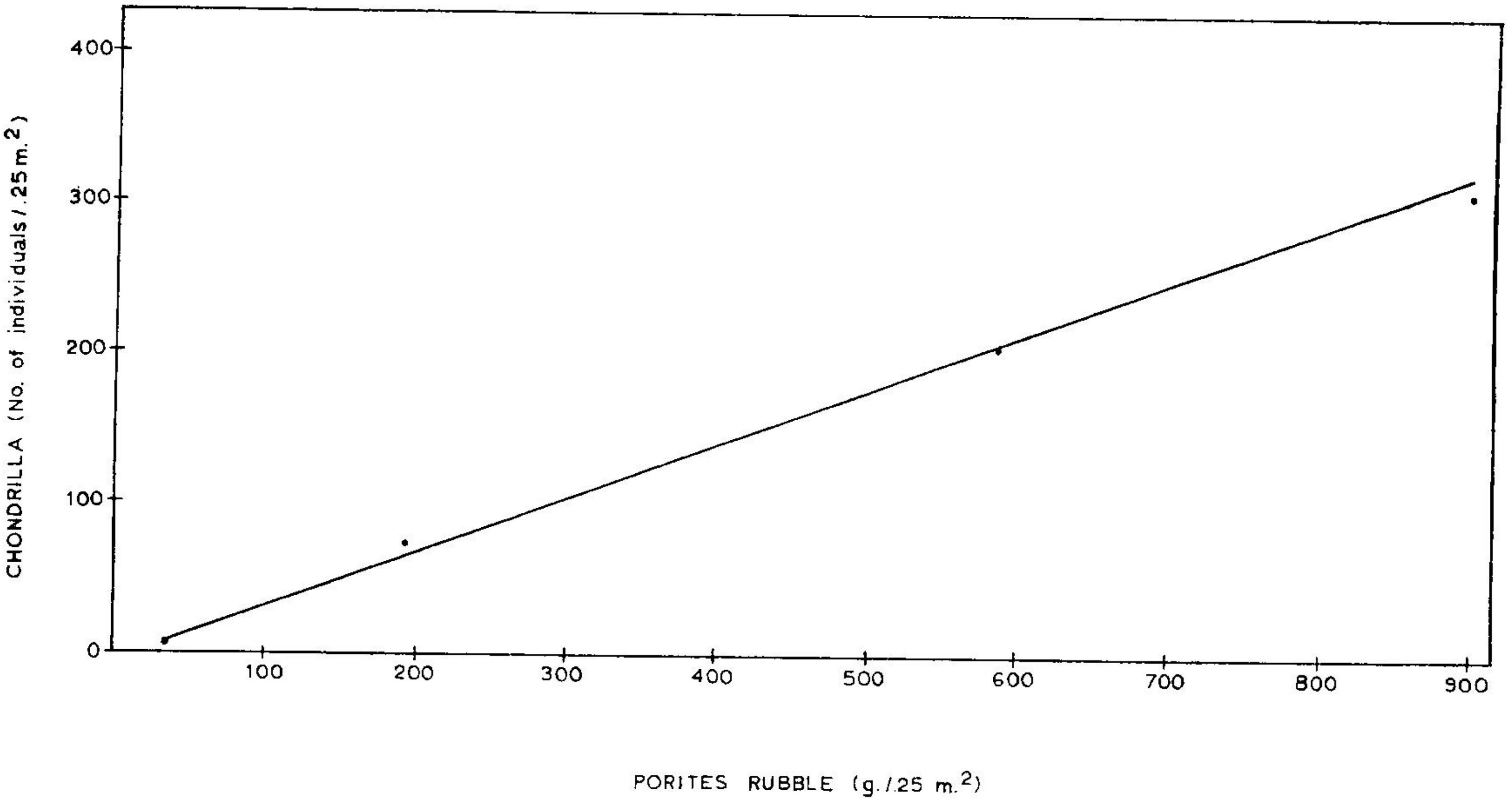


Fig. 13-C. Direct correlation between presence of *Porites* and frequency of *Chondrilla* at Station 8

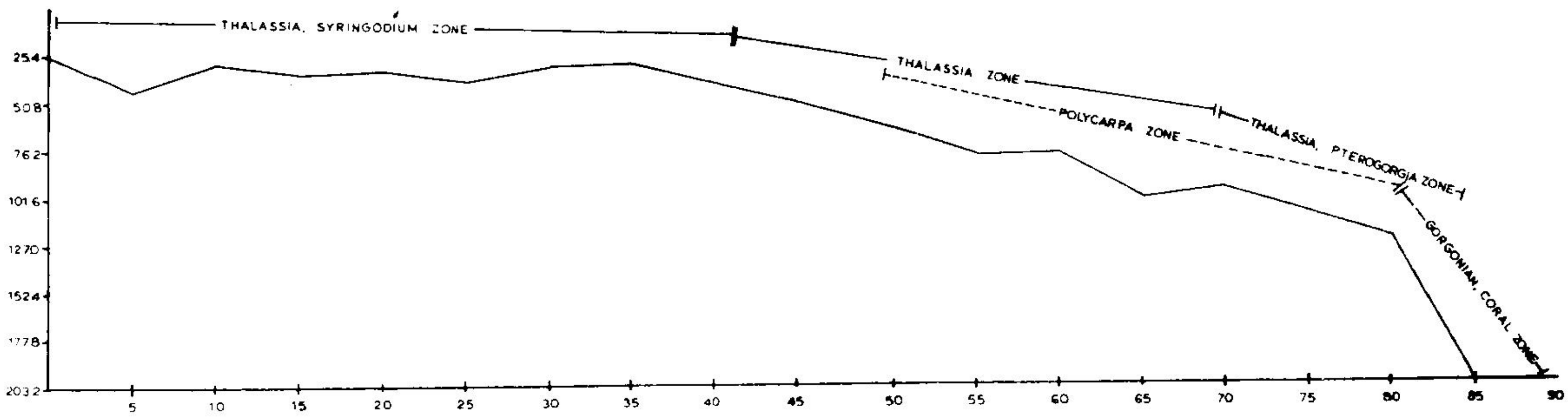


Fig. 14. Vertical profile and zonation pattern at Station X.

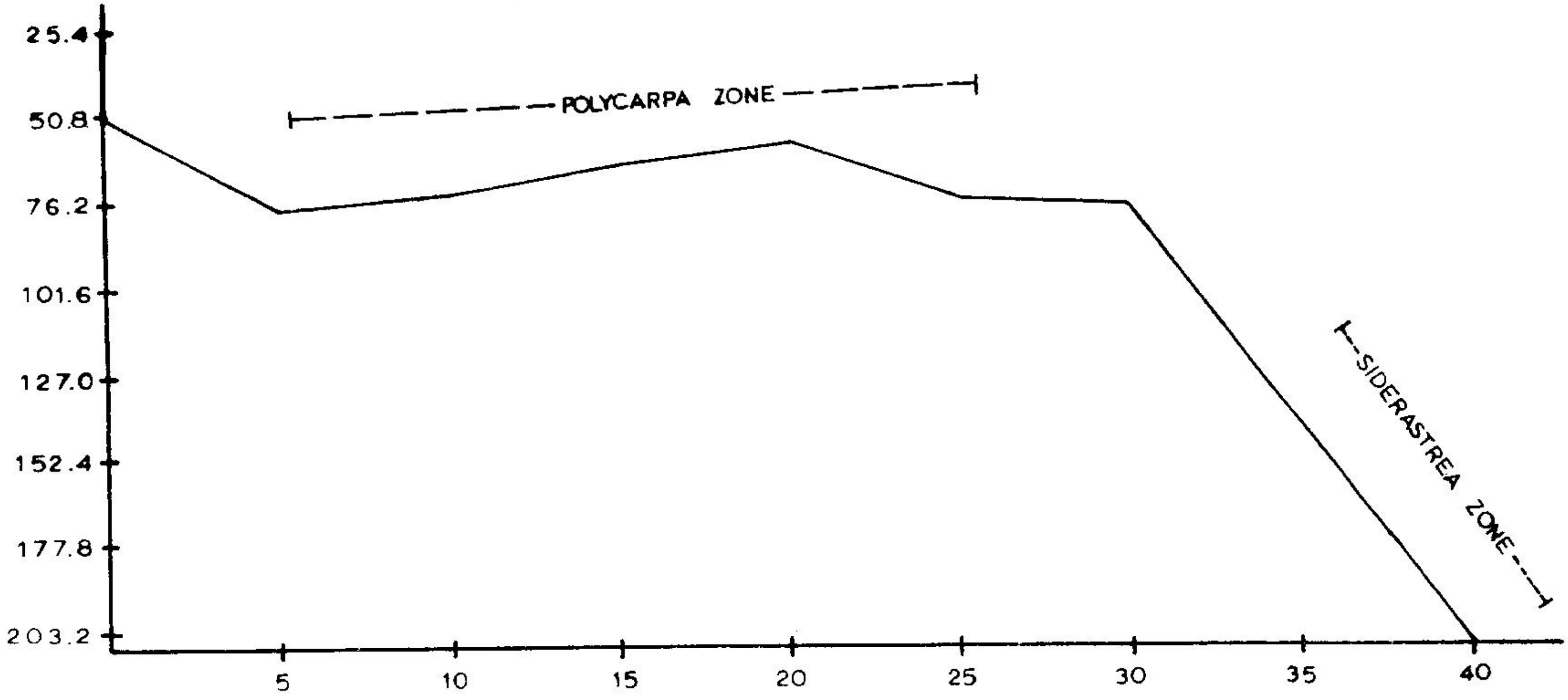


Fig. 15. Vertical profile and zonation pattern at Station IV.

Despite the abundance of Lytechinus inside the bay, the standing crop of Thalassia blades is greater there than it is at the stations outside the bay where Diadema is present. Unlike Diadema, the caged Lytechinus individuals were observed to feed on the upper edges of Thalassia blades, on the sheaths and decaying leaves at the base of the blade, and on the silt deposited on the blades (see Figure 16). This difference in feeding behavior, and possible different rates of consumption, between Lytechinus and Diadema may partially account for the greater standing crop of Thalassia blades in the inner bay.

STATION M 10/22/74

Fig. 16. Grazing pattern of Lytechinus variegatus on Thalassia

MANGROVE ROOT COMMUNITIES IN JOBOS BAY

by

Paul M. Yoshioka

INTRODUCTION

The mangrove root communities of Jobos Bay in Puerto Rico have been studied previously by Kolehmainen (1972). Studies of mangrove root organisms at other locations include those by Goodbody and Gibson (1974), Kolehmainen et al. (1972), McNae (1971), Walsh (1967), McNae and Kalh (1962), Goodbody (1965, 1963, 1962, 1961a, 1961b, 1961) and Mattox (1949). In general, these studies attempted to correlate pre-selected physical and chemical parameters such as temperature, salinity, dissolved oxygen, and pH with the distributional patterns of mangrove root communities.

The present study used the opposite approach. Major distributional patterns were first determined. Then environmental parameters correlating with those patterns were ascertained. By this procedure, environmental parameters could be detected in the order of their relative importance.

Several ecological patterns were examined. When applicable, life history parameters of selected species were recorded. Frank (1968), Murphy (1968), and Hutchinson (1951) have discussed the importance of life history in providing insight into the structure and dynamics of natural communities. Large scale (between station) and small scale (within station) horizontal and vertical distribution patterns of individual species in terms of presence and abundance were investigated. Each of these distributional patterns was examined separately because factors associated with one pattern are not necessarily associated with another. Interspecies or community patterns were studied by comparing faunal and floral associations between the stations to ascertain the presence of community patterns, if any.

The major objective in studying the community aspects of mangrove root organisms was the determination of those factors responsible for community organization and structure. Several studies have indicated the potential importance of biological interactions in determining the ecological outcome of any environmental perturbation. The organization of many natural communities, e.g., terrestrial vegetation (Janzen 1970, Harper 1969), lakes (Zaret 1972, Hall et al. 1970, and Brooks and Dodson 1965), and the marine subtidal (Ogden et al. 1973, Paine and Vadas 1969), has been found to be highly dependent on biological interactions. In such cases the major result of any physical or chemical change, such as thermal pollution, would depend on its secondary or tertiary biological effects.

MATERIALS AND METHODS

Sampling stations are shown in Figure 17. Stations 1 through 5 were sampled in February 1974. Five replicate roots were taken in February and three thereafter.

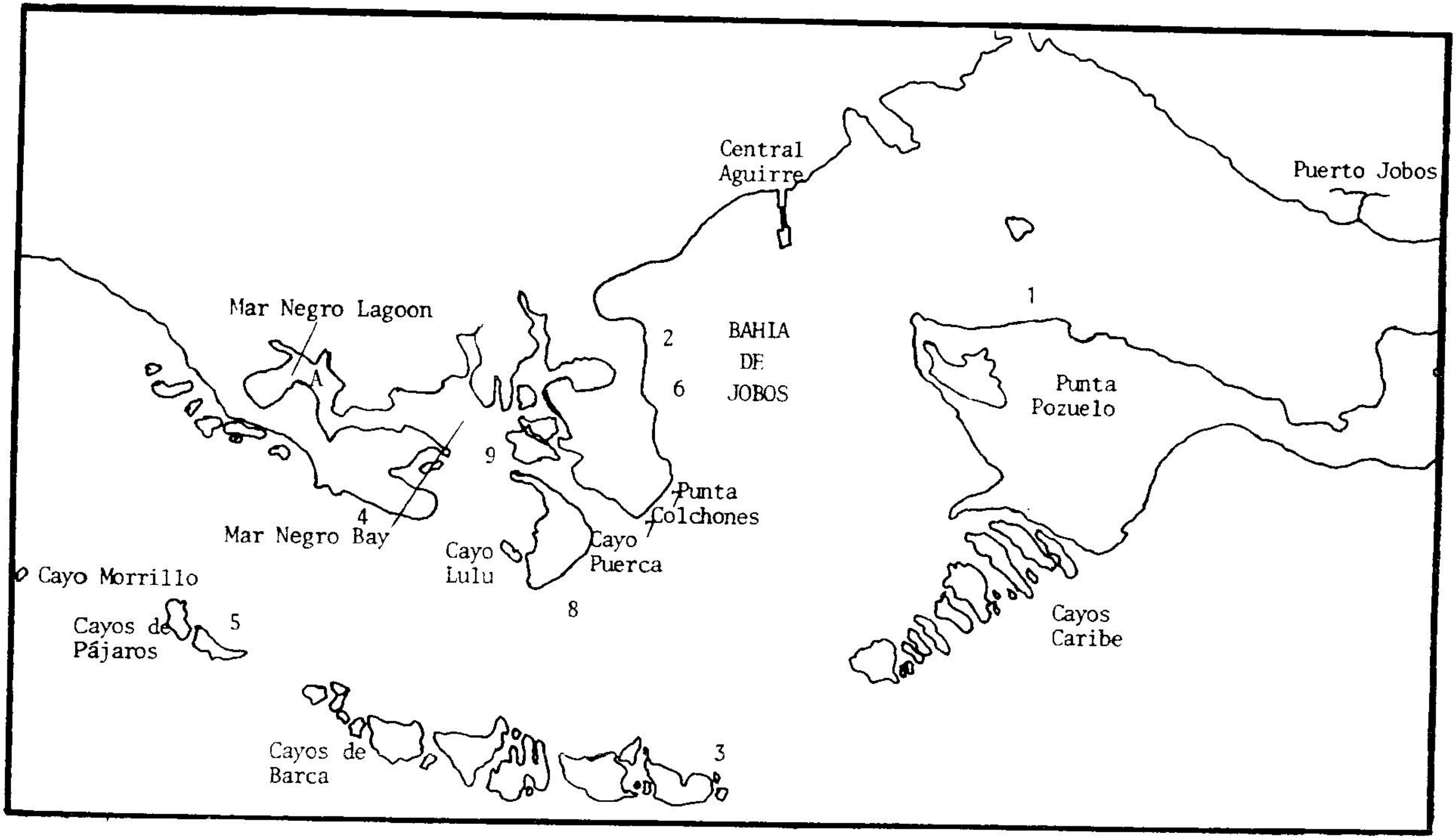


Fig. 17. Mangrove root community sampling stations.

Sampling at Stations 6 through 9 began in April 1974. Sampling was carried out monthly from February to June, and then quarterly. Stations 3 through 8 were dropped in September because their biotas were dissimilar to the most thermally affected site, Station 2. Station 1 was retained as a control station.

Root collection methods were essentially those described by Kolehmainen (1972), but a non-systematic method was used. The use of a plankton net to surround the root immediately prior to sampling to prevent loss of motile organisms was discontinued because the net caught only a few organisms and other sessile ones were frequently knocked off the roots. Consequently, vertical zonation studies were affected. Two or three roots at each station were tagged and monitored visually and photographically on approximately the same schedule as the root sampling.

The roots were examined in 10 cm sections measured approximately from the mean high water level downward to the tip of the root. When applicable, the size frequency distribution of individual species was recorded as well as the size and probable cause of mortality of dead individuals. The biomass of individual species was noted.

RESULTS AND DISCUSSION

Between-station Comparisons: Biomass

Total biomass for each station is shown in Table 11 . Biomass totals for April and May were analyzed by a 2-way ANOVA to test for differences between times and stations. (February was not analyzed due to the unbalanced sampling design.) No significant differences were found in total biomass between the two sampling periods. Control roots, which were visually inspected, showed no major changes in community structure throughout the entire sampling period. The only discernible change observed in the course of the study was the deteriorating condition of the mangroves and the mangrove roots themselves at Station 2. This may have resulted from an oil spill in March 1974 rather than from the thermal effluent.

Biomass totals were significantly different between stations at the 0.05 level (Table 12. To identify the source of this significance, replicates for the two time periods were pooled and the resultant data were analyzed by a Tukey 1-way ANOVA. The biomasses between stations 1 and 9 were not significantly different from each other, but both were significantly greater than the remaining stations. Differences between the other stations were not significant.

Differences in total biomasses between stations must be interpreted with caution because the biota between stations may be quite dissimilar (see following section). It may be significant that Stations 1 and 9 are relatively protected from wave action generated by the predominant southeasterly winds. Goodbody (1961), Weiss (1948), and McDougall (1943) have pointed out that fouling communities similar to those found on mangrove roots in Jobos Bay are often sloughed off the substrate when biomass becomes too high. This process evidently occurs in Jobos Bay as portions of mangrove root communities have been observed on the bottom near mangrove roots. The relatively calm conditions at Stations 1 and 9 may permit a greater buildup of the encrusting community before the sloughing-off process occurs. Thus, biomass totals may be an index of physical disturbance rather than biological processes.

TABLE 11. Total biomass of mangrove root organisms at each station

Station		February	April	May
1	x	147.1	190.9	59.4
	w	(81-203)	(86.15-391.0)	(21.6-126.5)
2	x	135.6	104.7	45.4
	w	(64-208)	(44.5 -189.1)	(47.2-101.0)
3	x	13.7	5.5	5.7
	w	(2.5-27.5)	(0-13.4)	(4.0-9.0)
4	x	183.8	28.8	47.3
		(32-316)	(17.9-37.2)	(3.7-78.0)
5	x	5.9	9.0	2.6
	w	(1.0-12.0)	(4.15-16.35)	(0-4.8)
6	x	non-significant	23.9	29.4
	w		(0-46.5)	(13.6-50.0)
7	x	non-significant	21.7	14.6
	w		(16.0-28.5)	(11.8-16.5)
8	x	non-significant	.9	4.6
	w		(0-2.7)	(1-9.2)
9	x	non-significant	174.7	200.4
	w		(0-464.4)	(113.6-286.8)

TABLE 12. Results from a 2-way ANOVA showing significant differences in biomass between stations and times

	SS	d.f.	MS	F ratio
Between stations	179,996	8	22,499	$F_{8,44} = 3.93$ (p .05)
Between time	5,016	1	5,016	$F_{1,44} = 0.876$ N.S.
Error	251,822	44	5,723	
Total	436,834	53		

Between-station Comparison: Species Groups

Over 180 species have been recorded from the mangrove roots at Jobos Bay (Appendix J). Presence and absence data were used to compare and contrast the biotas at each station. A variation of the contingency table format was used to calculate the expected number of co-occurrences of species between the stations (Table 13). Comparison of this number with the observed number of co-occurrences of species gives an indication of similarities among biotas between stations.

TABLE 13. Observed and expected (observed/expected)* number of species co-occurrences between mangrove root stations

Station	1	2	3	4	5	6	7	8	9
	1	34/21	9/10	14/17.5	15/17	16/11	6/5	3/3	18/12
		2	10/10	13/18	18/18	16/11	5/6	2/3	18/13
			3	12/9	14/8	9/5	8/3	8/2	2/6
				4	19/15	8/9	4/5	6/3	7/11
					5	12/9	5/5	5/3	6/10
						6	6/3	3/2	9/6
							7	6/1	2/3
								8	0/2
									9

* Expected number of co-occurrences = $N_A/N_{total} \times N_B/N_{total} \times N_{total}$

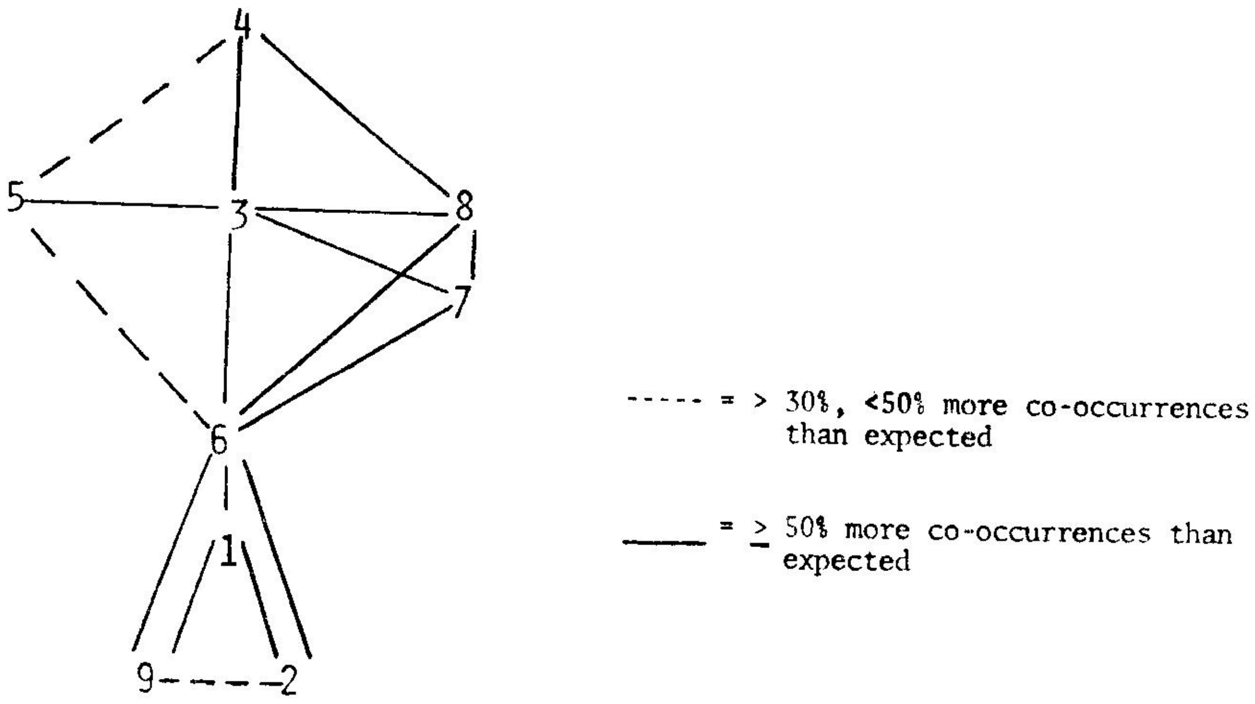
where N_A = number of species at Station A
N_B = number of species at Station B
N_{total} = total number of species at all stations

A schematic representation of similarities between stations is shown in Figure 18. There are apparently two major types of biotic assemblages. The biotas of Stations 1, 2, and 9 are characteristic of bays or estuaries, and those of Stations 3, 4, 5, 7, and 8 are suggestive of coastal conditions (McNae and Kalh 1962, Bousfield 1955, Weiss 1948, and McDougall 1943). The biota at Station 6 is a mixture of both groups.

Hydrographic, or water mass, properties give a proximal explanation for the different community patterns observed. In some instances currents may be responsible for these patterns. However, further investigation is necessary before the importance of these considerations in Jobos Bay can be established.

The communities at the two groups of stations were identified by associations based on presence-absence data. Data providing insight into how the communities are structured in terms of absolute or relative abundance of the component species and their functional roles are discussed in the following sections.

Fig. 18. Similarities of species presences between mangrove root stations.



Between-station Comparisons: Abundances of Selected Species

The barnacles *Chthamalus stellatus*, *Balanus amphitrite*, and *Balanus eburneus* were among the most frequent and abundant species on the mangrove roots. Special attention was given to the barnacles because their relatively high abundances, individual rather than colonial form, and sessile habits make them especially suitable for ecological study.

Chthamalus stellatus occurred at all stations except Station 9, where a single dead individual was found. The largest populations of this species were found at Stations 7, 6, 2, and 8 in decreasing order of abundance (Table 14). The distributional limits of *Chthamalus* in Jobos Bay suggest that it most commonly occurs in areas influenced by coastal waters. Weiss (1948) found a similar pattern in southern Florida.

Differences in *Chthamalus* population sizes among the nine stations for April and May were analyzed by a 2-way ANOVA (Table 15). There were no significant differences between the two sampling periods, although differences between stations were significant at the 0.01 level. a Tukey 1-way ANOVA showed that populations at Stations 7 and 6 were significantly greater than at the other stations. No significant differences were found among the remaining stations. The stations with the highest abundances of *Chthamalus* were located in areas subject to the greatest amount of wind-induced wave action.

TABLE 14. Numbers of *Chthamalus stellatus* per root in Jobos Bay

Station		February	April	May
1	x	51.6	39.0	43.0
	w	(2-100)	(16-78)	(20-57)
2	x	97.4	201.0	117.3
	w	(56-189)	(32-370)	(32-250)
3	x	91.2	165.7	38.0
	w	(20-194)	(5-374)	(0-76)
4	x	6.6	46.7	5.0
	w	(0-24)	(0-140)	(0-15)
5	x	126.6	51.7	134.7
	w	(2-232)	(25-168)	(50-184)
6	x	not sampled	410.5	404.3
	w		(247-574)	(25-770)
7	x	not sampled	569.0	261.3
	w		(379-904)	(170-336)
8	x	not sampled	86.0	217.5
	w		(3-139)	(156-279)
9	x	not sampled	0	0
	w		0	0

TABLE 15. Results from a 2-way ANOVA of the population densities of *Chthamalus stellatus*

	SS	d.f.	m.s.	F ratio	p
Between times	13,636	1	13,636	0.55	n-s
Between stations	1,141,430	8	142,678	5.76	.01
Error	1,089,166	44	24,753		
Total	2,244,232	53			

Balanus amphitrite and *B. eburneus* occurred in much lower numbers than *Chthamalus*. Their distributions appear to be restricted to embayment-type waters (Tables 16 and 17). Similar patterns of occurrence for *Balanus* have been noted by Weiss (1948) and Darwin (1854). No significant changes in population sizes were noted between the April and May sampling periods.

TABLE 16. Numbers of *Balanus amphitrite*/root (x = mean, w = range)

Station		February	April	May
1	x	59.2	13.0	41.3
	w	(0-158)	(9-18)	(10-98)
2	x	236.2	20.0	46.8
	w	(104-358)	(6-34)	(25-86)
3	x	0	0	0
	w	0	0	0
4	x	0	0	0
	w	0	0	0
5	x	0	0	0
	w	0	0	0
6	x	non-significant	62.0	22.0
	w		(12-112)	(0-58)
7	x	non-significant	18.0	8.3
	w		(2-26)	(6-13)
8	x	non-significant	0	0
	w		0	0
9	x	non-significant	3.5	0.3
	w		(2-5)	(0-1)

B. amphitrite and *B. eburneus* had a negative correlation in abundances at Stations 6, 2, 1, and 9 where they both occurred ($p = .05$, Fisher Randomization Test, 1-tailed). The highest abundance of *B. amphitrite* was found at Station 6 (42 barnacles/root) and the lowest at Station 9 (1.9 barnacles/root). *B. eburneus* was most abundant at Station 9 (45 barnacles/root) and least abundant at Station 6 (0.4 barnacles/root). These stations evidently follow a hydrographic gradient from Station 9 (most sheltered) to Stations 1, 2, and 6 (most coastally influenced). To verify these trends, three mangrove roots were sampled in a very sheltered channel near Mar Negro Lagoon (Station A) in February 1975. An average of 43 *B. eburneus* (range 23-60) and 1.7 *B. amphitrite* (range 0-3) were found per root.

TABLE 17. Numbers of Balanus eburneus/root (x = mean, w = range)

Station		February	April	May
1	x	9.4	5.3	4.3
	w	(0-17)	(0-13)	(3-6)
2	x	6.0	2.0	1.7
	w	(4-9)	(0-4)	(0-3)
3	x	0	0	0
	w	0	0	0
4	x	0	0	0
	w	0	0	0
5	x	0	0	0
	w	0	0	0
6	x	non-significant	0*	0.7
	w		0	(0-2)
7	x	non-significant	0	0
	w		0	0
8	x	non-significant	0	0
	w		0	0
9	x	non-significant	84.0	7.0
	w		(59-109)	(1-13)

* dead barnacles present

Within-station Comparisons: Absolute and Relative Abundances

Several community and species population characteristics were examined among replicate roots at the mangrove stations. Total biomass (Table 11), biomass of individual species, and numbers of individuals were analyzed (Tables 14,16&17). The amount of variability associated with each characteristic was considered too large to be of value in monitoring changes in the mangrove root community or its component populations. The number of samples required to lower the confidence limits of the means to an acceptable level would have entailed removing a large part of the mangrove roots.

Community structure was analyzed by examining the relative abundances (in grams wet weight) of the component species in the February samples. No significant concordance was found at any of the stations. The presence of colonial organisms made precise calculation of diversity, in terms of number of individuals, difficult, and biomass, numbers, and relative abundances showed high variability between replicate roots. Diversity indices derived from these parameters would be highly biased by sampling variability. Consequently, diversity indices were not calculated.

Within-station Comparisons: Field Experiments

Field experiments were conducted at Stations 1 and 9 to identify some of the sources of variability in mangrove root community parameters. The effects of local position, predation, and time on mangrove root communities were studied.

It was observed that the roots closest to shore often had lower population densities of barnacles. To test the effect of inshore-offshore position on barnacle populations, four aerial roots were placed in a line perpendicular to shore at both stations. The distance between the most offshore and most inshore roots was 2 meters. When sampled one month later, the highest population of barnacles occurred on the root furthest offshore and the lowest population on the root closest inshore at Station 1 (p = .05 Fisher Randomization Test, Table 18). A similar but non-significant trend was found on the three inshore roots at Station 9. At both stations recruitment of barnacles was dependent on local position.

TABLE 18. The effect of local position on the recruitment of *Balanus* (30 August 1974 - 27 September 1974)

			STATION 1		
Inshore					Offshore
Root		#1	#2	#3	#4
Barnacles/ root	(live)	304	760	1212	2228
	(dead)	30	282	571	1082
Total		334	942	1783	3310
			STATION 9		
Root		#1	#2	#3	#4
Barnacles/	(live)	288	768	992	0
root	(dead)	1376	2073	2336	936
Total		1664	2846	3328	936

The newly settled recruits could not be distinguished between *B. amphitrite* and *B. eburneus*, but the vast majority (>95%) of the older individuals were *B. amphitrite*. For those individuals identified as *B. eburneus* the same general trends, i.e., higher densities on the offshore roots and higher densities and mortality rates at Station 9, were observed. Lower mortality rates were observed for *B. eburneus* than for *B. amphitrite* of comparable size.

In the artificial root experiment the unexpected effect of predation on barnacle populations was noted. Substantial portions of the population were dead (10 to 100%). Low numbers of organisms capable of smothering barnacles on these roots indicate that predation may have been the cause of mortality. At both stations higher percentages of dead individuals were found with increasing distance from shore. A much higher rate of mortality was found at Station 9 than at Station 1.

Field observations indicated that predator-associated mortality plays an important role in determining the presence and abundance of various species on mangrove roots. In the vicinity of Station 9 the highest abundances of the oyster *Crassostrea rhizophorae* were observed either on partially submerged roots or on branches which grazed the water surface. About 20% of the dead oysters sampled had been drilled, probably by *Murex brevifrons*. Evidently, those *Crassostrea* individuals on branches or on roots not in contact with the bottom substrate had been enjoying a refuge from predation by *Murex*.

To test the general applicability of this phenomenon, several pairs of roots were placed in the substrate or suspended off the bottom at Station 1: Results of the first pair of roots retrieved after a month's submergence are given in Table 19. The two *Balanus* species comprised the major part of the community. Most of those individuals which could be identified were *B. amphitrite*.

TABLE 19. Effect of root position on predator-associated mortality (16 September 1974 - 23 October 1974)

	Root suspended off bottom		
	Number of *Balanus*		
Depth (cm)	Live	Dead	Dead/Live
0-10	78	4	.05
10-20	336	208	.62
20-30	160	220	1.37
30-40	120	100	.83
	694	537	.76
	Root in contact with bottom		
0-10	76	328	4.32
10-20	260	248	.95
20-30	244	240	.98
30-50	20	372	18.6
	600	1188	1.95

About 66% of the barnalces on the root touching the bottom were dead compared to 43% on the root tied off the bottom. This difference was significant at the 0.01 level (Chart 4, Tate and Clelland 1959).

The artificial roots retrieved after a month's interval displayed many of the features described in the literature. Among the species observed were the three barnacles *B. eburneus*, *B. amphitrite*, and *Chthamalus stellatus*; the oyster *Crassostrea rhizophorae*; and the colonial ascidian *Botrylloides*. Roots retrieved in December 1974 and February 1975 confirmed the colonizing strategy of *Balanus*. A total of 28 live *Balanus* were found in the December sample and none in the February sample (Table 20).

TABLE 20. Number of *Balanus* on mangrove roots after various intervals of submergence. Roots set out 16 September 1974.

Date retrieved	Root on bottom		Root off bottom	
	Live	Dead	Live	Dead
23 Oct 1974	600	1188	694	532
12 Dec 1974	26	568	2	264
13 Feb 1975	0	31	0	38

Several features of the mangrove root communities appear to be related to developmental or successional changes. Mattox (1949) observed that the oyster *Crassostrea rhizophorae* is among the first colonizers on newly submerged roots. Other life history parameters characteristic of colonizing or fugitive species (Hutchinson 1951) can be applied to *Crassostrea*. *C. rhizophorae* matures three to four months after settling and reaches marketable commercial size (>50 mm) after four to five months. These life history parameters enable *Crassostrea* to settle, grow, and reproduce before succumbing to competition or predation.

Several other species found on mangrove roots have similar life traits. McDougall (1943) notes that *Balanus eburneus* reaches sexual maturity after only two months and that an even shorter period may be required for *Balanus amphitrite* and *Chthamalus stellatus*. Goodbody (1974, 1965, 1963, 1962), in a series of papers on *Ascidia negra*, notes that this species is among the primary colonizers on newly opened substrate space. Sponges and other ascidians appear later and seem to be the dominant forms in mature communities.

Within-root Comparisons: Vertical Distribution

The four species examined in detail, *Crassostrea rhizophorae*, *Chthamalus stellatus*, *Balanus amphitrite*, and *Balanus eburneus*, displayed definite vertical patterns of distribution. The highest numbers of *Chthamalus* and *Crassostrea* occurred in the intertidal regions (0-10 cm) of the roots (Table 21). Similar patterns for *Crassostrea* have been noted by Kolehmainen (1972) and Mattox (1949) and for *Chthamalus* by Connell (1961), Weiss (1948) and McDougall (1943). Peak densities for Balanus amphitrite occurred slightly lower (10-30 cm), and Balanus eburneus (except at Station 9) occurred at the lowest levels (20-40 cm). McDougall (1949) and Weiss (1948) have reported similar distribution patterns for Balanus. Ascidians, sponges, and the bryozoan Schizoporella were usually found on the subtidal portions of the roots.

TABLE 21. Vertical distribution of Crassostrea, Chthamalus, B. amphitrite, and B. eburneus on mangrove roots

Depth	Crassostrea		Chthamalus		B. amphitrite		B. eburneus		B. eburneus*	
(cm)	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead
0-10	2.3	1.0	81.5	9.1	2.9	3.3	0.26	0.02	7.8	4.0
10-20	2.0	1.0	50.3	14.5	14.4	21.7	0.61	1.5	16.0	15.0
20-30	0	0	6.2	4.2	13.2	16.3	1.1	1.0		
30-40	0	0	0.3	0.7	9.8	16.6	0.87	1.0	9.0	7.0
40-50	0	0	0	0	4.5	7.6	0.41	0.41		

Chthamalus averages: Stations 1-5 in February and
1-8 in April and May.
Crassostrea and B. amphitrite averages:
Stations 1 and 2 in February
Stations 1,2,6,7, and 9 in April and May.
B. eburneus averages: Stations 1 and 2 in February
Stations 1,2,6 and 7 in April and May.
*B. eburneus averages: Station 9 in April and May.

The vertical distribution patterns of Crassostrea and the three barnacles are probably due to the settling behavior of their planktonic larvae, based on the vertical distribution patterns on the artificial roots (Table 19). Connell (1961), Mattox (1949), Weiss (1948), and McDougall (1943) have reported similar patterns for larval settlement. The choice of a settling site can be interpreted in terms of natural selective forces favoring the greatest reproduction of the population at that site. For instance, if the survival and reproduction of Chthamalus is optimized in the upper 10 cm of the root, then selective forces should favor larval settlement in that area.

Physiological factors play an important role in determining these selective forces. Connell (1961) and Weiss (1948) found that physiological factors such as desiccation are responsible for the upper distributional limits of Chthamalus. Physiological tolerances, however, do not account for the lower distribution limits of Chthamalus. In fact, Chthamalus grows faster if constantly submerged (McDougall 1943) as does Crassostrea (K.W. Watters, personal communication).

Connell (1961) found the lower distributional limit of *Chthamalus* to be determined by competition for space by *Balanus* and predation by the gastropod *Thais*. The higher proportion of dead *Chthamalus* with increasing depth (Table 21) suggests that predation is important in determining the species' lower vertical limit on mangrove roots. Predation by *Murex* may similarly determine the lower distributional limits of *Crassostrea*.

The lower distribution limits of *B. amphitrite* and *B. eburneus* may be similarly determined. One cause of mortality of these barnacles is smothering. Occasionally *Balanus* with scuta and terga still intact have been found covered by the bryozoan *Schizoporella*, indicating that the barnacles were smothered alive. *Schizoporella*, when found, usually occurred on the lower portions of roots. Weiss (1948) and McDougall (1943), working with settling plates, both noted that greater proportions of dead *B. amphitrite* and *B. eburneus* were found near their lower distribution limits, but no consistent pattern of mortality with depth could be discerned in the mangrove samples from Jobos Bay (Table 21). However, depth-associated mortality patterns were evident on the artificial roots (Table 19), indicating that this phenomenon is most apparent during the initial colonizing.

An interesting deviation from the observed vertical distribution patterns occurred at Station 9 where the highest densities of *B. eburneus* were found in the upper 20 cm of the mangrove roots (Table 21). The artificial roots indicated that the cyprids settled subtidally, but with increased competition and predation at Station 9 all except the uppermost *B. eburneus* may eventually have been killed. Because of its larger size, *B. eburneus* is probably more resistant than *B. amphitrite* to competition and predation. McDougall (1943) found that smothering occurred only with barnacles less than 1 cm in basal diameter. Over 80% of the *B. eburneus* found at Station 9 and in the Mar Negro area were larger than this size. *B. cariosus* on the west coast of the United States is relatively immune from predation because of its large size (Dayton 1971).

SUMMARY AND CONCLUSIONS

Based on the presence and absence of species, at least two major types of mangrove root communities exist in Jobos Bay. One community, occurring mainly along the Aguirre Ship Channel, is composed of species characteristic of coastal waters. Another occurring in Jobos Bay and in mangrove channels in the vicinity of Mar Negro Lagoon is characterized by embayment species. Water mass is the best single parameter which correlates with the different communities. The exact nature of the causal mechanisms associated with hydrographic properties responsible for the maintenance of the communities is largely unknown.

At any given location, interspecific ecological interactions play an important role in the organization of the mangrove root community. This is most graphically illustrated by examining mechanisms which may maintain species diversity of mangrove root communities despite the tendency for the competitive and predatory exclusion of many species. Currently there are two widely accepted mechanisms by which species diversity can be maintained. Competitive interactions may be alleviated by partitioning the limiting resource(s) among the potentially competing species. Schoener (1974) gives examples of resource partitioning in several natural communities. The different vertical depth distributions of the three barnacle species in Jobos Bay can be interpreted as a mechanism by which the limited substrate is partitioned among those species. However, it is important to note that predation and probably competition are also involved in maintaining depth distribution. It has also been suggested that competitive interactions and predation are important factors in community organization. Competitive exclusion does not occur, because predation limits the populations of the competing species to the extent that no resource becomes limiting. Paine is a leading exponent of this view. The maintenance of species diversity by predation is most easily demonstrated in those cases where the predator selects the competitive dominant species, thereby insuring the persistence of competitive inferior species.

Predation evidently plays a completely different role in Jobos Bay. The species suffering the greatest mortality from predation, the oyster Crassostrea and the three barnacle species, are also competitive inferior species which would probably be excluded by competitive processes eventually. Thus, predation lowers rather than maintains or increases species diversity in Jobos.

Species diversity in the case of mangrove root communities is best explained in terms of successional (developmental) events and physical disturbance. Many species found on mangrove roots have life history attributes of colonizing species. The continual recruitment of new roots provides the new substrate space required for the persistence of these species. Because later additions to the mangrove root communities grow over dead individuals of colonizing species, the entire community is inherently unstable. Given enough time, biomass, and physical disturbance, the community will eventually fall off the root. With the sloughing off of the more mature communities, the developmental sequence of the community could be maintained on a single root. However, Goodbody (1961) gives evidence that the initial colonizing sequence may be suppressed in such cases.

Several tentative predictions on the effects of thermal pollution on mangrove root communities can be made on the basis of the ecological studies completed thus far. Predation and possibly competition are of great importance in the organization of the root communities. Predatory and competitive interactions are also important in the developmental changes occurring in this community. The effect of elevated temperatures which differentially affect different species populations will be manifested through these interactions.

In general, subtidal species are more susceptible to elevated temperatures than intertidal species and consequently will be the first affected. Because most of the predators and competitors are subtidal, the predation and competition which limit populations may be cut back. The effect will first be seen in increased populations of barnacles, because they are severely limited by predation and competition but are physiologically quite tolerant. The intertidal species should flourish (on a relative basis) and their vertical distributions should be extended downward. The results obtained by Kolehmainen (1972) in the thermally affected parts of Guayanilla Bay can be interpreted on these grounds.

These effects are only primary. Many species which would do best in thermally altered situations are colonizing or fugitive species. It is unknown whether such an assemblage could persist with continued recruitment and growth of new individuals. The dominance of these colonizing or fugitive species may be only temporary, however, because blue-green algae are tolerant of elevated temperatures and have a negative effect on barnacle recruitment and growth (Fager 1971, Weiss 1948, and McDougall 1943). Consequently, blue-green algae may eventually dominate thermally affected mangrove roots.

DIVERSITY, SEASONAL DISTRIBUTION, AND FEEDING ECOLOGY OF THE FISHES OF JOBOS BAY

by

F. Douglas Martin

INTRODUCTION

The primary purpose of these studies has been to furnish a scientific baseline for further studies in order to evaluate the effects of power plant operations in the Jobos Bay area.

Jobos Bay is a bay rather than an estuary. Bays and estuaries are fundamentally different. Estuaries tend to have low diversity and simple food webs; they serve as nursery grounds for juvenile fish and crustaceans; and are quite unstable (Odum 1970, Caspers 1967). Jobos Bay is a shallow, tropical, semi-enclosed bay with high diversity and complex food webs. It serves an apparently limited role as a nursery. The bay does not receive appreciable amounts of fresh water and its salinities are basically those of the surrounding Caribbean Sea.

Jobos Bay is located on the south coast of Puerto Rico, 45 kilometers east of Ponce between Salinas and Guayama. Puerto de Jobos and Aguirre are located on the bay. Both villages dump raw sewage into the adjacent waters. The inner bay receives the sewage of Puerto de Jobos and is shallow so that wave surge keeps the water turbid. Most of the shoreline of the inner bay is densely covered with mangroves. The red mangrove, *Rhizophora mangle*, predominates (PRWRA 1972). The reef and cay areas are fringed with, or completely covered by, red mangroves. From Punta Colchones westward the Bahai de Cayo Puerca complex and ship channel shoreline contain the largest extant stands of mangroves on the south coast of Puerto Rico, and the second largest on the island. There are 542.3 hectares of mangrove swamp in the entire Jobos Bay area (PRWRA 1972).

Until 1972, Central Aguirre, a sugar cane processing plant, allowed its wastes, primarily bagasse, to enter the Bahia de Cayo Puerca complex. Lesser but significant quantities were dumped into the central bay. Oil and molasses spills have occurred, also. These have caused stresses from which the bay has not yet fully recovered.

Figure 19 shows a map of Jobos Bay divided into the functional subunits which were used for data analysis of this study.

MATERIALS AND METHODS

The environment in Jobos Bay is "spotty." Therefore, sampling areas such as coral rubble and *Thalassia* beds were chosen for random sampling. Fish toxin (Pronoxfish), nylon monofilament gill nets (1.3cm, 1.9cm, 2.5cm, 3.8cm, 5.1cm, 6.4cm, and 8.9cm square mesh)

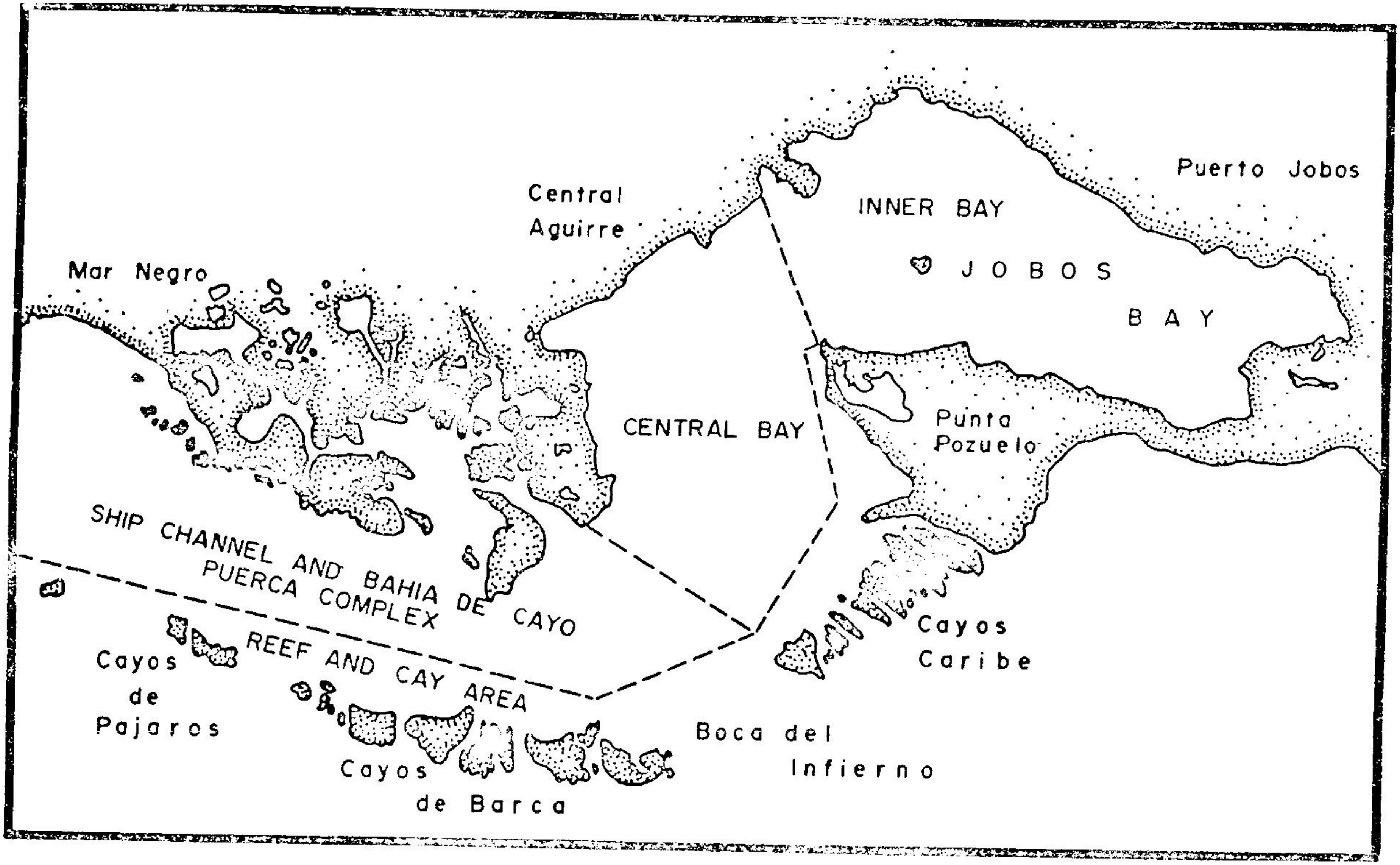


Fig. 19. Functional subunits of Jobos Bay used for data analysis.

and seine nets were used for collecting fish. Trammel nets were introduced late in 1974 to check the efficiency of the gill nets. No significant differences were found between the two methods. Poison stations were established by surrounding 8 or 10 m^2 areas with a 0.6cm mesh seine for semi-quantitative sampling. Captured fish were placed on ice and frozen as soon as possible. In the laboratory they were thawed, identified, counted, and weighed.

Shannan-Weaver species diversity indices were estimated by using the calculation methods of Lloyd, Zar and Karr (1968). Similarity indices were calculated according to Sorenson (1948). Statistical analyses were made with a Digital Corporation PDP-10 computer. The association analysis methods of Williams and Lambert (1960) was used to define "critical species," that is, species which have highest positive or negative associations with other species in the samples. This method was applied only to species taken in ten or more collections.

RESULTS AND DISCUSSION

Pielou (1966, 1969), Emlen (1973) and Lloyd et al. (1968) discuss species diversity and its theoretical implications. It has been assumed that higher diversity indicates greater stability. Jobos Bay has a fairly high diversity. Martin (1972a) reported values of 107 species/thousand for the reef and cay areas. Table 22 gives the H' values for Jobos Bay where this value ranges from 3.852 to 5.309.

TABLE 22. Shannon-Weaver estimate of diversity calculated using $\log_2$

Area	H' value
Inner bay	3.852
Central bay	5.122
Reef and cay	5.309
Ship channel and Bahia de Cayo Puerca complex	4.813
Outfall	4.024

A list of species taken in Jobos Bay and the distribution of all species taken in ten or more collections is found in Appendix K. Table 23 below summarized the species data and compares the same data from Guayanilla Bay.

TABLE 23. Number of species by subareas

Jobos Bay	Number	Guayanilla Bay	Number
Reef and cay	148	Reef	53
Inner bay	26	Inner bay	53
Central bay	70	Thermal cove	28
Ship channel	85		

Seasonal Distribution

It appears that there is no seasonal distribution effect in the reef and cay areas. In the inner and central bays the only species showing a seasonal distribution pattern is the sea bream, Archozargus rhomboidalis, which was not taken in the fall. In contrast to these two areas, the ship channel-Bahia de Cayo Puerca complex has a fairly large number of species which show seasonal variations in distributional patterns. The factors influencing these patterns are unknown. The summer absence patterns may be artifacts of the sample size, but the other seasons were sampled twice and winter absence patterns appear to be present. There does not seem to be a correlation between gonadal development and these patterns.

Gross distribution of fishes is usually related to food and shelter resources. Sale (1971, 1972), Low (1971), Bardach (1950), and Smith and Tyler (1971) all indicate that the majority of reef fishes are territorial and suitable space may be a limiting factor in population size, density and distribution. Territorial species would not be expected to shift distributional patterns unless their habitats changed. Most of the species taken in the central bay are territorial, also, although they are not reef dwellers. This may explain the lack of seasonal variation in this area.

Diapterus rhombeus is a "critical species" in a large area of the bay, primarily around the Bahia de Cayo Puerca complex and in the area around Punta Pozuelo and Mata Redonda. The different areas of Jobos Bay show differences in their species compositions and in the characteristics of seasonal distribution patterns. Appendix L lists seasonal occurrence of species taken in two or more collections.

Breeding

Breeding in tropical marine fishes usually takes place over a long period of time. Peaks frequently are not well defined (Marshall 1966).

Juveniles. Juvenile fishes showed four peaks of abundance. The March 1972 peak was composed mainly of parrotfish (Sparisoma spp.); the October 1972 peak of grunts (Haemulon spp.); and the April 1973 peak of morays (Gymnothorax funebris and G. vicinus). The October 1972 grunt peak was noted from fishes captured from one rotenone station established over a clump of spiny sea urchins (Diadema antillarum). It was observed that large aggregations of juvenile grunts in mixed species schools frequently seek protection from predators among the spines of Diadema. The July 1972 peak had no dominant group or species.

Adults. For adults in spawning condition there were five peaks: June and July 1972, February and March 1973, and December 1971 and 1972. The June and July peaks consisted primarily of the live bearing brotulid Ogilbia sp. The February 1973 peak was dominated by a large collection of onespot live bearers, Poecilia vivipara, from Mar Negro. Poecillids are perennial breeders as long as the water is above a minimum temperature and a suitable habitat, in this instance a semi-isolated, very shallow black mangrove slough, is found. Almost all females are pregnant at any given time. The March 1973 peak consisted mostly of thread herring, Opisthonema oglinum. The December peaks in 1971 and 1972 had no single dominant species and may represent a real increase in spawning by many species in the bay. These data should not be construed as indicating seasonality, however.

Almost all individuals in all collections showed mature gonads. Collections in February and April contained large numbers of individuals with mature or maturing gonads.

No notable peaks were evident in 1972 in the slow, prolonged breeding period of the thread herring. However, 1973 showed a considerable increase in breeding numbers. Talbot (1960), reporting on snappers in East Africa, and Martin (1972) reporting on Cyprinodon variegatus in Texas, have both suggested that breeding cues depend on salinity reduction from rain and subsequent runoff. As Puerto Rico had drought conditions for much of the period from November 1972 to June 1973, this suggestion seems valid.

Nursery Areas

No intensely used nursery areas have been located in Jobos Bay. Juvenile fishes were taken in large concentrations only in the cases mentioned above. Thread herring were segregated into groups based on size with the smallest individuals found in the channel leading back to Mar Negro, and the largest (about four or five times heavier than the smallest) found in the area around Cayos de Barca and Cayos de Pajaros. Even the smallest individuals were mature. The smallest individual taken in Mar Negro Channel, weighing less than 6 grams, had mature eggs in its ovaries. Either the thread herring in the Mar Negro area are a different, smaller population, or first year fish live there and migrate out to less sheltered waters as they get older and larger.

Feeding Ecology

A comprehensive food web for a tropical aquatic system has been prepared for a Hawaiian estuary (Walsh 1967). The webs involved few species and were from a true estuary where fresh water dominated. Jobos Bay represents a very different and complex system.

Food Web Diagrams. Because of the distinctiveness of the faunas, separate webs were constructed for the different areas of Jobos Bay: inner and central bay together; reef and cay area; ship channel and Bahia de Cayo Puerca complex. Food web diagrams are found in the Jobos Bay Annual Environment Report, Volume I (March, 1975). For implications of this complex food web for heavy metals accumulation, see Canoy (1972).

Complexity of food webs, coupled with evenness of energy flow, leads to community stability (MacArthur 1955). On the whole, the food webs for the combined inner and central bays are less complex than for either the reef and cay areas or the Bahia de Cayo Puerca and ship channel areas. These are not greatly different in complexity, but the reef and cay areas have a greater evenness of flow than does the ship channe .

Feeding habits. Individuals used for these studies were adults or large subadult juveniles. Small juveniles frequently have feeding habits that differ from adult patterns (Bellinger and Avault 1971). Austin and Austin (1971) list feeding habits for juveniles in a number of species found in mangrove areas in western Puerto Rico. Randall (1967) has reported the feeding habits of Caribbean reef fishes. Randall's findings correlate with the findings of this study.

Stomach content analyses of fishes indicated that food items of terrestrial origin are more common in the inner bay and the Bahia de Cayo Puerca complex than in the reef and cay areas. It is unusual to find fresh water nymphs in brackish water and unlikely that they would be found in sea water (Green 1969). Parrish (1974) found a surface salinity of 39 $^{0}/oo$ in the area where these fish were taken indicating that they had moved some distance to low salinity brackish or fresh water in order to capture the nymphs. A small barracuda was captured in the Mar Negro Channel near Bahia de Cayo Puerca in November 1972. This individual had two Rivulus marmoratus in its stomach. Since the only definitely known population of Rivulus is in Mar Negro proper, a distance of more than 1 kilometer by water, it is possible that barracudas also move about considerably while foraging for food.

For distributions of all species taken in ten or more collections in Jobos Bay, please refer to the Puerto Rico Nuclear Center Jobos Bay Annual Environmental Report, 1975 as follows:

1. Seasonal Distributions of Fishes, Figures 2 through 48, pages 112-158,
2. Critical Species, Figures 49 and 50, pages 159 and 160, and
3. for visual delineation of food webs, see Food Webs, Figures 54 through 78, pages 165-189.

AN ESTIMATE OF ENTRAINMENT OF FISH EGGS IN A COOLING-WATER CONDENSER SYSTEM IN JOBOS BAY, PUERTO RICO

by

K.W. Watters

INTRODUCTION

A side effect of using once-through cooling water in a condenser system for power generation is entrainment of organisms in the water. Research investigations at Guayanilla Bay, Puerto Rico, in the winter and spring of 1971-1972, showed that there is virtually no survival following passage of zooplankters through the condensers of an operating power plant (Kohlemainen, 1972).

One of the concerns of siting power generating facilities at Jobos Bay has been the possibility of entrainment and subsequent destruction of significant quantities of fish eggs and larvae. If Jobos Bay is an important nursery area for many species of fish, then entrainment would cause large-scale destruction of this important resource.

The purpose of this study has been to examine this possibility and to discuss whether the bay might be an important nursery area for fish, and the magnitude of fish egg mortality that might be expected as a result of operating two 460 MW fossil fuel plants.

DISCUSSION

Fish Collections

From September 1971 to March 1973, bi-monthly collections of fish were made in Jobos Bay, using gill netting and rotenone methods. A total of 3503 fish was collected and 190 species identified for all areas of Jobos Bay (Jobos Bay Annual Report, 1972).

Fish considered in an assessment of entrainment damage to a nursery area should meet two criteria: they should have pelagic eggs, as demersal eggs are not subject to entrainment, and they should be "resident" species whose eggs and/or juveniles are present in significant numbers. Seventeen of the 190 species taken in this series had pelagic eggs and/or showed evidence of spawning (Table 1), or were collected as juveniles. For this study, "resident" was defined as any species taken ten or more times. As can be seen in Table 24, 235 of 1240 fish, or approximately 19% of those taken in this group, were juveniles, and 50 fish, or approximately 4%, showed some evidence of spawning.

TABLE 24. Resident fish species of Jobos Bay with pelagic eggs.

Species	Numbers of Fish Taken		
	Total	Evidence of Spawning	Juveniles
Chloroscombrus chrysurus	63	2	[illegible]
Haemulon flavolineatum	158	0	48
H. plumieri	31	1	8
H. sciurus	60	0	1
Lagodon rhomboides	36	5	4
Lutjanus griseus	59	0	12
Lutjanus synagris	18	0	2
Ocyurus chrysurus	28	0	11
Ophioscion adustus	28	14	[illegible]
Polydactylus virginicus	32	17	[illegible]
Scomberomorus regalis	27	2	8
Sparisoma chrysopterum	73	0	47
S. radians	122	2	[illegible]
Diapterus olisthostomus	33	2	
D. rhombeus	300	0	[illegible]
Eucinostomus gula	36	5	[illegible]
E. jonesii	73	0	41
TOTAL	1240	50 or 4.0%	[illegible] or [illegible]

According to Harden Jones (1968), movements of fishes may often be reduced to a simple triangular pattern, with the spawning area, nursery area, and adult stock at the three corners. It would appear that Jobos represents all three areas to some degree for some species. However, it is doubtful that the Bay is a major spawning area with an observed incidence of only 4%. It is also questionable that the Bay represents a major nursery ground since less than 20% of the population present were juveniles.

Fish Eggs and Larvae

Between 13 December 1971, and 13 June 1972, eight plankton tows were made in the area of the proposed intake in Jobos Bay. The tows strained a total of 480 cubic meters of water, and yielded an average density of 4.02 fish eggs per cubic meter, of which 50%, or 2.03 eggs, were identified as anchovy (Table 25). There do not appear to be any clear peaks of egg abundance with time, but rather a spotty spread over the entire sampling period. This is in accordance with Harden Jones (1968), who states that in tropical waters conditions could be favorable for the development and survival of eggs and larvae at all times of the year.

TABLE 25. Fish egg and larvae counts from plankton tows in intake area, Jobos Bay.

	Total #/m^3		
Date	Fish Eggs	Anchovy Eggs	Larvae
12/13/71	15/ 0.1		---
1/28/72	560/10.3	---	360/6.0
2/4/72	560/ 7.0	400/5.0	---
2/4/72	40/ 2.0	20/1.0	---
4/26/72	60/ 0.8	60/0.8	---
5/26/72	360/10.3	340/9.7	120/3.4
6/13/72	186/ 5.3	80/2.3	53/1.5
6/13/72	150/ 3.7	69/1.7	---
*Average density/m^3	4.02	2.03	1.11

*Averages calculated from data contained in Jobos Bay Annual Report, 1972.

Entrainment

It has been estimated that two 460 MW fossil fuel units will circulate 650 million gallons of sea water per day through their condensers (PRNC, 1972). This is equivalent to 2,460,500 cubic meters of water per day. Based on the above densities of eggs, it is estimated that about 9,800,000 fish eggs will be entrained per 24-hour day, of which 50% may be anchovy eggs. This number was converted into equivalent numbers of spawning fish. By measuring egg and ovary size for some species considered resident, an average number of 140,000 eggs per spawning female was calculated. Therefore, the approximate equivalent of the spawn of 35 female fishes, excluding anchovies, would be entrained during each 24-hour period.

The anchovy is not considered a resident species in spite of the high number of eggs found in the plankton. Therefore the egg number calculation was not made. Patterns seem to indicate a spotty distribution of schools rather than a stable population. The anchovy has not been a commercially important species in Puerto Rico. No landings were reported in 1971 (Juhl and Suarez-Caabro, 1972). Further, the anchovy appears to be of minor importance in the ecological food web in Jobos Bay. Only one carnivore has been found to utilize it for food (PRNC, 1972). This fish, therefore, was not considered in this entrainment study.

The catch statistics for the Salinas area, which includes Jobos Bay, were examined. A rough comparison between the effects of the fishery and the expected entrainment effect were drawn. As calculated above, we would expect that the spawning products of approximately 35 fish, other than anchovies, would be entrained within a 24-hour period. In 1971, a total catch of 126,395 pounds of fish was reported for the Salinas area (Juhl and Suarez-Caabro, 1972). Assuming an average weight of two pounds per fish, 173 fish were taken per day. It would appear, therefore, that fishing pressure would affect five times as many fish daily as entrainment. It may be assumed, also, that an undetermined portion of the catch would consist of pre-spawning females, which would be removed permanently from the population. This would have a greater effect than removal of spawning products alone.

CONCLUSIONS

It is therefore concluded that Jobos Bay is not a major spawning or nursery ground for fishes, and entrainment of fish eggs should not have a major effect on the fisheries of Jobos Bay or the surrounding region.

Limitations of the Data

These conclusions are based on limited plankton data (8 tows) and on fish collections intended to be primarily qualitative rather than quantitative in nature. A quantitative study of juvenile fishes in Jobos Bay may corroborate, or weaken, these conclusions.

LATE HOLOCENE CHANGES OF THE FORAMINIFERAL ASSEMBLAGES OF JOBOS BAY AND SURROUNDINGS, PUERTO RICO

by

George A. Seiglie

INTRODUCTION

The purpose of this paper is to describe the late Holocene changes in the foraminiferal assemblages in Jobos Bay and Mar Negro Lagoon.

Jobos Bay is located in southern Puerto Rico. Mar Negro Lagoon and Mar Negro Bay are located northwest of Jobos Bay (Figure 21). The salinities in both areas, from 35.5 to 37 ppt, equal normal marine levels throughout the year. Water temperatures range from 24.5°C to 30.0°C. No river discharges its waters into Jobos Bay nor into Mar Negro Lagoon.

Stress conditions in the Mar Negro Lagoon, Station 43A (see Figure 21) are caused by high turbidity in water and values of dissolved oxygen which ranged from 1.6 to 3 ppm (September, 1972; July, 1973). The values of dissolved oxygen at Station 24 of Jobos Bay ranged from 0 to 0.5 ppm until December, 1971. The presence of algae, mainly the genus Dictyota, increased the values of dissolved oxygen after 1972. The surface sediments of the two stations consist mostly of sand and clay. Station 43A contained about 13 percent organic matter and Station 24 contained about 7 percent organic matter in August, 1972.

Three related papers have been published previously with reference to the foraminifers of Jobos Bay. In 1971, I illustrated deformed specimens of Ammonia of Jobos Bay and attributed them to pollution and in 1973, I reported on the living pyritized Ammonia. The third paper (in press) shows that deformation of Ammonia is caused by pollution.

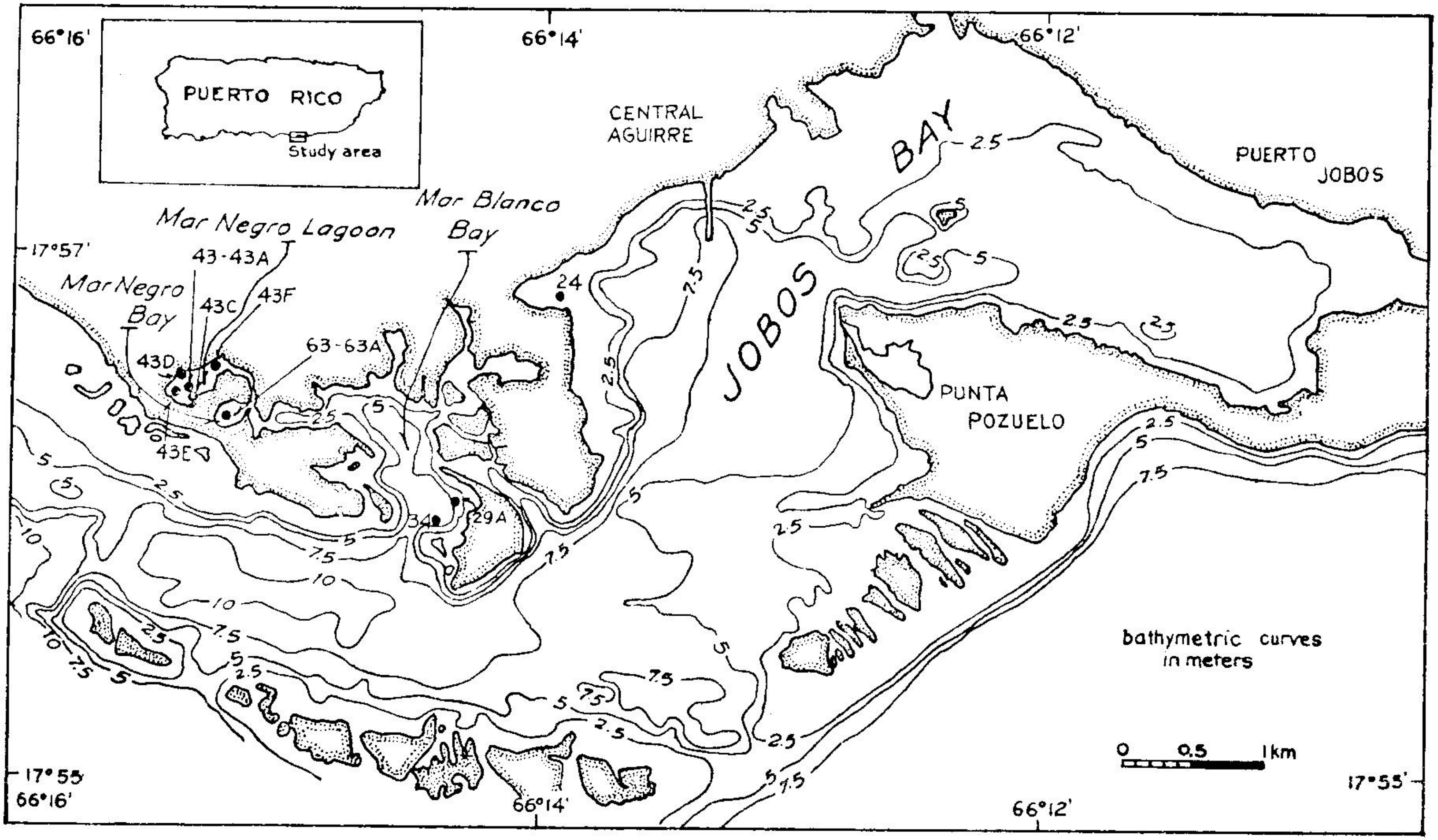


Fig. 21. Location of stations at Jobos Bay and surrounding area.

MATERIALS AND METHODS

Three localities in southern Puerto Rico where faunal late Holocene changes are clearly shown were selected for this study: Mar Negro Lagoon, Mar Negro Bay, and the northwest area of Jobos Bay.

A core 41.5 cm long was taken at a water depth of 4 meters in Mar Negro Lagoon. The most important biogenic grains in the sand fraction of the core were *Halimeda*, molluscs, and foraminifers. *Halimeda*, the most abundant constituent of the sand from 41.5 to 22 cm in the core, decreases to the top of the core. Molluscs are well preserved and maintain their shell color from 41.5 to 22 cm in the core. From 16 cm to the top of the core shells are thin and fragmentary. Foraminifers constitute the dominant group of the sand sized grains from 19 cm to the top of the core, miliolids are the dominant group of foraminifers from 41.5 to 25 cm in the core. Miliolids decreased in percentage from 25 cm to 20 cm (probably because of dissolution in the tests) and are rare in the present living faunas. *Ammonia* is the dominant foraminifer from 25 cm to the top of the core.

Samples were taken in Mar Negro Bay. The bay is in an evolutionary stage equivalent at depths of 16 to 22 cm in the core to the lagoon. *Ammonia* is the dominant foraminifer. Living miliolids are present but they are absent in dead fauna, probably because the tests were dissolved.

A core 35 cm long was taken at a water depth of 2 meters in the northwestern part of Jobos Bay. An Elphididae assemblage is dominant from 35 to 15 cm of depth in the core, where *Ammonia* is rare or absent. *Ammonia* is dominant from 15 cm to the top of the core. Its dominance indicates the onset of stress conditions in the area. Decrease with time of specific diversity and extreme deformation of individuals of *Ammonia* are related to pollution. This area was used by Central Aguirre (sugar mill) for dumping of wastes until December, 1971.

RESULTS AND DISCUSSION

Mar Negro Lagoon

Samples were taken at Station 43A from 1971 to 1973. In 1971 there were equal numbers of *Ammonia catesbyana* and *Cribroelphidium poeyanum* forma *kugleri*. From one sample taken in 1972 and four in 1973 *Ammonia* now appears to be more than five times more abundant than *Cribroelphidium*. The decrease in the percentages of *Cribroelphidium* in relation to *Ammonia* is a general trend found in the shallow waters off Puerto Rico (Seiglie 1975). A considerable part of the bottom of Mar Negro Lagoon is covered with the alga *Enteromorpha*, an indicator of pollution (Díaz-Piferrer 1967), and the values of dissolved oxygen are very low. The bottom mud and waters are black in the middle part of the lagoon, which bottom is not covered by algae. Probably these stress environmental conditions in the Lagoon are a consequence, first, of natural processes and, second, human activities. The prevailing winds and waves are westward. The lagoon has a very narrow, shallow and long connection with the sea. The wastes thrown into the water by fishermen living at the western part of the lagoon are retained in the lagoon by wind and wave action which prevents movement of debris toward the entrance at the east. The bottom configuration is similar to a basin with the deepest part in its center which contributes to disposal retention. The lagoon characteristics and processes determine the stress conditions, even though the amount of wastes dumped into the lagoon is probably relatively small.

Shells of 43 species of molluscs have been identified. Four species are still found in the mangroves which surround the lagoon. The other 39 species previously reported (Seiglie 1971) are no longer found alive and their shells are now worn and have lost their color. The former most abundant species, *Anomalocardia brasiliana* and *Chione cancellata*, are now represented only by worn shells found close to the shore of the lagoon.

A core 41.5 cm long was taken at Station 43A. It showed that in the past this lagoon had had a wider connection with the sea (as indicated by old maps as well) and that process of eutrophication is now occurring. Figure 22 shows the changes which have occurred in the assemblages of shelled organisms which lived in the lagoon. The lower part of the core, 41.5 to 22 cm from the top, consists mostly of skeletal sand. The most abundant constituents of the sand are *Halimeda* fragments and the most abundant foraminifers are Elphididae (*Cribroelphidium*, *Elphidium*, *Cellanthus* and *Astrononion*) and Miliolidae. The most significant change in the core occurs from 24 to 20 cm from the top. Above 20 cm the percentage and number of *Halimeda* fragments and Miliolidae decrease and the percentage and number of *Ammonia* increase. The ratio of foraminifers increases from the bottom to the top of the core.

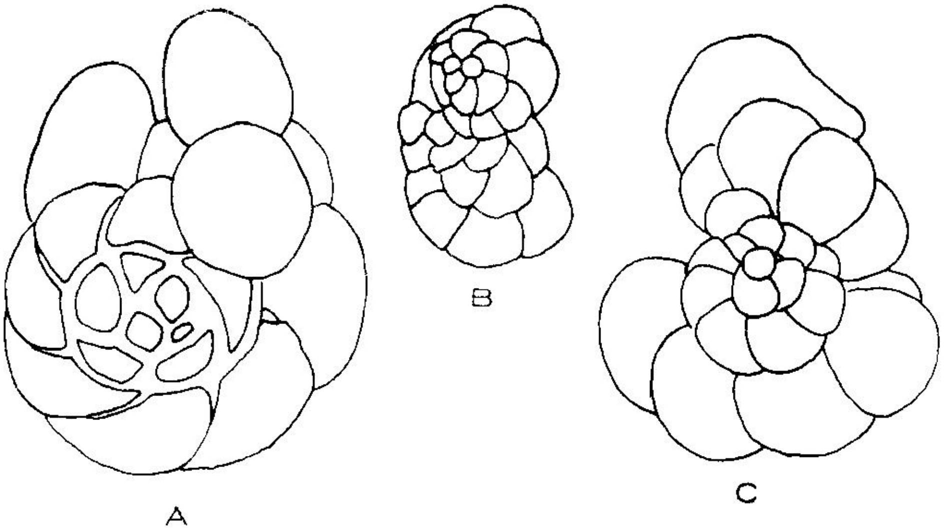


Fig. 22

Abnormal specimens of **Ammonia** catesbyana (d'Orbigny) from Station 43A, Mar Negro Lagoon: a) and b) specimens with abnormally arranged chambers, maximum dimension, a) .054 mm, b) 0.27 mm; c) "Welded" twin specimens, maximum dimensions 0.59 mm.

The diversity index according to Shannon's formula (MacArthur 1965) was also higher below 24 cm in the core. Fragmented molluscs increased in the upper part of the core, but in the lower part the molluscs were complete and their color was preserved. The last perfectly preserved Anomalocardia brasiliana occurred at 19 cm from the top of the core. In the upper part of the core Ammonia was the dominant foraminifer. The percentages of living foraminifers of Mar Negro Lagoon and the percentages in the core of Station 43A are shown in Table 26. Less than 1 percent of Ammonia catesbyana of Mar Negro are deformed. These deformations (see Figure 22) differ from those reported by Seiglie (1975) in several areas of Puerto Rico. One of the types of deformation (a) and (b) is similar to the deformation reported by Hofker (1971) in Piscadero Bay, Curacao, for "Streblus compactus" (abnormally arranged chambers). The other type of deformation, (c) consists of "welded" twin specimens which are relatively frequent in the area (about 1 percent of the population).

Mar Negro Bay

Reference samples were taken in Mar Negro Bay (Station 63A) which has a wider connection with the sea. The bottom of the bay is formed mostly by carbonate sediments similar to the central and lower parts of Mar Negro Lagoon. The percentages of living foraminifers of Mar Negro Bay are shown in Table 31. The percentage of living miliolids is relatively high in Station 63A, but 1 cm below the surface the tests disappear. This is caused by acidity, which dissolves the high magnesium calcite of miliolid tests. This is also probably the cause of the scarcity of miliolids in the middle part of the core of Station 43A (Mar Negro Lagoon). If Table 26-A and Figure 23 are used as models, the evolutionary stage of Station 63A, if miliolids are not considered, corresponds to depths in the core from 15 to 19 cm. If the miliolids are considered, this stage corresponds in part to the depth in the core of about 22 cm. This suggests that environmental conditions are changing in Mar Negro Bay so that they now resemble the conditions at Mar Negro Lagoon more closely.

Four other stations were sampled in Mar Negro Lagoon in 1973 which confirmed the large percentage of <u>Ammonia catesbyana</u> in the area of the lagoon (see Table 26).

TABLE 26. Percentages of significant groups of foraminifers in stations of the area surrounding Jobos Bay

	43C	43D	43E	43F	29A	34
Ammonia catesbyana	67.7	68.4	74.1	86.1	47.6	32.8
Elphididae	9.6	0.4	0.0	1.0	4.7	1.4
Miliolidae	6.5	30.2	14.6	5.0	19.1	14.3
Other foraminifers	16.2	1.0	11.3	8.0	28.6	51.5

A profile of the warm water lagoon of Guayanilla Bay (Seiglie 1975) indicates a change in environmental conditions because the increase of water temperature from 35°C to 40°C caused a decrease (close to zero) in the percentage of Elphididae and increase in the percentage of <u>Ammonia</u> found in the cores.

<u>Mar Blanco Bay</u>

This bay has wide communication with the sea, normal salinity, and dissolved oxygen close to saturation. Two samples were taken at less than 5 m of depth from Stations 29A and 34 (see Figure 21). They contained foraminiferal faunas similar to those of Mar Negro Bay. Samples taken from depths more than 5 m contained a fauna different from and not comparable to the shallower faunas of this study.

<u>Jobos Bay</u>

Station 24 is located at the extreme northwestern end of Jobos Bay at a depth of 2 meters, not far from the sugar mill (Central Aguirre). Stations 18 and 5, at 7.0 meters and 7.3 meters of depth, respectively, are also located in an area which has been altered by human activities, but their foraminiferal faunas consist of <u>Fursenkoina punctata</u>, <u>Quinqueloculina thodiensis</u> and <u>Ammonia catesbyana</u> which are not comparable at present with the fauna found at Station 24. The fauna of Station 18 has been reported by Seiglie (1971, 1975).

	43A/1971 surface; living	43A/1972 surface; living	43A/1973 surface; living	43A; core 4-5 cm	43A; core: 6-7 cm	43A; core: 8-9 cm	43A; core: 11-12 cm	43A; core: 13-14 cm	43A; core: 15-16 cm	43A; core: 17-18 cm	43A; core: 19-20 cm	43A; core: 21-22 cm	43A; core: 23-24 cm	43A; core: 25-26 cm	43A; core: 27-28 cm	43A; core: 29-30 cm	43A; core: 31-32 cm	43A; core 33-34 cm	43A; core 35-36 cm	43A; core: 37-38 cm	43A; core: 40-41 cm	63A surface; living
Ammonia catesbyana	60.6	98.9	71.7	85.5	82.6	78.6	67.8	95.4	96.0	89.0	89.9	70.0	74.7	26.5	20.5	18.7	12.0	17.0	16.6	17.7	18.8	37.1
A. spp.																						
Amphistegina gibbosa																0.5						
Archaias angulatus																		1.0			0.5	
Articulina? mexicana																	0.5					
Astrononion sp				0.9	1.2	2.9	3.3			0.9	1.1	3.0	4.1	10.0	4.4	2.9	5.0	4.0	1.7	2.0	2.5	
Brizalina spp.			3.5	0.9								0.5	0.5	7.5	6.4	3.5	3.5	2.5	2.8	3.0	5.0	8.6
Buliminella elegantissima						0.4						0.5		0.5	0.5	0.5	2.0	0.5		0.5	0.5	
Buliminoides milletti																	0.5					
B. paralella															1.0						0.5	
Bolivina sp.														0.5								
Cellanthus spp. (1)				0.5				3.4		1.0		2.5	2.8	1.5	1.9	0.5		1.5	3.9	0.5		
Cibicides sp.																	0.5					
Cribroelphidium spp. (2)	39.4	1.1	14.1	5.4	14.5	17.6	19.9	1.1	3.5	9.1	6.9	12.5	13.6	32.0	25.2	23.6	15.5	15.5	0.6	20.1	12.0	2.9
Cyclogyra involvens												0.5		1.0		1.4	3.0	2.0	2.9	2.5	3.0	
Dendritina elegans															0.5				0.6			
Discorbina mira													0.9	0.5	0.4		1.5	2.0				
Discorbis sp.												1.5				3.0				1.5	0.5	
Elphidium sagro						0.4			0.5		0.5		0.5		0.4	0.5		0.4				
Fissurina pelucida													0.5		0.4		2.0	1.0		0.5		2.9
Florilus grateloupii				0.9			0.8					0.5		11.0	12.9	10.3	4.5	7.0	2.2	8.0	5.5	2.9
Fursenkoina complanata														1.0		0.5		0.5		1.5		
F. punctata														1.0	4.7	1.9	5.0	3.0	2.0	6.1	3.5	
Hopkinsina pacifica																				0.5		
Loxostomum sp.													0.5					1.0				
Miliolidae (small)			7.0	1.4			7.4				1.6	7.0	1.4	1.0	8.4	23.1	36.0	34.4	56.0	29.6	41.8	40.1
Nodobaculariella spp.														0.5	1.4	1.9	1.0	1.0	2.2	1.0		
Nonionella "opima"																				1.0		
Peneroplis proteus																			0.6			
Protelphidium sp.			3.6				0.8							4.0	1.4	2.5	1.5	0.4	3.8	0.5	1.5	5.5
Planorbulina mediterranensis																	0.5					
Rosalina floridana												1.5		1.0	3.4	0.9	2.0	1.0		0.5	0.5	
Sagrina pulchella															1.0			0.4	0.6	0.5	0.5	
Sorites orbitolitoides																			0.6			
Spirillina densepunctata																			0.6	0.5		
Textularia earlandi																		0.4		0.6		
Tretomphalus bulloides																	0.5				0.5	
Vertebralina? mucronata														0.5	3.4	3.4	3.0	3.5	2.0	1.5	3.0	
Cribrononion sp.				4.5	1.7								0.5		1.9	0.5						

TABLE 26-A. Percentages of foraminifers in the core and stations of Mar Negro Lagoon (43A) and Mar Negro Bay (63B)

(1) Including: C. discoidalis C. cariacoensis and C. sp.
(2) C. poeyanum, C. delicatulum and C. sp.
(3) Hauerina bradyi, Miliolinella subrotunda, M. sp., Pyrgo elongata, P. subspaerica, P. sp., Quinqueloculina agglutianans, W. angulata, Q. candeiana, Q. collumnosa, Q. cf. costata, Q. lamarckiana, Q. poeyana, Q. rhodiensis, Q. spp., Triloculina sidebottomi, T. trigonula, T. sp.

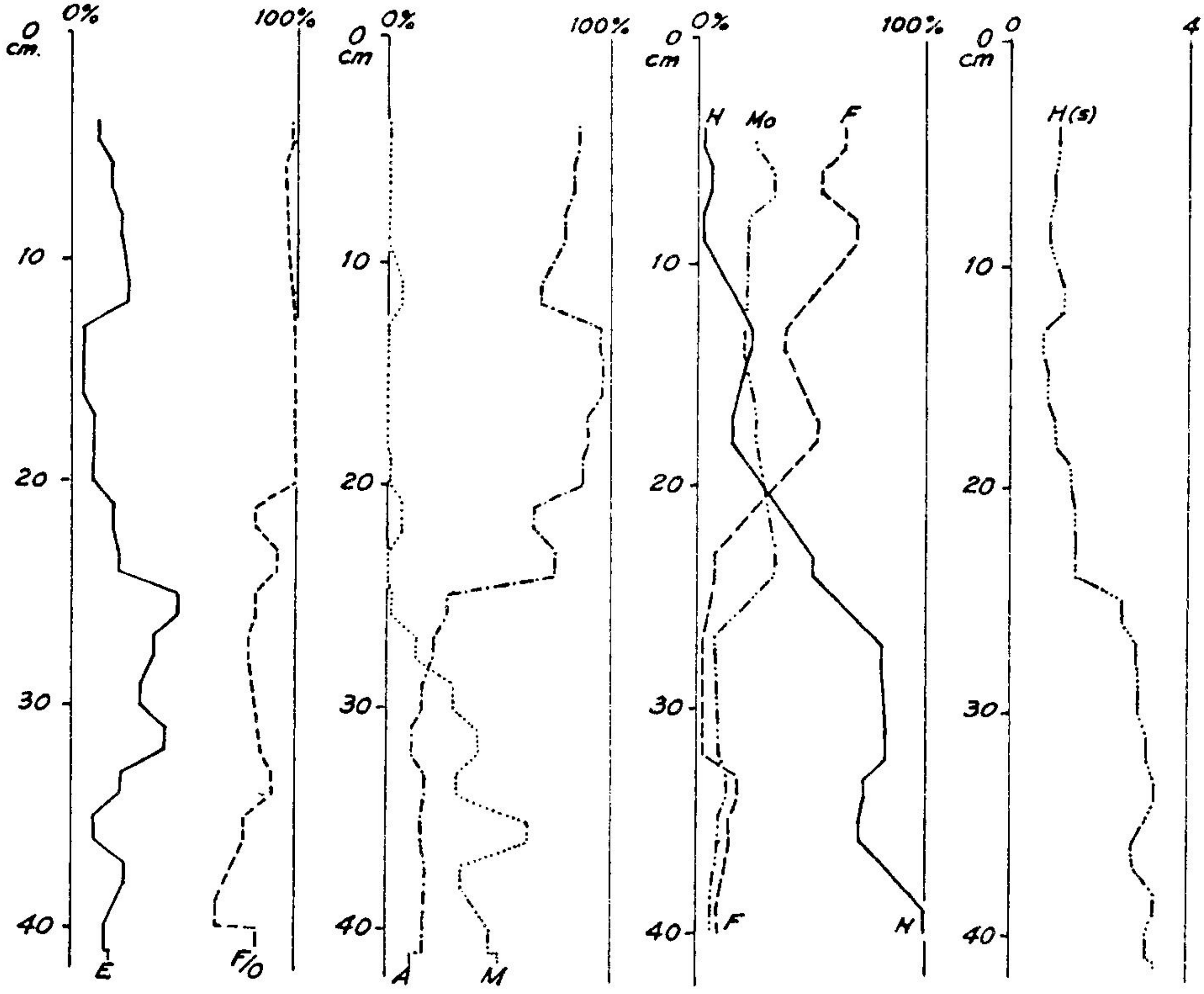


Fig. 23. Mar Muerto Lagoon. Percentages of organic remains in the sand size fraction: E, Elphididae; F/O, ratio foraminifers to ostracods; A, Ammonia, % to total foraminiferal fauna; M, miliolids, % to foraminiferal fauna; H, Halimeda, % in sand fraction; Mo, molluscs, % in sand fraction; F, foraminifers, % in sand fraction; H(s), species diversity according to Shannon's formula.

Station 24 was sampled on several dates (Figure 24). A core 35 cm long was taken. The percentages of Ammonia and specific diversity of foraminiferal assemblages, according to Shannon's formula (MacArthur 1965) at different depths in the core, and of five surface faunas taken at different dates are

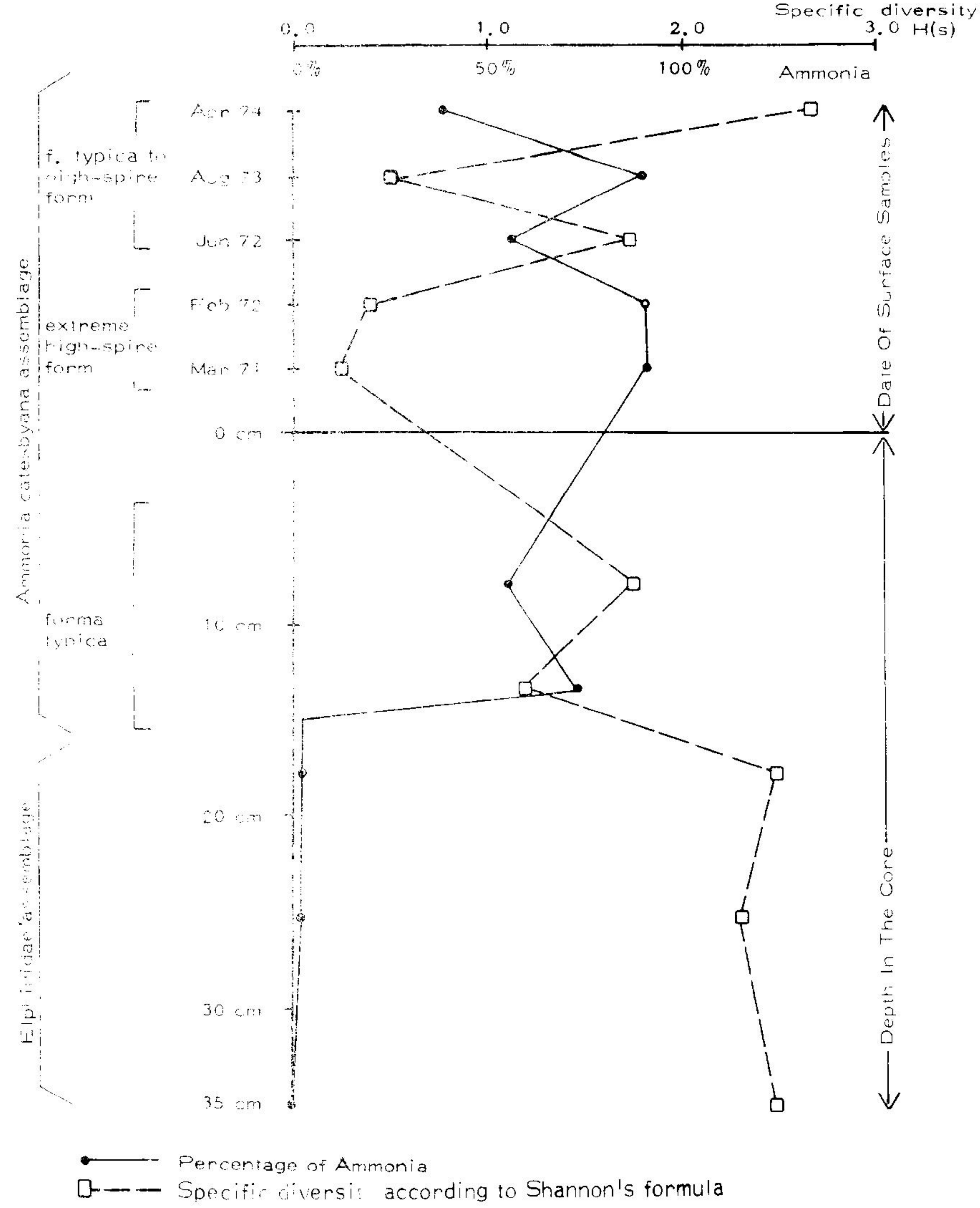


Fig. 24. Changes in foraminiferal assemblages as indicated by specific diversity. Ammonia catesbyana Zages; core and surface samples indicated by dates in the figure.

shown in Figure 25. The Elphididae assemblages, which dominate the lower part of the core, disappear at 14 cm from the top of the core. This level probably marks the onset of change in conditions when the sugar mill began to pour its wastes into the bay. Ammonia catesbyana has dominated the foraminiferal assemblages of this locality since the onset of this pollution from the sugar mill. Below 15 cm from the top of the core, carbonate sediments are dominant and at 15 cm the last bivalve shell is present. Above that depth mollusc shells disappear.

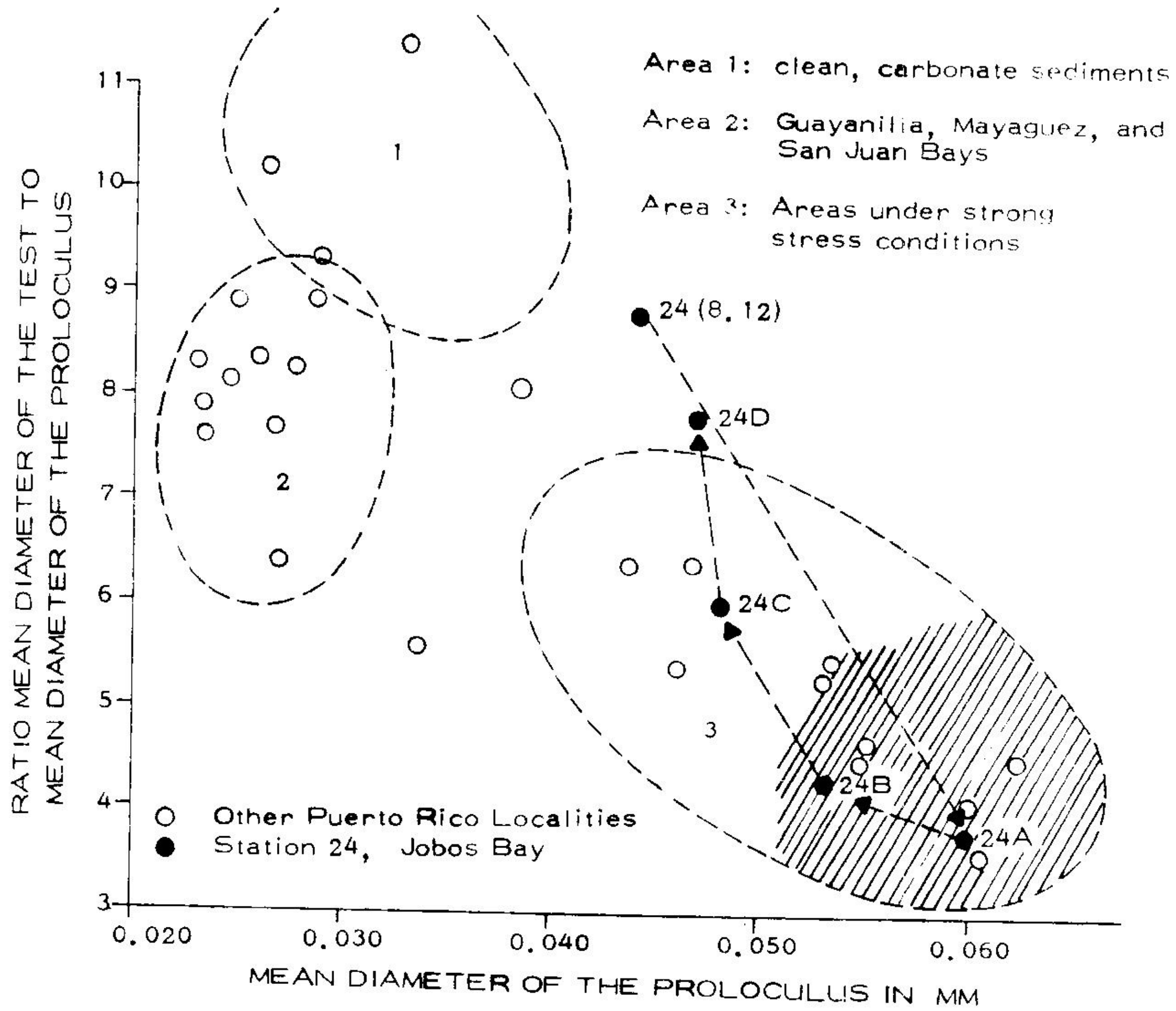


Fig. 25. Mean dimension of populations of Ammonia catesbyana (d'Orbigny). Area 1: forma typica in clean carbonate sediments: Area 2, forma tepida in Guayanilla, Mayaguez and San Juan Bays; Area 3, high-spire form in environments under stress conditions; shaded area corresponds to polluted environments.

The relationships between mean proloculus and the mean ratio of diameter to proloculus of A. catesbyana are shown in the scatter diagram of Figure 24. The mean values were based on measurements in populations from 50 to 100 specimens. The numbers of microspheric specimens in the study areas were too low to show a relation to coiling ratio as shown by Brooks (1967) and Hofker (1971) in other areas. Area 1 of Figure 25 corresponds to the largest form of A. catesbyana, which occurs in clean carbonate sediments. Area 2 corresponds to A. catesbyana forma tepida, found in the Guayanilla, Mayaguez, and San Juan Bays. It represents a wide range of environmental conditions. Area 3 corresponds to environments under strong stress conditions, and its shaded area corresponds to polluted environments.

Station 24 is located in the area where sugar mill wastes were dumped until December, 1971. Changes in foraminiferal fauna have been plotted on the scatter diagram of Figure 24 (see also Seiglie 1975). Sample 24 (8.12) corresponds to the Ammonia population at 8 to 12 cm in the core. Sample 24A corresponds to the population in March, 1971, where the most abnormal specimens occurred. Sample 24B was taken in February, 1972, two months after the dumping area was removed from this locality. Sample 24C was taken in June, 1972, and 24D in August, 1973. These last specimens were observed to be practically normal. The populations of Ammonia had cycled from the onset of pollution in the years before 1971 to 1973 when the area had partially recovered (the cycle is shown by arrows in Figure 5). The sample taken in April, 1974 shows a decrease in the percentage of Ammonia and an increase in specific diversity closer to the Elphididae assemblage. Bivalve shells have appeared since 1972.

This locality will not recover completely to the original environmental conditions represented by the lower part of the core because part of the mangroves growing around the area have been cut and sedimentation is now higher than before.

CONCLUSIONS

The profiles of the cores of Stations 24 and 43A may indicate how in the shallow waters of Puerto Rico, and possibly the other islands in the Antilles group, the onset of stress conditions may develop either because of natural alteration of the environment and/or human activities. A scatter diagram (see Figure 24) could be used for lagoons and other environments which are shallower than 5 meters (see Seiglie 1975) to indicate stress conditions and pollution.

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