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Annual Report

APPENDIX

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AGUIRRE POWER PROJECT

ENVIRONMENTAL STUDIES 1972

ANNUAL REPORT

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APPENDIX A

MACROZOOPLANKTON OF JOBOS AND GUAYANILLA BAYS, SOUTHERN PUERTO RICO, AND ITS FLUCTUATIONS UNDER SPECIAL CONDITIONS

by

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INTRODUCTION

This paper deals with the species diversity, abundance and distribution of marine macrozooplankton in Jobos and Guayanilla Bays, southern Puerto Rico. It is part of the environmental studies undertaken by the Puerto Rico Nuclear Center at the proposed Jobos Bay thermoelectric power plant site and at the Guayanilla Bay power plant site where a fossil fuel power plant has been generating 300 megawatts from 1957 to 1972 and 710 megawatts since 1972.

Information about the plankton of tropical estuaries and bays is limited and scattered, especially in the Caribbean area and adjacent waters. One of the first research efforts on zooplankton of Puerto Rico was conducted by Duran (1957), who worked on tintinnids of the island. Later, Coker and Gonzalez (1960) and Gonzalez and Bowman (1965) studied copepods from Bahia Fosforescente, southern Puerto Rico.

In the Caribbean area and adjacent waters there have been several zooplankton studies reported, including those of Moore (1948), Suarez-Caabro (1959), Suarez-Caabro and Madruga (1960), Legare (1961), Zoppi (1961), Cuzon du Rest (1963), Reeve (1964, 1970), Suarez-Caabro and Gomez Aguirre (1965), Moryakova and Campos (1966), Owre and Foyo (1967) and Bowman and McCain (1971). An extensive bibliography on general plankton and the main groups of the area can be found in Björnberg (1971).

The main objectives of this study were to establish the main components of the macrozooplankton in Jobos and Guayanilla Bays, and their abundance and distribution over a relatively short period of time as a baseline for understanding their future fluctuations with environmental changes.

Since the number of sampling stations and the time were limited, and the sampling procedures and the net sizes were variable, this research is restricted mainly to the identification and distribution of the most abundant and common species of the macrozooplankton of Jobos and Guayanilla Bays during November and December 1971 and January, February and March 1972. An extensive, scheduled study of the ecology of plankton in both bays and other areas around Puerto Rico is being continued by the Radioecology Division of the Puerto Rico Nuclear Center. Nevertheless, it is felt that the paucity of literature dealing with planktonic communities in Puerto Rico justifies this preliminary paper.

STUDY AREA

Jobos Bay

Jobos Bay is located in the southeastern part of Puerto Rico (Fig. 1) 20 nautical miles westward of Punta Tuna Light (approximately 17° 55' 00" - 17° 57' 30" N and 66°10' 00" - 66°17' 29" W). Jobos Bay is one of the few natural harbors in the southern coast of Puerto Rico. It is formed by a complex of tropical marine communities: mangrove swamps, turtle grass (Thalassia testudinum) beds, muddy and silty bottoms, sandy beaches, and coral reefs. The total length of Jobos Bay, from the eastern tip of Cayos Ratones to the eastern-most part at Puerto Jobos, is approximately 7 nautical miles (Fig. 2). The widest area is 2.2 nautical miles from Central Aguirre to Boca del Infierno. The bay is divided into three different zones: Inner Bay, Mid Bay and Aguirre Navigational Channel.

The Inner Bay is the eastern-most end of the bay separated from the Mid Bay by the line between Punta Rodeo and Central Aguirre Dock (Fig. 2). The Inner Bay is a shallow end of Jobos Bay surrounded by a narrow zone of mangroves on the shores. The average depth is about 3 - 4 m, but there are also a few shallow turtle grass beds at the mouth of the Inner Bay. A 6 m deep dredged channel is found near the southern shore. The Inner Bay has a silty bottom which gets stirred up during the normal 10-knot trade winds. The surface currents move the turbid water westward to the Mid Bay. There is an upwelling along the entire Inner Bay due

to trade winds. The deep current enters the Inner Bay from the Aguirre Navigational Channel and the Mid Bay (Puerto Rico Water Resources Authority, 1972).

The Mid Bay is bordered by Punta Rodeo on the east, Cayos Caribes on the south, and Punta Colchones on the west. The Mid Bay has mangroves growing on the eastern and western shores, while the southern side has mangrove-covered keys and a protecting fringing coral reef separating it from the Caribbean. There are turtle grass beds along the eastern and western shores. The central part of the Mid Bay is about 8 m deep.

The Aguirre Navigational Channel is open to the Caribbean on the west between Cayos de Ratones, Cayo Morrillo and Cayos de Pajaros, which channels are about 15 m deep. On the east there is a 4-meter deep channel called Boca del Infierno. The northern side of the Aguirre Navigational Channel has extensive mangrove areas and on the southern side there are keys with mangroves and fringing reefs. Along the shores of the keys and along the entire shoreline in the north there are extensive turtle grass beds. The depth in the central part of the Aguirre Navigational Channel is between 10 and 12 m. The surface currents are moving to the west generated by the trade winds, the North Equatorial current entering through Boca del Infierno and the hydrostatic head that pushes waves over the fringing reef and through the mangrove channels between the keys in Cayos de Barca and Cayos Caribes. A deep current brings water through the entrances in the west into the Aguirre Navigational Channel during the flood tide. This water moves toward the east into the Mar Negro area, the Mid Bay and the Inner Bay. During the ebb tide water moves out of the bay in the entire water column (Puerto Rico Water Resources Authority, 1972).

Tides in Jobos Bay are primarily diurnal with a complex pattern composed of two tidal waves, one with a daily cycle and another with a cycle of 13.3 days (Puerto Rico Water Resources Authority, 1972). The extreme tides of 30 c/m occur when these two cycles are in phase.

Surface temperatures in January varied from 28° C. to 29° C. in the Inner Bay, from 29° C. to 30° C. in the Mid Bay and from 25° C. to 26° C. in the Aguirre Navigational Channel. In August the temperatures were from 30° C. to 31° C. in the Inner Bay, from 31° C. to 32° C. in the Mid Bay and from 29° C. to 30° C. in the Aguirre Navigational Channel (Puerto Rico Water Resources Authority, 1972).

Guayanilla Bay

This bay (Fig. 1) is located 25 nautical miles eastward of Cabo Rojo Light (approximately 17° 57' 30" - 18° 00' 00" N and 66° 45' 00" - 66° 48' 30" W). It is both the largest and one of the best hurricane harbors in Puerto Rico. The reefs and islands to the southeast break the sea, but not the wind. The harbor, between low and denuded Punta Guayanilla (Fig. 3) on the east and bluff-faced Punta Verraco on the west, is protected at its entrance by extensive reefs which extend a mile or more offshore. The entire bay is 4 nautical miles in length with a maximum width of 2 nautical miles.

This study is concerned with the area of the bay immediately adjacent to the power plant (Fig. 3). Cooling water is taken from an embayment to the west of the plant, and effluents are released into a cove to the southeast. The embayment from which water is taken is approximately a uniform 500 meters wide and 1050 meters long. Temperature ranges from 25.5° C. in winter to 30.5° C. in summer. The receiving cove is approximately 900 meters in length, the major part being about 380 meters wide and constricting to about 30 meters wide at its mouth. Cooling water was discharged into the cove at 10° C. above ambient, i.e. above the inlet bay temperatures. This temperature dropped to + 8° C. Δt within 100 m from the mouth of the discharge canal with a further decrease to + 5° C. Δt toward the mouth of the cove. There was a 0.1 - 0.5 knot steady surface current flowing out of the cove and a 0.1 - 0.2 knot deep current flowing into the cove at its mouth.

Depth in the embayment varied from 2 to 5 m, dropping to as much as 20 m at its mouth. An average depth was about 4 m. The discharge cove is more uniform, varying from 2 - 5 m, averaging about 4 m deep.

METHODS AND MATERIALS

Thirty-two surface stations were sampled in ten different areas during November and December 1971, and January, February and March 1972, at Jobos and Guayanilla Bays (Fig. 1). All were surface plankton samples taken with three mesh size 0.5 m Ø nets that were provided with small flowmeters. Most of the samples were collected with a

macroplankton net of mesh opening size 380 mμ, ten stations were sampled using a net of mesh opening size of 60 mμ and three samples were obtained with a net of mesh opening size of 300 mμ.

The length of the tows ranged between 5 and 20 minutes. Samples were preserved in 4% buffered formalin. Temperature, salinity and dissolved oxygen concentrations were also measured at the station during the towing.

For counting organisms, aliquots of each sample were removed from a well-shaken container by means of 5 cc, 10 cc or 20 cc spoons and diluted into a squared Petri dish. All zooplankters in the subsamples were counted.

COMPOSITION OF MACROZOOPLANKTON

Jobos Bay

As in Guayanilla Bay, copepods were the most numerous holoplanktonic forms in Jobos Bay. Among the calanoids Acartia tonsa Dana was found in every area sampled (Fig. 2). A. lilljeborgii Giesbrecht occurred in areas 2, 3, 4, and 5, which were located in the Mid Bay and close to shore in the Aguirre Navigational Channel. Acartia spinata Esterly was present in areas 2, 3, and 5, and Acartia longiremis (Lilljeborg) in area 5 only.

Temora turbinata (Dana) was the second most common calanoid. It was recorded for all areas except number 3. Pseudodiaptomus cokeri Gonzalez and Bowman occurred in areas 3, 5 and 6 in the western part of the bay.

Other calanoid species which appeared less common were Calanopia americana F. Dahl, Clausocalanus furcatus (Brady), Paracalanus crassirostris F. Dahl, Paracalanus aculeatus Giesbrecht, Paracalanus spp., Labidocera scotti Giesbrecht and Labidocera spp.

The Cyclopoid copepods Oithona hebes Giesbrecht, O. nana Giesbrecht and the harpacticoid Euterpina acutifrons (Dana) also occurred in the bay.

All those species of copepods except genus Labidocera mentioned above have been reported in Puerto Rico by Gonzalez

and Bowman (1965). In Puerto Rico L. scotti Giesbrecht is recorded by Coker and Gonzalez (1960) only in Bahia Montalva, southwestern Puerto Rico. This species also occurs in South Biscayne Bay, Florida (Reeve, 1970; Woodmansee, 1958; and Davis, 1950). A. longiremis is not previously reported in Puerto Rico, but it is recorded in Cuban waters by Suarez-Caabro (1959).

Lucifer faxoni was present in all areas of Jobos Bay. Juveniles of this species are reported in area 6, located at the mouth of the bay. Among the larvaceans Oikopleura (Vexillaria) dioica Fol, Oikopleura (Vexillaria) parva Lohmann, Oikopleura (Coecaria) longicauda (Vogt), and Oikopleura (Coecaria) fusiformis f. cornutogastra (Aida) were present in Jobos Bay.

Immature specimens of chaetognaths as Sagitta spp. were present in all areas except in the Inner Bay (area 1) where S. hispida Conant was identified. S. enflata Grassi and Krohnitta subtilis (Grassi) were also found in Jobos Bay.

A cladocer, Evadne spp., was recorded in areas 4, 5 and 6, which were located in the entrances and in the midchannel of the bay. No identified species of pteropods and siphonophors were present in those entrances.

Two species of mysids were identified. Siriella chierchiae (Coifmann) was taken in areas 3 and 5 at night and in area 6 during the day. Mysidopsis sp. (identified by Dr. Brattegard as a new species he first found in Columbian coastal waters in 1971 and called Mysidopsis C) was taken during a daytime tow in area 4. Among the hyperiid amphipods the genus Brachyscelus was identified in area 2. Also a gammarid, Erichtonius sp., was reported in area 3.

Guayanilla Bay

Copepods were the most abundant holoplanktonic group found in the areas sampled at Guayanilla Bay (Fig. 1). Acartia tonsa was the most common species of copepod reported and appeared in all areas. Acartia lilljeborgii and Oithona hebes were present in areas 3 and 4 and Temora turbinata in areas 2 and 4. Other less common species were Euterpina acutifrons, Microsetella norvegica (Boeck) and juveniles of Pseudodiaptomus cokeri. Some non-identified harpacticoid copepods were also present.

All those species were previously reported for Bahia Fosforescente and adjacent waters, southern Puerto Rico, either by Gonzalez and Bowman (1965) or Coker and Gonzalez (1960). Most of the species mentioned above are recorded for similar areas by Davis (1950), Davis and Williams (1950), Woodmansee (1958), Suarez-Caabro (1959) and Reeve (1964, 1970).

A sergestid, Lucifer faxoni Borradaile, and immature specimens of Sagitta spp. occurred in all areas. Sagitta tenuis Conant was identified in area 4. L. faxoni has been reported as abundant near the coast and specifically in Biscayne Bay, Florida (Bowman and McCain, 1967; and Woodmansee, 1968). S. tenuis is a typical neritic species (Suarez-Caabro, 1955; and Alvariño, 1965).

Unidentified isopods were also found in different areas of the bay. Some gammarid amphipods, Podocerus spp. (probably P. brasiliensis) and Corophium spp., were also identified in Guayanilla Bay.

Among the larvaceans, Oikopleura (Vexillaria) dioica, O. (Coecaria) longicauda, O. (Vexillaria) rufescens Fol, Fritillaria (Eurycercus) borealis f. sargassi (Lohmann) and F. (Eurycercus) pellucida (Busch) were recorded in the bay. All these species of larvaceans are reported for Puerto Rico for the first time, to the author's knowledge. They were found in Cuban waters by Tokioka and Suarez-Caabro (1956) and in Trinidad Island, Brazil, by Björnberg and Forneris (1955). Also, Flores (1965) reported these species of the genus Oikopleura for the coastal waters of Veracruz, Mexico.

The mysid Mysidium columbiae (Zimmer) was taken during May in area 1. A large school was taken with a band net at the surface near a mangrove stand.

DISTRIBUTION OF THE MACROZOOPLANKTON

Jobos Bay

Jobos Bay has been divided arbitrarily into six sampling areas (Figs. 1 and 2). The Inner Bay, area 1, has been given little emphasis as the predicted current patterns caused by the proposed power plants should have little

effect there. Most of the sampling effort has gone into area 2 (the intake area) and area 5 (the outfall area). Area 4, Boca del Infierno and the area sheltered by Cayos Caribe and Cayos Barca should be indicative of recruitment potential provided to the coastal areas directly adjacent to the power plant complex. Area 3 was sampled only in November 1971, and then only because it is a break point for surface waters coming through Boca del Infierno. This area is probably the most unstable environment, but at the same time the richest in the bay. Area 6 was sampled to determine a possible trend toward seaward drift from area 5 and to estimate recruitment problems associated with detrimental effects the heated effluent might have. Table 1 is a complete tabulation of plankton hauls analyzed to date. It shows the location, date, time and other parameters of the sampling. Tables 2 through 7 list plankton concentrations according to: (A) number taken per cubic meter of water sampled (#/m^3) and (B) percentage of total catch that each plankter category constitutes (% total catch).

As stated before, the Inner Bay (area 1) has been sampled scantily. Holoplanktonic forms caught in this area reached 50.4% in December 1971 (Table 2). The main groups were copepods (43.8%), fish eggs (2.0% -- anchovy eggs 0.5%), siphonophors (0.3%) and appendicularia (0.3%). Lucifer faxoni accounted for 4.0% in this area. Siphonophors were not common in these inshore waters. Specimens found in area 1 were probably taken there by deep water currents which enter from the open sea during flood tide and flow easterly along the bottom of the Aguirre Ship Channel in through the mouth of the bay and eastward along the bottom of Jobos Bay (Puerto Rico Water Resources Authority, 1972). The percentage of meroplankton (49.6%) in mid December was slightly lower than that of holoplankton. The major groups were brachyuran zoeas (28.0%), cirripede nauplii (8.0%) and penaeid larvae (3.1%).

Copepods were the most abundant group among all plankters in area 2 (Table 3), from mid December 1971 to the end of January and early February 1972, accounting for 96.6%, 74.4% and 64.3% respectively. Permanent plankton in mid December included, in addition to copepods, appendicularia (0.2%) and L. faxoni (0.2%). Chaetognaths (9.3%), appendicularia (0.4%), medusae (1.0%) and very few L. faxoni (0.1%) were present at the end of January. Chaetognaths decreased to 0.9%; appendicularia increased to 3.1%; medusae decreased to 0.2%; and L. faxoni

disappeared, but nemertineans (0.2%) were reported for the first time in area 2. It is interesting to note that copepods decreased, but cirripede nauplii increased to 11.4%.

Area 3 (Table 4) in early November was predominately holoplanktonic. Copepods, 86.4% during the night and 49.8% in the day, were the most abundant group. Other permanent plankters were chaetognaths (1.8%, 1.9%); appendicularia (3.6%, 0.5%); and L. faxoni (0.3%, 1.4%). Nauplius larvae (0.2%), pluteus larvae (0.7%) and porcellanid larvae (1.6%) were present only during the day station.

Area 4 (Table 5) in early November was also holoplanktonic (56.4%), but appendicularia (19.2%), chaetognaths (8.0%), cladocers (9.0%), medusae (1.0%) and siphonophors (2.0%) together accounted for more than copepods (16.2%). Medusae, pluteus larvae and polychaete larvae were not present in early December, but L. faxoni (0.4%) appeared at that time.

Area 5 (Table 6, station JB-7, JB-8 and JB-10) in early December was typically meroplanktonic. Brachyuran larvae (16%), decapod larvae (16%), fish eggs (20%), fish larvae (0.8%), nauplius larvae (12%), polychaete larvae (0.1%) and porcellanid larvae (0.1%) accounted for a total of about 49%. Almost two months later (station JB-26, JB-27 and JB-29) the same area had become strongly holoplanktonic. Copepods, amphipods, appendicularia, chaetognaths, and L. faxoni reached a total of 82% in area 5.

Area 6 (Table 7), same as areas 3 and 4, was predominately holoplanktonic in early November. Copepods (34.5%), chaetognaths (29.2%), appendicularia (3.3%), cladocers (1.1%) and siphonophors (0.8%) reached a total of 68.9% of the whole plankton community. Meroplankton accounted for 31.1%, consisting of brachyuran larvae (10.3%), decapod larvae (12.3%), fish eggs (3.9%) and others (4.6%). In early December and February copepod peaks of 67.3% and 93% were found, respectively. In February larvae had decreased to a total of only 3.5%.

Guayanilla Bay

The area of sampling in Guayanilla Bay was located in the northeastern side of the bay (Fig. 3). General characteristics of stations are shown in Table 8. Tables 9 through 12 list plankton concentrations as: (A) number per cubic

meter of water sampled (#/m^3) and (B) percentage of total catch that each plankter category constituted (% total catch).

Area 1 (Table 9) in early December was predominately holoplanktonic (90.5% of all plankters captured). Copepods and their nauplii accounted for 76.7% and 7.1% respectively, polychaetes for 6.4%, chaetognaths for 0.3%. The only major meroplankters were cirripede nauplii (5.2%). In mid December (GB-A, GB-B) holoplankton had decreased to 69% of the plankton community (66.8% copepods, 2.1% chaetognaths, 0.1% polychaetes). Of the meroplankton 4% were brachyuran larvae (2/3 of which were porcellanid zoeas), caridean larvae accounted for 3.2%, penaeid larvae for 2.2%, and cirripede nauplii for 2%. It is interesting to note that copepod nauplii had disappeared and that fish eggs and larvae had remained relatively unimportant during this period. Brachiopods and bivalves were present in early December in minute quantities, but were absent later. Note that penaeid larvae appeared in mid December (2.2%).

In area 2 (Table 10), 90.21% of the community was holoplanktonic during November, a figure that dropped to 68.9% in December, and further to 30.8% in March. The primary reason seemed to be the increasing numbers of amphipods: 10% in December, 30.8% in March; fish eggs: 7.6% in December, 10.3% in March; fish larvae: 0.5% in December, 5.4% in March; isopods: 1.8% in December, 6% in March; cirripede nauplii: 4.6% in December, 1% in March; and brachyurans: 2.8% in December, 4% in March. None of these latter groups occurred in significant numbers in November. (November samples were taken with 60 mμ nets, later samples with 380 and 300 mμ nets; therefore, the decrease in the number of copepods may have been due to smaller copepods not being caught.)

In early March, bivalves occurred (3%) as well as small bursts of foraminifers (0.3%), ostracods (0.2%), and tintinnids (1.4%), none of which were found at other times. Gastropod larvae constituted 3.8% of the early March samples but were present in insignificant numbers (0.03%) during November. Nemerteans occurred in both November and March (0.03% and 0.2% respectively). It is interesting that brachyura became important only during December (2.8%) and late March (4%), and that polychaetes were abundant (2.7%) only in March. Carideans appeared only in March (9.4%). Copepod nauplii peaked in November (where they made up most of the 6.6%), and early March (21.4%), and disappeared (for all practical purposes) in

late March. Cirripede nauplii were also more abundant (3%) in early than late March (2%), but also peaked in December (4.6%).

In area 3 (Table 11) holoplankton accounted for 61.6% of the community during November, 84.9% in December, and 60.5% in March. A high meroplankton percentage in November was primarily a function of fish egg production (16.3%), gastropod reproduction (1.8%), and appearance of tintinnids (6.7%) and foraminifers (2.5%). The latter two were absent in other periods. It should be noted that November was also the only time appendicularia (0.6%) and polychaetes (0.3%) appeared in area 3.

The 39.5% meroplankton concentration in March was a function of a brachyuran breeding period (37.4%), a burst of cirripede nauplii (6.0%), and a healthy concentration of caridean larvae (3.3%) and penaeid larvae (2.1%). The latter two appeared in area 3 only in March. Note that the concentration of brachyuran zoeas was greater than the combined total for copepod adults and nauplii (34.9%). Apparently cirripede reproduction occurred both in November (11%) and March, preceding the copepod nauplii outburst in March by a day. In December, fish larvae outnumbered fish eggs, the only time this occurred. chaetognaths peaked during December (4.3%) and March (7.1%), L. faxoni, absent in November, was found in small quantities in December and March. December was the only period pluteus larvae (0.6%) and bivalve larvae (0.6%) were found in area 3. Small concentrations of mysids and siphonophors occurred solely in March.

In area 4 (Table 12) holoplankton constituted 83.8% of the planktonic community. No copepod nauplii occurred while 77.7% of the community was copepod adults and immatures. Brachyuran larvae made up as much as 14.8% (6.7% porcellanid and as little as 3.6% within a 24-hour period toward the end of the month). Cirripede nauplii constituted 5.8%, penaeid larvae 2.1%. Caridean larvae dropped from 3.4% to 0.2% within a matter of hours.

DISCUSSION

The plankton at Johns and Guayanilla Bays was fundamentally neritic. However, it could be that some oceanic forms entered occasionally into the bays with tides

and oceanic surface currents.

The neritic plankton tended to have a far higher proportion of meroplanktonic forms. Crustaceans were easily predominant, both in numbers and species. The copepods represented the major group of crustacea in the zooplankton. Most of the species in this group belonged to Calanoida.

Acartia tonsa was the most abundant and common of Calanoida. It was present in all areas of both bays. A. lilljeborgii was also very common. A. spinata was limited to areas 2, 3 and 5 in Jobos Bay. Another calanoid, Temora turbinata, was relatively easy to identify in Jobos and Guayanilla Bays. Pseudodiaptomus cokeri, a calanoid which goes to the surface during the night, was reported in night stations at some Jobos and Guayanilla Bay areas. Similarly to A. tonsa, a sergestid, Lucifer faxoni was present in all Jobos and Guayanilla Bay areas.

Among the chaetognaths, immature specimens of the genus Sagitta were reported in most of the areas of both bays. S. hispida, S. tenuis and S. enflata were identified when mature specimens appeared. A few appendicularians, such as Oikopleura (Vexillaria) dioica and O. (Coecaria) longicauda were also identified in Jobos and Guayanilla Bays.

December distributions for the two study areas were representative of zooplankton concentrations in general. The larger copepods occurred in at least twice as great a number in every area in Guayanilla than at Jobos. Brachyuran larvae were comparable on the intake side and the effluent bay at Guayanilla to the most productive Jobos area, two and a half times greater at the mouth of the bay. Area 5 at Jobos had an appreciably greater fish egg concentration than anywhere else in Guayanilla or Jobos, but again Guayanilla had a better overall production. Jobos area 1 was comparable to Guayanilla area 1 for chaetognaths, but Guayanilla 2 and 3 were much richer than any other Jobos area, the mouth of Guayanilla (area 4) three and a half times better than Jobos 1. For total macrozooplankton, area 5 at Jobos (99.6/m^3) had the richest concentration recorded, still only about 1/4 that of the Guayanilla input bay (area 1). The Guayanilla effluent bay had almost twice as great a concentration and almost ten times as many plankters at its mouth as the most productive area in Jobos.

The mouth of the effluent cove, even though the water temperature there is 5° C. above ambient, has three times as many copepods and fish eggs, two and a half times as many brachyuran larvae, three and a half times the chaetognath concentration and, in fact, approximately three times the total plankters than the embayment near the cooling water intake.

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TABLE 1

CHARACTERISTICS OF JOBOS BAY STATIONS

Station Number	Date of Samples	Time	Area	Mesh Size	Length of tow minutes	# M^3 Sampled	% of Copepods	#/M^3
13	12-13-71	1515	1	380	15	134.9	36.5	55.8
12	12-13-71	1335	2	380	15	140.8	91.7	8.0
21	1-28-72	0003	2	380	5	54.6	74.3	512.1
31	2-4 -72	1030	2	60	20	80.0	64.3	225
32	2-4 -72	1100	2	60	5	20.0		
2	11-9 -71	2215	3	380	5	30.1	86.7	91.0
3	11-10-71	0845	3	380	5	44.3	49.8	174.3
1	11-9 -71	1400	4	380	5	25.9	17.4	22.7
6	12-8 -71	1532	4	380	15	92.3	44.2	28.4
11	12-9 -71	1449	4	380	15	56.3	20.0	10.7
7b	12-8 -71	1625	5	380	15	110.3	7.5	8.6
8	12-8 -71	2303	5	380	15	69.8	29.9	99.6
10	12-9 -71	1036	5	380	25	72.9	24.0	12.0
26	2-3 -72	1710	5	60	15	60.0	66.5	790.8
27	2-3 -72	1731	5	60	5	20.0		
29	2-4 -72	0458	5	60	5	20.0	92.8	4316.0
4	11-10-71	1000	6	380	10	57.6	34.5	186.2
9	12-8 -71	1012	6	380	10	61.8	67.3	64.3
22	2-3 -72	1503	6	60	10	40.0	93.4	1534.0

TABLE 2

SUMMARY OF ZOOPLANKTON DATA FOR AREA I

JOBOS BAY

	Station JB - 13	
	A	B
Amphipods		
Appendicularia	0.2	0.3
Bivalve larvae		
Brachyuran zoea	13.0	28.0
Caridean larvae	6.3	9.5
Chaetognaths		
Cladocera		
Copepods	24.3	43.8
Cumaceans		
Decapod larvae		
Euphausids		
Fish eggs (total)	1.4	2.0
Anchovy eggs	0.4	0.5
Fish larvae		
Foraminifers		
Gastropod larvae		
Isopods		
Lucifer faxoni	2.6	4.0
Medusae		
Mysidae		
Nauplii (total)	5.2	8.0
Copepods	-	-
Cirripedes	5.2	8.0
Ostracods		
Penaeid larvae	2.0	3.1
Pluteus larvae		
Polychaete larvae		
Porcellanids	0.6	1.0
Siphonophors	0.2	0.3
Tintinnids		
Totals	55.8	100.0

A = #/M^3 B = % of total catch

TABLE 3

SUMMARY OF ZOOPLANKTON DATA FOR AREA 2

JOBOS BAY

	Station 12		Station 21		Station 31 & 32	
	A	B	A	B	A	B
Amphipods	0.0	0.2			0.3	0.1
Appendicularia	0.0	0.2	2.2	0.4	7.0	3.1
Bivalve larvae					2.0	0.9
Brachyuran larvae	0.1	1.4	30.0	5.9	1.7	0.8
Caridean larvae			5.1	1.0	3.0	1.3
Chaetognaths			46.9	9.3	2.0	0.9
Copepods	7.4	91.6	381.0	74.4	144.7	64.3
Decapod larvae	0.2	2.1	10.3	2.0	0.8	0.3
Fish eggs (total)	0.1	1.2	10.3	2.0	4.5	2.0
Anchovy eggs	0.0	0.4			3.0	1.3
Fish larvae			6.6	1.3		
Isopods	0.0	0.2				
Lucifer faxoni	0.0	0.2	0.7	0.1		
Medusae			5.1	1.0	0.5	0.2
Nauplii (total)	0.2	2.5	8.8	1.7	25.7	11.4
Cirripedes			8.8	1.7	25.8	11.4
Nemertineans					0.5	0.2
Ostracods					2.7	1.2
Peneid larvae			0.7	0.1		
Polychaete larvae			2.2	0.4		
Porcellanid larvae	0.0	0.4	2.2	0.4	1.3	0.6
Totals	8.0	100.0	512.1	100.0	225.5	100

A = #/M^3 sampled

B = % of total catch

TABLE 4

SUMMARY OF ZOOPLANKTON DATA FOR AREA 3

JOBOS BAY

	Station JB - 2		Station JB - 3	
	A	B	A	B
Amphipods	0.2	0.3		
Appendicularia	3.3	3.6	0.8	0.5
Bivalve larvae				
Brachyuran larvae	1.6	1.8	60.6	34.4
Caridean larvae				
Chaetognaths	1.6	1.8	3.2	1.9
Copepods	79.1	86.4	86.3	49.8
Decapod larvae	3.7	4.1	14.6	8.4
Fish eggs (total)	0.7	0.8	1.6	0.9
Anchovy eggs				
Fish larvae	0.2	0.3	0.4	0.2
Isopods	0.2	0.3		
Lucifer faxoni	0.2	0.3	2.4	1.4
Mysids	0.2	0.3		
Nauplii (total)			0.4	0.2
Copepods				
Cirripedes				
Pluteus larvae			1.2	0.7
Porcellanid larvae			2.8	1.6
Totals	91.0	100.0	174.3	100.0

A = #/M^3 B = % of total catch

TABLE 5

SUMMARY OF ZOOPLANKTON DATA FOR AREA 4

JOBOS BAY

	JB - 1		JB - 6		JB - 11	
	A	B	A	B	A	B
Amphipods					1.1	10.0
Appendicularia	4.4	19.2	2.9	11.0	0.4	3.3
Brachyuran larvae	4.6	20.2	1.9	6.4	1.1	10.0
Chaetognaths	1.8	8.0	0.5	1.8		
Cladocers	2.1	9.0	0.1	0.7		
Copepods	3.7	16.2	17.6	61.4	2.1	20.0
Cumaceans						
Decapod larvae	1.6	7.0	2.3	8.0	3.5	33.3
Euphausid larvae						
Fish Eggs (total)	3.2	14.1	2.1	7.2	1.4	13.3
Anchovy eggs						
Fish larvae	0.2	1.2	0.8	2.7		
Lucifer faxoni			0.1	0.4		
Medusae	0.2	1.1				
Pluteus larvae	0.2	1.0				
Polychaete larvae	0.2	1.0				
Siphonophors	0.5	2.0	0.1	0.4		
Unidentified					1.1	10.1
Totals	22.7	100.0	28.4	100.0	10.7	100.0

A = # M^3 B = % of total catch

TABLE 6

SUMMARY OF ZOOPLANKTON DATA FOR AREA 5

JOBOS BAY

	JB - 7b		JB - 8		JB - 10		JB - 26 & 27		JB - 29	
	A	B	A	B	A	B	A	B	A	B
Amphipods			0.5	0.5			1.0	0.1	42.0	1.0
Appendicularia	0.3	3.0	12.4	12.4	0.8	6.9	10.0	1.3	16.0	0.4
Ascidian larvae							2.0	0.3	8.0	0.2
Bivalve larvae							1.0	0.1	4.0	0.1
Brachyuran larvae	1.8	21.1	6.6	6.7	2.4	21.3	12.3	1.6	38.0	0.9
Caridean larvae							9.0	1.1	20.0	0.5
Chaetognaths			0.9	0.9	0.0	0.5	2.4	0.3	42.0	1.0
Cladocers			1.4	1.4	0.1	1.0				
Copepods	0.6	7.4	29.8	29.9	2.6	23.8	526.3	66.5	4000.0	92.8
Decapod larvae	2.2	25.3	12.8	12.9	1.0	9.4	8.0	1.0	6.0	0.1
Fish eggs (total)	0.5	6.3	26.6	26.7	3.0	27.2	10.0	1.3	36.0	0.8
Anchovy eggs									2.0	0.3
Fish larvae	0.1	1.0	0.9	0.9	0.0	0.5	2.0	0.3	8.0	0.2
Foraminifers							0.8	0.1		
Gastropod larvae							14.5	1.8	4.0	0.1
Lucifer faxoni	0.3	3.2	0.9	0.9	0.2	0.1	3.9	0.5	14.0	0.3
Medusae	0.2	2.1			0.2	1.5				
Mysids			0.7	0.7			5.0	0.6	2.0	0.0
Nauplii (total)	2.5	29.5	5.7	5.8	1.2	1.3	108.1	13.7	54.0	1.2
Copepods					0.5	5.0				
Cirripedes					0.1	1.0	66.0	8.4	54.0	1.2
Ostracods							2.5	0.3	14.0	0.3
Penaeid larvae							1.0	0.1	2.0	0.0
Pluteus larvae	0.1	1.1			0.0	0.5	1.0	0.1		
Polychaete larvae			0.2	0.2			4.0	0.5		
Porcellanid larvae			0.2	0.1						
Totals	8.6	100.0	99.6	100.0	12.1	100.0	790.8	100.0	4316.0	100.0

A = #/M^3 B = % of total catch

TABLE 7

SUMMARY OF ZOOPLANKTON DATA FOR AREA 6

JOBOS BAY

	JB - 4		JB - 9		JB - 22	
	A	B	A	B	A	B
Amphipods			0.4	0.6		
Appendicularia	6.2	3.3	1.2	1.9	4.0	0.3
Ascidian larvae	1.6	0.8				
Brachiopod larvae	0.5	0.3				
Brachyuran larvae	19.2	10.3	4.0	6.3	2.0	0.1
Caridean larvae					1.0	0.1
Chaetognaths	54.6	29.2	0.4	0.6	8.0	0.5
Cladocers	2.1	1.1				
Copepods	64.5	34.5	43.3	67.3	1385.0	93.0
Decapod larvae	22.9	12.3	6.1	9.4	3.0	0.2
Fish eggs (total)	7.3	3.9	4.5	6.9	36.0	2.4
Fish larvae	2.1	1.1	0.8	1.3	1.0	0.1
Gastropod larvae					3.0	0.2
Lucifer faxoni			0.8	1.3		
Mysids			0.4	0.6		
Nauplii (total)			2.0	3.1	44.0	2.9
Copepods					5.0	0.3
Cirripedes					39.0	2.6
Ostracods					2.0	0.1
Pluteus larvae	1.0	1.0			1.0	0.1
Polychaete larvae	0.5	0.3				
Porcellanid larvae	2.1	1.1				
Siphonophors	1.6	0.8				
Unidentified			0.4	0.7		
Totals	186.2	100.0	64.3	100.0	1534.0	100.0

A = #/M^3 B = % of total catch

TABLE 8

CHARACTERISTICS OF GUAYANILLA BAY STATIONS

Station Number	Date of Samples	Time	Area	Mesh Size	Length of tow minutes	# M^3 Sampled	% of Copepods	#/M^3
Area of inlet	12-6 -71	1500	1	60	15	60	76.7	3505.0
GB-A	12-19-71	1400	1	380	13	82.4	66.8	342
GB-B	12-19-71	1425	1	380	10	77.2		
GB-6	11-18-71	1400	2	60	5	40.0	89.9	2008.9
GB-J	12-21-71	1830	2	380	15	116.6	64.3	188.9
Small net	3-9 -72	1400	*	60	3	36	61.4	2561.6
GB-Y	3-22-72	1922	*	300	5	120	24.2	49.7
GB-8	11-18-71	1425	3	60	5	20	60.2	4568.1
GB-G	12-20-71	1530	3	380	15	104.9	60.6	39.8
GB-L	12-21-71	1900	3	380	15	119.0	72.3	138.3
GB-Q	3-15-72	1442	3	300	13	90.0	24.6	56.4
GB-E	12-20-71	1430	4	300	5	3.5	70.7	288.6
GB-H	12-20-71	1600	4	380	5	3.5	77.0	962.4

*Net placed directly in mouth of discharge canal.

TABLE 9

SUMMARY OF ZOOPLANKTON DATA FOR AREA 1 IN GUAYANILLA

	Area of Inlet		Station GB-A & B	
	A	B	A	B
Amphipods				
Appendicularia			2.7	0.8
Ascidian larvae				
Bivalve larvae	6.7	0.2		
Brachyuran larvae	3.3	0.1	13.6	4.0
Brachiopod larvae	3.3	0.1		
Brachiopod adults	6.7	0.2		
Caridean larvae			10.9	3.2
Chaetognaths	10.0	0.3	7.1	2.1
Cladocers				
Copepods	2691.7	76.7	228.6	66.8
Decapods			21.4	6.3
Fish eggs (total)	23.3	0.7	7.6	2.2
Anchovy eggs			1.5	0.4
Fish larvae	16.7	0.5	3.3	1.0
Gastropods	86.7	2.5	1.0	0.3
Lucifer faxoni			0.5	0.2
Nauplii (total)	433.3	12.3	13.3	3.9
Copepods	250.0	7.1		
Cirripedes	183.3	5.2	6.8	2.0
Penaeid larvae			7.7	2.2
Pluteus larvae				
Polychaete larvae	223.3	6.4	0.5	0.1
Porcellanid larvae			15.5	4.5
Total	3505.0	100	342.0	100

A = #/M^3 B = % of total catch

TABLE 10

SUMMARY OF ZOOPLANKTON DATA FOR AREA 2 IN GUAYANILLA BAY

	Station GB-6		Station GB-J		Station - Small Output		Station GB-Y	
	A	B	A	B	A	B	A	B
Amphipods	1.9	0.1	18.9	10.0	4.4	0.2	15.3	30.8
Bivalve larvae					75.6	3.0		
Brachyuran larvae			5.2	2.8			2.0	4.0
Caridean larvae							4.7	9.4
Chaetognaths	1.3	0.1	3.4	1.8			0.7	1.3
Copepods	1806.3	89.9	121.8	64.3	1573.3	61.4	12.0	24.2
Decapod larvae			4.3	2.3				
Fish Eggs (total)			14.6	7.6	26.7	1.0	5.0	10.3
Fish larvae			0.9	0.5	4.4	0.2	2.7	5.4
Foraminifers					8.9	0.3		
Gastropod larvae	0.6	0.0			97.8	3.8		
Isopods			3.4	1.8			3.0	6.0
Lucifer faxoni			2.6	1.4			1.3	2.6
Medusae			0.9	0.5	1.7	0.1		
Nauplii (total)	193.8	9.6	9.5	5.1	720.0	28.0	1.0	2.0
Copepods			0.9	0.5	551.1	21.4		
Cirripedes			8.9	4.6	168.9	6.6	1.0	2.0
Nemertineans	0.6	0.1			4.4	0.2		
Ostracods					4.4	0.2		
Polychaete larvae	4.4	0.2	1.7	1.0	4.4	0.2	1.3	2.7
Porcellanid larvae			1.7	0.9			0.7	1.3
Siphonophors								
Tintinnids					35.6	1.4		
Total	2008.9	100	188.9	100	2561.6	100	49.7	100

A = #/M^3 B = % of total catch

TABLE 11

SUMMARY OF ZOOPLANKTON DATA FOR AREA 3 IN GUAYANILLA BAY

	Station G-8		Station GB-G		Station GB-L		Station GB-Q	
	A	B	A	B	A	B	A	B
Amphipods			0.2	0.6	1.0	0.7	3.3	5.9
Appendicularia	26.8	0.6						
Bivalve larvae			0.2	0.6				
Brachyuran larvae			4.5	11.3	10.9	7.9	21.0	37.4
Caridean larvae			0.5	1.2			1.8	3.3
Chaetognaths			1.2	3.0	5.9	4.3	4.0	7.1
Copepods	2750.0	60.2	24.3	60.6	100.0	72.3	13.8	24.6
Decapod larvae					6.7	4.8		
Stomatopod larvae					0.2	0.1		
Fish Eggs (total)	743.7	16.3			0.2	0.2	0.6	0.9
Anchovy eggs							0.2	0.3
Fish larvae					2.1	1.5	0.2	0.3
Foraminifers	113.9	2.5						
Gastropods	80.4	1.8			0.2	0.1	0.1	0.2
Lucifer faxoni					0.8	0.6	0.1	0.2
Medusae	6.7	0.1	0.2	0.6				
Mysids							0.2	0.2
Nauplii (total)	525.0	11.5	8.3	20.9	10.1	7.3	9.2	16.3
Copepods			0.2	0.6	9.7	7.0		10.3
Cirripedes			8.1	20.3	0.4	0.3		6.0
Penaeid larvae							1.2	2.1
Pluteus larvae			0.2	0.6				
Polychaete larvae	13.4	0.3						
Porcellanids			0.2	0.6	0.4	0.3	0.7	1.2
Siphonophors							0.2	0.3
Tintinnids	308.2	6.7						
Totals	4568.1	100	39.8	100	138.3	100	56.4	100

A = #/M^3 B = % of total catch

TABLE 12

SUMMARY OF ZOOPLANKTON DATA FOR AREA 4 IN GUAYANILLA BAY

	Station GB-E		Station GB-H	
	A	B	A	B
Amphipods			2.3	0.5
Appendicularia			2.3	0.5
Bivalve larvae			2.3	0.5
Brachyuran larvae	23.4	8.1	34.3	3.6
Caridean larvae	9.7	3.4	2.3	0.2
Chaetognaths	0.6	0.2	32.0	3.3
Copepods	204.0	70.7	748.6	77.0
Decapod larvae	2.3	0.8		
Fish Eggs (total)	0.6	0.2	9.1	0.9
Anchovy eggs	0.6	0.2	2.3	0.2
Fish larvae			4.6	0.5
Gastropod larvae			4.6	0.5
Isopods (Parasitic)			4.6	0.5
Lucifer faxoni	4.6	1.6	2.3	0.2
Medusae			9.1	1.0
Nauplii (total)	24.0	8.3	56.0	5.8
Copepods				
Cirripedes	24.0	8.3	56.0	5.8
Nemerteans			4.6	0.5
Penaeid larvae			20.6	2.1
Pluteus larvae				
Polychaete larvae			22.8	2.4
Porcellanid larvae	19.4	6.7		
Totals	288.6	100	962.4	100

A = #/M^3 B = % of total catch

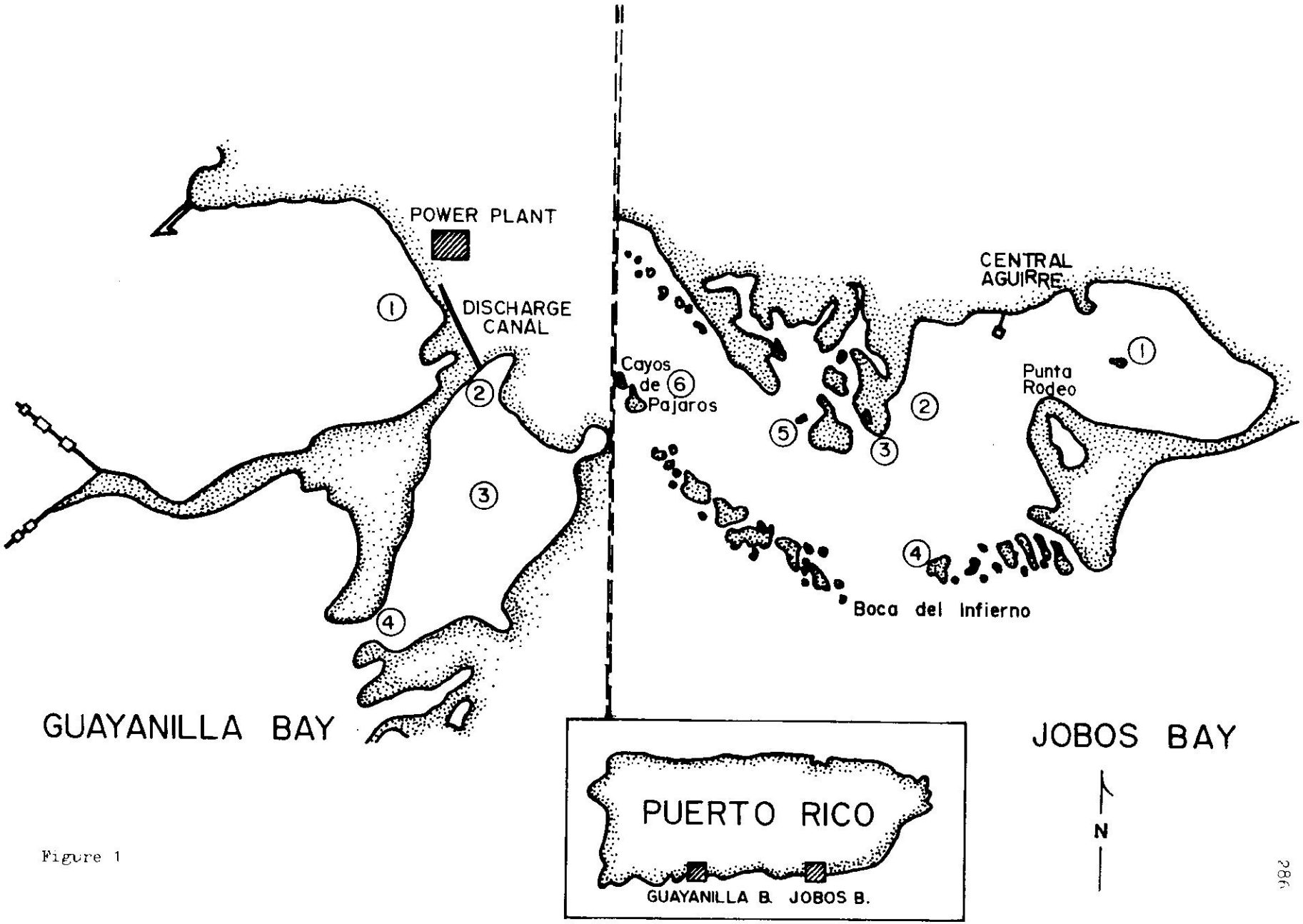
POWER PLANT
DISCHARGE CANAL
CENTRAL AGUIRRE
Cayos de Pajaros
Punta Rodeo
Boca del Infierno
GUAYANILLA BAY
JOBOS BAY
PUERTO RICO
GUAYANILLA B.
JOBOS B.
N

Figure 1

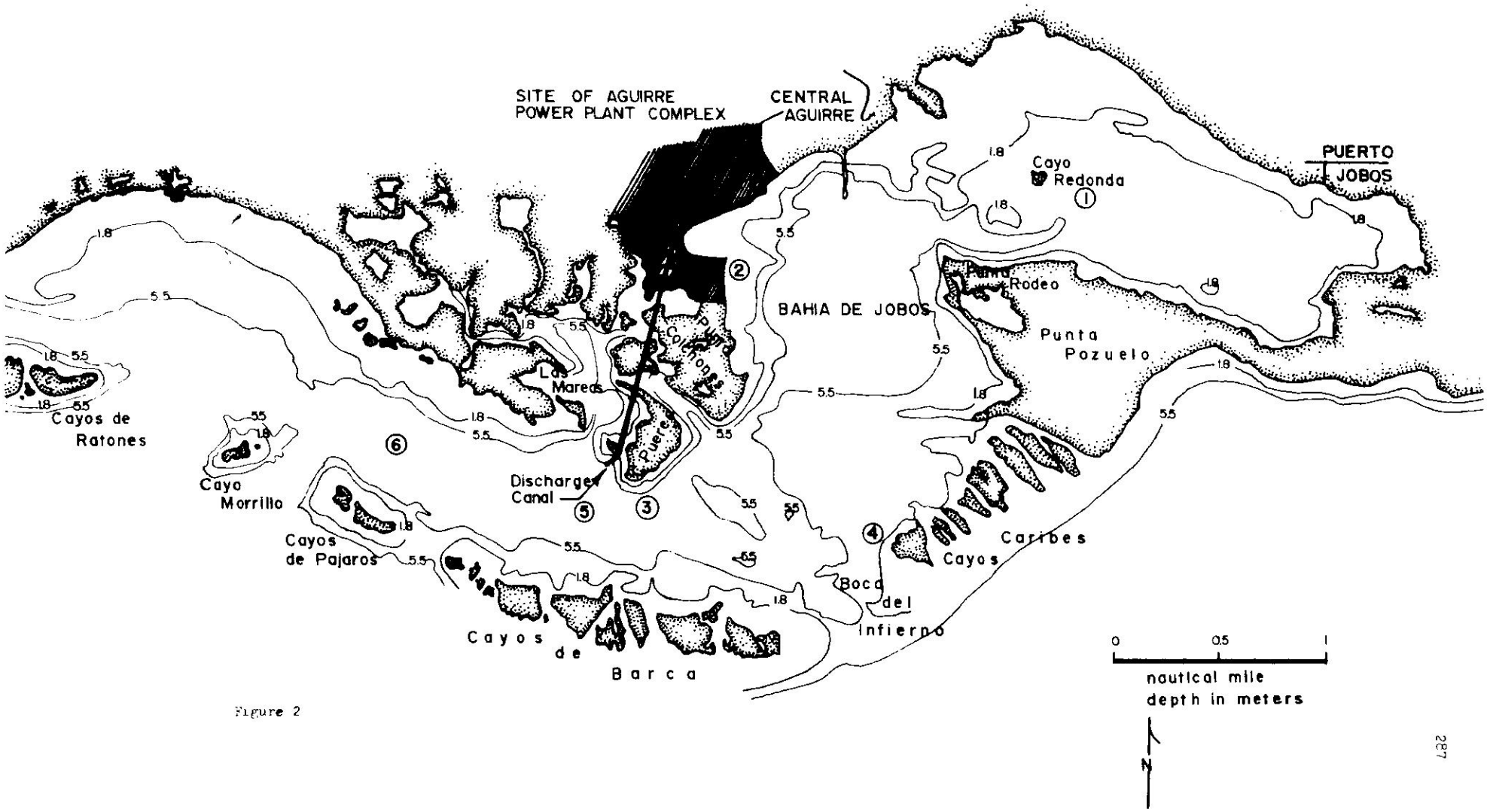
SITE OF AGUIRRE
POWER PLANT COMPLEX
CENTRAL
AGUIRRE
PUERTO
JOBOS
Cayo
Redonda
BAHIA DE JOBOS
Punta
Rodeo
Punta
Pozuelo
Las
Mareas
Punta
Colchones
Puerco
Cayos de
Ratones
Cayo
Morrillo
Discharge
Canal
Cayos
de Pajaros
Cayos
Caribes
Boca
del
Infierno
Cayos
de
Barca
1.8
5.5
0
0.5
1
nautical mile
depth in meters
N

Figure 2

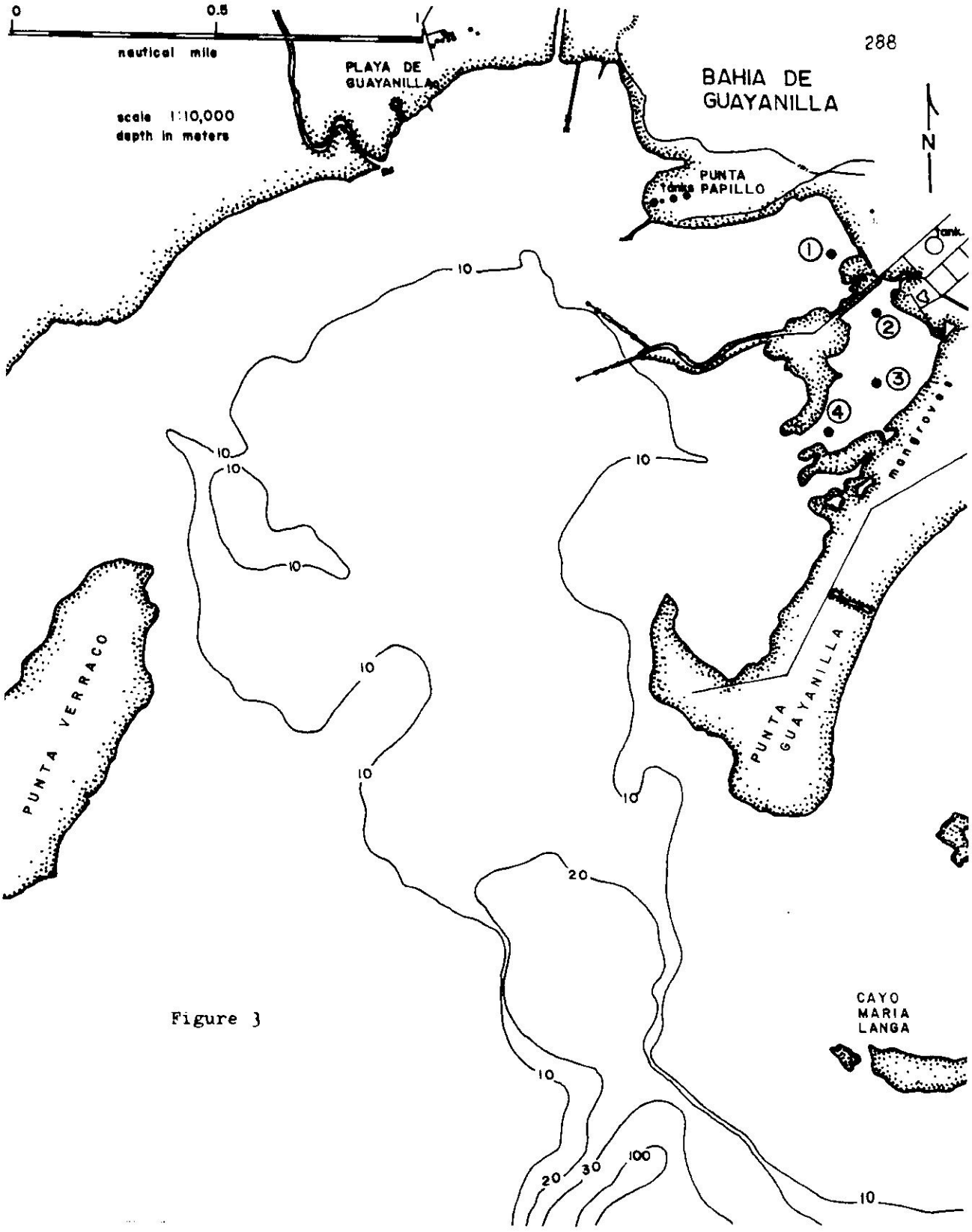
0
0.5
1
nautical mile
scale 1:10,000
depth in meters
PLAYA DE GUAYANILLA
BAHIA DE GUAYANILLA
288
N
PUNTA PAPILLO
Tanks
Tank.
1
2
3
4
10
20
30
100
mangrove
PUNTA VERRACO
PUNTA GUAYANILLA
CAYO MARIA LANGA

Figure 3

FORAMINIFERS OF GUAYANILLA BAY

Report No. 2

Introduction

The purpose of this study is to report the foraminiferal assemblages of sediment samples taken in Guayanilla Bay and to indicate their possible relationships to pollution.

Samples of Stations G-3A to G-9A were taken on May 16, 1972 and samples of Stations G-22 to G-29 were taken on June 10, 1972.

Samples were taken with a Phleger corer of about 10 cm^2 inside diameter. The upper centimeter section of each core was taken from all samples. The sections from 1 to 2 cm and from 2 to 3 cm from the top of the core were taken from some of the samples. The sections were preserved in 30% ethyl alcohol in the field. The protoplasm of the foraminifers was stained in the laboratory with Bengal rose.

The foraminifers and other organisms of about the same size were counted per sample.

The map of Text - figure 1 shows the position of stations in Guayanilla Bay.

Temperatures and Salinities

Table No. 2 shows temperatures and salinities. The highest temperature, 36.2°C., is at Station G-3A in the Eastern Central Lagoon and the closest to the outfall of hot water of the electric plant.

Salinities are in the normal range in most of the bay.

Organisms of the Size of Foraminifers in the Sediments of the Bay

Tables 3, 3A and 3B show the organisms comparable in size to foraminifers in Guayanilla, Mayaguez and Jobos Bay, respectively.

Nematodes are the most abundant organisms of Mayaguez and Jobos Bays. Generally they are several times more abundant than foraminifers. The largest number of nematodes per

sample, 3580 individuals, is from Station 16, Jobos Bay, and they are about 30 times more abundant than foraminifers (119 individuals).

The total number of foraminifers per sample is similar in the three bays. The total number of the other organisms is proportionally smaller in Guayanilla Bay than in Mayaguez and Jobos Bays. The number of nematodes is not only small in Guayanilla Bay, but also the foraminifers are several times more abundant than nematodes.

The pollution of Guayanilla Bay is influenced mainly by industrial chemicals, while the pollution of Mayaguez and Jobos Bays is mostly organic. Marszaleck et al. (1969) suggested that the test of the foraminifers is a defense against environmental changes. The nematodes do not have any shell to protect their bodies, which are exposed to chemical pollution, while the test of foraminifers appears to constitute a protection against this type of pollution. This may be the explanation of their abundance in relation to other organisms in Guayanilla Bay.

Foraminiferal Biofacies

The most abundant foraminifer in the bay is Ammonia catesbyana tepida. This species, associated with two other groups of foraminifers, constitutes the two biofacies determined in Guayanilla Bay. The biofacies are: Ammonia-Quinqueloculina-Ammobaculities and Ammonia-Fursenkoina. Table No. 4 shows the distribution of foraminiferal populations per station on which the division in biofacies was made.

The Ammonia populations of Guayanilla Bay are mostly constituted by one subspecies, A. catesbyana tepida (Cushman). Some specimens may be included as A. "advena (Cushman", but the small individuals are difficult to distinguish from A. catesbyana tepida. Only a few individuals are large and well developed and may be included as A. catesbyana catesbyana.

Ammonia-Quinqueloculina-Ammonbaculites Biofacies

This biofacies covers the shallowest part of the study area (the stations range from 1 m to 4.5 m of water depth).

Most of the stations are in Eastern Central Lagoon: Stations G-3A, G-5A, G-6A and G-9A. The Station G-7A is close to the entrance to the lagoon.

The dominant species is Ammonia catesbyana tepida. A large population was found in the sample of G-3A at a temperature of 36.2°C. This value is above the maximum growth temperature (34°C.) and the maximum temperature for reproduction (30°C.) found by Bradshaw (1961) for specimens of this species from Southern California and Baja California. The abundance of this species in Station G-3A shows its high resistance to thermal pollution.

Quinqueloculina rhodiensis is the most abundant species of the genus in Station G-9A. The specimens of this species in this bay are larger and with thicker costae than the ones reported for the polluted waters from Jobos Bay (Seiglie).

Ammonia Fursenkoina Biofacies

This biofacies includes the stations from 8.5 to 17.0 meters of water depth, Stations G-24 to G-29. The dominant species is Ammonia catesbyana tepida and the second in abundance is Fursenkoina pontoni.

Fursenkoina-Ammonia Biofacies

This biofacies corresponds to water depths from 17.5 to 18.5 meters (Stations G-22 to G-23).

F. pontoni is the dominant species and A. catesbyana tepida the second species in number.

"Pyritized" Living Foraminifers

Table No. 5 shows the living specimens of foraminifers with pyrite inside the test, and the stations in which they have been found. Ammonia catesbyana forma tepida is the most common pyritized foraminifer and constitute the 10% as mean value of the total population of this species in the stations in which it occurs. Fursenkoina pontoni is the second in number, but the percentage of "pyritized" specimens is only the 2.5% as mean value of the total living populations of this species.

Species Diversity

Species diversity was determined per station by the formula of the information function. Its values are shown in Table No. 6 and in Text - figure 2. The formula of information function is used by the communication to predict the name of the next letter in a message. It is considered a good measure of species diversity (McArthur and McArthur, 1969, McArthur, 1965). It is expressed by:

$$H = - \sum_{i=1}^{N} pi \log pi$$

Where N is the total number of species in the sample and pi the proportion between the number of specimens of the i^{th} species and the total number of specimens.

The values of Table No. 6 are not very different from the ones determined for Mayaguez Bay (Seiglie, 1972) and for Jobos Bay (Seiglie, Manuscript). The values are lower, generally, in the shallower stations than in the deeper ones. The lowest values are in the western central lagoon. Species diversity is lower in polluted water than in unpolluted waters, but the values determined in Guayanilla Bay cannot be directly related to pollution, because the values before pollution are not known. The species diversity was also determined for the top centimeter (0-1 cm), for the second (1-2 cm) and for the third centimeter (2-3 cm). Distortion of the surface may increase the number of foraminifers and the species diversity in the second and third centimeters. However, despite this possibility, the species diversity is the lowest in the second and third centimeters (see Table No. 6).

Conclusions and Summary

The low ratio between the number of nematodes and the number of foraminifers and the small number of nematodes per sample are the most important relationships between the microfauna and the pollution. These relationships suggest that the foraminiferal test is an effective protection against pollution.

The Ammonia populations of Guayanilla Bay and Mayaguez Bay are constituted mostly by A. catesbyana tepida, while most

of Jobos Bay populations are constitutes by A. catesbyana catesbyana. Some faunas of Jobos Bay are deformed and it is difficult to include them in a suospecies. The Eastern Central Lagoon also contains large populations of A. catesbyana tepida under conditions of thermal pollution.

The most abundant foraminifers in most of Mayaguez Bay are, in order of aoundance, Fursenkoina pontoni and Florilus grateloupii, while in Guayanilla Bay the most abundant species are Ammonia catesbyana tepida and Fursenkoina pontoni. The scarcity of Florilus grateloupii in Guayanilla Bay suggests that this species is not resistant to chemical pollution. The dominance of Ammonia catesbyana tepida, at depths in which Fursenkoina pontoni is dominant in Mayaguez Bay, suggests that this species is more resistant than F. pontoni to chemical pollution.

TABLE 2

TEMPERATURES IN DEGREES CENTIGRADE AND SALINITIES IN P.P.T.

Station	Depth in m	Surface Temperature	Bottom Temperature	Surface Salinity	Bottom Salinity	
G-3A	1.0	36.2°				1:30 P.M.
G-5A	2.0	35.0°				1:45 P.M.
G-6A	2.5	33.5°				2:30 P.M.
G-7A	1.5	29.1°				3:00 P.M.
G-9A	4.5					
G-20	21.0	29.3°	28.4°	35.9	35.6	7:50 A.M.
G-21	20.0	29.4°	28.6°	35.9	35.5	7:40 A.M.
G-22	18.0	29.5°	28.8°	36.0	35.7	7:20 A.M.
G-23	17.5	29.7°	29.6°	35.9	35.9	7:04 A.M.
G-24	15.0	29.8°	28.9°	36.0	35.9	6:45 A.M.
G-25	12.0	29.7°	29.6°	36.1	35.9	6:35 A.M.
G-26	9.0	30.3°	30.3°	36.0	35.9	6:00 P.M.
G-27	11.0	29.7°	29.8°	35.9	35.9	6:20 A.M.
G-28	8.5	29.8°	29.8°	36.0	36.0	6:53 A.M.
G-29	17.0	29.6°	29.6°	35.9	35.9	7:10 A.M.

Samples G-3A to G-7A: May 16, 1972
Samples G-20 to G-25 and G-27 to G-29: June 9, 1972
Sample G-26: June 10, 1972

TABLE 3

NUMBER OF ORGANISMS OF THE SIZE OF FORAMINIFERS PER SAMPLE, GUAYANILLA BAY

	22	23	24	25	26	27	28	29
Foraminifers	45	157	124	88	23	85	222	115
Crustaceans	1	6	4	4	4	7	4	8
Ostracods				4			2	
Nematodes	4	9		1	17	4		1
Other worms	1		2			2		
Bivalves				1				
Gastropods							1	
Unidentified	3	3	5				1	4

TABLE 3A

NUMBER OF FORAMINIFERS, NEMATODES AND OTHER ORGANISMS (OTHER WORMS, OSTRACODS, CRUSTACEANS, BIVALVES AND GASTROPODS) PER SAMPLE, JULY 1970

STATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Foraminifers	102	10	10	111	112	155	67	40	35	31	61	7	45	267	98
Nematodes	142	50	25	88	126	238	377	157	80	210	203	114	36	25	110
Other organisms	40	25	19	93	112	232	184	104	20	7	96	57	31	6	161

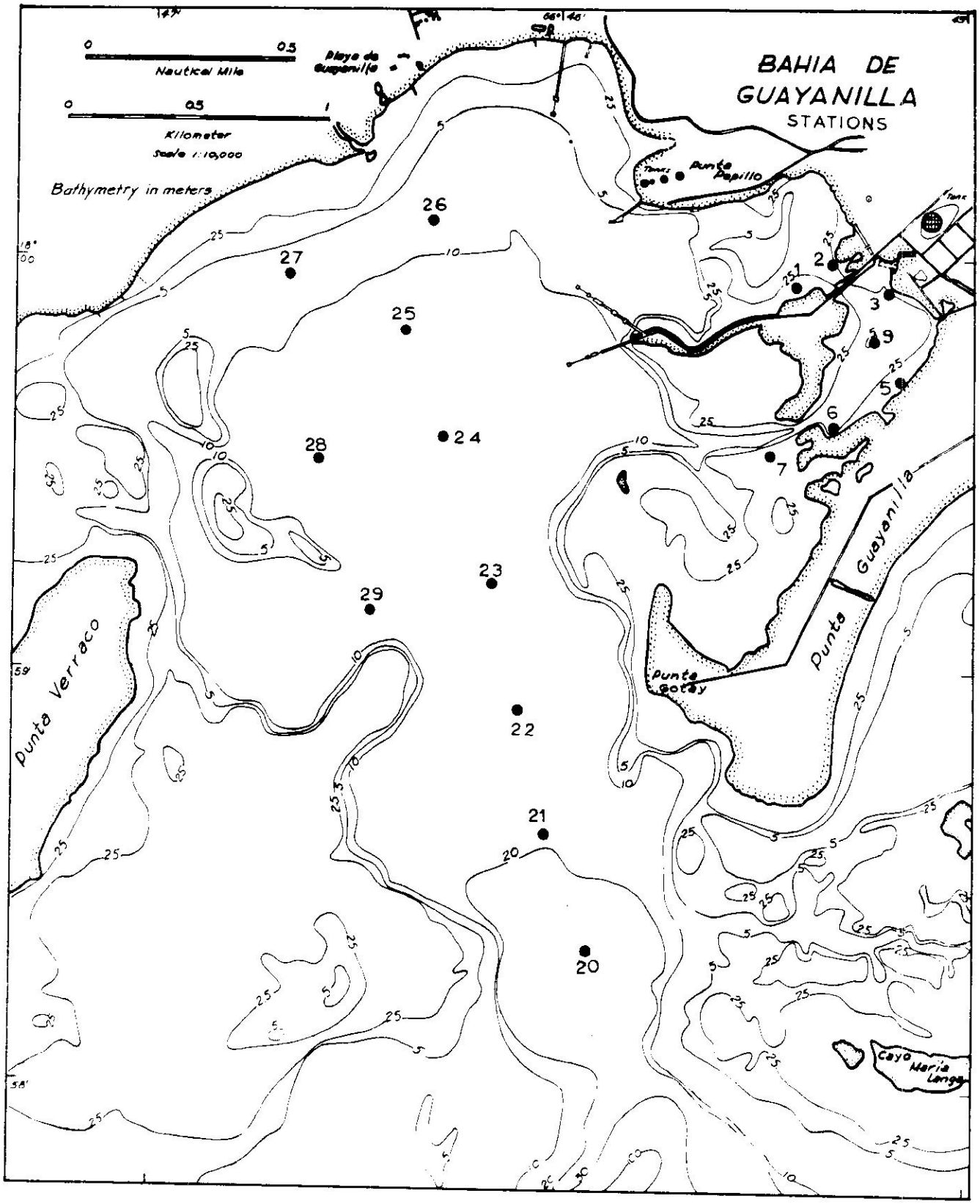
BAHIA DE
GUAYANILLA
STATIONS
Nautical Mile
Kilometer
Scale 1:10,000
Bathymetry in meters
Punta Papillo
Punta Verraco
Punta Gotay
Punta Guayanilla
Cayo Maria Langa
Playa de Guayanilla
1
2
3
4
5
6
7
20
21
22
23
24
25
26
27
28
29

Figure 1

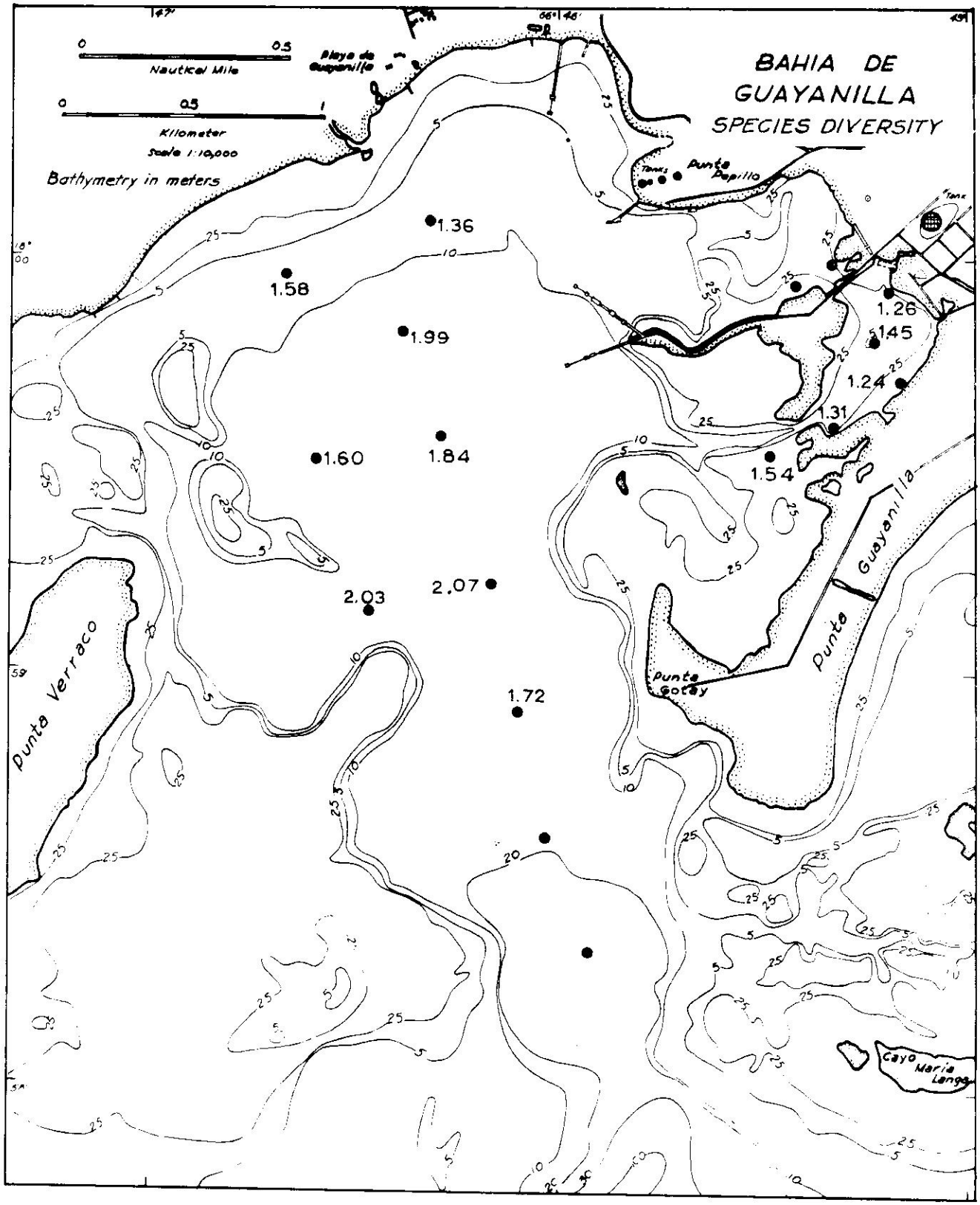
BAHIA DE
GUAYANILLA
SPECIES DIVERSITY
0 0.5
Nautical Mile
0 0.5 1
Kilometer
Scale 1:10,000
Bathymetry in meters
Playa de Guayanilla
Punta Papillo
Tanks
Tank
1.36
1.58
1.99
1.26
1.45
1.24
1.31
1.60
1.84
1.54
2.03
2.07
1.72
Punta Verraco
Punta Gotay
Punta Guayanilla
Cayo Maria Langa

Figure 2

TABLE 3B

NUMBER BY STATION OF THE MICROSCOPI ORGANISMS: NEMATODES, OTHER WORMS, FORAMINIFERANS, CRUSTACEANS, PELECYPODS, OSTRACODS AND OTHERS

STATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Nematodes	988	210	403	454	802	342	418	70	908	34	183	974	1728	496	518	801	707	3036	276
Other worms	26	53	14	35	141	52	48	14	44	5	38	54	26	68	16	43	42	112	26
Foraminiferans	30	58	35	73	382	94	81	22	109	33	23	34	137	58	42	63	144	260	20
Crustaceans	56	34	61	81	110	64	74	16	46	1	34	32	24	58	13	34	15	24	2
Pelecypods	6	1	3	4	4	4	0	1	0	0	2	7	4	5	1	5	0	4	0
Ostracods	0	3	3	2	0	2	0	0	2	5	2	4	0	19	3	4	0	0	0
Gastropods	0	0	0	2	0	0	0	0	0	0	0	0	4	6	0	0	0	0	0
Unidentified	62	0	18	0	200	36	50	5	58	0	0	35	18	39	5	6	39	72	4
	1167	374	537	674	1638	594	671	121	1157	78	282	1038	1974	746	597	956	947	3508	328

TABLE 4

FORAMINIFERAL POPULATIONS PER SAMPLE IN GUAYANILLA BAY

	G-3A 0-1 cm.	G-3A 1-2 cm.	G-3A 2-3 cm.	G-5A 0-1 cm.	G-6A 0-1 cm.	G-7A 0-1 cm.	G-7A 1-2 cm.
Ammobaculites directus							
A. salsus		4		22		2	
Ammodiscus sp.							
Ammomarginulina foliacea	13				2	2	1
Ammonia catesbyiana tepida (1)	89	24	8	26	15	80	22
A. sp.	1						
Angulogerina cf. angulosa							
Bolivina cf.inflata							
B. pseudoplicata							
B. rhomboidalis							
B. sp.							
B. variabilis						1	
Brizalina lowmani	1						
B. striatula							
Bulimina marginata							
Buliminella elegantissima						1	
Cribroelphidium discoidale							
C. poeyanum	2				2		1
C. sp.						2	
Cyclogyra involvens							
Discorbinella floridensis					1		
Eggerella cf. advena							
Fissurina pellucida					1		
Florilus grateloupii	1					5	2
Fursenkoina pontoni						12	
Globocassidulina minuta							
Glomospira gordicelis					1		
G. sp. A							
Hopkinsina milletti							
Lagena laevis							
Miliolinella labiosa							
M. subrotunda							
Nonionella? fragilis							
Parvigenerina sp.							
Cf. Protoelphidium sp.							
Pseudonodosaria tenuistriata							
P. cf. torrida							
Quinqueloculina cf. candeiana							
Q. cf. poeyana							
Q. rhodiensis	13	2				13	5
Q. rhodiensis? (smooth var.?)	35	14	12			24	5
Q. spp.				10	1	3	
Q. subpoeyana					1		
Reophax caribensis							
R. nana				2			
R. scotti							
Rosalina floridana		1					
Sagrina cubana							
Sigmoilopsis arenata							
Textularia carlandi	1			2			
Triloculina sp.							
T. trigonula							
Trochammina cf. advena							
T. discorbis							
Otros							
	158	45	20	62	24	146	36

(1)Four abnormal specimens
*Confertum: cf.
**Affinis: aff.

TABLE 4 (CONT.) a

FORAMINIFERAL POPULATIONS PER SAMPLE IN GUAYANILLA BAY

	G-9A 0-1 cm.	G-9A 1-2 cm.	G-22 0-1 cm.	G-23 0-1 cm.	G-24 0-1 cm.	G-24 1-2 cm.
Ammobaculites directus						
A. salsus						1
Ammodiscus sp.						
Ammomarginulina foliacea	4	1				
Ammonia catesbyiana tepida (1)	7	3	13	21	68	5
A. sp.						
Angulogerina cf. angulosa			1	5		
Bolivina cf. inflata					1	
B. pseudoplicata			1	1		
B. rhomboidalis					1	
B. sp.					5	
B. variabilis				8	3	3
Brizalina lowmani			2*	10*	3*	
B. striatula			1		1	
Bulimina marginata					2	
Buliminella elegantissima					1	
Cribroelphidium discoidale						
C. poeyanum				1		
C. sp.			1			
Cyclogyra involvens				1	1	
Discorbinella floridensis						
Eggerella cf. advena				3	1	
Fissurina pellucida			2			1
Florilus grateloupii			1	1	1	
Fursenkoina pontoni			19	71	17	1
Globocassidulina minuta			1	7	1	
Glomospira gordialis						
G. sp. A						
Hopkinsina milletti						
Lagena laevis						
Miliolinella labiosa					1	
M . subrotunda				2		
Nonionella? fragilis				3	5	
Parvigenerina sp.						
Cf. Protoelphidium sp.				2		
Pseudonodosaria				1		
P. cf. torrida					1	
Quinqueloculina cf. candeiana						
Q. cf. poeyana				2		
Q. rhodiensis	4	11				
Q. rhodiensis? (smooth var.?)	8	1				
Q. spp.	1		2	4	4	
Q. subpoeyana					1	
Reophax caribensis			1	4		
R. nana						
R. scotti				1		
Rosalina floridana				1		
Sagrina cubana				4		
Sigmoilopsis arenata						
Textularia carlandi				2		
Triloculina sp.					3	
T. trigonula				1		
Trochammina cf. advena						
T. discorbis				1	3*	
Otros						
	24	16	45	157	124	11

(1) Four abnormal specimens

*Confertum: cf.

**Affinis: aff.

TABLE 4 (CONT.) b

FORAMINIFERAL POPULATIONS PER SAMPLE IN GUAYANILLA BAY

	G-25 0-1 cm.	G-26 0-1 cm.	G-26 1-2 cm.	G-27 0-1 cm.	G-28 0-1 cm.	G-29 0-1 cm.
Ammobaculites directus					1	
A. salsus		4				1
Ammodiscus sp.					1	
Ammomarginulina foliacea						
Ammonia catesbyiana tepida (1)	36	10	19	53	135	38
A. sp.						
Angulogerina cf. angulosa				1	1	3
Bolivina cf. inflata						
B. pseudoplicata					1	1
B. rhomboidalis						1
B. sp.						
B. variabilis						2
Brizalina lowmani	5				8*	1
B. striatula			1	3	3	
Bulimina marginata			2	1	3	1
Buliminella elegantissima						
Cribroelphidium discoidale				1		
C. poeyanum					1	
C. sp.				3	1	
Cyclogyra involvens						
Discorbinella floridensis						
Eggerella cf. advena						
Fissurina pellucida						
Florilus grateloupii	4			2	8	1
Fursenkoina pontoni	17	2		8	29	39
Globocassidulina minuta	3			1		
Glomospira gordialis						2
G. sp. A	1					
Hopkinsina milletti					3	
Lagena laevis	1				1	1
Miliolinella labiosa						1
M. subrotunda						
Nonionella? fragilis	5					1
Parvigenerina sp.					2	
Cf. Protoelphidium sp.				1		
Pseudonodosaria						
P. cf. torrida						
Quinqueloculina cf. candeiana					1	1
Q. cf. poeyana				1**		
Q. rhodiensis						
Q. rhodiensis? (smooth var.?)						
Q. spp.	9	6		3	5	4
Q. subpoeyana						
Reophax caribensis	1					3
R. nana				1		
R. scotti				1	2	
Rosalina floridana		1			1	4
Sagrina cubana	1			1		
Sigmoilopsis areanta					1	
Textularia carlandi	2				3	3
Triloculina sp.	1					
T. trigonula						
Trochammina cf. advena						2
T. discorbis	1		2	4	11	5
Otros	1					
	88	23	24	85	222	115

(1) Four abnormal specimens
*Confertum: cf.
**Affinis : aff.

Table No. 5. "Pyritized" living foraminifers at the stations of Guayanilla Bay

	G-23 0-1 cm	G-24 0-1 cm	G-24 1-2 cm	G-25 0-1 cm	G-27 0-1 cm	G-29 0-1 cm
Ammonia catesbyana f. tepida	4	9	4	4	3	1
Fursenkoina pontoni	1	2			1	
Globocassidulina minuta	2					
Nonionella cf. fragilis	1					
Brizalina cf. inflata		1				

Table No. 6. Specific diversity by information function, H.

Station	H	Station	
G-3A, 0-1 cm.	1.26	G-23, 0-1 cm.	2.07
G-3A, 1-2 cm.	1.13	G-24, 0-1 cm.	1.84
G-3A, 2-3 cm.	0.68	G-24, 1-2 cm.	1.37
G-5A, 0-1 cm.	1.24	G-25, 0-1 cm.	1.99
G-6A, 0-1 cm.	1.31	G-26, 0-1 cm.	1.36
G-7A, 0-1 cm.	1.54	G-26, 1-2 cm.	0.74
G-7A, 1-2 cm.	0.93	G-27, 0-1 cm.	1.58
G-9A, 0-1 cm.	1.45	G-28, 0-1 cm.	1.60
G-9A, 1-2 cm.	0.92	G-29, 0-1 cm.	2.03
G-22, 0-1 cm.	1.72		

Study of the Effect of Heated Water on Turtle Grass,

Thalassia testudinum Konig, in Guayanilla Bay

by Peter Schroeder

Guayanilla Bay has a number of turtle grass beds, most of which appear to be dense, healthy and relatively unstressed by man's activities. Those beds of marine grasses found on either side of the mouth of the cove receiving heated effluence from the fossil fuel thermoelectric plant appear to be thinner, stressed and mixed with red-brown algal complexes.

Five stations have been established in the various turtle grass flats at Guayanilla. Station 1 is located immediately to the south of the entrance to the thermally affected cove; Station 2 is located to the north of the cove's entrance and Station 3 is located some distance to the west of the entrance. Stations 4 and 5 are control stations located in a different part of Guayanilla Bay near the intake to the power plant and are not subjected to thermal stress form the power plant.

Stations 1 and 2 show possible stress from current and/or the heated water leaving the cove. Station 3 is farther from the entrance of the cove and is an extremely thick, large bed of Thalassia evidently nearly unaffected by the power plant. This bed of grass compares in biomass with the control Stations 4 and 5.

Periodic samples have been taken with a specially constructed sampler (see diagram) from all five Thalassia stations and biomass figures for Thalassia from each sample have been ascertained. Dry weights of various parts of the Thalassia plant (according to Tomlinson and Vargo, 1966) have been recorded as well as total weight of plant material.

After dry weight was recorded, the plant material was ground with mortar and pestle and stored in anticipation of chemical analyses. (In Florida elemental ratios go through annual fluctuation; see Walsh and Grow, 1972).

In order to determine the effect of the thermal discharge on Thalassia plants in Guayanilla Bay, a turtle grass transplant experiment is envisioned. Floating plant boxes have been constructed from wood which are designed to hold nine samples taken from thick, healthy Thalassia flats in Guayanilla Bay. These boxes will hold the plants approximately fifteen inches below the surface and can be anchored wherever convenient. Once anchored, they can rise and fall with the tide and maintain the plants under nearly equivalent light conditions. In every sample certain blades will be marked (according to the technique of Zieman, 1968) in

order to determine growth rates. At intervals of two to four weeks one sample will be replaced in each box and examined for chemical analyses. Concurrent examination of associated organisms can be made to determine the effects of thermal water on the species diversity within the turtle grass community.

The plant boxes will hold Taylor maximum-minimum thermometers and will be anchored at three points within the thermally affected cove. Two boxes will be located outside the cove in Guayanilla Bay to serve as controls. These will be located near existing apparently healthy grass beds.

It is hoped that this experiment will lead to a determination of maximum temperature at which Thalassia communities can exist in Puerto Rico. It may also indicate what form thermal stress first affects the plant itself.

THALASSIA SAMPLER

.0203 METER^2

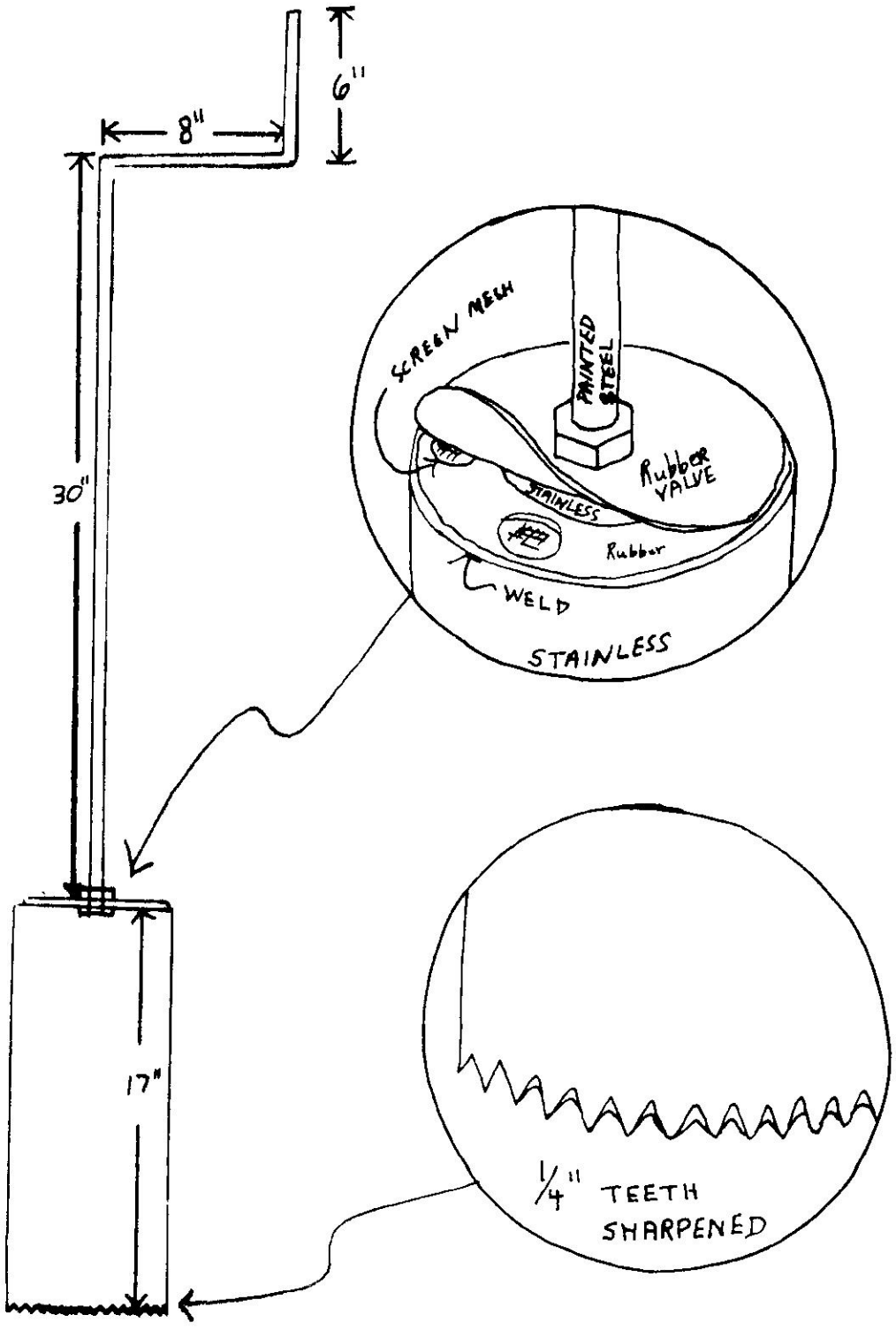

Figure 1

PLANT BOX FOR GROWING

THALASSIA

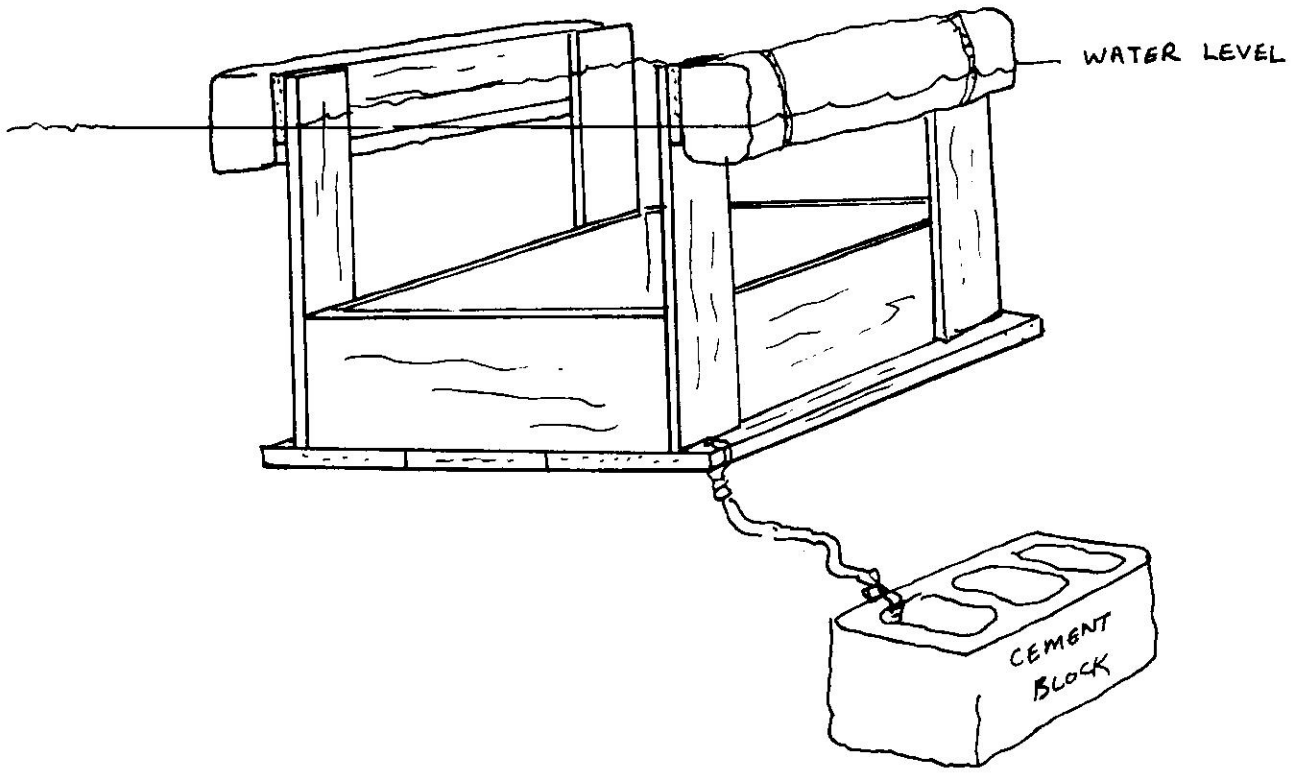

Figure 2

Station	Date collected	Wet weight	Dry weight(grams)
1A	7/5/72		
Growing tips 3			
Roots		5.6	.7596
Rhizomes		8.8	1.9433
vertical (short) shoots		1.4	.3379
new leaves		12.2	1.1901
old leaves		31.4	3.2343
old sheathing leaves		7.1	.7890
Total		66.5	8.254
Grams per meter square		3,276	406.6
3A			
Growing tips 8			
Roots		39.4952	3.8410
Rhizomes		27.8235	5.5819
vertical (short) shoots		8.6453	2.0720
new leaves		28.9616	3.6130
old leaves		52.4558	3.5765
old sheathing leaves		- - - -	2.8814
Total		157.4558	21.5658
Grams per meter square		7,756	1062.4

Station	Date collected	Wet weight	Dry weight (grams)
4A	7/5/72		
Growing tips	19		
Roots		71.6	6.3063
Rhizomes		42.6	6.9540
vertical (short) shoots		2.5	2.2959
new leaves		15.5	2.3040
old leaves		44.0	4.9123
old sheathing leaves		20.5	2.4976
Total		196.7	25.2701
Grams per meter square		9704.	1244.8
5A	7/5/72		
Growing tips	8		
Roots		52.5	4.3671
Rhizpmes		25.6	.4940
vertical (short) shoots		2.5	.3395
new leaves		11.6	1.7307
old leaves		49.7	5.6310
old sheathing leaves		30.0	2.5356
Total		171.9	15.0979
Grams per meter square		8468.	743.7

Station	Date collected	Wet weight	Dry weight (grams)
3B	7/5/72		
Growing tips	0		
Roots		52.3	6.0251
Rhizome		22.0	3.6436
Vertical - Shoats		1.7	.3313
New leaves		18.2	1.6558
Old leaves		36.8	4.7481
Sheathing		13.2	1.4384
Total		144.2	17.8423
Grams per meter square		7103	878.9
4B	7/5/72		
Growing tips	5		
Roots		92.1	9.7106
Rhizome		71.0	10.2325
Vertical shoots		3.6	.4981
New leaves		13.7	1.4897
Old leaves		70.4	6.7504
Sheathing		50.3	4.8225
Total		301.0	33.5038
Grams per meter square		14.832	1650.2
5B	7/5/72		
Roots		69.3	6.0076
Rhizome		27.8	3.9867
Vertical shoots		11.1	2.3280
New leaves		16.0	1.9849
Old leaves		49.7	4.0910
Sheathing		35.4	2.1054
Total		209.3	20.5036
Grams per meter square		10310.	1009.8

Station	Date collected	Wet weight	Dry Weight (grams)
1A	7/19/72		
Growing tips	3		
Roots		6.1	.5384
Rhizome		7.1	1.1910
Vertical shoots		1.7	.3116
New leaves		1.3	.1452
Old leaves		9.1	.8011
Sheathing		1.5	1.0447
Total		26.8	4.0320
Grams per meter square		1320.	198.6
2A	7/19/72		
Growing tips	6		
Roots		42.9	4.6713
Rhizome		26.0	4.7439
Vertical shoots		10.0	1.2880
New leaves		11.2	1.2577
Old leaves		45.9	4.4390
Sheathing		14.2	1.3285
Total		150.2	17.7284
Grams per meter square		7399.	873.4
3A	7/19/72		
Growing tips	3		
Roots		39.4	3.9966
Rhizome		47.4	7.6478
Vertical shoots		10.2	1.5865
New leaves		21.3	2.6354
Old leaves		63.5	6.5108
Sheathings		22.2	2.2224
Total		204.0	24.5995
Grams per meter square		10049	1211.8

Station	Date collected	Wet weight	Dry weight (grams)
5A	7/19/72		
Growing tips	12		
Roots		30.0	4.8821
Rhizome		17.9	4.6692
Vertical shoots		63.9	7.4637
New leaves		29.9	4.4300
Old leaves		46.7	4.7482
Sheathing		17.7	2.1363
Total		206.1	28.3295
Grams per meter square		10153	1395.5
1B	7/19/72		
Growing tips	0		
Roots		9.7	.9686
Rhizome		8.8	1.7347
Vertical Shoots		4.6	1.0090
New leaves		3.6	.4901
Old leaves		8.1	6.6416
Sheathing		13.4	1.1680
Total		50.2	12.0120
Grams per meter square		2473	591.7
2B	7/19/72		
Growing tips	4		
Roots		33.10	3.2841
Vertical Shoots		12.10	1.9203
New leaves		3.10	.3530
Old leaves		11.7	1.5469
Sheathing		8.8	.8289
Rhizome		14.1	2.4334
Total		82.9	10.3666
Grams per meter square		4084	510.7

Station	Date collected	Wet weight	Dry weight (grams)
3B	7/19/72		
Growing tips	4		
Roots		53.6	5.0299
Rhizome		45.2	7.2897
Vertical Shoots		9.9	1.4021
New leaves		11.5	1.1856
Old leaves		50.5	8.8149
Sheathing		40.1	3.7715
Total		210.8	27.4937
Grams per meter square		10384	1354.4
4B	7/19/72		
Growing tips	5		
Roots		49.00	5.6480
Rhizome		18.0	3.3848
Vertical shoots		5.1	.8900
New leaves		21.3	2.6417
Old leaves		63.5	6.0976
Sheathing		21.3	1.9040
Total		178.2	20.5661
Grams per meter square		8778.	1013.1
5B	7/19/72		
Growing tips	3		
Roots		119.4	11.2036
Rhizome		33.9	5.3456
Vertical shoots		15.0	2.5130
New leaves		32.0	3.9680
Old leaves		79.8	7.9486
Sheathing		66.0	6.2230
Total		346.1	33.2338
Grams per meter square		17049	1637.1

Station	Date collected	Wet weight	Dry weight (grams)
1A	8/9/72		
Growing tips	0		
Roots		1.0	.0572
Rhizome		4.2	.5827
Vertical Shoots		1.0	.1319
New leaves		6.0	.4680
Old leaves		3.4	.2597
Sheathing		3.0	.2165
Total		18.6	1.7160
Grams per meter square		916	84.5
2A	8/9/72		
Growing tips	6		
Roots		45.3	4.6880
Rhizome		30.4	5.7043
Vertical shoots		25.8	4.3285
New leaves		9.6	1.0026
Old leaves		22.1	2.0432
Sheathing		26.0	2.3293
Total		159.2	20.0959
Grams per meter square		7842	989.9
3A	8/9/72		
Roots		27.6	2.8075
Rhizome		20.2	3.8404
Vertical shoots		11.0	2.0002
New leaves		21.5	2.4467
Old leaves		37.5	5.2816
Sheathing		50.0	5.0420
Total		167.8	21.4184
Grams per meter square		8266	1055.1

Station	Date collected	Wet weight	Dry weight (grams)
4A	8/9/72		
Growing tips	3		
Roots		59.0	5.7621
Rhizome		25.0	3.9134
Vertical shoots		17.0	2.5309
New leaves		23.0	2.4296
Old leaves		63.4	6.5341
Sheathing		35.7	3.4081
Total		223.1	24.5782
Grams per meter square		10990	1210.7
1B	8/9/72		
Growing tips	0		
Roots		2.7	.2780
Rhizome		5.0	.8416
Vertical shoots		2.1	.3334
New leaves		2.0	.1638
Old leaves		9.1	.9355
Sheathing		7.0	No
Total		27.9	2.5523
Grams per meter square		1374	125.7
2B	8/9/72		
Growing tips	2		
Roots		27.3	2.9340
Rhizome		13.2	2.3580
Vertical shoots		15.7	2.1389
New leaves		9.0	.6617
Old leaves		27.7	2.1294
Sheathing		17.2	2.4950
Total		110.1	12.7170
Grams per meter square		5424	626.5

Station	Date collected	Wet weight	Dry weight (grams)
3B	8/9/72		
Growing tips	0		
Roots		35.2	3.1940
Rhizome		28.4	5.3607
Vertical shoots		10.0	1.5805
New leaves		12.6	1.4264
Old leaves		36.0	4.2980
Sheathing		21.6	4.9496
Total		143.8	19.3892
Grams per meter square		7084	955.1
4B	8/9/72		
Growing tips	3		
Roots		75.3	7.4103
Rhizome		28.1	4.8020
Vertical shoots		14.5	1.7390
New leaves		21.3	2.4201
Old leaves		61.0	6.0315
Sheathing		45.0	4.1425
Total		245.2	26.5454
Grams per meter square		12079.	1307.7
5B	8/9/72		
Growing tips	3		
Roots		123.0	11.3560
Rhizome		25.4	4.5698
Vertical shoots		18.0	3.4536
New leaves		29.2	3.0132
Old leaves		79.2	6.8974
Sheathing		67.2	5.7636
Total		342.0	5.7636
Grams per meter square		16847	1726.8

Station	Date collected	Wet weight	Dry weight (grams)
1A	6/20/72		
Growing tips	4		
Roots		21.2	2.4209
Rhizome		22.2	3.5903
Vertical shoots		9.4	1.6339
New leaves		21.5	2.3455
Old leaves		40.5	3.6655
Sheathing		16.5	1.7134
Total		131.3	15.3695
Grams per meter square		6468	757.1

MEAN WEIGHTS (GRAMS PER METER SQUARE)

Station	Wet Weight	Dry Weight
1	2638 g/m^2	360.7 g/m^2
2	6187 g/m^2	750.1 g/m^2
3	8440 g/m^2	1086.2 g/m^2
4	11277 g/m^2	1285.3 g/m^2
5	12565 g/m^2	1302.6 g/m^2

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MANGROVE ROOT COMMUNITIES IN A THERMALLY ALTERED AREA IN GUAYANILLA BAY

by

Seppo Kolehmainen,
Thomas Morgan
and Roberto Castro

INTRODUCTION

Thermal tolerance of tropical ecosystems and marine organisms have been studied very little and much of the available information in this respect comes from subtropics where the annual mean temperature is lower and the seasonal variation greater than in the tropics. Most of the thermal studies with tropical marine organisms in the Caribbean have been made in Biscayne Bay, Florida (Bader et al., 1970; Zieman, 1970; Thorhaug, 1970; Roessler and Zieman, 1970; Singletary, 1971). Some old studies (Mayer, 1914, 1918) are still the only existing data for the Caribbean corals. Only some intertidal species have been studied in this respect in the West Indies (Southward, 1962).

To get applicable data on the thermal tolerance of the species in Jobos Bay, studies were started in Guayanilla, fifty miles west of Jobos Bay, at the fossil fuel power plant site in October, 1971. The power plant has been operating on the eastern shore of Guayanilla Bay since 1957. Until the spring of 1972 the output of the plant was 310 MW. Now the plant produces 710 MW. The ecosystems around the discharge area of the cooling water resembles those in the Aguirre Navigational Channel, viz., mangrove swamps, turtle grass beds and mud bottom communities.

The effects of elevated temperatures upon plankton, benthic organisms, turtle grass beds, mangrove root communities and fish are studied in Guayanilla Bay in their natural environment. The results of these studies show the effect of long-term exposures of living populations to elevated temperatures. This section presents the data on the mangrove root communities over a period of one year. Some preliminary data have been given earlier (Kolehmainen and Morgan, 1972). Data on plankton, turtle grass and fish are given elsewhere in this report.

The power plant in Guayanilla takes cooling water from an embayment on the west side of the plant and discharges the water 10° C. above the ambient through a 100 m long canal into a 900 m long semi-enclosed cove on the southeastern side of the plant (Figure 1). Until March, 1972, the output of cooling water was 750 m^3/min. (188,000 gal./min.) and after a new 400 MW unit was added the output was raised to 1510 m^3/min. (398,000 gal./min.), the Δt being the same as before.

In addition to the heated water, Guayanilla Bay receives chemical and carbohydrate pollutants from the nearby oil refineries and chemical plants. Oil slicks appear periodically and the concentration of heavy metals, including Hg, Cd, Cr, Ni, Pb and V, is high in sea water and the resident marine organisms. The power plant uses chlorine treatment against fouling organisms in the condensers and chromates as an anti-corrodant. Free chlorine disappears quite fast, however, in the discharge canal. Part of free chlorine could have been associated with dissolved organic compounds of which many have been known to be toxic in a chlorinated form.

Fish kills have been reported occasionally around and downwind from the oil docks of Commonwealth Oil-refining Company (CORCO) and near the effluent discharge of Pittsburg Plat Glass, Inc. (PPG). These fish kills are attributed to dumping of toxic chemicals. No fish kills have ever been reported in the cove that receives cooling water from the power plant. Since the cooling water is taken from the bay *per se*, it is polluted by chemicals and hydrocarbons. It is therefore impossible to separate entirely the effects of elevated temperatures from other pollution. By using the intake area of the cooling water as a control area, the additional effect of elevated temperatures can be seen, however. The combination of chemical pollutants and heat may produce synergism, but if it exists, it only means that the effects of elevated temperatures are seen more pronounced. Therefore, it is safe to assume that whatever predictions on the effects of elevated temperatures are made with the data obtained in Guayanilla Bay, they will be conservative.

METHODS

Temperatures were recorded at several mangrove stations and turtle grass beds with recording thermographs. In addition

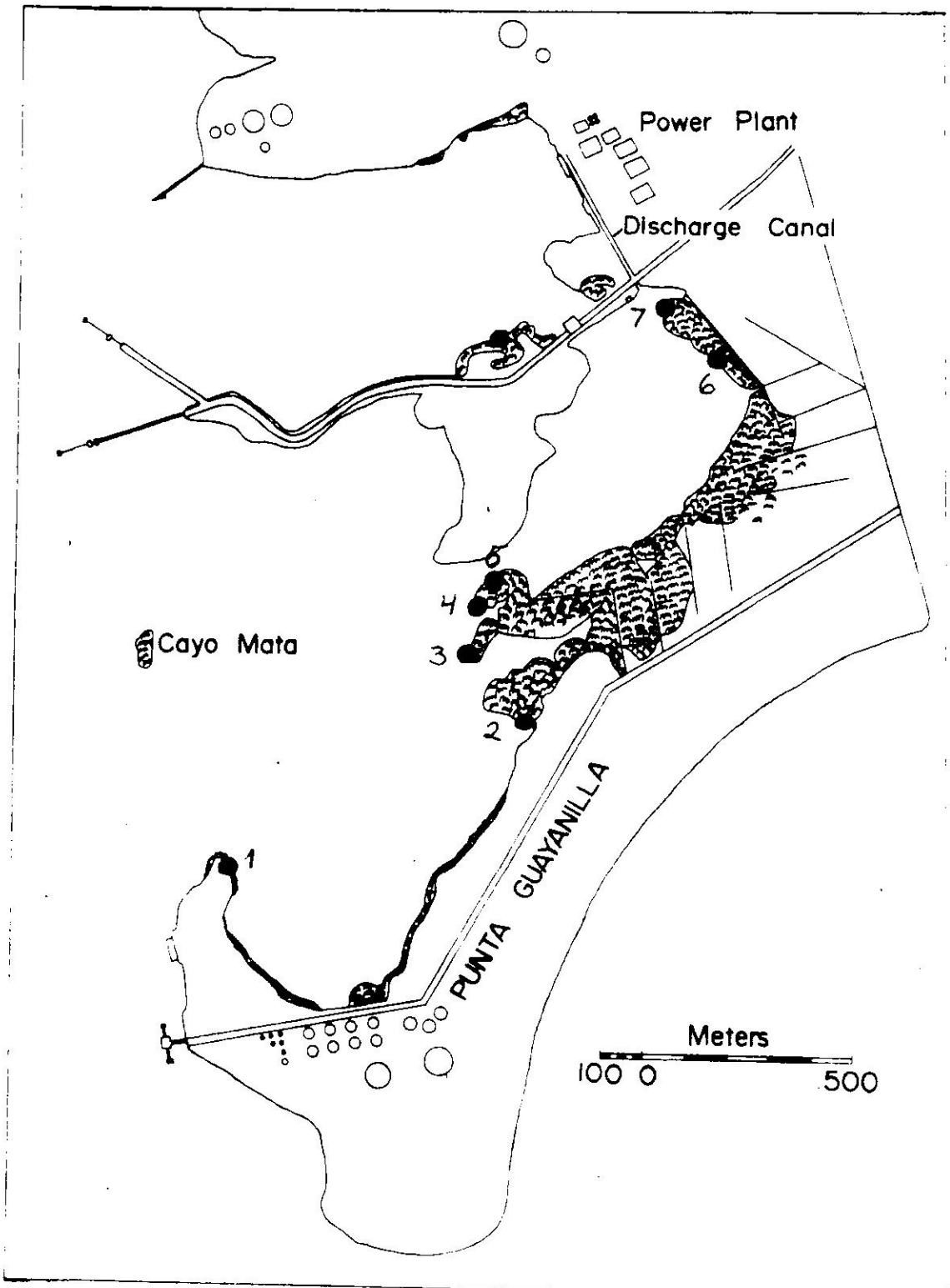


Figure 1. East side of Guayanilla Bay showing the location of the power plant and the sampling stations.

to this continuous monitoring of water temperatures, temperatures were measured with a calibrated thermometer whenever samples were taken. The horizontal and vertical distribution of temperature in the heated area was measured three times -- 9 October 1971, 13 January 1972, and 20 October 1972. Currents were measured in the cove with recording current meters and with flow meters.

Mangrove roots with organisms were collected periodically at eight stations (Figure 1) and, in addition, spot checks were made in twelve other stations. The species present, their biomass and vertical zonation were determined with three to six randomly sampled roots at each of the eight stations. The randomness was achieved by selecting every third root of every third tree if the root was over 0.5 m long. These roots were cut at mean water level and surrounded with a 0.5 mm mesh net before lifting into the boat. Crustaceans and fish were collected from the net and preserved with 70% alcohol while the roots with sessile organisms were put into polyethylene bags and kept in an icebox before they were taken to the laboratory. In the laboratory the roots were cut to 10 cm sections and the species present, the number of individuals (when applicable) and the biomass of each species as wet weight were determined in each section. The wet weight of species included the shells of mollusks and cirripedes, tubes of polychaetes and tests of ascidians, but only those of living specimens. Wet weight - dry weight ratios of the species are being determined presently. Besides sampling of roots, collecting of species and visual observations were made at each station to establish a list of species present at each temperature zone.

RESULTS

Temperature of Water

Ambient surface temperatures near the intake varied from 25° C. in winter to 31° C. in summer (Figure 2) and the temperature of the effluent varied from 35 to 40° C. When only the old generating units were operating two thermal plumes could be seen, one at the mouth of the discharge canal and one at the mouth of the cove to Guayanilla Bay (Figures 3, 4 and Plates I A - E). At the mouth of the discharge canal a rapid entrainment was observed. The temperature decreased over 2.5° C. within a distance of 100 m. From this distance toward the mouth of the cove

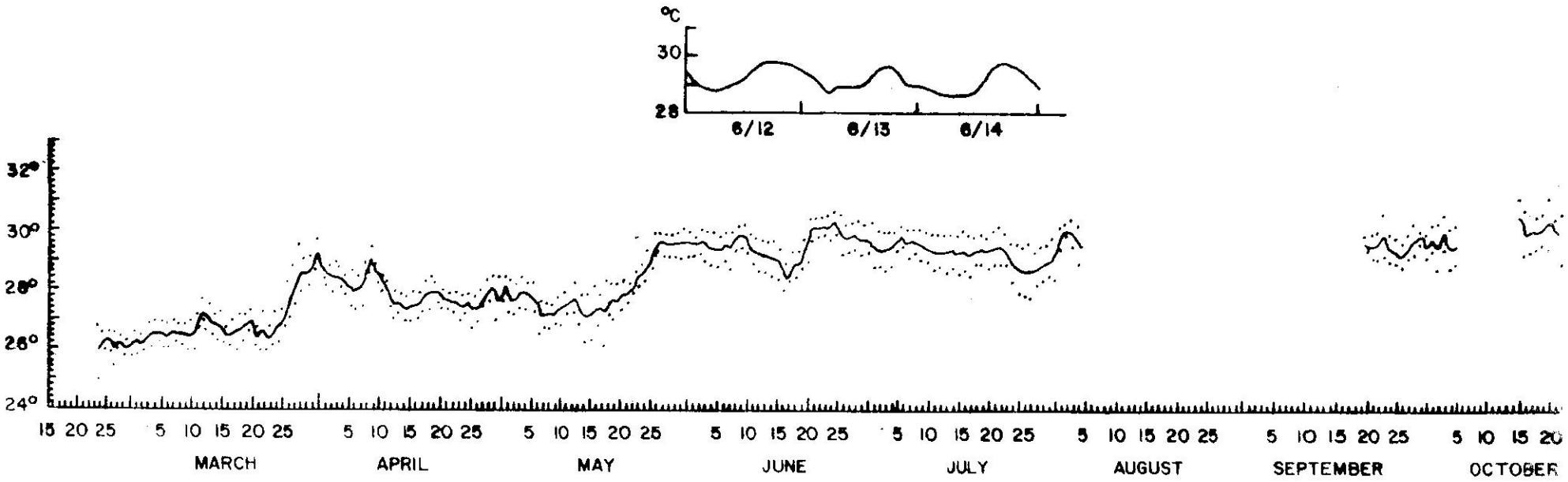
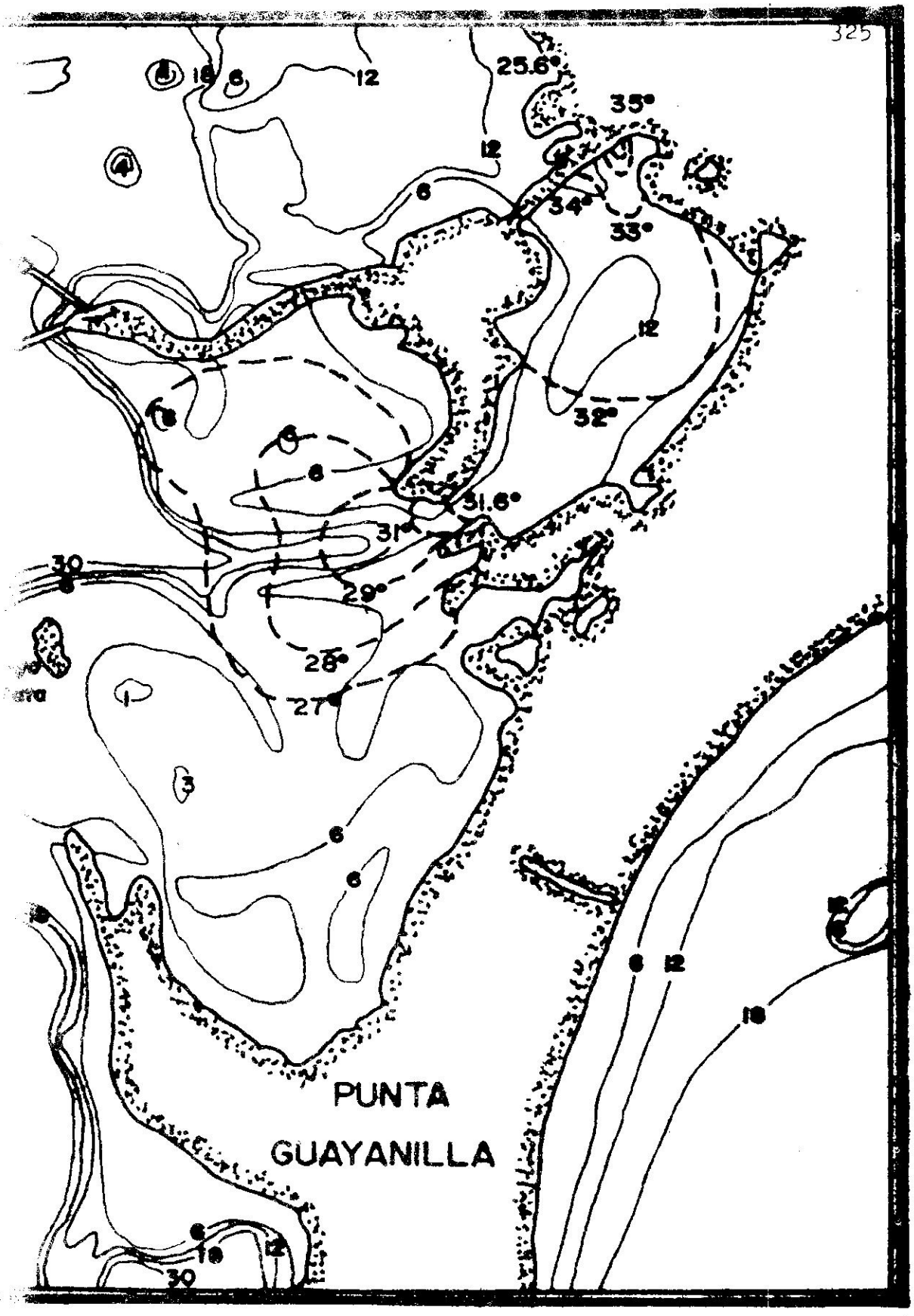


Figure 2 Water temperature in the mangroves at Control Station 20 cm. below the mean water level. The solid line is the daily mean while the dot express daily maxima and minima.



...ace temperature on Jan. 13, 1972. Soundings are in feet.

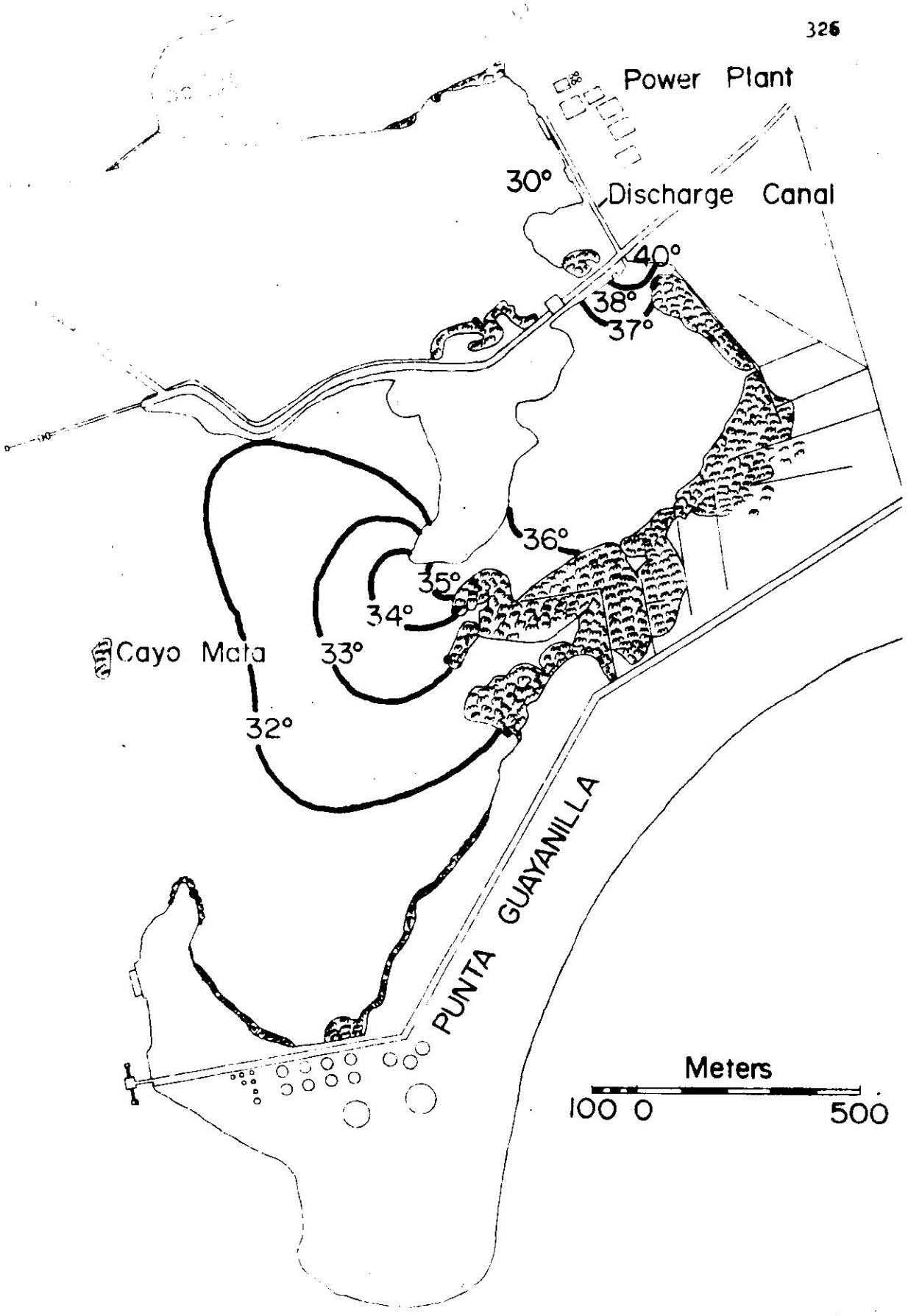


Figure 4 . Surface temperatures on October 9, 1972. Distribution of mangroves also shown.

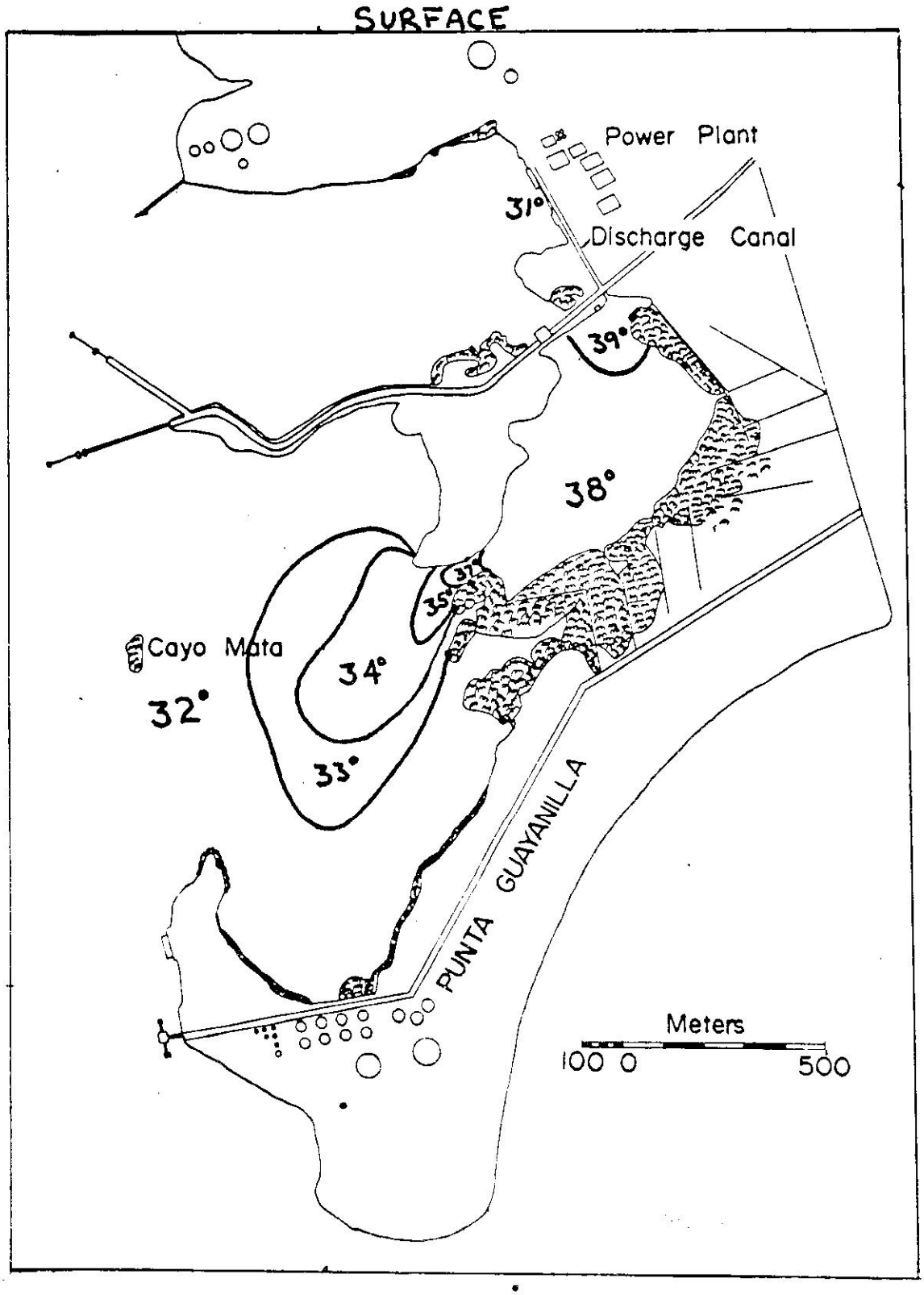


PLATE IA. Water temperature on the surface - October 20, 1972

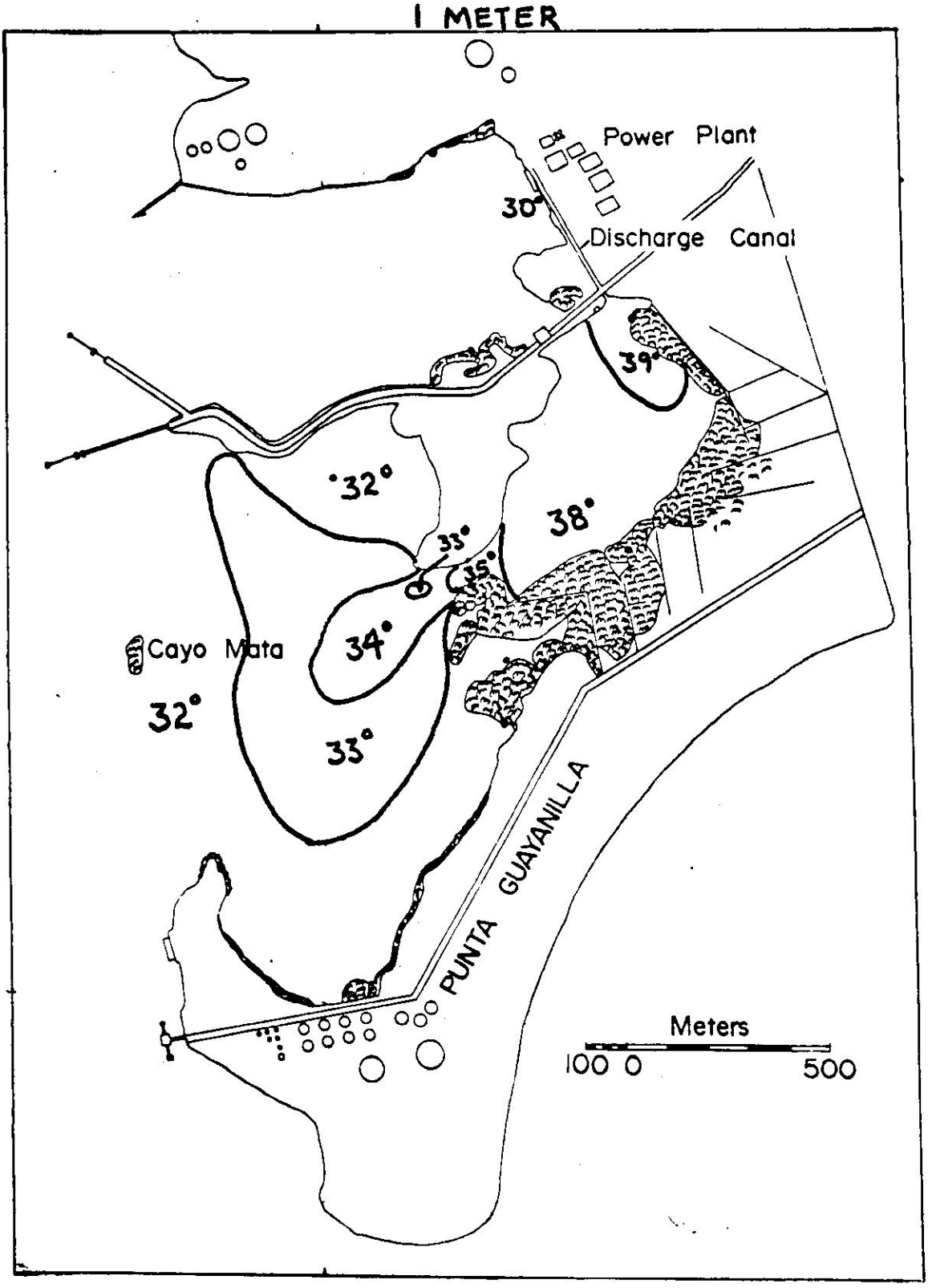


PLATE IB. Water temperature at one meter's depth.
October 20, 1972

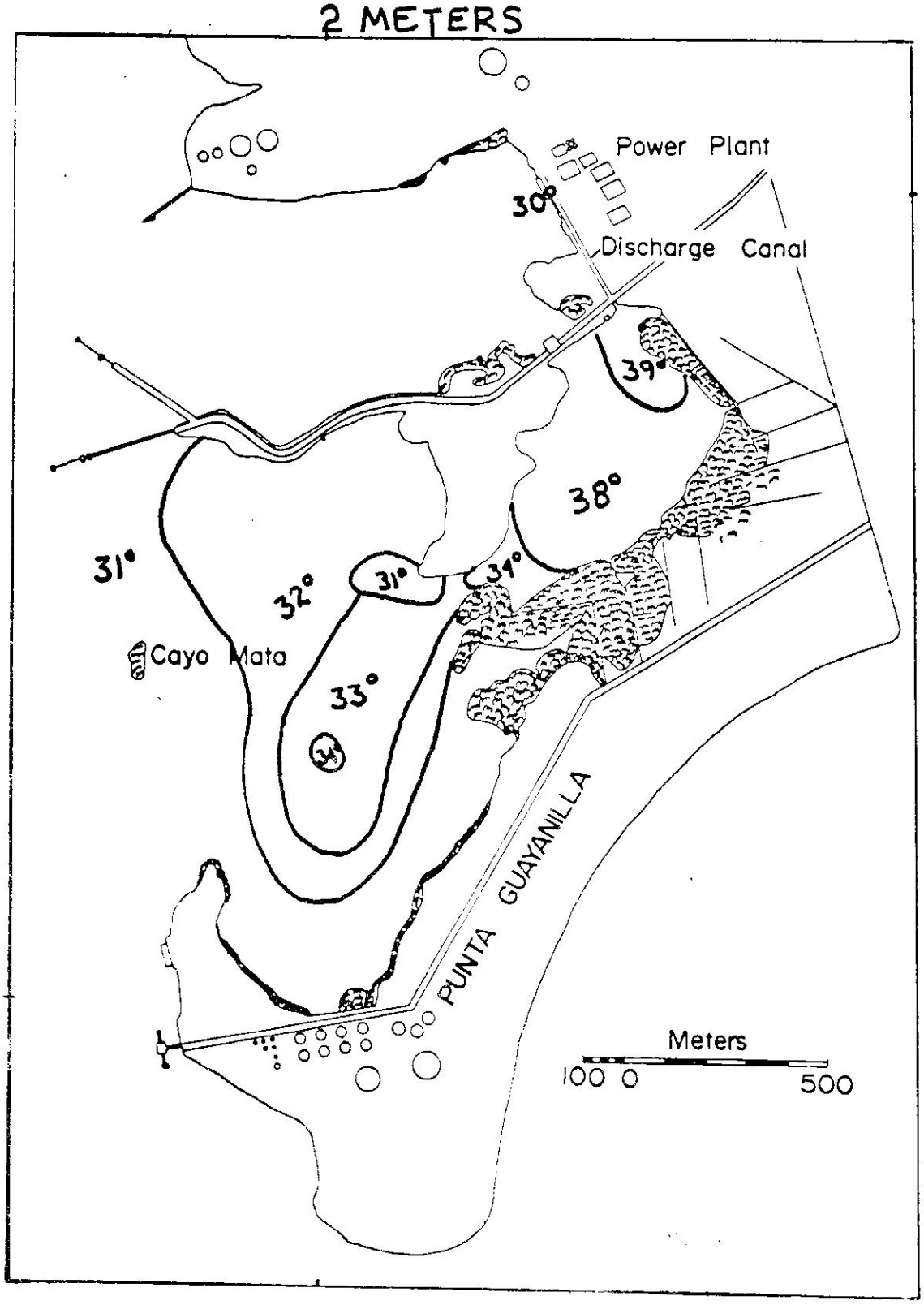


PLATE IC. Water temperature at 2 meters depth , October 20, 1972.

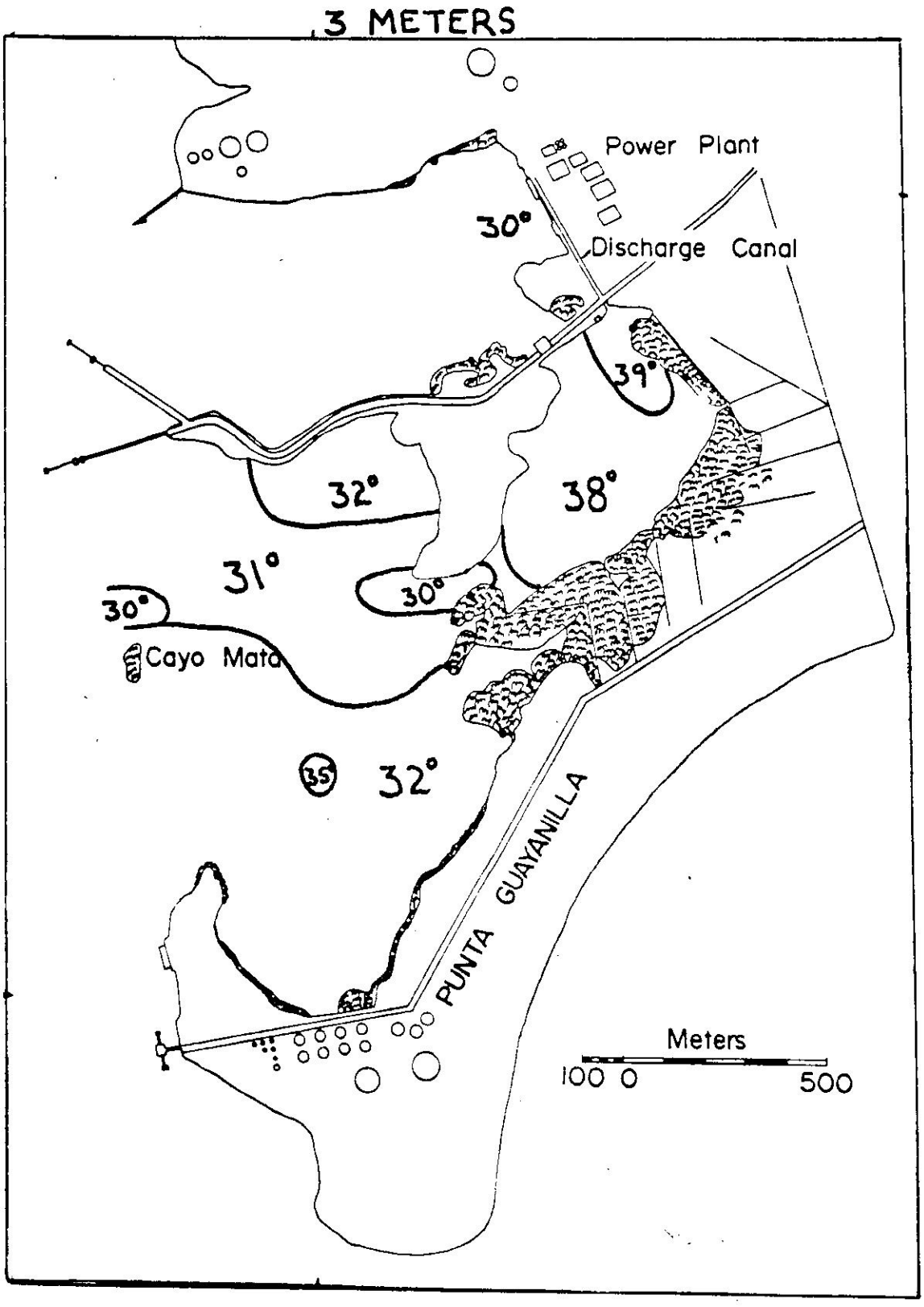


PLATE ID. Water temperature at 3 meters depth, October 20, 1972.

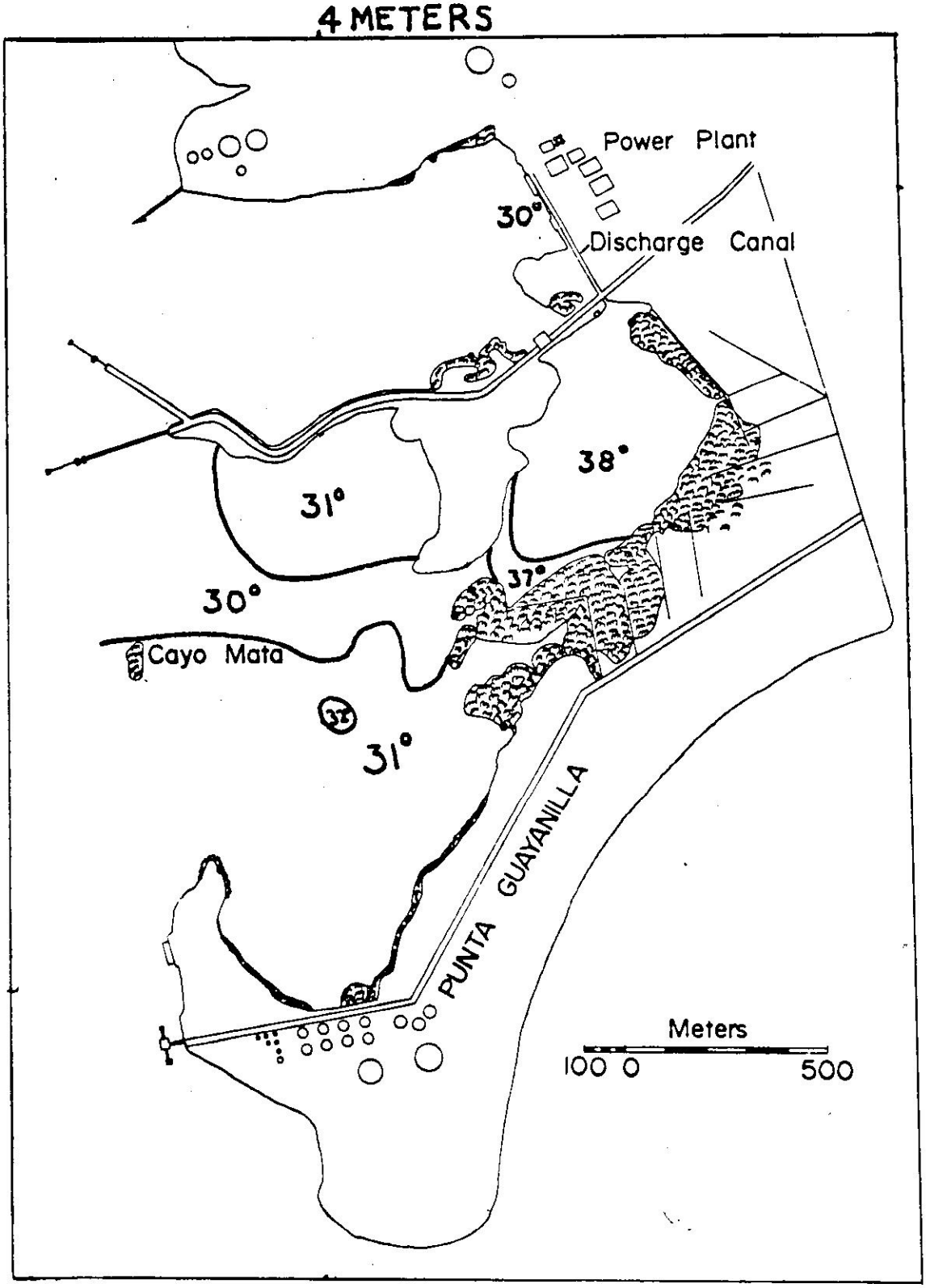


PLATE IE. Water temperature at 4 meters depth, October 20, 1972.

the temperature decreased an additional 1.5° C. At the mouth of the cove the water was still 5.5° C. above the ambient. Inside the cove there was a thermocline at the depth of 2.5 - 3 m. Below this depth the temperature of water was about 0.5° C. above the ambient (Figure 5). At the mouth of the cove the heated water rose to the surface and dissipated within 600 m (Figure 6). At the mouth of the cove there was a narrow deep channel coming toward the cove from the west. Outside this channel water here is very shallow (Figure 3) and, consequently, there is a limited supply of entrainment water.

Testing of the cooling system for the new generating unit was started in the middle of February by pumping water occasionally at ambient temperature through the system. This lowered the temperature of the effluent about 5° C. This testing continued, on and off, until May, after which time test firing of the generating unit was started. While the new unit has been operating the temperature at the mouth of the cove has been 7.5° C. above the ambient. The daily mean temperature and the maximum and minimum at the mouth of the cove are given in Figure 7. The diurnal fluctuation of ambient temperature was about 1° C. while the diurnal fluctuation at the mouth of the cove was about 2° C.

Currents

The water was discharged from the old units at the mouth of the canal 0.75 m/sec. and the current at the nearest mangroves was 0.1 - 0.2 m/sec. At the mouth of the cove below the thermocline water was flowing into the cove at a velocity of 0.1 - 0.2 m/sec. The water going in was 0.5°C. above the ambient, and thus 345 m^3/min. was needed to entrain 750 m^3/min. of heated water that came out of the discharge canal at 10° C. above the ambient to lower the temperature down to 5.5° C. above the ambient in the cove. Subsequent to the operation of the new unit the currents have increased considerably. Earlier the current was laminal and flowed toward the mouth of the cove on the surface. Now there is a large eddy inside the cove circulating counterclockwise (Figure 8). Current velocities for the present situation are not yet studied, but according to the calculations 395 m^3/min. entrainment water was needed to lower 1510 m^3/min. from 10 to 7.5° C. above the ambient within the cove. This means that there was about the same volume of entrainment water going into the cove as before.

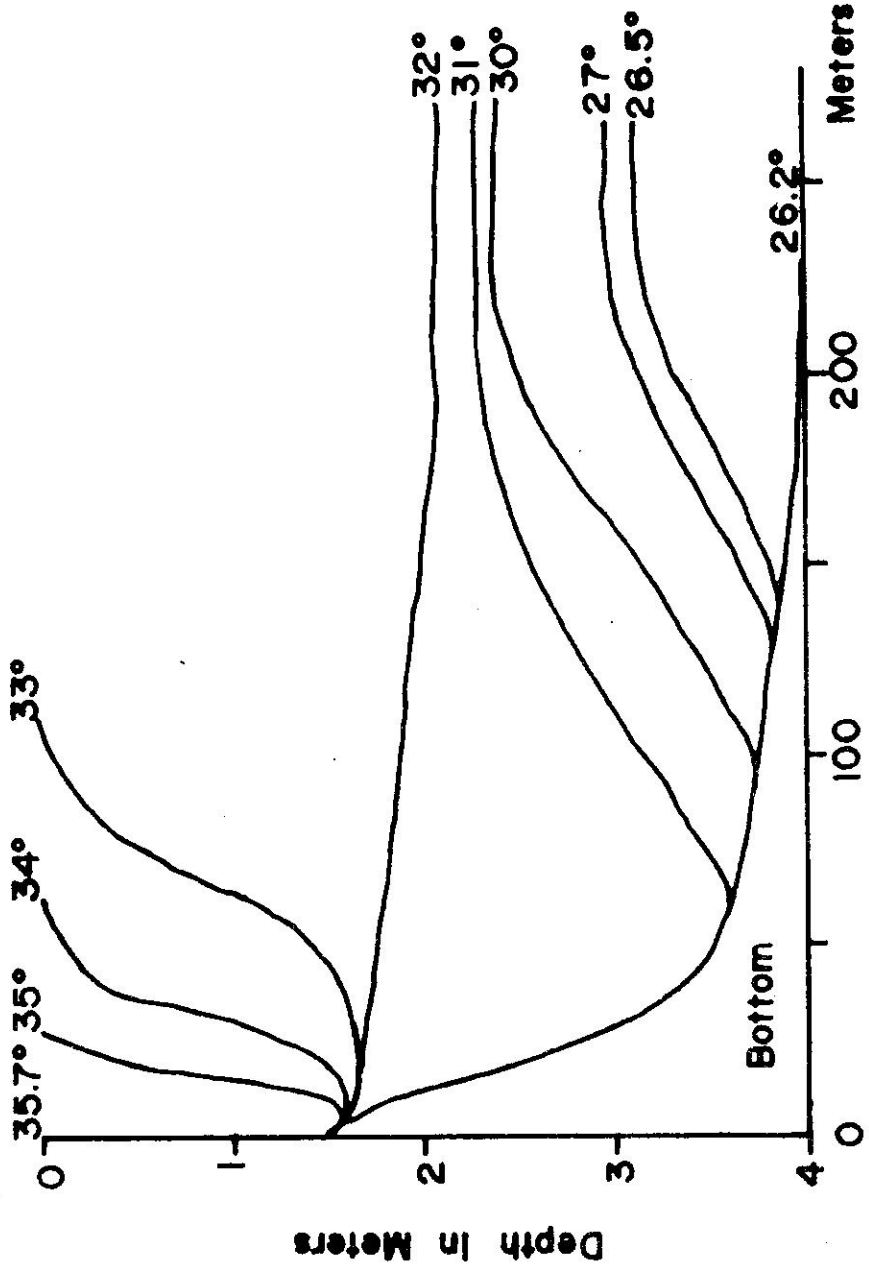


Figure 5. Vertical distributions of temperature in the plume in the mouth of the discharge canal.

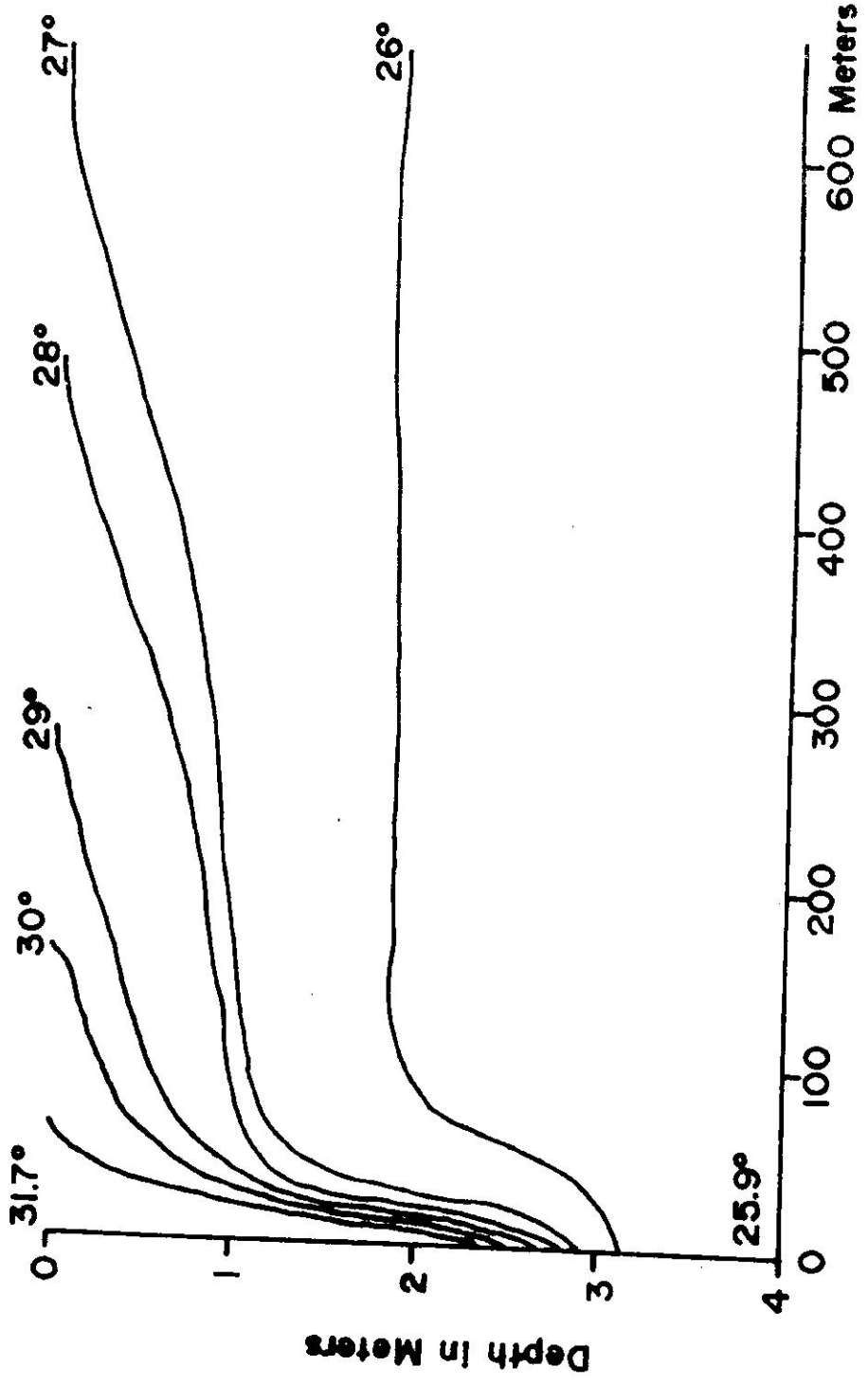


Figure 6. Vertical distribution of temperature in the plume at the mouth of the cove.

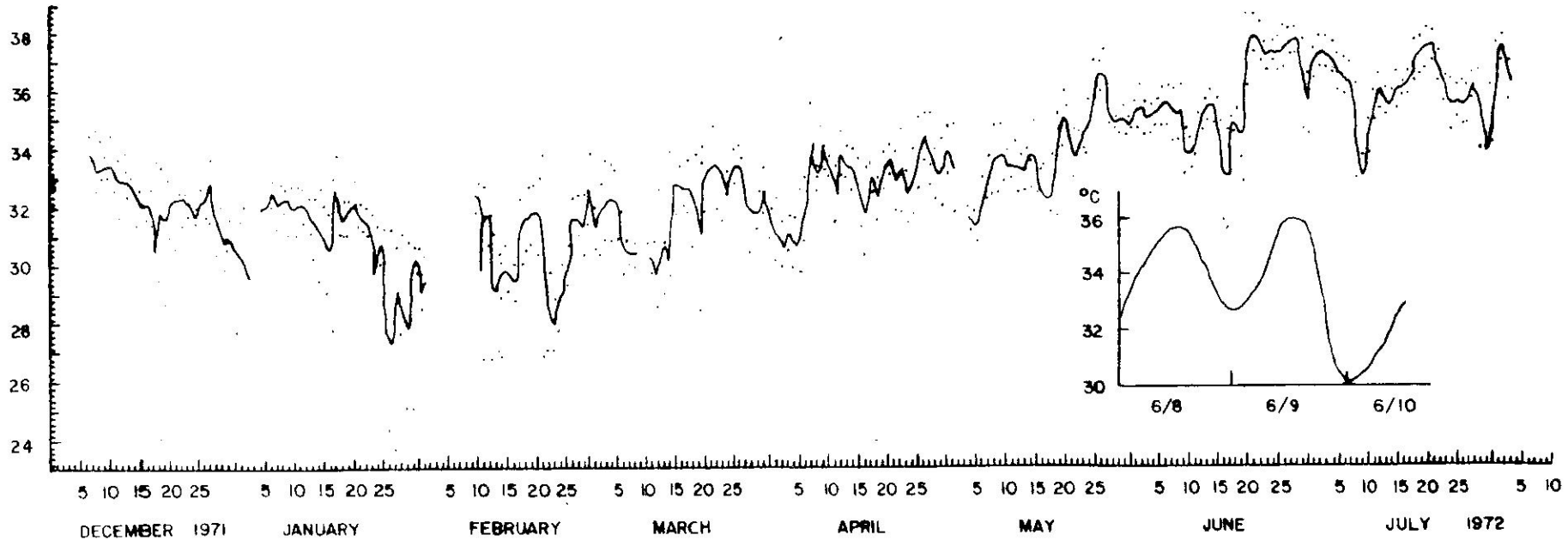


Figure 7. Water temperatures at Station 5, the mouth of the cove, in the mangroves 20 cm. below the mean water level. The solid line is the daily mean while the dots express the daily maxima and minima.

The separate curve at the lower right corner shows the typical daily fluctuation in the summertime.

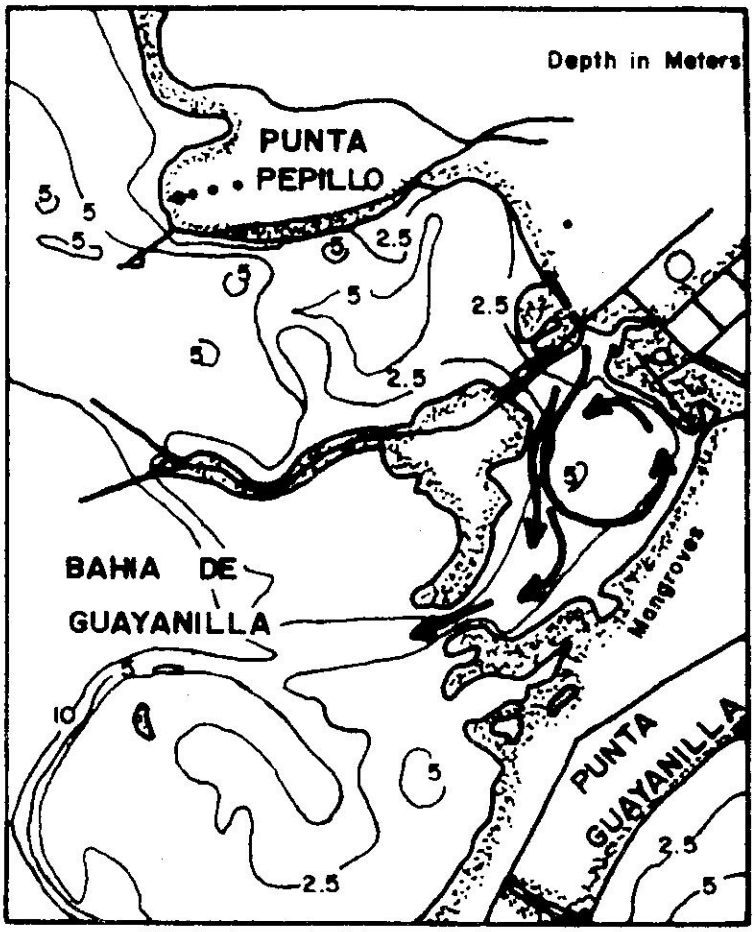


Figure 8. Surface water currents in the cove in summer 1972.

The turbulances in the discharge canal saturate the cooling water with oxygen and, consequently, oxygen readings in the thermal plume area were between 5 and 7 mg O_2/1.

Tides

Tides in this area resembled those in Jobos Bay. The difference between the high and low tide was about 30 cm.

Mangroves

Guayanilla Bay was once surrounded by mangroves on all sides, but the construction of industrial plants, piers, jetties and landfills have decreased the area of mangroves to a small proportion of the original cover. The area of the mangroves adjacent to the power plant covered 19.6 hectares. At the waterline about 95% of the mangroves were red mangroves (Rhizophora mangle), the rest being black mangroves (Avicennia nitida) and white mangroves (Laguncularia racemosa). In the cove there were mangroves growing along the entire length of the east shore. The water temperature in the warmest place around the mangrove roots varied before from 33° C. in winter to 38° C. in summer. Now with the new unit in line the temperature in the summer of 1972 was 39.5° C. The mangroves were reproducing in the cove even though the temperature was 9° C. above the ambient. Earlier there were a few dead trees at station 7 (Figure 1) and at the mouth of the cove at station 5, but this was not due to the temperature, but rather to the current which was eroding the sediment from around the roots of mangroves in such a degree that the trees were uprooted and fell down. Now with increased water currents more trees were falling and dying. The mangroves in other parts of the cove still appeared to be surviving.

Mangrove Root Communities

Species composition: Mangrove root communities in the cove and outside reflect the effects of elevated temperatures. The number of species on the mangrove roots and the temperature of water on 9 October 1971 at eight stations (Figure 1) are given below:

	STATIONS							
	Control	1	2	3	4	5	6	7
Temp. ° C.	30.0	31.2	31.8	33.2	34.5	35.5	36.7	37.1
Spp. Algae	6	3	5	8	7	4	5	5
Spp. Invertebrates	90	45	69	67	58	25	21	10
Total # Spp.	96	48	74	75	65	29	26	15

The number of invertebrate species at control station are very high. This station had more species than any station in Jobos Bay, an area that does not have chemical pollution like Guayanilla Bay. There appeared to be some unknown ecological factors that made this station so favorable for sessile organisms. The natural variation of the number of species is great in the mangrove root communities (see the section on mangrove root communities in Jobos Bay1972 Annual report) and no two areas are exactly alike. A t-test was made between the different stations comparing the number of species in each phylum. This showed that station 1 differed significantly from stations Control, 2, 3 and 4. Station 1 had only one row of poor-looking mangrove trees along the shoreline which may have been the reason for the small number of species living on the roots. Stations Control, 2, 3 and 4 did not differ from each other significantly, but stations 5, 6 and 7 did differ significantly from all the other stations ($P = 0.05$). At 35° C. all the sensitive species were eliminated while above that temperature a few species dominated the root communities. The importance of this temperature was seen clearly in the winter when the effluent was coming from the discharge canal at 35 - 36° C. Then many of the organisms that in summer were found only outside the cove immigrated into the cove and established fast-growing populations. This was especially noticeable among ascidians, polychaetes and crabs. They followed the reduction of the 35° C. isotherm into the cove all the way to station 7. When the water temperature increased in the spring these species gradually died and disappeared from the cove.

The number of species in different phyla is given in Table 1. Macroalgae were not as numerous in Guayanilla as in Jobos Bay. Molluscs had the most species at Control

TABLE I

NUMBER OF SPECIES IN DIFFERENT PHYIA ON THE MANGROVE ROOTS ON ON OCTOBER 9, 1971

PHYLUM	Control	1	2	3	4	5	6	7
Cyanophyta						2	3	3
Chlorophyta	3	2	4	4	5	2	2	2
Phaeophyta				1				
Rhodophyta	3	1	1	3	2			
Porifera	2	3	1	4	3	3	1	1
Coelenterata	1	1	1	1	1	1		
Annelida	9	3	10	7	9	5	3	1
Sipunculida	1	1	1	1			1	
Mollusca	27	7	14	17	10	4	3	2
Arthropoda	25	12	22	16	18	8	12	5
Bryozoa	5	5	4	3	3	1	1	1
Echinodermata	1	1	1	2	1			
Chordata (Ascidiacea)	19	12	16	16	13	4	—	—
Algae	6	3	5	8	7	4	5	5
Invertebrates	90	45	70	67	58	25	21	10
Total	96	48	75	75	65	29	26	15

station and at station 3, but arthropods were the most numerous at most stations. At station 1 ascidians had most species of all phyla. Annelids, molluscs, arthropods and ascidians were the most important groups at all stations. The list of species found at different stations is given in Table 2.

The species composition in the cove and at station 4 changed during the winter. When the temperature decreased larvae that were coming into the cove with the countercurrent on the bottom settled on the mangrove roots and established colonies and populations. The number of species of macroorganisms in winter, 1972, at different stations is given below.

	STATIONS							
	Control	1	2	3	4	5	6	7
Temperature °C	25.5	26.0	26.4	27.2	28.9	31.5	33.0	34.5
# Species	94	45	74	76	71	54	42	32

The most pronounced increase in the number of species happened at stations 5, 6 and 7. Stations 4 and Control also showed a slight increase. The increase in the species diversity was due to the additional species of sponges, polychaetes, crustaceans and ascidians. These changes all occurred in a four-month period which showed that a thermally altered area can recover rapidly. In this respect, thermal pollution is different from some other types of pollution. There are no residues left from thermal addition.

When the ambient temperature and, consequently, the temperature in the cove rose in the spring, the populations of the more sensitive species gradually disappeared. When the more sensitive species such as ascidians died, the surface area that became available was quickly utilized by the hardy species. Bluegreen algae, an encrusting sponge (Halisarca sp.), a calcareous tube dwelling polychaete (Pomatostegus stellatus), a tree oyster (Isognomon alatus), a periwinkle (Littorina angulifera), two Balanus species and two crabs (Aratus pisonii and Pachygrapsus transversus) were the more hardy species. Macroalgae, coelenterates, echinoderms and ascidians were the most sensitive species.

TABLE 2

LIST OF SPECIES FOUND ON MANGROVE ROOTS IN GUAYANILLA BAY IN OCTOBER 1971

	Stations							
	Control	1	2	3	4	5	6	7
ALGAE								
Cyanophyta								
Lyngbya sp.						x	x	x
Oscillatoria sp.						x	x	x
Phormidium sp.							x	x
Chlorophyta								
Caulerpa fastigiata					x			
Caulerpa racemosa			x	x	x			
v. *macrophysa*	x							
Caulerpa sertularioides			x	x	x			
Caulerpa verticilata	x	x	x	x	x	x		
Enteromorpha sp.	x	x	x	x	x		x	x
Ulothrix sp.						x	x	x
Phaeophyta								
Dictyota divaricata				x				
Rhodophyta								
Acanthophora spicifera	x	x	x	x	x			
Agardhiella ramosissima				x				
Eucheuma acanthocladum					x			

TABLE 2 (cont'd.)

	Stations							
	Control	1	2	3	4	5	6	7
Rhodophyta								
Lomentaria sp.				x				
Polysiphonia howei	x							
Polysiphonia sp.	x							
INVERTEBRATES								
Porifera								
Callyspongia sp.						x		
Halichondria sp.	x		x	x	x	x		
Halisarca sp.		x		x	x	x	x	x
Ircinia strobilina		x						
Mycale sp.				x	x			
Tedania ignis	x			x				
Tethya sp.		x						
COELENTERATA								
Hydrozoa								
Unident. Hydroidea			x					
Anthozoa								
Bartolomea annulata	x	x			x	x		
Erythropodium caribaeorum				x				

TABLE 2 (cont'd.)

	Stations							
	Control	1	2	3	4	5	6	7
ANNELIDA								
Polychaeta								
Cirratulus sp.				x				
Dasybranchus sp.					x			
Hesione proctochona			x					
Hesionidae sp.	x							
Leodice fucata	x		x					
Leodice rubra			x	x	x	x		
Leodice sp.				x		x	x	
Lumbrinereis maculata					x			
Marphysa regalis						x		
Nereis dumerilii	x		x		x			
Nereis sp.	x				x			
Phyllodoce sp.	x							
Pomatostegus stellatus	x	x	x	x	x	x	x	x
Sabella melanostigma	x	x	x	x	x	x		
Sabella alba			x		x			
Sabellastarte magnifica	x	x	x	x				
Syllis sp.	x		x	x	x		x	
Terebella sp.			x					
SIPUNCULIDA								
Sipunculida, unident.	x	x	x	x			x	
MOLLUSCA								
Gastropoda								
Atys. sp.					x			
Bulla striata					x			

TABLE 2 (cont'd.)

	Stations							
Gastropoda	Control	1	2	3	4	5	6	7
Cerithium eburneum				x				
Crepidula aculeata	x							
Crepidula convexa	x							
Crepidula glauca	x							
Cymatium caribaeum				x	x			
Cymatium pileare	x		x					
Cymatium vespaceum				x	x			
Diodora arcuata	x							
Diodora cayenensis	x		x					
Diodora sayi			x					
Diodora variegata	x							
Haminoea antillarum			x					
Haminoea elegans				x				
Jaspidella jaspidea				x	x			
Littorina angulifera	x	x	x	x	x	x	x	x
Modulus carchedonius				x				
Murex brevifrons	x							
Nassarius vibex						x		
Petaloconchus irregularis	x							
Petaloconchus mcgintyi	x			x				
Petaloconchus rudis				x				
Serpulorbis decussata	x				x			
Serpulorbis riisei	x							
Thais haemastoma	x	x		x				
Bivalvia								
Arca imbricata	x							
Barbatia candida	x							
Brachidontes exustus	x	x	x	x	x	x	x	
Chama congregata		x						

TABLE 2 (cont'd.)

	Control	1	2	3	4	5	6	7
Bivalvia								
Chama macrophylla	x							
Corbula caribaea			x					
Crassostrea rhizophorea	x		x	x	x			
Isognomon alatus	x	x	x	x	x	x	x	x
Leptopecten bavayi	x		x					
Lyonsia beana	x							
Musculus lateralis	x	x	x	x	x			
Ostrea equestris	x	x	x	x				
Ostrea frons	x							
Pinctada radiata			x					
Pododesmus rudis				x				
Sphenia antillensis			x	x				
Sphenia sp.	x							
Spondylus americanus	x							
ARTHROPODA								
Cirripedia								
Balanus amphitrite var. *pallidus*	x	x	x	x	x	x	x	x
Balanus eburneus	x	x	x	x	x	x	x	x
Chthamalus fragilis					x			
Amphipoda								
Caprella sp.	x							
Caprellidae	x	x	x	x				
Corophium sp.					x			
Melita fresnelii	x	x						

TABLE 2 (cont'd.)

	Stations							
	Control	1	2	3	4	5	6	7
Isopoda								
Cirolana parva	x		x		x		x	
Excorallana quadricornis			x					
Excorallana sexticornis			x	x				
Excorallana tricornis	x		x	x	x			
Excorallana sp.			x		x			
Podochela crossipes	x							
Sphaeroma walkeri	x	x				x	x	
Decapoda								
Macrura								
Panulirus argus	x		x					
Periclimenes americanus	x			x	x			
Synalpheus fritzmüllerii	x	x	x		x			
Synalpheus minus	x							
Synalpheus townsendi	x		x					
Synalpheus sp.				x				
Brachyura								
Aratus pisonii	x					x	x	x
Callinectes marginatus			x					
Goniopsis cruentata	x	x	x	x	x	x	x	
Hexapanopeus caribbaeus			x	x	x		x	
Microphrys bicornutus	x	x	x	x				
Mithrax hispidus		x						
Pachygrapsus colliegatus					x			
Pachygrapsus transversus	x	x	x	x	x	x	x	x
Panopeus bermudensis	x	x	x	x	x	x	x	
Panopeus harttii	x						x	
Panopeus herbstii			x	x				

TABLE 2 (cont'd.)

	Control	1	2	3	4	5	6	7
Brachyura								
Panopeus occidentalis	x		x	x	x			
Pilumnus carribaeus	x							
Pilumnus nudimanus	x							
Pilumnus sayi			x					
Podochela grossipes				x				
Sternorhynchus seticornis	x		x					
Anomura								
Clibanarius cubensis							x	x
Clibanarius vittatus					x			
Petrolisthes polita	x	x	x	x	x	x	x	
Upogebia affinis					x			
BRYOZOA								
Bugula maritima	x			x				
Caulibugula levinseni					x			
Crisia elongata		x	x					
Crisia sp.	x	x		x	x	x	x	x
Halophilia johnstoniae	x		x					
Hippodina sp.		x						
Savignyella lafontii	x							
Schizoporella errata	x	x	x	x	x			
ECHINODERMATA								
Echinoidea								
Lytechinus variegatus				x				

TABLE 2 (cont'd.)

	Stations							
	Control	1	2	3	4	5	6	7
Ophiuroidea								
Ophiothrix angulata	x		x	x				
Ophiotreta littoralis					x			
Unid. ophiuroid		x						
CHORDATA								
Ascidiacea								
Amaroucium bermudae	x		x					
Amaroucium sp.	x							
Ascidia curvata	x	x	x	x				
Ascidia interrupta			x					
Ascidia nigra	x		x	x	x	x		
Botrylloides nigrum	x							
Botryllus planus		x	x	x	x			
Clavelina picta	x	x		x				
Didemnum candidum	x		x	x	x			
Diplosoma macdonaldi	x	x	x			x		
Distaplia bermudensis	x	x	x		x			
Ecteinascidia turbinata	x		x	x	x			
Herdmania momus	x			x	x			
Microcosmus exasperatus	x	x	x	x	x			
Molgula occidentalis		x						
Perophora viridis	x	x	x	x	x	x		
Polycarpa obtecta			x	x				
Polycitor olivaceus				x				
Polyclinum constellatum	x	x	x	x	x	x		
Pyura vittata		x						
Rhodosoma turcicum	x		x	x	x			
Styela partita	x	x	x	x	x			
Stela plicata	x				x			
Symplegma viride	x	x	x	x	x			
Tridemnum savignii	x			x				

Biomass

The biomass of organisms living on mangrove roots was also affected by the temperature and by water currents. The lowest biomass, in October 1971, was at the warmest area of the mangroves at station 7 (Figure 9). In this area the water current came from the discharge canal directly into the mangroves at high velocity. About 30 meters further behind a small point where the current velocity was very slow the biomass was more than an order of magnitude greater than at station 7, even though the temperature was only 0.1 - 0.2° C. lower than at station 7. Station 6 is about 100 m from station 7. Temperature there was 0.4° C. lower than at station 7 and the current was very weak. The biomass at this station was the highest of all stations, but it was made up mainly of two species, the tree oyster and Balanus amplitrite var. pallidus. Station 5 had a lower biomass than the station on each side of it. The reason for this is not known, but the low biomass may have been the result of the strong current at this station. All the stations outside the cove had biomasses between 200 and 300 grams.

At stations Control, 1, 3, 5 and 6 molluscs were the dominant group, while at station 2 ascidians, at station 4 algae and at station 7 cirripeds were the most important groups (Table 3). In general, algae, molluscs, cirripeds and ascidians contributed most to the biomass.

In the winter the biomass of sponges, polychaetes, crustaceans and ascidians increased in the cove, but no visible change was seen at the station outside the cove.

After the new power generating unit was fired the biomass on the roots at station 5 increased because of the increase in the number of tree oysters and Balanus spp. It appeared that tree oysters and cirripeds could compete better at higher temperatures. These species were also able to withstand stronger water currents than other species living on mangrove roots. The other stations inside the cove did not change their biomass, but bluegreen algae increased their proportion of the total biomass from the summer of 1971. Stations outside the cove exhibited only small changes in the biomass or species diversity except station 4 where the number of species of ascidians decreased. The biomass and the temperatures of five stations on 20 September 1972 are given below.

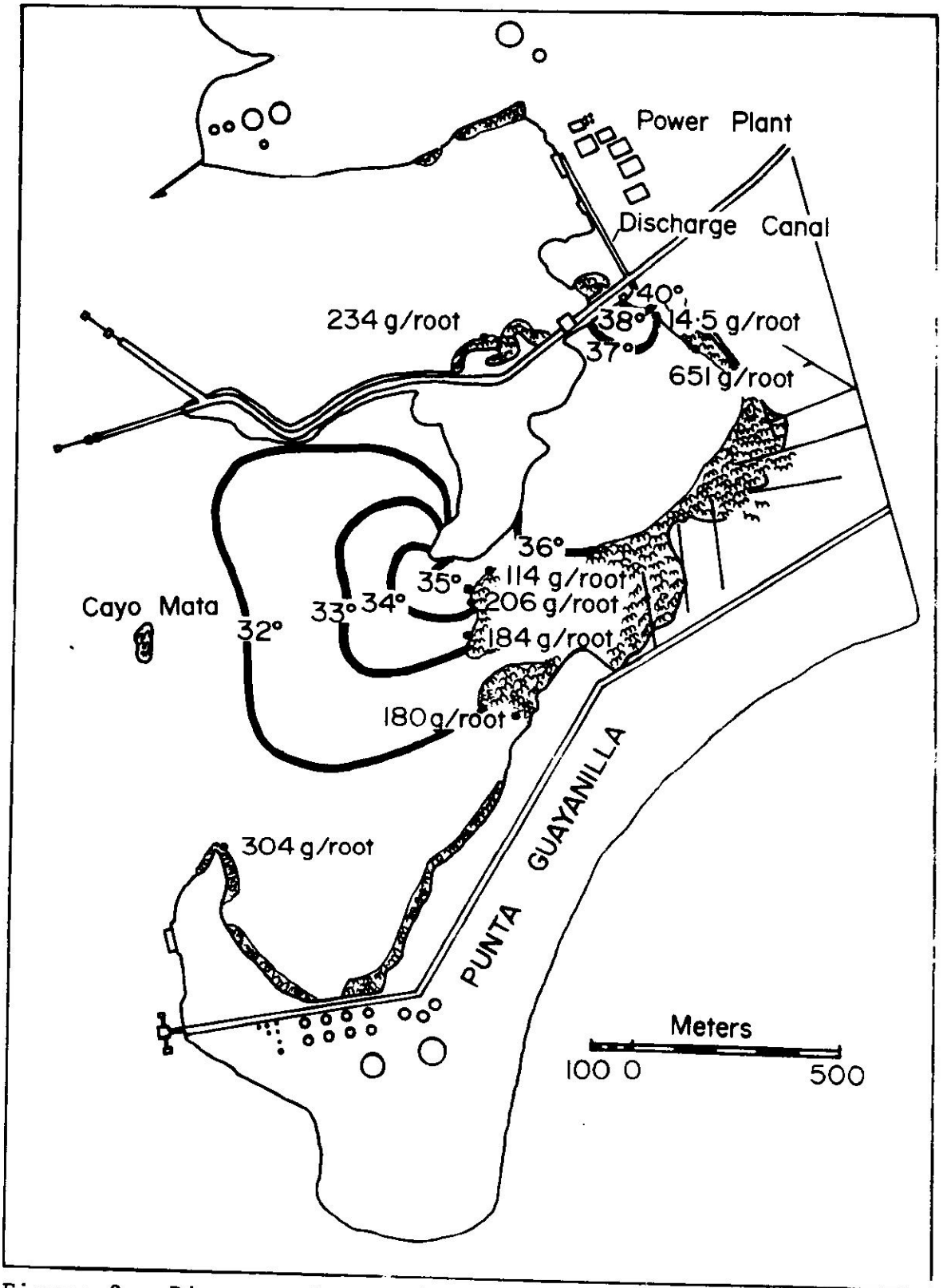


Figure 9. Biomass of organisms living on mangrove roots on October 9, 1971 at different stations as grams wet weight per root. The isotherms at the same date are given too.

TABLE 3

BIOMASS OF ORGANISMS ON MANGROVE ROOTS AT DIFFERENT STATIONS ON OCTOBER 9, 1971

Weights given as wet weight per root

	Control	Stations 1	2	3	4	5	6	7
ALGAE								
Cyanophyta								
Lyngbya sp.						0.2	0.2	1.1
Oscillatoria sp.						0.1	0.2	0.1
Phormidium sp.							0.1	
Chlorophyta								
Caulerpa fastigiata					0.2			
Caulerpa racemosa				2.2				
Caulerpa sertularioides			0.7	0.6	11.4			
Caulerpa verticillata			0.4					
Enteromorpha sp.	1.6		12.1		7.6			
Rhodophyta								
Acanthophora spicifera			8.3	20.6	71.0			
Eucheuma acanthocladum					0.1			

TABLE 3 (cont'd.)	Control	Stations 1	2	3	4	5	6	7
INVERTEBRATES								
Porifera								
Halichondria sp.			2.6		8.6			
Halisarca sp.		10.8	2.0				5.1	
Ircinia strobilina		44.8						
Mycale sp.					6.1			
COELENTERATA								
Anthozoa								
Bartolomea angulata	0.1							
ANNEDILIA								
Polychaeta								
Leodice fucata	0.1							
Pomatostegus stellatus	8.5	4.8	3.0	2.7	1.9		0.2	0.2
Sabella melanostigma	20.3	1.8	20.2	12.1	30.9			
Sabellastarte magnifica		0.4	3.2	0.1	0.7			
Syllis sp.							0.1	
Terebella sp.	0.3		0.8	0.2	0.9			
Unident.							0.2	
MOLLUSCA								
Gastropoda								
Crepidula aculeata	1.4							
Diodora variegata	0.3							
Murex brevifrons					2.5			

TABLE 3 (cont'd.)

	Control	Stations 1	2	3	4	5	6	7
MOLLUSCA								
Gastropoda								
Petaloconchus mcgintyi	51.5							
Serpulorbis riisei	0.5							
Thais haemastoma	0.9	1.8		0.3				
Bivalvia								
Arca imbricata	19.2							
Brachidontes exustus	5.4	11.3	1.0	1.3			0.4	
Crassostrea rhizophorae	13.9	130.8	12.3	45.0	9.8			
Cymathia sp.				1.0				
Diplodonta semiaspera								
Isognomon alatus	2.0	10.1	13.6	22.2	1.6	63.1	622.2	
Lyonsia beana	0.2							
Musculus lateralis		0.2						
Ostrea equestris	0.6			0.5				
Ostrea frons	1.7							
Spondylus americanus	0.6		3.4					
ANTHROPODA								
Cirripeda								
Balanus amphitrite var. pallidus	40.9	25.4	10.8	30.5	5.0	41.4	21.0	13.1
Balanus eburneus	10.0	8.0	1.0	7.2	2.5	9.1	1.2	
Amphipoda								
Caprella sp.			0.1					

TABLE 3 (cont'd.)

	Control	Stations 1	2	3	4	5	6	7
ANTHROPODA								
Isopoda								
Cirolana parva	0.1	0.1			0.1		0.1	
Excorallana quadricornis	0.1			0.4				
Excorallana sexticornis	0.1				0.1			
Sphaeroma walkeri	0.3				0.1			
Decapoda								
Macrura								
Synalpheus fritzmülleri			1.0					
Brachyura								
Aratus pisonii					0.1			
Pachygraspsus transversus	0.8	7.0		1.6	1.1			
Panopeus bermudensis	1.2		0.8	1.7	0.7			
Panopeus boekei					0.2			
Panopeus sp.		2.0						
Microphrys bicornutus					1.8			
Anomura								
Petrolisthes polita	4.3	11.5	1.0	5.7	2.8			
BRYOZOA								
Bugula maritima		1.6						
Crisia sp.	0.2	0.1	0.1	0.1	0.2	0.1	0.1	
Schizoporella errata	4.9	3.3	40.2	0.4	0.5			

TABLE 3 (cont'd.)

	Control	Stations 1	2	3	4	5	6	7
ECHINODERMATA								
Ophiuroidea								
Ophiothrix angulata			0.3	1.0	0.5			
CHORDATA								
Ascidiacea								
Ascidia curvata	15.2	0.5	0.4	0.1				
Ascidia interrupta			0.5					
Ascidia nigra	12.2		15.1	15.8	7.9			
Botrylloides nigrum	1.7							
Botyllus planus		0.2						
Clavelina picta		6.3						
Didemnum candidum	0.2		1.0	2.5	0.4			
Diplosoma macdonaldi	0.5	3.2		0.1	0.4			
Distaplia bermudensis	0.2	8.4		5.0	1.3			
Herdmania momus	1.0							
Microcosmus exasperatus	5.8		18.9		14.7			
Microcosmus helleri				1.7				
Molgula occidentalis		5.6				0.1		
Perophora viridis								
Polyclinum constellatum		0.5	1.1		8.7			
Pyura vittata		3.4						
Rhodosoma turcicum					1.1			
Styela partita	8.8	0.2	3.7	1.4	2.2			
Symplegma viride	2.4							
TOTAL	240.1	304.1	179.6	184.0	205.7	114.1	651.0	14.5

STATIONS

	[illegible]	[illegible]	[illegible]	4	[illegible]
[illegible]	33.4	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	167.8	
[illegible]		[illegible]		[illegible]	
[illegible]	[illegible]	5.0			
[illegible]	[illegible]	[illegible]	13.5	[illegible]	
Nematoda [illegible]	50.8	[illegible]	3.5	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Other Crustacea	5.0	0.8	2.6	3.4	
[illegible]	[illegible]				
[illegible]	[illegible]				
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

[illegible]

[illegible] had a [illegible] distribution and [illegible]

[illegible] of the number of [illegible] percent of the total.

[illegible] of the organisms were [illegible]

TABLE 4

Vertical Distribution of the Number of Species and the Biomass (Wet Weight) Calculated for All Stations on 9 October 1971

Depth, cm	# of Species % of Total	Biomass % of Total
0 - 9	3	0.9
10 - 19	10	8.6
20 - 29	20	22.2
30 - 39	22.5	21.9
40 - 49	20	16.5
50 - 59	12	12.2
60 - 69	7	10.5
70 - 79	3.5	5.6
80 - 89	2	1.6

below the mean water level. In Jobos Bay most of the biomass was somewhat deeper because the biomass of ascidians in Jobos Bay was much higher than in Guayanilla Bay.

THERMAL EFFECTS IN MANGROVE ROOT COMMUNITIES

The mangrove trees in Guayanilla Bay were living in temperatures up to 40° C. Until May 1972 the maximum temperature in the mangroves there was up to 38° C. and even at this high temperature the mangroves constituted a reproducing population. In the summer of 1972 the temperature increased to 40° C. for the first time due to a new generating unit that more than doubled the volume of cooling water. During summer 1972 the mangroves in the heated cove appeared still to be surviving, but whether this high temperature will eventually have adverse effects on the mangroves will be seen in the future.

Mangrove root communities were much more sensitive to elevated temperatures than mangrove trees. Species composition and biomass of organisms living on the mangrove roots in Guayanilla Bay reflected the long-term effects of the elevated temperatures. These effects showed in the population dynamics, growth rates, competition between species and in the seasonal migration of species.

The situation in Guayanilla was convenient for thermal effect studies because the cooling water was discharged into a semi-enclosed area where the surface area between isotherms was large enough and constant enough to illustrate the horizontal zonation of organisms according to the temperature. Since the elevated temperatures here were produced by a power plant, the data are directly applicable to other power plant - plume areas with similar populations of organisms. A low number of macroalgae in Guayanilla Bay compared to that of Jobos Bay may be an indication of stress by chemical pollution in Guayanilla Bay. However, more invertebrates were found in Guayanilla Bay than in Jobos Bay on mangrove roots. Nine species of algae and eighty-five species of invertebrates were found in common in both bays.

The most hardy sessile species were intertidal cirripeds, Balanus amphitrite var. pallidus and Balanus eburneus, but almost as tolerant was the tree oyster, Isognomon alatus which lives in the lower part of the intertidal zone and deeper. A polychaete, Pomatostegus stellatus, that lives

TABLE 5

Maximum Daily Temperatures that the Following Species have been found in Guayanilla Bay.

P L A N T S		
Cyanophyta	*Ulothrix* sp.	40 C
	Lyngbya sp.	40
	Oscillatoria sp.	40
	Phormidium sp.	40
Chlorophyta	*Enteromorpha* sp.	39
	Caulerpa verticillata	36
	C. fastigiata	35
	C. sertularioides	35
	C. racemosa	35
Phaeophyta	*Dictyota divaricata*	34
Rhodophyta	*Acanthophora spicifera*	35
	Eucheuma acanthocladum	34
Tracheophyta	*Rhizophora mangle*	40
	Avicennia nitida	40
	Laguncularia racemosa	40
A N I M A L S		
Porifera	*Halisarca* sp.	39
	Callyspongia sp.	36
	Mycale sp.	35
	Halichondria	35
	Tedania ignis	34
Coelenterata	*Bartholomaea angulata*	34
	Erythropodium caribeorum	33
Annelida	*Pomatostegus stellatus*	38
	Syllis sp.	37
	Phyllochaetopsus claparedii	36
	Leodice rubra	36
	Sabella melanostigma	36
	S. alga	35
	Nereis dumerilii	35
	Lumbrinereis maculata	35

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	C. fastigiata	35
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Phaeophyta	*Dictyota divaricata*	34
Rhodophyta	*Acanthophora spicifera*	35
	Eucheuma acanthocladum	34
Tracheophyta	*Rhizophora mangle*	40
	Avicennia nitida	40
	Laguncularia racemosa	40
ANIMALS		
Porifera	*Halisarca* sp.	39
	Callyspongia sp.	36
	Mycale sp.	35
	Halichondria	35
	Tedania ignis	34
Coelenterata	*Bartholomaea angulata*	34
	Erythropodium caribeorum	33
Annelida	*Pomatostegus stellatus*	38
	Syllis sp.	37
	Phyllochaetopsus claparedii	36
	Leodice rubra	36
	Sabella melanostigma	36
	S. alga	35
	Nereis dumerilii	35
	Lumbrinereis maculata	35

Annelida	Terebella annulifilis	34
	Cirratulus sp.	33
	Sabellastarte magnifica	33
Mollusca	Isognomon alatus	38
	Littorina angulifera	38
	Brachidontes exustus	37
	Nassarius vibex	36
	Crassostrea rhizophorae	35
	Cymatium vespaceum	34
	Musculus lateralis	34
	Ostrea equestris	34
	Petaloconchus mcgintyi	33
	Haminoea elegans	33
	Pododesmus rudis	33
Arthropoda	Balanus amphitrite v. pallidus	40
	Pachygrapsus transversus	39
	Balanus eburneus	38
	Aratus pisonii	38
	Goniopsis cruentata	38
	Clibanarius cubensis	38
	Hexapanopeus caribbaeus	36
	Panopeus bermudensis	36
	Panopeus harttii	36
	Petrolisthes polita	36
	Sphaerosoma walkeri	36
	Excorallana quadricornis	36
	Chthamalus fragilis	35
	Corophium sp.	35
	Synalpheus frizmüllerii	34
	Periclimenes americanus	34
	Tetraclita squamosa	34
	Microphrys bicornutus	34
Bryozoa	Crisia sp.	38
Echinodermata	Ophiotreta littoralis	35
	Ophiothrix angulata	34
Chordata	Botrylloides nigrum	36
	Distaplia bermudensis	36
	Polyclinum constellatum	36
	Diplosoma macdonaldi	36
	Perophora viridis	36
	Styela partita	36
	Ascidia nigra	35
	Botryllus planus	35
	Didemnum candidum	35
	Symplegma viride	34

Chordata	Microcosmus exasperatus	34
	Styela plicata	34
	Rhodosoma turcicum	34
	Ascidia curvata	34
	Esteinascidia turbinata	34
	Herdmania momus	33
	Clavelina picta	33
	Polycitor olivaceus	33

in the intertidal zone and below the intertidal zone was associated with the former species in temperatures up to 38° C. (Table 5). All these species have adapted for living in extreme conditions, not only in high temperatures, but also in varying salinities, low dissolved oxygen concentrations and polluted conditions. In these extreme conditions these species occupied all depths on the mangrove roots. These sessile species were poor competitors and in optimal conditions for mangrove roots organisms in the middle and lower parts of the root these species were covered by macroalgae, encrusting sponges and colonial ascidians until they died. An encrusting sponge (Halisarca sp.) was also found in temperatures up to 39° C. This species grew as a thin layer around the roots in the heated cove, but outside the cove it was uncommon.

Free moving animals were in a better position to avoid too high temperatures. Once species of snail, periwinkle (Littorina angulifera) and two species of crabs (Aratus pisonii and Pachygrapsus transversus) were found at station 7 as well as in the discharge canal along with Balanus amphitrite var. pallidus. Periwinkle and the two crabs were capable of climbing above the surface to avoid water that was too hot. Bluegreen algae were found as a think layer covering the bottom in shallow banks and also on the mangrove roots at station 7. In September 1972 when the temperature in the cove was between 37.5 and 39.7° C. biomass of bluegreen algae was increased greatly from the situation in the previous summer. While bluegreen algae were found covering parts of mangrove roots only at station 7 in 1971, now bluegreen algae were seen on all mangrove roots in the cove, and there were large areas in the cove where the surface of water had flakes of bluegreen algae floating.

Enteromorpha and Ulothrix were the only algae besides bluegreens found in the cove in October 1971. Three other polychaetes (Syllis sp., Leodice sp. and Marphysa regalis) besides Pomatostegus were found in the cove above 36° C. Two molluscs (Brachidontes exustus and Nassarius vibex) were living in the cove in summer, too. Two isopods (Sphaerosoma walkeri and Cirolana parva) and several crabs (Clibanarius cubensis, Petrolisthes polita, Goniopsis cruentata, Panopeus bermudensis, Callinectes marginatus)) were found in the cove in October 1971. One species of Bryozoa (Crisia sp.) lived in temperatures up to 38° C. Five species of ascidians (Distaplia bermudensis,

Polyclinum constellatum, Didemnum candidum, Diplosoma macdonaldi and Styela partita) were found living in temperatures up to 36° C. Most of the other species did not occur above 35° C. (Table 5).

About 3/4 of all species were found living in temperatures above 33° C. The rest may very well be able to live at these high temperatures, but there may have been some other ecological factors preventing their living in the area where the temperature was this high in Guayanilla. The diversity of species on mangrove roots varies normally greatly and the factors affecting this are still mostly unknown (see the section on the mangrove root communities in Jobos Bay 1972 Annual Report).

The results of this study show that both the species composition and biomass of mangrove root communities were not affected adversely in temperatures below 34° C. Between 34 and 35° C. the number of species dropped abruptly and above this temperature the number of species was inversely related to the temperature of water.

All the temperatures given in this paper are long-term mean temperatures, thus there were short times, a few hours, once in a while when the temperature at the stations collected exceeded the mean temperature by one to two degrees.

The lack of information on the thermal tolerance of tropical marine organisms makes it impossible to compare the maximum thermal limits of the most important species found in Guayanilla Bay. A population of the snail, Nassarius vibex, was found at 36° C. in Guayanilla Bay while Thorhaug et al. (1971) reported 37.5 - 40.2° C. as the upper thermal limit for this species in a 72-hour laboratory experiment. The same authors found the upper thermal limit of 36.1 - 37.6° C. for a shrimp, Periclimenes americanus, while in Guayanilla the same species had a living population at 34° C. On the basis of these two limited examples it appeared that the populations were living about two to three degrees below their upper short-term thermal limits. Actually the populations in Guayanilla were sometimes exposed to temperatures up to 2° C. above the reported mean temperature. This means that even the most sensitive life stages of these species were able to take these short-term heat maxima. Fast immigration of larval forms that established populations in the cove during the winter months showed that the reproduction and the larval stages were not adversely affected by temperatures below 34° C.

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APPENDIX B

INVESTIGATIONS OF PRIMARY PRODUCTION

The few preliminary measurements made to date suggest that the biomass and production of phytoplankton in Jobos Bay are substantial. Nutrient level measurements are consistent with high productivity where light intensity is adequate in the upper water column and on shallow bottoms containing sea grasses and benthic algae. The magnitude of primary production in the major compartments of the system is of interest both for estimating the total primary production of the Bay and for establishing base line productivity data for comparison with later values in the altered system.

Major sources of primary production are (1) phytoplankton in the water column, (2) rooted sea grasses (primarily Thalassia) and their algal epiphytes, (3) benthic algae, (4) allocthonous material entering the Bay waters, primarily from mangrove areas. The mangrove studies in progress should supply information to estimate the input from the trees. The input of allocthonous organic material (other than sugar mill wastes) from shore run-off may be minor, since there are no permanent streams. There are inputs, especially to the Central Bay and Ship Channel, from the ocean. Except for water entering the Bay through the Boca del Infierno and between the outer cayos, these inputs are at depth and may thus be less significant to the total productivity. Coastal marine values of biomass and productivity (e.g. Hargraves et al., 1970; Burkholder et al., 1967) may be useful for estimating this component of input production. If water transport into the Bay from the southeast is quantitatively significant, measurement of productivity on the fringing reefs and shallow grass beds of the cayos may be indicated.

Studies in similar shallow marine situations (e.g. Pomeroy, 1960) suggest that where depths are greater than about 2 m, the bulk of primary production is by phytoplankton, even where ambient light levels at the bottom are higher than those that occur in parts of the Bay. Although much of the Inner Bay is shallower than 2 m (Fig. 1), the low ambient light level at the bottom (< 2% of surface intensity at 1 m depth in many places) and the scarcity of Thalassia deeper than 1 m suggest that benthic productivity may be low in

much of the Inner Bay. In view of this and of the limited exchange with ocean water (probably lower in productivity), an estimate of production in the Inner Bay based on local phytoplankton alone may be sufficiently accurate.

The sampling program should undertake productivity measurements at a few locations within the Inner Bay near the surface and a set of measurements at one or more locations to get a vertical profile of productivity vs. light and depth (App. 1). The vertical profile data could be extrapolated to much of the Inner Bay, and the productivity vs. light data could be used to estimate sub-surface productivity in other areas, based on light measurements and surface productivity measurements. Productivity for the entire water column could be obtained by integrating the productivity vs. depth curves so obtained (e.g. Burkholder et al., 1967).

It seems unlikely that the small area of sea grasses in the Inner Bay (Fig. 2) could contribute significantly to the total production. These beds are not expected to experience heating due to power plant effluent. If grass distribution and abundance change significantly due to power plant operation (e.g. because of reduced turbidity in the Inner Bay), repeated surveys of the type already conducted (see "Ecology of Turtlegrass . . ." section, this report) should detect the changes.

The distribution of significant quantities of macroalgae in the Bay is poorly known. The benthic microalgae have not been studied, but they may be presumed to occur wherever light levels are adequate. Their productivity is significant in some similar shallow marine situations (e.g. Pomeroy, 1959, 1960; Jones, 1968). It is difficult to guess their importance in the extensive shallows of the Inner Bay ($\leq$ 1 m depth). Information about the compensation depth of phytoplankton from the vertical profile work discussed above should be helpful in estimating their distribution. In addition, some productivity measurements should be made of bare mud bottom in situ. Macroalgae, if present, would be included in the measurements (App. 2).

In both the Central Bay and the Ship Channel, shallows make a much smaller fraction of the total area than in the

Inner Bay (Fig. 1). Although the water is less turbid, probably 10% or less of the area is shallow enough for significant benthic production (Fig. 2). There are, however, a number of acres of Thalassia present, which should be unaffected by power plant operations and which might provide a useful control site. Moreover, much of shallow area occurring in the Central Bay does contain Thalassia. A station should be sampled for primary productivity and leaf growth (App. 3). Probably either station 6 or 7 (see Fig. 2) should be used so as to permit correlation with existing and planned biomass data. A few measurements of bare bottom area at successively greater depths near the same station should be made to estimate benthic algal productivity (App. 2).

In the Ship Channel, the bottom area divides rather abruptly into a major area that is much too deep for significant benthic production and a much smaller area of shallows, most of which has a considerable cover of Thalassia (Fig. 1). Only in parts of the Bahia de Cayo Puerca and Mar Negro are there extensive shallows without Thalassia. Much of the area will experience some temperature elevation from power plant operation, and major changes in currents will occur locally. Phytoplankton productivity should be measured in a few locations in the open Channel and in the Bahia de Cayo Puerca/Mar Negro area (App. 1). Productivity and leaf growth of Thalassia should be measured (App. 3) in Thalassia beds on both sides of the Channel, e.g. stations 2 and 3 (Fig. 2). In at least one case, an adjacent bare bottom area should be measured (App. 2). A bare bottom area in the Bahia de Cayo Puerca/Mar Negro area should also be measured.

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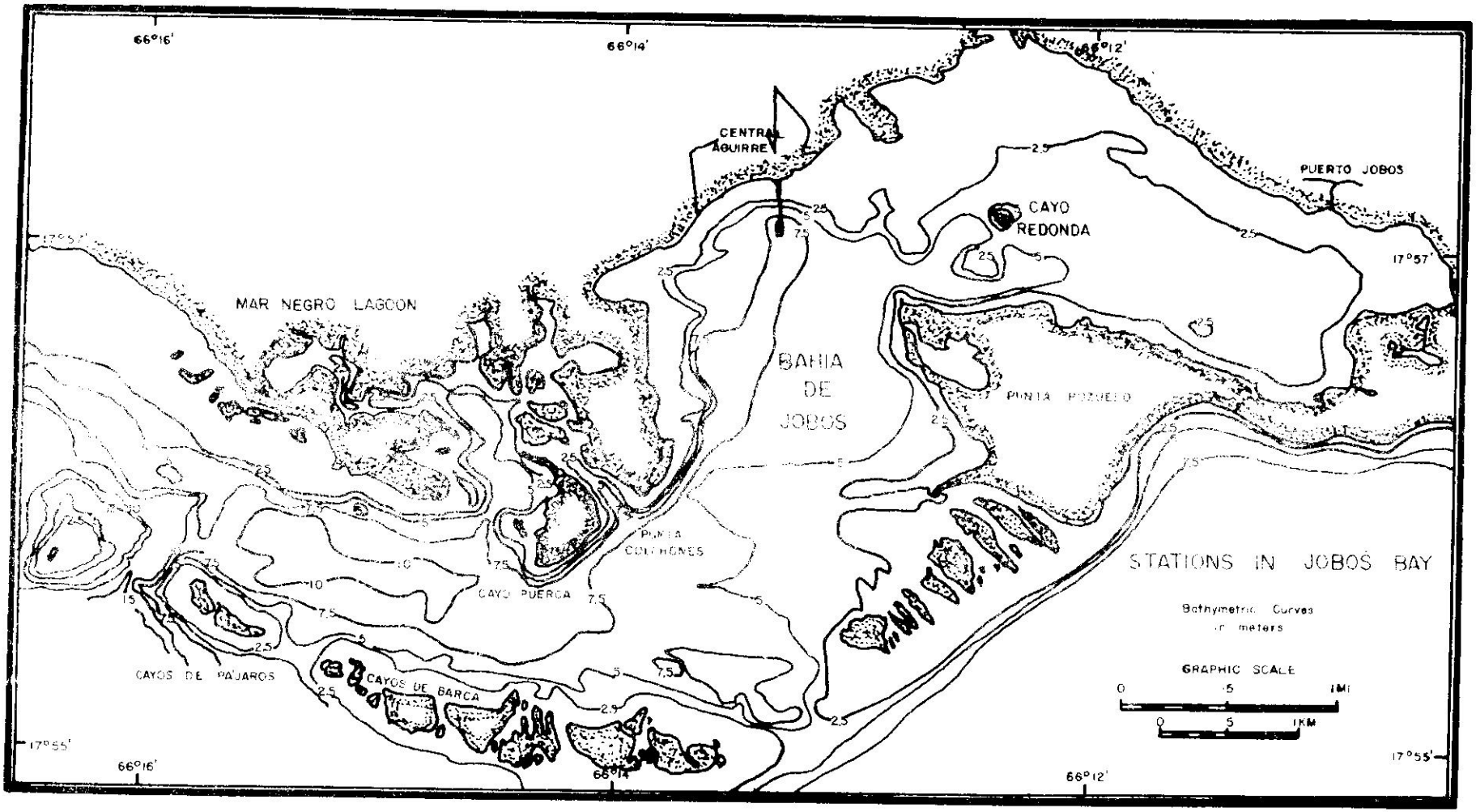

Figure 1. Bathymetry of Jobos Bay

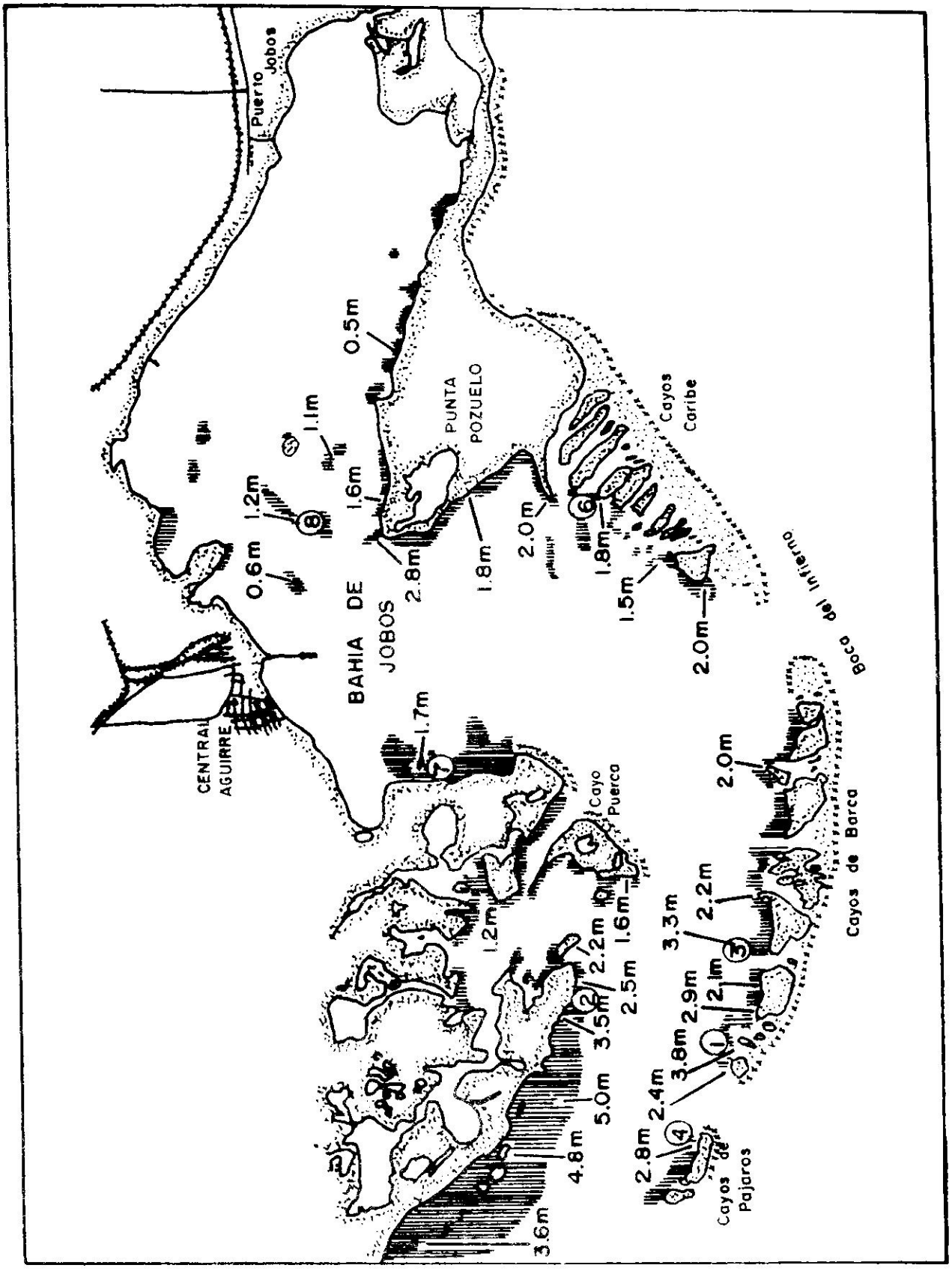

Figure 2 The distribution of Thalassia beds in Jobos Bay. The location of sampling stations for the biomass and species diversity are shown as well as the maximum depth of Thalassia beds at different parts of Jobos Bay.

APPENDIX I

MEASUREMENT OF BIOMASS AND PRODUCTIVITY OF PHYTOPLANKTON

Phytoplankton biomass would be measured directly by weighing the quantity of cells filtered from a large volume of water. It can be estimated indirectly from measurement of chlorophyll a extracted from cells filtered from the water. The measurement of chlorophyll a also provides a measurement of "photosynthetic potential" from which, at known light intensity, productivity and efficiency can be estimated. Productivity would also be measured by changes in dissolved oxygen caused by photosynthesis and respiration. Light and dark bottles would be suspended in the Bay at various depths, and oxygen changes would be determined initially by Winkler analysis. After development of the polarographic "oxygen electrode" equipment (see Appendix 2), it may be feasible and preferable to adapt this equipment to plankton productivity measurements also.

The following steps would be involved in making the above measurements, using the Winkler analysis for oxygen.[1] Initially, step I.A would be repeated successively at a station throughout the daylight hours (e.g. once every 2 hours). From these results, a method would be derived for estimating daily production from a single measurement (e.g. Doty et al., 1967).

I. Sampling Plan

A. Take a sample of about 1 gallon from just below the surface (avoiding the surface film) at each of the specified stations. Use a clean glass or

---

[1] For further details and discussion of analytical procedures, see Strickland and Parsons (1968).

plastic container.[2] Measure surface irradiance and irradiance at the depth of the center of the sample.

B. Measure temperature and oxygen concentration of the Bay water using the surface oxygen meter. Measure salinity using the AO Refraction Salinometer.

C. Fill a clean 2-1/2 gallon cubitainer with water from just below the surface.[2]

D. At specified "Profile" stations, take a sample as in A (above) and an identical sample at each 1/2 meter depth to within a few centimeters of the bottom.

II. Treat samples immediately in the boat as follows:

A. Pour the 1 gallon surface sample through a piece of 0.3 mm clean nylon netting. Deoxygenate this filtered sample per detailed instructions. Fill 4 clear 300 ml BOD bottles and 2 opaque 300 ml BOD bottles completely full with the filtered sample water. (Insert stoppers if necessary while handling).

Label 2 clear bottles "IB". To each, add 1.0 ml of manganous sulphate by putting the tip of the automatic pipette just below the surface of the water in the bottle. Then add 1.0 ml of alkaline iodide solution in the same way, using its own automatic pipette. Stopper the bottles tightly immediately without including air space, and shake the bottles

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[2] Initially an additional sample or two would be taken within a few tens of meters of the location to evaluate patchiness of phytoplankton.

thoroughly until the precipitate is evenly dispersed. Store the bottles out of the sun (do not refrigerate). After a few minutes, shake them again and return them to storage.

Immediately stopper the other 2 clear bottles after filling, without including air space, and label "LB". Do the same with the 2 opaque bottles and label them "DB". Wire stoppers on tight using stainless steel or chrome-nickel wire and put all LB and DB bottles back at the depth from which they were taken (use an anchor weight and a float just sufficient to keep the bottle up). Note the time the BOD bottles are put back in the Bay.

After the specified time, N, recover the LB and DB bottles from the Bay, remove stoppers and add manganous sulphate and alkaline iodide in the same way as for the IB bottles. Shake well twice and store with the IB bottles. Record incubation time, N.

D. To the remainder of the 1 gal. surface sample add about 8 drops of well-shaken magnesium carbonate suspension using an eye dropper, label the container "Pigments", shake well and store in the dark on ice.

III. At the shore base, within several hours, treat samples as follows:

A. Store IB, LB and DB bottles out of the sun (do not refrigerate).

B. Pour the water from the 2-1/2 gallon cubitainer through a piece of 0.3 mm clean nylon netting. Measure and record the amount of water filtered. Filter this water again through a 47 mm diameter, 0.45μ Millipore filter. As soon as all water has been filtered[3], sprinkle a few drops of HCl on the

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[3] If phytoplankton are sufficiently numerous, an adequate sample for weighing may be obtained without filtering the full volume of water.

filter paper.[4] Drain the filter thoroughly dry under suction. Weigh and record the weight of the paper with phytoplankton.

C. Filter the "Pigments" sample through a 47 mm diameter, 0.45μ (HA) Millipore filter. Record the quantity of water filtered, V_W. Shake vigorously in the bottle before filtering. Drain the filter paper thoroughly dry under suction, remove it from the filtration equipment, and trim away as much excess paper around the periphery as possible with clean scissors. Keep only the part containing plankton.

Place the filter paper in a 50 ml stoppered graduated centrifuge tube. Add approximately 40 ml of 90% acetone using a polyethylene wash bottle, stopper the tube, and dissolve the filter paper by shaking the tube vigorously. Place the tube under refrigeration in complete darkness. Shake the tube once more after about 1 to 2 hours under refrigeration.

IV. At the Nuclear Center laboratory, treat the samples as follows:

A. Within a few days after collection of the samples, perform the following analysis on all LB, DB and IB bottles:

Take bottle from storage without shaking and remove stopper. Add 1.0 ml of concentrated (specific gravity 1.84) sulphuric acid to the sample, placing the tip of the pipette just below the surface of the water. Restopper and shake thoroughly until the precipitate dissolves fully. Do not permit air to become trapped in the bottle. Keep out of direct sunlight.

---

4 A few tests will be run initially weighing papers before and after adding HCl to get an estimate of carbonate sediment in the samples. A tare weight for filter papers will also be established.

Within a few hours, transfer 50.0 ml of the solution into a painted conical flask using a volumetric pipette. Titrate at once with standard 0.01 N thiosulphate solution until a very pale straw color remains. Add 5 ml of starch indicator and finish the titration, adding thiosulphate carefully until the blue solution just clears. Use this first "end point"; do not wait for the solution to color again. Record the number of ml of thiosulphate solution used. If a "blank" value has been supplied when the reagents[5] were prepared, subtract it from this number of ml. The result is called V, i.e. V_{LB} V_{DB} or V_{IB}. Obtain the value of f supplied with the reagents.[5]

Calculate the dissolved oxygen, 0, in the bottle and record:

$$0 = 1.6096 \times f \times V$$

where 0 is in mg 0_2/liter

Calculate the productivity values for the sample as follows, and record:

Gross photosynthesis, mg carbon/m^3 - hr =

$$\frac{605 \times f \times \left[V_{LB} - V_{DB}\right]}{N \times 1.2}$$

Net photosynthesis, mg carbon/m^3 - hr =

$$\frac{605 \times f \times \left[V_{LB} - V_{IB}\right]}{N \times 1.2}$$

---

5 Manganous sulfate and alkaline iodide.

Respiration, mg carbon/m^3 - hr =

$$\frac{605 \times f \times [V_{IB} - V_{DB}]}{N}$$

C. At least 20 hours but not more than 2 days after filtering from the water, analyze the "Pigments" samples as follows:

Remove centrifuge tubes from refrigeration and let them warm to room temperature. Add 90% acetone using a polyethylene wash bottle to make the liquid up to exactly 40.0 ml. Replace the glass tube stoppers with plastic stoppers and centrifuge for about 10 min. at about 3000 - 4000 rpm.

Pour the clear liquid from the tube carefully to fill a Beckman DU spectrophotometer sample cell having a path length of 10 cm and volume of about 30 ml. Immediately measure the extinction, E, of the solution in the spectrophotometer against a reference cell filled with 90% acetone only. Measure at wave lengths: 7500, 6650, 6450, 6300 and 4800 A. Record values to the nearest 0.001 unit in the range 0 - 0.4 and to the nearest 0.005 unit for extinctions greater than about 0.4. Then fill both cells with 90% acetone (sample cell and reference cell) and measure extinction at each of the above wave lengths. This gives a cell-to-cell blank correction, E_{cc}. Calculate the corrected extinctions at each wave length as follows:

$E_{6650} = E_{6650}$ (as measured) - E_{7500} (as measured)

$\pm\ E_{cc_{6650}}$

$$E_{6450} = E_{6450} \text{ (as measured)} - E_{7500} \text{ (as measured)} \pm Ecc_{6450}$$

$$E_{6300} = E_{6300} \text{ (as measured)} - E_{7500} \text{ (as measured)} \pm Ecc_{6300}$$

$$E_{4800} = E_{4800} \text{ (as measured)} - 3 \times E_{7500} \text{ (as measured)} \pm Ecc_{4800}$$

The sign for E_{cc} depends on the relative readings for the 2 cells when they were compared with both containing 90% acetone. Calculate the concentration ratios, C, of chlorophyll *a* as follows:[6]

$$C = 4 \left[\frac{11.6\ E_{6650} - 1.31\ E_{6450} - 0.14\ E_{6300}}{V_w} \right]$$

where V_w is the volume, in liters, of water passed through the Millipore filter. C is in mg pigment/m^3 water.

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6 Or get C value from nomograph supplied, using the corrected E values.

Doty, M.S., J. Newhouse and R.T. Tsuda. 1967. Daily phytoplankton primary productivity relative to hourly rates. In: Improvement and Application of Benthic Algal Isotope Productivity Measuring Methods. Hawaii Botanical Science Paper No. 3. University of Hawaii.

Strickland, J.D.H. and T.R. Parsons. 1968. A practical handbook of seawater analysis. Bulletin Fisheries Research Board of Canada 167.

APPENDIX 2

MEASUREMENT OF PRODUCTIVITY OF BENTHIC ALGAE

The details of this method are yet to be developed. It is planned to enclose an area of bottom mud and a small amount of overlying water in situ by placing the open side of a clear or opaque plastic chamber on the bottom. (A clear chamber would be used for measurement of net photosynthesis; an opaque chamber would measure respiration). It is desirable to provide stirring, e.g. by including a magnetic stirrer driven by battery power or compressed air. Plastic bags can be used as disposable test chambers to seal on very uneven bottoms.

An initial oxygen concentration measurement would be made immediately and one or more made subsequently after sufficient "incubation" time in situ to produce changes in oxygen sufficient for productivity computations. Initially the oxygen would be monitored frequently and tests run sequentially throughout most of the daylight hours. From these results, a method would be devised for estimating daily production from a single measurement (e.g. Doty et al., 1967). A light intensity measurement would be made with each oxygen measurement.

Oxygen could be measured by any method available, but the use of a polarographic "oxygen electrode" is much preferred for ease of frequent (or continuous) monitoring, minimum contamination (dilution) of samples and accuracy unaffected by oxygen saturation of water. The polarographic techniques and submersible equipment of Wells (e.g. Wells and Wells, 1971) appear applicable almost unchanged, and equipment of this sort would be assembled for the purpose.

The routine test procedure would involve (1) placing a clear and an opaque chamber on an appropriate bottom area with minimum disturbance of sediments, (2) connecting the stirrer power supply (battery or air), (3) taking an initial dissolved oxygen reading for each chamber, (4) taking a submerged and a surface irradiance reading, (5) marking the location, and (6) returning after the proper interval to take further readings. The oxygen electrode calibration should be checked occasionally (e.g. in water -

saturated air). A calibration sheet would be used to convert current readings to oxygen concentrations.

Gross photosynthesis, net photosynthesis and respiration would be computed from oxygen concentration measurements in the same general manner as in Appendix 1, section IV.A. The productivity estimates so obtained would include the effects of the phytoplankton in the volume of water enclosed within the chamber. Values for phytoplankton productivity measured at the same light intensity either concurrently or at some similar station would be used, together with the known volume of water enclosed, to correct the chamber measurements so as to yield benthic productivity values.

Doty, M. S., J. Newhouse and R. T. Tsuda. 1967. Daily phytoplankton primary productivity relative to hourly rates. In: Improvement and Application of Benthic Algal Isotope Productivity Measuring Methods. Hawaii Botanical Science Paper No. 3. University of Hawaii.

Wells, J. M. and A. H. Wells. 1971. Photosynthesis in coral - algal associations. In: Scientists-in-the-Sea (J. W. Miller, J. G. Van Derwalker and R. A. Waller, eds.). U. S. Dept. of the Interior.

APPENDIX 3

MEASUREMENT OF PRODUCTIVITY OF SEA GRASSES

The method for measurement of productivity of the entire plant is basically the same as that used for measurement of benthic algal productivity (Appendix 2). The same or very similar equipment would be used. Bottom chambers would be sized so as to contain the height of sea grass leaves without excessive crowding and to cover an area containing a number of "short-shoots" (clumps of green leaves) in a moderately thick growth of Thalassia. Measurements of oxygen and light intensity would be taken in the same way. The measured oxygen concentrations would be converted to productivity and respiration values in the same way for the enclosed system. Phytoplankton productivity would be subtracted out in the same way to give a total benthic productivity value. For sparse growths of Thalassia, benthic algal productivity and respiration should also be subtracted out to obtain estimates of values for Thalassia alone (see Jones, 1968). Benthic algal productivity per unit area from an adjacent parcel of bare bottom, measured as in Appendix 2, would be used, together with the area of the chamber, to compute the correction. For dense growth of Thalassia, the shading of the bottom is probably such that the benthic algal correction would be negligible (see Pomeroy, 1960). In any case, for estimation of primary productivity of the bay, it is the total benthic value-benthic algae plus sea grasses, as measured-that is of major interest. Although the productivity of algae epiphytic on Thalassia may be considerable (Jones, 1968), for purposes of this study, it seems unnecessary to separate this component from the productivity of the Thalassia plants.

Much of the photosynthetic production of Thalassia goes into growth of roots, rhizomes and the basal portion of "short-shoots", which cannot be conveniently marked and subsequently harvested to measure growth. However, a substantial fraction of net photosynthesis results in growth of visible green leaf blades (Jones, 1968). Measurement of growth rate of these leaves gives an estimate of productivity that is at least useful for comparative purposes. It provides some check on the estimate obtained by oxygen measurement. The leaves constitute the portion of the plant

which has most rapid turnover and is passed along the food chain most quickly and conspicuously (Wood et al., 1967). Measurement of green leaves gives information on the amount of plant material available to participate in photosynthesis.

Measurement of leaf growth would be included in future ecological Thalassia studies. The present sampling procedures include biomass measurements of leaves and other plant parts (see "Ecology of Turtle grass ..." section, this report). Additional information to be recorded would include number of green leaves, width of blade and length of blade, since the work of Thorhaug and Stearns (unpublished manuscript) suggests that elevated water temperatures produce different effects on these different plant characteristics. As a means of monitoring effects of elevated temperatures and seasonal effects, at some stations, semi-permanent quadrats should be defined, and a blade count should be made at each biomass sampling occasion.

In addition to the biomass measurements, leaf growth should be measured in the field by marking a group of leaves at the station and subsequently harvesting the leaves to measure the elongation. A marking method similar to that of Zieman (1970) could be used (also see "Studies of the Effect of Heated Water on Turtle Grass ..." section, this report). Leaves should be marked initially at the point of transition from sheath to blade. Zieman's results (Zieman, 1970, Fig.3) could be used to estimate total leaf elongation from elongation at the blade base. The sum of this new material plus the total length of any new leaves produced comprises the growth for the time interval. It would be convenient to mark a group of leaves in this way at each station sampling occasion and harvest all or a portion of these leaves as a routine biomass sample at the next occasion. The length, width and weight of new leaf growth would then be taken along with present biomass data. Leaves should be cleaned of epiphytes before weighing by washing in dilute acid in order to produce accurate and meaningful Thalassia biomass values.

The blade density and blade growth data would be especially effective for simple estimation of production in many areas having widely different grass coverage. The work of Thorhaug and Stearns (unpublished manuscript) indicates very similar growth per blade over a wide range of blade densities in Card Sound and good agreement between increase in blade area and increase in blade weight.

Jones, J.A. 1968. Primary productivity of the tropical marine turtle grass, Thalassia testudinum König, and its epiphytes. Unpublished PhD thesis. Univ. of Miami.

Pomeroy, L.R. 1960. Primary productivity of Boca Ciega Bay, Florida. Bull. Mar. Sci. Gulf Carib. 10: 1-10.

Thorhaug, A. and R.D. Stearns. An ecological study of Thalassia testudinum in unstressed and thermally stressed estuaries.

Wood, E.J.F., W.E. Odum and J.C. Zieman. 1967. Influence of sea grasses on the productivity of coastal lagoons. In: Lagunas Costeras. UNAM-UNESCO.

Zieman, J.C. 1970. A study of the growth and decomposition of the sea grass, Thalassia testudinum. Unpublished MS thesis. Univ. Miami.

PHYSICAL OCEANOGRAPHIC

METHODS

CURRENT STUDIES

by

E. D. WOOD

1. Meters - Hydro products Model 503

   a. Calibrated in a swimming pool, the meters were suspended by floats and towed the length of the pool at constant speed. Tows up and down the length of the pool were averaged for velocity calculations. The pools circulating pumps were off for several hours before and during calibration. Calibration was done at velocities of: .2, .5, and .8kt. The velocities shown by the meters were all lower than measured and the correction factors determined were:

Meter #	Factor
1	1.2
2	1.05
3	1.02
4	1.09

   The meters are checked periodically in the electronics shop; and adjustments to the read-out circuitry made as required.

   b. Current meter placement.
   The current meters have been installed by two different methods.

      (i) Individually anchored meter installation is used where the meters are to be in different locations. The meter is attached to a weight (lead or cement) by a line measured to give the desired depth for the sensors. A Danforth anchor is attached to the weight by a 3m section of chain. The meter is suspended by a float which displaces about 20 liters. The float depth is adjusted so that it is about one meter below the surface. This puts the system out of sight of those who may molest the equipment and deep enough so that it will not interfere with small craft operation. The meters are located by triangulation sites on shore or occassionally marked with a small bouy anchored separately.

(ii) Group anchored meters are suspended from a platform, either a raft, bouy, or ship. Surface meters are tethered and suspended by floats and actually measure currents at a depth of about 0.5 m rather than 0 m. The other meters are suspended from the platform in such a fashion as not to interfere with one another. Usual depths for our measurements have been 0 (015), 2, 4, 6 m measured from the sea surface to a point mid-way between the Savonius rotor and the direction vane of the meter.

(iii) The platform is usually secured with two anchors to reduce swinging caused by current meandering. Most measurements are for at least 24 hours to take into account tidal and wind effects. The current meters are periodically checked by dives to insure that they are functioning properly.

1 c. Interpretation of the data.
The current data is recorded by a Rustrak recorder on pressure sensitive paper tape. The settings are such that the paper moves approximately 2.5 cm hr^{-1}. The exact rate is determined on individual recordings from the "in" and "out" times marked on the tapes. The data are transcribed onto graph paper manually with meter error correcting and some smoothing.

The velocities and directions for each meter are averaged over convenient time periods and correlated usually with tide and wind data.

When calculating the flow through a channel, the cross-section is determined either from the charts or by direct measurement. The cross-section is then divided into appropriate sub-sections to correspond to the meter, e.g., if current meter depths are 0, 2, 4, & 6 m then the depths of the sections are 0-1, 1-3, 3-5, and 5-bottom (in meters). From this information, flow can be determined by summing average vector velocity through the sub-section on a daily basis or on an hourly basis. Thus net flow can be determined as well as total flow in each direction. The data is usually reported as the average flow rate.

2. Drogue studies.
Drogues have been used to determine flow over a distance. The drogues were made of crossed sheets of plywood in some cases and parachutes in others. The main part of the drogue was placed at varying depths. A pole was mounted on the float of the drogue and equiped with a radar reflector for tracking. The drogues were tested both with and without structures above the water to determine the effect of wind drag. It was found to be on the order of 20% for a 12 mph wind and all drogue velocities were corrected accordingly.

3. Dye Studies.
   a. Spot releases of rhodamine-B dye are used to determine rates of flow over a distance and degree of mixing. The dye is dissolved in acetic acid and mixed with fresh water in the ratio of about 75 g/1. The resultant mixture is nearly the same density as sea water. A study usually entails 8-12 releases of 10 liters each either from a small boat or dropped from an airplane. The dye spots are then photographed over a period of several hours to deliniate the surface current patterns of a particular region. Releases are repeated for various sets of conditions. Since the photography is limited to daylight hours, a release is made early in the day to measure the effects of low wind velocity usually experienced during the night. Late afternoon releases then give results for windy conditions. This usually takes the tides into account as Puerto Rico has essentially one tide a day.

      Photography is often complicated by poor light, low clouds, or lack of landmarks. These problems have been partially solved by using high speed film, taking angle shots normal to the shoreline and placing float markers for reference points.

      Dye studies are correlated with current meter measurements when practical.

   b. Continuous Dye Releases.
      Soluble rhodomine-B was released into the study region from an anchored raft at the rate of 7 kg/day for a three day period. The continuous dye release allowed visual and instrumental tracking of the surface currents of a period of

(3b) time. The dye plume was photographed from the air at three different times a day. Transects fo the dye plume were made to map the extent surface spreading of the plume. Equipment was loaded in a 17' boat equipped with a portable generator. The concentration of dye in the plume was measured with a flourometer equipped with a "flow-thru" cell. The water was pumped through a tube 3 in. long at a fast rate. The cell was fed through by-pass which gave nearly an instantaneous response to the water near the boat. The depth of the intake could be adjusted from surface to 3 m.

COLLECTION AND PREPARATIVE METHODS

COLLECTING METHODS FOR FISHES

F. D. MARTIN

Fishes are collected for our studies by a number of methods including, gill nets, seines, cast nets, dip nets, hand lines, fish toxins, spear guns and traps. The methods most commonly used are gill nets, seines and fish toxins. Each method has its special uses and limitations and outlines of these three methods will be given here.

Gill nets are nets which depend on fish trying to force their way through the mesh of the net and becoming entangled therein by their gill coverings and/or fins. The nets we use are constructed of monofilament nylon which is virtually invisible in water. A lead line is used to hold the bottom down and a float line holds the net vertical. Normally we wish the net to remain stationary so that it does not tangle up or become lost while left in place. To accomplish this, 5 pound lead weights are attached to the lead lines at each end of the net. If currents in the area are strong, additional weights are attached as needed. Marker buoys are attached to the float lines at both ends of the net by enough heavy cord (200 lb. test minimum) so that the buoy floats with some slack in the line. Since the nets we have are rigged to be set on the bottom, in the event that floating nets are desired, empty plastic jugs (1/2 gallon or larger) are attached every 8-10 meters along the float line as the net is played out.

When setting nets near shorelines, we normally set the net perpendicular to the shoreline because, on the average, fish move more often parallel to the shoreline than to or from it. Occasionally it is desirable to attach the net to an object on shore. In this event, attach only the float line so that the lead line can have enough slack to remain on the bottom.

The gill nets we use are normally stored in plastic garbage cans and when being set are fed directly from these over the side of the boat. In order to facilitate this, the net is usually fed over the bow or one of the sides well away from the motor and any cleats or other potential snags. As it is fed out, any tangles or kinks in the lines are

straightened out as these are potential tearing or breaking points when pressure is put on the net to pull it in.

Normally the net is set in a straight line and with enough slack to keep the net from being pulled tight. Tight nets do not entangle fish as effectively as loose nets.

If wind direction allows it is generally easiest to feed the net out at about the speed the wind drifts the boat and to have the motor off. (Remember: gill nets do bad things to outboard motors when wrapped around a prop and vice versa). Otherwise one or two people play the net out while another backs the boat in the direction the gill net should run and at a very slow speed.

The net is then left for a period of time (never less than 30 minutes) and is then pulled back in starting from the down wind end or the end away from shore. All attachments are removed as the net is pulled over the side and the net is fed directly back into its garbage can. Fish are removed as they are pulled over the side and are placed in properly labled containers. Techniques of removal depend on the fish, the mesh size of the net and degree of entanglement. Experience is the only effective teacher in this area.

Gill nets are seldom left more than 2-4 hours because: 1.) of the danger of it drifting and becoming fouled on coral heads or other snags; 2.) crabs congregate and dine on the trapped fish thus eliminating much of your catch; and 3.) untended nets are temptations to persons who chance upon them.

Nets are rinsed with fresh water as soon as possible upon return to PRNC and then dried with as little exposure to direct sunlight as possible. Sun light breaks down nylon and must be avoided as <u>much</u> as possible.

Gill nets are ineffective in catching eels of any kind and seldom catch territorial fish as they do not normally move enough to take them in the area of the net. They are quite selective in size, as fish below a certain size go through the mesh and do not become entangled.

Another method of fish capture is the seine. This is a flat net which is pulled through the water (some are not flat but have bags in the center, but these are not used here). It is equipped with a lead line to keep the bottom down, a

float line to keep the top on the surface and poles at each end to make pulling both lines at the same time possible. The net is pulled by two or more people through the water and then either pulled up on the beach or lifted by getting the lead line well in advance of the float line and picking it up so that the fish are picked up on the surface of the net. The most common reasons for ineffectiveness are: 1.) failure to keep the lead line on the bottom; 2.) snagging the net so that progress stops while the net is undone; 3.) allowing the net to roll up while being pulled through grassy areas and, 4.) persons walking in front of the net and frightening the fish away before the net gets there.

Seines are ineffective in collecting: 1.) fish which are strong swimmers and can move faster than the seine; 2.) fish which bury in the bottom or hide among snags when approached; 3.) jumping fish which can go over the net and 4.) fish which can force their way through the mesh (e.g. eels and needlefish)

The other common method used in collecting fish is fish toxins. The toxin we use is Pro-Noxfish® which is a solution of rotenone in xylene with emulsifiers and synergists. The toxic effect is upon the gills of the fish so that they come to the surface for oxygen where they can be dipped up with long handled dip nets. When we do a poison station we are interested in establishing the biomass of fish for a given surface area. For this reason we fence off an area with a fine meshed net before introducing the toxin. If the station is to be near a convenient shore, we use the shore as one side of the fenced in area. We use a 100 foot net as the fence and if the station is using a shore as one side, two poles are driven into the bottom 33 feet from the shore and 33 feet apart and the net is pulled around them to make a 33' by 33' square. Otherwise four poles are driven into the bottom so as to make a 25' x 25' square and the net is pulled around them. Also before introducing the poison, the lead line of the net is checked to make sure it is snug against the bottom. About 300 ml of the toxin are poured into a 2 gallon bucket containing 1 1/2 gallons of sea water. This is introduced into the enclosure in the following manner. About 1/2 is put in on the upcurrent side so that it will wash through the whole enclosure and the rest is spread over the surface of the enclosure as evenly as is feasable. Then the poison is mixed by swimming or wading through the area! (Note: If you get any of the concentrated poison on your skin, rinse it off immediately; if you contact some of the diluted toxin while swimming in the area, it will <u>not</u> do any

permanent damage but may irritate your eyes or produce nausea if ingested). Within 5-10 minutes, fish should start surfacing and should be dipped up immediately as they will not stay on the surface once they die. If no fish come up within 10 minutes, a second treatment using 500 - 700 ml of concentrate is applied in the same manner as the first dose. In any case, when action slacks off (after 30-45 minutes) another dose similar to the first effective dose should be applied.

For obvious reasons fish from the enclosure must be kept separate from any fish captured outside the enclosure. Fish seen to enter the enclosure from the outside are to be counted as off station fish and the reverse situation will be counted as on station fish. If you are not sure where it came from, it is an off station fish.

Collecting is terminated when fish are no longer coming up regularly and periods of 4 or 5 minutes occur between catches. The procedure at this point is to pull up all corner poles and to purse the fencing net by pulling lead lines together so that the enclosure has a bottom of net. This is done by dragging the net along the bottom - the lead line should never be lifted from the bottom. The easiest way to do this is by pulling the net slowly onto the shore or into the boat by the lead line. The fishes which died and did not come to the surface will be picked up in this way.

Poison stations are less selective than most but certain species are not taken by this method. Strong swimmers frequently leave the area during the setting up process and for this reason the set up should be accomplished as quickly and with as little wading and splashing as possible and with no wading in the area to be enclosed until after the fencing operation is complete. Many small fishes which live in crevices and among the plants die in place and are not seen. The other group not taken by toxins are the sharks and rays. They are not sensitive to this toxin and on occassion sharks come into the general area to feed on the incapacitated fish. In the event that this happens (and this partically never happens) get out of the water with all due haste but with as little splashing as possible.

The other methods of collecting are methods widely known and I will not discuss them here.

The one remaining point of discussion is the criteria for deciding on sampling areas. First priority is placed on establishing base lines for areas which should be directly effected by whatever is to happen in the areas. In the case of Jobos this is the intake area, the outfall area and the areas down current from the outfall which could receive effects directly from the thermal plume or which might be exposed to chemical effluents. A few areas which should receive no effects are sampled regularly as control stations.

Within each major area under consideration, subareas are established based on habitat type (mangrove root areas, turtle grass beds, open bottom areas, etc.) and each area is sampled by means appropriate for the habitat and at intervals so that seasonal variations can be established.

Normally the general area and the habitat types to be sampled are predetermined, but the suitability of a specific site for sampling on any given day is determined by the sampling technique to be used and conditions of tide, wind, etc. Seine stations cannot be deeper than 1 to 1 1/2 meters and must be relatively free of snags. Poison stations cannot be deeper than about 2 1/2 meters if they are to be quantitative and if they are deeper than about 1 meter, the visibility should be such that the bottom can be seen easily. Fast currents or heavy wave action limit the effectiveness of poison stations. Beyond this, there are no simple guidelines and experience is the only teacher.

THE THALASSIA BEDS

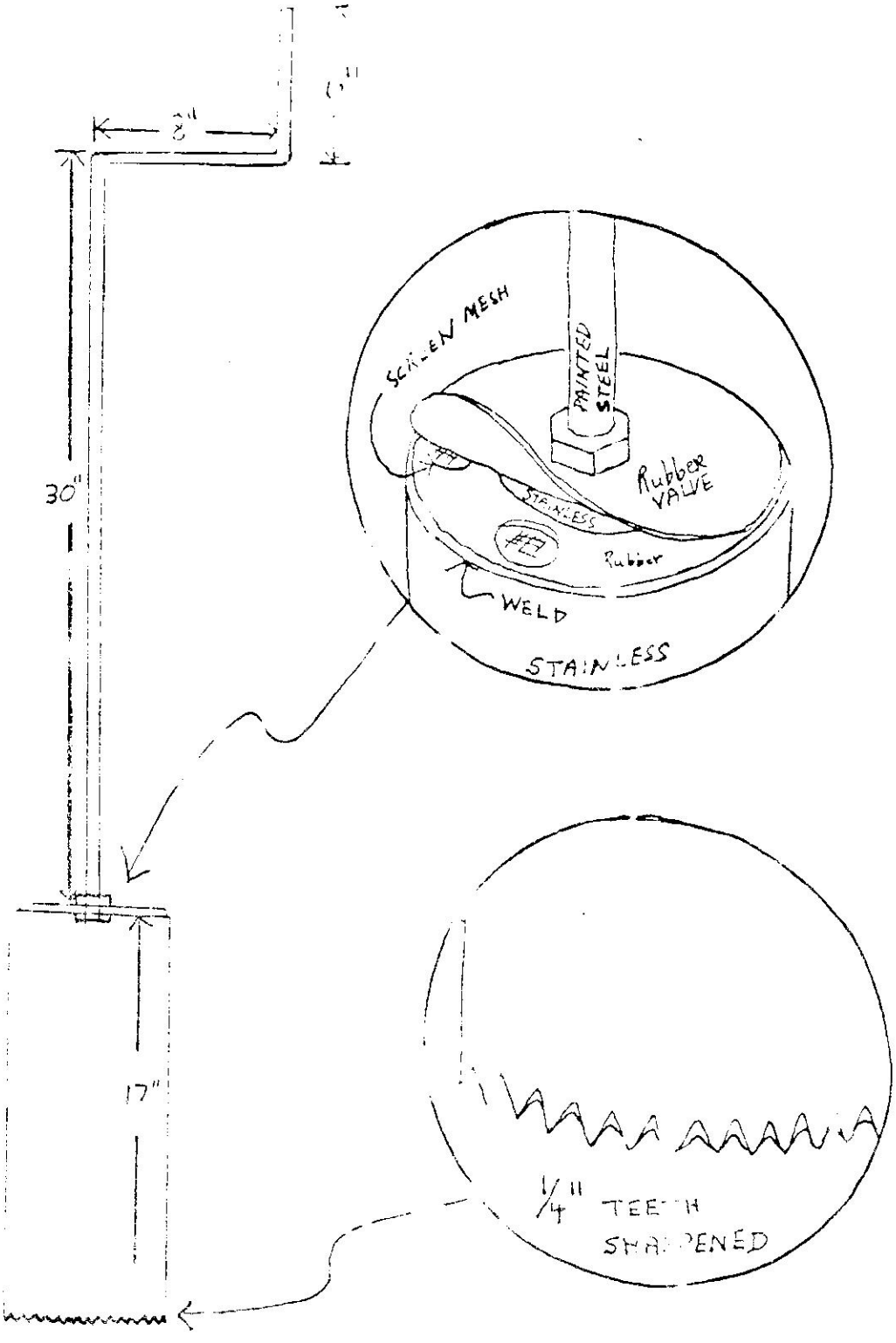
Sampling Methods:

The sampling biomass of plants and benthic invertebrates was done with a special core sampler that was designed by Mr. Peter Schroeder. This sampler consists of a stainless steel pipe (16.1 mm Ø with a crank. (Figure 1 in the section on Thalassia beds in Guayanilla Bay)). It samples an area of 203 cm^2. The upper end of the pipe is covered with a screen of 0.8 mm mesh to prevent free moving animals from escaping. A rubber flap seals the upper end and prevents the core from dropping off when the sampler is lifted from the bottom. This sampler has proved to be very fast and quantitative both for the plants and the invertebrates. Two cores were sampled at six stations at a depth between 0.5 to 1 meter.

Plants and animals were separated from sediments in a standard set of geological sieves. Thalassia was separated to six different parts: old leaves, new leaves, sheathing, rhizomes, vertical shoots and roots (see Tomlinson and Vargo, 1966). Thalassia leaves were weighed after cleaning off all the sediments and filamentous algae. No effort was made to remove attached microorganisms from old leaves. These microorganisms include: diatoms, filamentous algae, foraminiferans and small polychaetes dwelling in calcareous tubes. Their biomass is only a fraction of one percent of the biomass of Thalassia and usually proportional to the biomass of old leaves. The wet weight of plants and invertebrates and the number of specimens of different invertebrates were recorded. Dry weight was measured only for the biomass of plants.

THALASSIA SAMPLER

.0203 METER^2



CORAL REEFS

Materials and Methods

Sampling methods were geared to collect descriptive and quantitative data. Three methods were used, all involving the use of scuba diving:

1. Transects: A nylon line marked at 1 m intervals was used to make transects extending from as close to the reef flat as safe swimming allowed, to the beginning of the reef fore-slope. The transect usually covered a distance of 75 to 125 meters. Data from the first few transects were recorded on plexiglass plates, on which all corals and major cover organisms (such as sponges and gorgonians) along each meter interval were noted and recorded. Later transects were recorded photographically, but only every third meter was photographed. The transect data was used to describe the reef zonation and structure and to determine species dominance among the main cover organisms.

2. Measured Quadrats: Two meter by two meter areas were marked off with heavy stakes and nylon lines or with a metal rod frame. The plots were then divided into 1/4 m^2 grids. The areas covered by each species of coral and other important organisms were recorded on a plexiglass plate or on film. The resulting diagrams or photographs were used to calculate percentages of bottom coverage, and dominance and species diversity among the major encrusting organisms.

3. Collected Quadrats: 1/4 m^2 areas of the above quadrats were collected in their entirety. Crowbars and knives were used to remove sections of the reef rock which contained encrusting and boring organisms. The samples were immediately placed into large plastic bags, held next to the collecting site by a second diver, in order to

ensure that none of the small free-living organisms such as crabs and brittle stars could escape. The samples were stored in plastic buckets and refrigerated on their way back to the laboratory where they were sorted into phylogenetic groups, weighed and preserved for later identification. Corals were weighed and their surface area estimated. Pieces of pre-weighed and measured coral were dried at 110°C., reweighed, subjected to Clorox digestion, dried and weighed again to estimate the amount of living animal and plant material present. The pieces of coral rubble which remained after most of the encrusting and boring organisms had been removed were similarly treated to estimate the amount of non-removable material (some bryozoans, boring sponges, calcareous algae, and boring worms) still remaining. A factor was calculated from this and used to calculate the amount of organics in the total rubble sample. This total is listed in the biomass estimates as "miscellaneous."

In the case of station 10, three clumps of material were collected and labeled samples 10A, 10B and 10C. The narrowness and relief of the reef there made it very difficult to collect quadrat samples. For this reason, no transect data was collected for this area.

Total biomass estimates were derived by tracing the area covered by coral reefs from a standard USCGS map, cutting out and weighing the tracings and multiplying the estimated area by the average of the biomass estimates computed from the collected quadrats data.

Only the corals, gorgonians, mollusks, crustaceans and echinoderms were classified to genus and species level. The classification of the sponges, annelids (present in very large numbers), sipunculids and other worm-like organisms was not attempted. I wish to acknowledge and thank Mr. Carlos Carrera, Department of Marine Sciences, University of Puerto Rico for his help in classifying the brittle stars.

PREPARATION OF CUBITAINERS

Law #1 Label <u>everything</u> with date and station number.

1. Rinse with tap water.
2. Rinse with 4 N Nitric acid.
3. Rinse with distilled water.
4. Put on cap and put a piece of masking tape labeled "Prep." on the cubitainer so it won't be confused with dirty ones.

COLLECTION OF SEA WATER

1. On station rinse the cubitainer with a little of the sea water you will be sampling.

2. Fill cubitainer up current from the boat and motor to avoid paint flakes, gas, and oil.

3. Add 10 ml (cc) of concentrated HCl (hydrochloric acid).

4. Filter within 8 hours to get rid of bacteria and algae. If this can't be done add 1 ml chloroform and keep cool, or freeze the whole thing. Save filter in plastic bag.

METHODS MANGROVE ROOTS

Sampling Stations and Methods

The mangrove root communities in Jobos Bay show enormous variations in the species composition and biomass. The reasons for this are by in large unknown, but it seems like, salinity, temperature, food availability, wave action, depth and pollution are important factors controlling the mangrove root communities in Puerto Rico.

Eight sampling stations were selected to represent different types of mangrove root communities around the proposed intake and discharge areas of the cooling water for the power plants. Station #11 was north of Cayo Puerca at the end of a cove that has received effluents from the settling ponds of Central Aguirre (Figure 7). This area used to be badly polluted with dissolved organic compounds that utilized all oxygen from water. Part of the mangroves in this area were killed by the pollution and all of them showed signs of stress which could be seen from an unusually large number of aerial roots. Since spring 1972, this area has not been receiving waste from the sugar mill. Even months after the dumping of sugar mill effluents were stopped this area was anoxic on the bottom and producing H_2S and was well saturated with oxygen and currents were moderate. Sediments at this station were silt and fine sand. Water was shallow, between 0.3 and 0.5 meters. Temperatures up to 31 c were observed on the surface in the summer.

Station #7 was on the south side of Aguirre Navigational Channel at Cayos de Barca. This station was exposed to the wave action and the swells in the Navigational Channel. Water was well saturated with oxygen and clear. Summer temperatures up to 31 c were measured on the surface. Currents were moderate and flowing to the west. Water was shallow between 0.2 and 0.5 meters deep. Sediments were mud.

Station #3 was located on the east shore of Punta Colchionas in the Midbay. This station was exposed to the wave action and swells, but it was somewhat protected by a wide shallow turtle grass bed in front of it. Water at this station was light brown, well oxygenized. There was a weak southerly

current passing by the station. At times of strong winds water was silty. Water temperatures rose up to 31.5 c in summer. Water at this station was 0.7 meters deep and the sediments mud.

Samples were collected twice. The first time in September, 1971 and the second time in July - August, 1972. The first collecting involved cutting a 30 cm section of ten roots from the mean sea level down. The species, genera or phyla were identified and the biomass of each of them measured. The results are given in the Aguirre Nuclear Plant Annual Report 1971 pp. 34-43. This study uncovered so many interesting aspects of the mangrove root communities that a more thorough investigation was undertaken.

In the second sampling whole mangrove roots were collected by cutting them at the mean high water level, which coincides with the uppermost sessile organisms on the roots. The roots were carefully surrounded with a 0.5 mm mesh net before lifting up. This way all the free swimming crustaceans and fish were also recovered. Three to six randomly chosen roots were collected at each station.

The roots were placed into large poyethylene bags and transported into the laboratory in an ice chest. In the laboratory the roots were cut to 10 cm sections from the upper tide level down. The organisms in each section were separated, identified and the wet weight of each species was recorded. Because of the vertical zonation of organisms the biomass is given per root instead of per unit length of root.

PREPARATION OF SAMPLES FOR ANALYSIS

PREPARATION OF BIOLOGICAL SAMPLES FOR AAS

1. Grind the dried sample to a fine powder.
2. Weigh out about 2 g sample in 125 ml erlenmayer.
3. Add drop by drop about 25 ml of aqua-regia.
4. Place on the hot plate, digest about 20 minutes at very low heat.
5. Bring to near dryness.
6. Dissolve with double distilled water (DDW).
7. Filter through pre-washed glass filters.
8. Dilute with DDW to 50 ml. Put in screw cap plastic bottles.
9. Pipette out three 10 ml aliquats into small plastic bottles.
10. Add proper standards of different concentrations of each element to each one. (Standard addition technique)
11. Run at AAS.
12. By plotting each sample on the graph, find out concentrations of the samples.
13. Report the result in milligram per gram.

BIOLOGICAL SAMPLE COLLECTION AND PREPARATION FOR TRACE ELEMENT, NUTRIENT AND CHN ANALYSIS

Five or six organisms were collected at each sampling station. The species to be collected were selected: (1) to represent the various trophic levels (primary producers, herbivores and carnivores) and (2) because they made up a major part of the biomass.

Samples were collected from three habitats: the coral reef, the Thalassia beds, and the mangrove root communities. Immediately after collecting, the samples were placed on ice until they could be frozen back in the laboratory. The following collecting procedure was used:

A. Coral Reef Samples:

Divers, using SCUBA equipment and, where possible, wearing plastic gloves, collected the chosen organisms and placed them in clean, unused plastic bags. Encrusting organisms were collected by hand, when possible, but more usually with the aid of a stainless steel knife or spatula. Care was taken to pour out all the sea water from the sample bags before the bags were closed and stored on ice.

B. Thalassia Bed Samples:

Organisms from this habitat were also collected and cleaned underwater. Cleaning involved removing sediment and extraneous encrusting material from the sample organisms. Once collected, samples were treated as above.

C. Mangrove Root Community Samples:

Organisms growing on the mangrove roots were collected by hand or with the aid of a stainless steel knife in the case of the oysters. Sediment accumulated in the algae was washed out before the sample was collected. The mangrove and tree oyster were not cleaned of epiphytes since only the meat is used in the analysis. As before, sample bags were closed and stored on ice.

It was found that the chosen organisms were not equally present at all the sample stations. Substitutions were

made where necessary, but emphasis was placed on trying to collect the same organisms at all stations of the same habitat type.

The Sample Preparation Procedure Is The Following:

The samples were defrosted, placed into acid-cleaned beakers, and weighed together with any fluids which may have been in the sample bag. Since all the sea water had been removed from the bags soon after collection, all fluids in the bags, after defrosting, were considered vital fluids which had been lost by the organisms during the freezing-thawing process. The beakers were then covered and dried to constant weight at 110° C. The dried samples were ground to a fine powder with a porcelain mortar and pestle and reweighed. Two grams subsamples were dissolved for trace element analysis and one gram subsamples were used for CHN and nutrient analysis.

Mollusks were removed from their shells before obtaining the wet weight. Sea urchins were ground shell and all. Coral samples were not ground, but the coral tissues were dissolved off the skeleton with a strong base instead of an acid.

Care was taken during all steps of the sample collection and preparation to try to avoid contamination from glassware, metal utensils, and human hands.

TREATMENT OF WATER AND BIOLOGICAL SAMPLES FOR TRACE ELEMENT AND NUTRIENT ANALYSIS

Water:

Water samples should be filtered with 0.45 m filters as soon as possible after the collecting. After the filtering the samples should be acidified with concentrated HCl, 1 ml per liter of water.

For phosphate, nitrate and nitrite analysis 4 L of water is needed. Trace element analysis required 10 L.

Soluble orthophosphates are collected from 2 L of water by an anion exchange column and total soluble phosphates from 1 L of water, also with an anion exchange column, after all phosphates have been oxidized with a potassium persulfate digestion. The analysis of phosphates is carried out with an Autotechnicon autoanalyzer. Nitrate and nitrite are also run by the autoanalyzer.

Eight liters of water are scavenged with $Fe(OH)_3$ to pre-concentrate Mn, Mg, Co, Cu, Ni, Pb, Zn, Cd, Cr, Ca, and Sr for analysis by atomic absorption spectroscopy.

Biological Samples:

After the collecting all specimens are cleaned of silt and dirt, specimens of the same species put into a plastic bag, labeled, and frozen. In the laboratory the specimens are dissected, weighed, and dried at 105° C. Part of the frozen sample is saved for pesticide and Hg analysis.

Dried samples are cooled in a dessicator, weighed, and ground. Dried samples are analyzed for carbon, hydrogen, and nitrogen content with a gas chromatograph.

For phosphate and trace element analysis 2 g of dried sample are digested by aqua regia wet digestiong method.

Phosphates are analyzed with the autoanalyzer and trace elements (Fe, Mn, Mg, Co, Cu, Pb, Ni, Zn, Cd, Cr, Ca, and Sr) are analyzed with atomic absorption spectrophotmetry.

LABORATORY METHODS

CLEANING GLASSWARE

1) Rinse out all biological or chemical matter with tap water.

2) Wash using cleaner provided.

3) Rinse in tap water.

4) If biological material adheres to glassware, soak in NaOH solution. Rinse.

5) Rinse glassware with 6N. HCl.

6) Rinse two times with distilled water.

7) Dry glassware in low - heat oven.

LAB PREPARATION OF WATER SAMPLES

1. If the water has not been pre-filtered, do so. Save for counting.

2. Ferric Hydroxide Precipitation:

   a. Lower the pH of the sea water to 2.0.

   b. Add 10 ml of Ferric Chloride and mix well.

   c. Add slowly, 6N NH_4OH to raise the pH to 9.0.

   d. Add 10 ml of separan after 5 minutes of precipitation.

   e. Allow sample to sit for 24 hours.

   f. Filter the water.

   g. Put the precipitate in 250 ml plastic bottles.

   h. Centrifuge

   i. Put the precipitate in 150 ml beakers and boil until nearly dry.

   j. Put pre-cut filters into 1N HCl and leave for 20 minutes. Wash filters with distilled water and let sit for 15 minutes.

   k. Filter what is left of precipitate and put into 25 ml plastic bottles for Atomic Absorption.

NAA for TRACE METALS IN SUSPENDED PARTICLES IN SEA WATER

1. Cut to pieces a known weight of the filter and place the pieces in a 25 ml beaker.

2. Add 5 ml conc. H_2SO_4 and approximately 3 drops HNO_3, cover beaker loosely.

3. Heat slowly to a boil. Evaporate to dryness.

4. Wash beaker out 3 times with 3 ml aliquots of distilled water. Place washings in a 10 ml polyethylene vial, place in a vacuum desicator and evaporate to dryness.

5. Heat-seal vials under vacuum.

6. Irradiate for 5 minutes and allow 3 minutes for decay.

7. Count 400 seconds line-time (Al, S, Ca, Ti, V, Cu) then count 1000 seconds line-time starting 15 minutes after (Na, Mg, Cl, Mn, Br, In, I)

8. The same sample, or another portion of the same air filter, processed as above, should be then irradiated for 2-5 hours in the reactor core as was suggested in Air Tape Analysis (please see Annual Report 1972).

   a.) Allow to cool 20-30 hours and count 2000 sec.

   b.) Allow to cool 20-30 days and count 4000 seconds.

9. Run blanks using "clean" filters and standard reagents.

DETERMINATION OF REACTIVE PHOSPHORUS

Introduction:

All methods for phosphate in sea water rely on the formation of a phosphomolybdate complex and its subsequent reduction to highly colored blue compounds. Methods using stannous chloride as a reductant at room temperature have been favoured as they are most sensitive and give less interference from easily hydrolysable organic compounds than do other techniques. There are complexities in these methods due to interference from arsenic and to concealed blanks arising from the reduction of molybdate in sea water in the absence of phosphate. An excellent program of comparative tests has been described by Jones and Spenser (J. Marine Biol. Assoc. U.K., 43:251, 1963).

The procedure given below is taken from the recent publication of Murphy and Riley (Anal. Chim. Acta, 27:31, 1962) and is so superior to other methods in terms of the rapidity and ease of analysis that it probably represents the ultimate in sea-going techniques.

Method:

A. Capabilities

Range: 0.03-5 µg-at/liter

1. Precision at the 3 µG-AT/LITER LEVEL
The correct value lies in the range:

Mean of n determinations $\pm 0.03/n^{1/2}$ µg-at/liter.

2. Precision at the 0.3 µG-AT/LITER LEVEL
The correct value lies in the range:

Mean of n determinations $\pm 0.02/n^{1/2}$ µg-at/liter.

3. Limit of Detection

The smallest amount of phosphate that can be detected with certainty is about 0.03 µg-at P/liter.

Reject duplicate determinations if extinction values differ by more than 0.02 in the extinction range 0.5-1.0 or more than 0.01 in the extinction range 0.1-0.5.

If the duplicate extinction values differ by less than the above limits, take a mean value.

B. Outline of Method

The seawater sample is allowed to react with a composite reagent containing molybdic acid, ascorbic acid, and trivalent antimony. The resulting complex heteropoly acid is reduced in situ to give a blue solution the extinction of which is measured at 8850 A.

C. Special Apparatus and Equipment

130-ml capacity screw-capped polyethylene bottles marked on the side at 100 ml (±2 ml) with a band of black tape.

Neutron Activation Techniques:

Handling of the samples was done in a clean room equipped with a laminar-flow clean hood. Approximately 1g of the dried material as sealed in either quartz ampules or in medical grade polyethylene tubing. A number (10-20) of samples with appropriate standards were packaged polyethylene container and irradiated in a TRIGA - III reactor. An integrated flux of about 10^{18} $n.cm^{-2}$ was received by each package of samples. The samples were cooled for a period of 2-4 weeks before counting.

A portion of each irradiated sample was placed in a tared snap-top capsule, the weight determined and then counted on a 5% Ge (Li) detector. The analyzer was calibrated using radioactive standards. Three absorber's Cu, Cd and Pb, each about 1 mm in thickness, were placed between the sample and the detector to reduce the low energy Compton and Bremstrallen. The gamma-ray spectrum of each sample was analyzed and the concentrations calculated by a computer.

Standards of Ni-Co wire were placed in each package of samples to monitor the flux. The fast flux was calculated from the ^{58}Ni (n,p) ^{58}Co reaction and the thermal flux from the ^{59}Co (n,γ) ^{60}Co reaction. Inorganic standards were

included: Fe-Zn, Co-Cs and Hg packaged both dried on plastic tape and as liquid in quartz vials.

The blanks run were of the plastic tape on which inorganic standards were irradiated.

PLANKTON: METHODS AND MATERIALS

Methods and Materials:

Plankton samples were obtained in several ways. The majority were taken using plankton nets of mesh sizes 380μ, 300μ, 202μ, and 60μ, pulled behind 13 to 17 feet dories for 5 to 20 minutes. For uniformity, the nets were pulled at speeds to keep them 1 to 3 feet below the water surface. The samples were then preserved in 4% buffered formalin and taken back to the laboratory for analysis. A small flowmeter was suspended in the mouth of each 380μ mesh net, volumes of water sampled estimated for the remaining nets used.

For counting organisms, aliquots of each sample were removed from a well-shaken container by means of 5cc, 10cc, or 20cc spoons and diluted into a squared Petri dish or a counting tray. All zooplankton in the sub-samples were counted under 10 to 30 power magnification. Phytoplankton and zooplankton were identified using 30 to 400 power magnification.

A few plankton samples were obtained using a 2-quart bucket to pour surface water through a 60μ net sieve (primarily for phytoplankton and microzooplankton). One sample, JB-25, was taken utilizing a hand held concentrator over the side of a boat as it journeyed through a shallow canal between heavily mangroved cays.

Biomass estimates were obtained in the following manner. Zooplankton was sampled using a 202μ mesh net, animals (and incidental trash, phyto- and mannoplankton) transferred to bottles that were placed, without preservative, into an ice chest. Wet weights were determined as explained in the following. Phytoplankton and mannoplankton were sampled by using 2-quart buckets to fill a 5 gallon cubitainer. This was then first filtered through a 60μ mesh sieve, with frequent washing off of captured material to eliminate clogging, to separate phytoplankton and then filtered through 0.45μ membrane filters to separate mannoplankton. All samples were finally filtered through membrane filters that had been HCL treated. Initially the filters were wet with fresh water, a slight vacuum placed

on them, then the sample poured through. Ten filters were weighed wet (following 15 seconds of vacuum) and their average used as the weight of a standard filter. The filtered samples were subjugated to an additional 20 seconds of vacuum following apparent dryness, then were weighed on a Mettler balance accurate to 0.01 gram.

Future studies of zooplankton in Jobos Bay will emphasize seasonal and areal variability in the total standing stock and the more numerous species. Triplicate tows will be made at several stations with two 1/2 meter plankton nets (65μ and 200μ mesh size) to provide reliable estimates of the zooplankton community.

PROCEDURE FOR COLLECTION OF PLANKTON AND PREPARATION OF PLANKTON FOR NEUTRON ACTIVATION ANALYSIS AND ATOMIC ABSORPTION

1.) Sample should be collected off the front or sides of the boat to avoid contamination from boat oil and gasoline.

2.) Avoid smoking, eating or coughing close to plankton sample.

3.) Collected plankton should be put into a large plastic container. Then add 2 L. fresh sea water. (Take fresh sea water from the front or sides of boat).

4.) Filter plankton through a funnel fixed with same mesh size filter as tow, using low vacuum suction. (To avoid breaking cells of plankton).

5.) After filtering, put plankton sample into small plastic bags and heat seal to avoid contamination.

6.) Put plastic bag filled with plankton sample in plastic jars. Opening of jars should be the same size as the rest of the container.

7.) Freeze sample immediately.

NITRATE AND NITRITE IN SEA WATER

The procedure used for the analysis of nitrate plus nitrite in sea water is described in Industrial Method 43-69W, Technicon Instruments Corporation, Tarrytown, New York 10591. Millipore filtered aged sea water, in place of synthetic sea water, was used in the preparation of standard solutions and as a system wash. Air scrubbers were not used in the color reagent line.

Complete instructions for the operation of the Auto Analyzer is to be found in the General Operating Instruction manual supplied with the instrument.

THERMAL NEUTRON ACTIVATION ANALYSIS OF AIRBORNE PARTICULATE MATTER IN THE SOUTH COASTAL AREA OF PUERTO RICO

By

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INTRODUCTION

In the past several years there has been mounting awareness and concern over the addition into our atmosphere and water bodies of waste byproducts by modern industry which might be injurious to the public's health. The presence of "smoke", sulfates, and fallout in air is being routinely monitored by the U. S. Public Health Service, pollution control agencies of large cities, and many other scientific teams. The practice of burning coal, oil, and refuse, in addition to their combustion products, is continually injecting many trace elements into the atmosphere.

At present, on the island of Puerto Rico, no large-scale program is conducted which is directed toward the detection of trace metals, even though air filter tapes are collected and are available for detection. Data and information on the levels or concentrations of these pollutants in the air are necessary before they can be judged as hazardous.

In addition to this, a knowledge of these data, and the variation of the elemental distributions as a function of location and time is of importance in understanding the transport mechanisms for geochemical studies and for solving general problems of air pollution and pollution control. Correlations with public health problems can give an idea of the magnitude of potential problems.

The concentration of trace elements in air can be measured by many techniques. Thermal neutron activation analysis is relatively simple and is also nondestructive, if the study is limited to gamma-ray emitting nuclides and with the application of high resolution gamma-ray spectroscopy by means of lithium - drifted germanium [Ge(Li)] detectors. The object of this study is to evaluate and optimize the conditions and procedures for elemental analysis of air borne particulate matter by means of neutron activation analysis and Ge(Li) techniques (Dams et al, 1971, Dams et al, 1970, Tuttle, Vogt, Parkinson, 1971). Computer techniques for multi-nuclide gamma-ray spectrometry will be applied for data reduction (Dams et al, 1970). The measurement sensitivity for many induced nuclides should be more than adequate when the Puerto Rico Nuclear Center high flux Triga Flip reactor (1.5×10^{13} n. cm^{-2}. sec^{-1})

is used in conjunction with the 40 cc Canberra [Ge(Li)] detector (of about 3.5 kev energy resolution) coupled to a Packard 1024 channel analyzer.

Dust is usually collected on a filter by drawing air through a vacuum pump. This results in the filter becoming a part of the sample. Hence, the choice of filter material is important and the proper filter should be free of high thermal neutron cross section elements. The commonly used asbestos and glass base filters which have a high collection efficiency for small particles, are not suitable for thermal neutron activation analysis as they contain large amounts of Na, Cl, and other elements. In this study, a cellulose - base filter paper (furnished by the Environmental Science Division of Bendix Corporation, Baltimore, Maryland) which exhibits a low gamma-ray background after an exposure to thermal neutrons will be used.

EXPERIMENTAL PROCEDURES

Sampling

Air particulate samples are presently collected bi-weekly and simultaneously at ten different locations along the south coast of the island of Puerto Rico. (The locations are described in the PRNC Aguirre Power Project Environmental Studies 1971 Annual Report and are shown in Figure 1.) These locations range from low population to high population density areas, areas which are in the immediate vicinity of industrial plants and those at varying distances from them.

Each air pump (manufactured by Environmental Science Division of Bendix Corporation) sampled approximately 12,280 cubic meters of air through 1.27 cm^2 area of filter paper during a period of two weeks. The exposed filter tape after removal from the pump is sealed inside a polyethylene bag. One centimeter square of the exposed tape is cut out to be irradiated each time. Each sample to be irradiated contains the dust from approximately 9,670 cubic meters of air.

PREPARATION FOR IRRADIATION

The procedure to be followed for development of a non-destructive thermal neutron activation analysis system for routine determination of heavy metals such as Cd, Ni, V, Se and Hg in the paper tape samples are given below:

1. Using plastic gloves and a clean glass slide (or a sharp Teflon or polyethylene knife) tear off a piece of paper of 1 cm^2 area corresponding to every fourth spot of dust collected on the tape. Place in a small Petri dish. Dry under an infrared lamp. Cool in a dessicator and weigh. Roll up and put inside a 1 cc polyethylene snaptop irradiation vial. Heat seal in vacuum with a Teflon coated soldering iron tip so as to minimize contamination of the sample. (A reduced line voltage for the soldering iron is to be used for a satisfactory heat seal.) This sample is ready for irradiation.

2. Cut off five 1 cm^2 pieces of clean paper tape. Dry and weigh each one as done in 1.

3. To two of them, add known amounts of standard solutions of Ni, V, Hg, Zn and Se (1.0 μL of each with a concentration of 0.1 to 1.0 gm/L or 0.1 to 1.0 μg/spot). Dry under the infrared lamp. To the third piece of paper tape, add Cd carrier and repeat as above. Leave the remaining two paper pieces clean. Dry these under the infrared lamp too.

   Put all in a dessicator.

4. Heat seal under vacuum each sample inside a 1 cc polyethylene snaptop irradiation vessel.

IRRADIATION AND COUNTING PROCEDURES

Since some of the induced nuclides like ^{52}V have "short" half lives, the samples would be irradiated for a period of 1-2 minutes in 1.5 x 10^{13} cm^{-2} sec^{-1} flux of the PRNC reactor's fast transfer rabbit facility. Because

the neutron flux from one irradiation to the next cannot be assumed to be constant, an accurately weighed Co or Mn standard wire will be used as a flux monitor. These wires will be taped to the side of the small polyethylene irradiation vials before they are encapsulated inside the outer irradiation rabbit.

The short lived gamma-ray nuclides will be detected in the irradiated samples about 3 minutes after irradiation by means of the Canberra [Ge(Li)] detector coupled to a Packard 1024 channel analyzer by counting for 400 seconds live time. The flux monitors will be counted for 20 seconds each. Then the samples will be counted again for 1000 seconds live time at 15 minutes after the end of irradiation.

Later, the samples will be reirradiated for a period of 2 - 4 hours and counted at decay times of one and two days for 2000 seconds live time and then for 4000 seconds live time after 20 - 30 days of cooling to determine the contents of the long - lived nuclides. For the long irradiation all samples in irradiation vials will be placed in a polyethylene bottle, 4 cm in diameter, and lowered into the reactor pool. Sample cooling during irradiation will be accomplished by allowing the pool water to circulate through several holes punched in the container bottle. The samples will be confined to a single horizontal layer of vertically oriented tubes at the bottom of the bottle and the bottle will be rotated 180° at half of the irradiation time to effect normalization of flux. Fast neutron flux gradients are usually about twice as large as thermal gradients, but the only fast neutron reaction that will be used in this study is in the determination of nickel, $^{58}Ni\ (n, p)\ ^{58}Co$.

The ratio of thermal to fast neutron flux will be determined at both irradiation sites using the reactions $^{31}P\ (n, \gamma)\ ^{32}P$ and $^{32}S\ (n, p)\ ^{32}P$. Interferences by threshold reactions will be checked experimentally.

AUTOMATED DATA REDUCTION

For the procedure of nondestructive neutron activation analysis to be practical and efficient when applied to large numbers of samples, such as in routine monitoring, an automatic data reduction system is necessary (Dams et al 1970). An automatic instrumental data reduction system is fast and accurate and many human errors are eliminated. However, human judgement should still be used in the examination of the data and in devising procedures for checking the quality of the data.

In the present study a computer program will be developed to perform the following tasks:

1. qualitative determination of the presence of isotopes
2. calculation of net peak areas
3. conversion of peak areas to weights of trace elements
4. subtraction of analytical blanks due to filter materials
5. calculation of the concentrations of trace elements in the originally sampled air

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SCOR/UNESCO PROCEDURE FOR CHLOROPHYLLS

INTRODUCTION

The following procedure was agreed to by a SCOR/UNESCO working group and has been published by UNESCO in Monographs on Oceanographic Methodology.

METHOD:

Concentration of Sample:

Use a volume (Note a) of sea water which contains about 1 µg chlorophyll a. Filter (Note b) through a filter (Note c) covered by a layer of $MgCO_3$ (Note d).

Storage:

The filter can be stored in the dark over silica gel at 1 C or less for 2 months but it is preferable to extract the damp filter immediately and make the spectrophotometric measurement without delay.

Extraction:

Fold the filter (plankton inside) and place it in a small (5-15 ml) glass, pestle-type homogenizer. Add 2-3 ml 90% acetone. Grind 1 min at about 500 rpm. Transfer to a centrifuge tube and wash the pestle and homogenizer 2 or 3 times with 90% acetone so that the total volume is 5-10 ml. Keep 10 min in the dark at room temperature. Centrifuge (Note e) for 10 min at 4000-5000 g (Note f). Carefully pour into a graduated tube so the precipitate is not disturbed and if necessary dilute (Note g) to a convenient volume (Note h).

For Thalassia Leaves:

A weighed quantity of fresh Thalassia leaves ground in ceramic mortar and pestle with some quantity of distilled water. Wash motor and pestile with acetone so final solution 80% acetone. Keep 10 min in dark at room temperature than centrifuge for 10 min. Pour off supernate and read absorption or Beckman DU spectrophotometer. Re-extract precipitate with acetone to determine efficiency

of first extraction. Maximum absorption for chlorophyll a in acetone reported at 663 nanometers. Chlorophyll b absorption maximum around 640 nanometers.

Measurement:

Use a spectrophotometer with a band-width of 30 Å or less, and cells with a light path of 4-10 cm (Note i). Read the extinction (optical density, absorbance) at 7500 (Note j), 6630, 6450, and 6300 Å against a 90% acetone blank.

Calculation:

Subtract the extinction at 7500 Å from the extinctions at 6630, 6450 and 6300 Å. Divide the answers by the light path of the cells in centimeters. If these corrected extinctions are E_{6630}, E_{6450}, and E_{6300} the concentrations of chlorophylls in the 90% acetone extract as µg/ml are given by the SCOR/UNESCO equations (refer to Section IV.3.I). If the values are multiplied by the volume of extract in milliliters and divided by the volume of the seawater in liters, the concentration of the chlorophylls in the sea water is obtained as µg/liter (=mg/m^3).

NOTES:

(a) The amount of chlorophyll a should be less than 10 µg, otherwise a second extraction with 90% acetone might be necessary. With ocean water about 4-5 liters of sample should be used; with coastal and bay waters, sometimes one tenth of this amount is sufficient.

(b) Use no more than two thirds of full vacuum.

(c) Satisfactory filters include paper (Albet), cellulose (Cella "grob"), and cellulose ester (0.45-0.65 µ pore-size); the filter should be 30-60 mm in diameter. If these filters clog with inorganic detritus, use Schleicher & Schull 575.

(d) Add about 10 mg $MgCO_3/cm^2$ filter surface, either as a powder or as a suspension in filtered sea water.

(e) A swing-out centrifuge gives better separation than an angle centrifuge.

(f) If a stoppered, graduated centrifuge tube is used, the extract can be made up to volume and the supernatant carefully poured or pipetted into the spectrophotometer cell.

(g) If turbid, try to clear by adding a little 100% acetone or distilled water or by centrifuging again.

(h) This depends on the spectrophotometer cell used. The volume should be read to 0.1 ml.

(i) Dilute with 90% acetone if the extinction is greater than 0.8.

(j) If the 7500 Å reading is greater than 0.005/cm light path, reduce the turbidity as in Note g.

TRACE METALS AND MAJOR CATIONS IN BIOLOGICAL MARINE SAMPLES BY ATOMIC ABSORPTION SPECTROPHOTOMETRY

In the last decade trace inorganics in the marine environment have been getting attention as much as organics such as pesticides, etc.

Neutron activation and atomic absorption spectrometry are two common and sensitive methods in this field. We have been using a Jarrel Ash AAS and a Perkin Elmer burner.

We receive our samples in coarsely-ground form. Sometimes out of necessity, due to the coarseness and resulting prolonged and possible incomplete digestion, we find it appropriate to pulverize the samples. This is preferable for all samples, but considering the length of time involved has not been performed on all samples up to now.

Using various weights of samples (0.25 - 1.0 g), we found the 1.0 g weight to be the most suitable since some elements are not detectable using smaller weights.

To standardize techniques and to ascertain the most suitable one, i.e. giving the highest peaks, two sets of experiments were undertaken: the first to determine the best technique for dissolving and the second to determine the length of time for dissolving.

Table 1 shows the average readings for the various dissolving techniques. Methods using nitric acid, in general, were better than sulfuric acid methods. Loss of the sample with sulfuric acid methods may have contributed to the low readings because of the splattering when hydrogen peroxide was added. Aqua regia, by way of best and second best readings, was concluded to be the best method for getting the greatest peaks. Consequently, aqua regia is now the preparative method used in this lab.

In the second set of experiments samples were refluxed from time varying 15 minutes to 24 hours. No significant reading differences were noted. Therefore, we only reflux samples for approximately an hour, or possibly two, until dissolving appears to be complete.

Following is a step-by-step account of the method in use:

1. Grind to a fine powder.
2. Weigh out a one gram sample, record weight to the nearest ten-thousandth place.
3. Dissolve in a 50 ml beaker containing aqua region (11 ml/g), place on a hot plate.
4. Filter after two-hour refluxing.
5. Dilute with distilled water to 15 ml.

The following table shows the sensitivity of our readings and the per cent standard deviation of identically prepared samples:

Element	Detection Limit	% Standard Deviation
Cd	0.026 ppm	6.05 at 5 ppm level
Cu	0.08	5.51 at 50 ppm level
Fe	0.4	12.50 at 500 ppm level
Ni	0.3	7.24 at 20 ppm level
Zn	0.02	0.09 at 300 ppm level
Co	0.18	7.64 at 10 ppm level

Mathematical Calculations:

Our calculations are reported in parts per thousand (ppt, mg/g). The samples are concurrently run with two blanks, treated in the same manner in the preparation steps as the samples. Sets of standards are run through AAS at least before and after samples. The graph heights are read and recorded. From the standards we construct a curve from which the sample and blank concentrations are read. Blank values are then subtracted from sample values to account for impurities which may occur during preparation.

The final concentrations are calculated from the formula given below:

$$\frac{(R-B)V}{1000 \times wt} = \text{mg/gr. (ppt)}$$

R = Readings from standard curve
B = Blank
V = Volume of the dissolved sample
wt= Weight of sample

The standards are currently made from inorganic salts. For a comparison it might be worthwhile to use organic trace metal standards, preparing them in the same manner as the samples since the biotic material we receive is organic.

TABLE 1

CONCENTRATIONS (ppt) USING SIX PREPARATIVE METHODS.

Aqua regia was proved to be best for most elements.

	Cu	Mn	Ca	Mg	Fe	Sr	Zn	Cr	Co	Ni	Pb	Cd
Ag	'.0030	''.0612	4.011	7.271	'.1050	'.0135	'.0095	''.0060	''.0025	''.0050	.0090	''.00035
SP	.0026	.0214	.4363	.3410	.0300	T	.0080	T	.0020	'.0054	''.0103	'.00077
NP	''.0029	.0573	''5.251	'8.789	.0368	.0120	''.0085	T	'.0035	.0030	T	.00033
SH	.0024	.0184	.7377	.2933	.0103	.0030	.0027	'.0063	.0010	.0030	'.0147	T
N	.0026	'.0646	'5.501	''8.628	''.0620	''.0130	.0067	T	T	.0026	.0093	.00030
S	.0024	.0171	1.025	.3390	T	.0040	.0040	T	T	.0003	T	T

' Best Method

'' Second Best Method

Ag = aqua regia
SP = sulfuric acid & perchloric acid
NP = nitric acid & perchloric acid
N = nitric acid

SH = sulfuric acid & hydrogen peroxide
S = sulfuric acid, nitric acid, & hydrogen peroxide

PROCEDURE FOR ESTIMATING DISSOLVED OXYGEN
5 ML WINKLER METHOD

Introduction:

The method to be described here is a modification of Fox and Wingfield (1938). It is convenient in that it allows one to measure the sample of water and run the Winkler reaction in the same syringe. It is also useful since small, but manageable samples may be analyzed. Finally, with sufficient precaution the method is accurate enough for many research purposes.

The Winkler reaction may be summarized as follows:

$$2MnCl_2 + 4NaOH = 4NaCl + 2Mn(OH)_2$$

$$2Mn(OH)_2 + H_2O + 1/2\ O_2 = 2Mn(OH)_3$$

$$2Mn(OH)_3 + 2KI + 6HCl = 2MnCl_2 + 2KCl + 6H_2O + I_2$$

Thus the introduction of manganous chloride in the presence of alkali results in the formation of a manganous hydroxide precipitate. The manganous hydroxide is oxidized by the oxygen of the sample to manganic hydroxide. Acidification of the sample then results in the oxidation of the KI to iodine by the manganic ions. Each molecule of oxygen liberates two molecules of iodine. The extent of the iodine released depends upon the amount of manganic ion formed. One then titrates the iodine with sodium thiosulfate using starch as the indicator. The reduction of the iodine to iodide by thiosulfate results in a loss of color following the disappearance of the starch-iodine complex.

In the following procedure there are two steps which must be done carefully. These include the volume measurement of the water sample and the standardization and titration with the sodium thiosulfate. The remainder of the reagents are generally added in excess of that required for the reaction.

Equipment and Reagents:

Reaction sygringe - These are constructed from 10 ml syringes which have glass needle fittings. A capillary tube, which is drawn out to a fine tip, is attached to the

needle fitting with a piece of stiff plastic tubing. The capillary is fitted to the syringe in such a manner that there is a minimum of space between them. The fine capillary tip allows the reaction to proceed without diffusion of gases into or out of the syringe. For extremely accurate results the syringe volume should be calibrated by weighing with distilled water. For less accurate results, the volume of the sample can be measured using the syringe calibrations.

Burette - The burette is important, but need not be elaborate unless very accurate results are sought. For our purposes a 1 ml burette or a 1 ml tuberculin syringe with a capillary tip is adequate.

Titration Equipment - The most convenient arrangement is to make the determinations in a 25 ml beaker or Erlenmeyer flask which is stirred by a magnetic stirrer. The 'flea' can be easily constructed by cutting a small piece of wire, such as a paper clip, into 1 cm lengths and cover with a piece of capillary glass. The titration should be done on a white background with fluorescent lighting.

Reagents -

1. Sodium thiosulfate - Weigh out 24.82 g of sodium thiosulfate and dissolve in 1 liter of boiled and cooled distilled water. Dilute 1:9 for standardization. Weigh out exactly 0.8917 g KIO_3 and dissolve in 1 liter of distilled water to make 0.025N solution for standardizing the thiosulfate. Fill a 10 ml burette with the diluted thiosulfate. Pipette accurately 2.0 ml of KIO_3 into the titration vessel and add 1.0 ml of 1% KI. Add 5 drops of concentrated H_3PO_4 and 2 drops of starch and titrate. Repeat three times. Calculate the normality of the thiosulfate as follows:

$$N_{KIO_3} \times V_{KIO_3} = N_{Na_2S_2O_3} \times V_{Na_2S_2O_3}$$

$$0.05 = N \times V$$

Note: N/100 Sodium thiosulfate is now commercially available as a standard.

2. $MnCl_2$ - 40 g/100 ml distilled H_2O

3. Alkaline Iodide - 32 g NaOH and 10 g KI to 100 ml distilled H_2O.

4. KI - 1.0 g to 100 ml distilled H_2O.

5. Starch indicator - 1 g is added to 100 ml distilled water and heated slowly to 100° C. Cool and add 0.1 g of salicylic acid.

6. H_3PO_4 - Concentrated reagent.

Titration of Sample:

1. Using the 10 ml syringe with nozzle, fill the dead space carefully with $MnCl_2$. Be sure to remove all air bubbles.

2. Fill the syringe to the 5 ml mark with the water sample. Again, be sure to exclude all bubbles.

3. Take in two times the dead space volume of alkaline iodide.

4. Rotate the syringe to mix the manganous hydroxide thoroughly.

5. Allow the syringe to set three minutes for oxygen absorption.

6. Draw in three to four times the dead space volume of concentrated H_3PO_4. Rotate the syringe until the precipitate is thoroughly dissolved. The reaction has now stopped, and exposure of the solution to air does not result in error.

7. Eject the solution into a titration vessel, such as a 25 ml beaker, and wash the syringe twice with 2 ml aliquots of distilled water. Add the wash to the titration vessel.

8. Add two drops of starch indicator and titrate the sample with the standard thiosulfate. For this purpose, use a 1 ml tuberculin syringe or a 1 ml burette.

9. Rince the 10 ml syringe thoroughly in tap water and distilled water. When the syringe is again rinsed with $MnCl_2$ it is ready to use.

$$O_2 ml/l \text{ (STP)} = \frac{n.A.5600}{V}$$

n = ml thiosulfate used in the titration

A = normality of thiosulfate

V = volume of the water sample titrated

A correction should be applied for the dissolved oxygen in the reagents ($MnCl_2$ and the Alkaline iodide). It is assumed to be about 3.4 ml O_2/l.

Practice of the Technique:

1. Place a sample of distilled water in a beaker and stir vigorously for about 1 hour using a small stirring motor. Take the temperature of the water and read the barometer. Remove three samples of the water and determine the oxygen content. Compare your values with those obtained from the Handbook of Physics and Chemistry.

$$\frac{\text{Bar.}}{760} \times 0.209\ (1000\ \alpha) = ml O_2/l$$

where Bar. is the barometric pressure and α is the ml of oxygen which will dissolve in 1 ml of water at the specified temperature if the sample is in equilibrium with an atmosphere of oxygen. Estimate the reagent volume and make the correction for the reagent oxygen.

2. Try determining the oxygen content of a sample from which most of the oxygen has been removed by nitrogen washing or boiling.

References:

H. Barnes. Apparatus and Methods of Oceanography, George Allen and Unwin Ltd. London. 1959. Chapter 14.

Fox, H.M., and Wingfield, C.A. 1938. A portable apparatus for the determination of oxygen dissolved in a small volume of water. J. Exp. Biol., 15: 437.

STRONTIUM 89 AND 90 IN MILK

AND

IODINE - 131 IN MILK

by

Gülser G. Wood

IODINE - 131 in Milk

Apparatus:

1. 2.5 liter polyethylene annular counter containers.

Reagents:

1. 24% Trichloroacetic acid.
2. 12% Trichloroacetic acid.
3. 2% NaI Solution (20g $AgNO_3$/liter water).
4. 2% $AgNO_3$ solution (20g $AgNO_3$/liter water).

Determination:

1. Put 2 liters of the whole milk sample to a 3 liter beaker.
2. Add 2 ml of 40% formaldehyde solution.
3. Stir for 5 minutes and let stand at room temperature for 1 hour.
4. Transfer 1 liter of sample into annular counter container. Add 1 liter water; mix and gamma count (C_1).
5. To remaining sample, add with stirring, 900 ml of 24% trichloroacetic acid solution, and 1 ml of 2% NaI and then 1 ml of 2% $AgNO_3$ solution.
6. Stir for 30 minutes. Allow the precipitate to settle.

7. Filter by suction through a 15 cm WHATMAN #42 filter paper.

8. Wash with two 50 ml portions of 12% trichloroacetic acid solution. Discard the precipitate.

9. Transfer the liquid (filtrate and washings) to annular counter container. Mix well. Gamma count (C_2).

Calculations:

The net counting rate of $^{131}I = C_1 - C_2$.

The counter efficiency is determined by adding a known standard to a ^{131}I free milk. Decay constant is 0.086 day^{-1}. Half life is 8.05 days.

$$A = A_o.C^{-\lambda t}$$

Reference:

Harley, John H. 1967. Manual of Standard Procedures U.S.A.E.C. New York.

STRONTIUM 89 AND 90 IN MILK:

A. By Ion Exchange

Preservation:

Immediately after the collection of a milk sample, a preservative, formaldehyde (about 3 ml 37% formaldehyde solution per liter of milk) must be added. Sample must be refrigerated (at 32° - 34° F.) for at least two weeks to allow the Yttrium 90 daughter of Strontium 90 to reach into equilibrium with its parent.

Reagents:

Cation - Exchange resin: Dowex 50X-X8 (Na^+ form, 50-100 mesh), analytical grade (the chemical grade can be used for this purpose after purified by a method given by Harley, G-04-01).

Carrier Solution: Sr^{+2} as $Sr(NO_3)_2$: 20 mg Sr^{+2} per ml.

Citrate Solution: 3N (pH 6.5).

Apparatus:

Ion-exchange column:

Dimensions are shown at Fig.1.

Put 5 ml of distilled water in the 30 ml column, pour 170 ml Dowex 50 W resin into it.

Procedure:

1. Put 1 liter of milk into the reservoir.

2. Put 1 ml strontium carrier into 10 ml of citrate solution, mix until dissolved. Put this solution into the milk with 5 ml distilled water, mix well.

3. Open stopcock control flow rate at 1 ml/min.

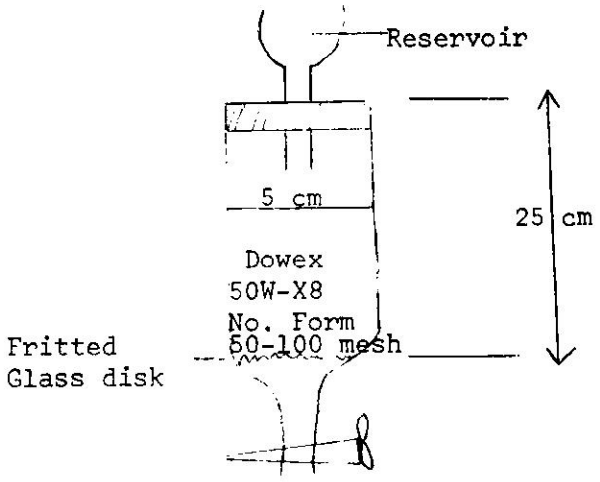
4. Stop flow when just enough milk remains in column to cover resin.

5. Discard effluent milk.

6. Put 300 ml of warm distilled water through the column (about 10 ml/min).

7. Discard the effluent water.

8. Push the resin out of column in a very small beaker or vial. Dry and gamma count.



B. By Ashing:

Apparatus:

Analytical oven

Corningware dish

Muffle furnace

Procedure:

1. Put 2.5 kg evaporated on 5 kg fresh milk into corningware dish.

2. Dry in oven at 100°C. for 48 hours.
3. Transfer the sample to a muffle furnace and raise the temperature slowly to 550°C. Ash at 550°C. for 24 hours.
4. Cool, weigh, and grind the ash to a fine powder.
5. Gamma count or
6. Dissolve in 1 ml of 6 $\underline{N}$ HNO_3
7. Dilute to a 25 ml in volumetric flask.
8. Run at Atomic Absorption.

APPENDIX C

MATHEMATICAL SIMULATION OF THERMAL PLUMES

Introduction:

The material in Appendix C, consisting of two parts, represents a reexamination Section III-D-1-b (The Plant-Effluent Systems-Heat-Environmental Influences, pp 64-65) of the Aguirre Power Plant Complex Environmental Report.

The first part is a detailed check (including data, equations used and references) of the values listed in Tables III-2 and III-3 of the Report, made at the request of the Puerto Rico Water Resources Authority. In addition, the distortion of the plume centerline by an ambient current of 0.5 ft/sec at 45° is computed by superposition of jet and ambient velocities.

The second part contains calculations, parametric studies and a modification of the basic Pritchard model intended to provide a quantitative basis for the evaluation of the applicability of the model to conditions existing in the Aguirre Ship Channel, and to examine the effect of re-entrainment on the predicted plume extent. Specifically, this part consists of an outline of the basic model equations, a comparison of required entrainment flow to ambient flow, the effect of entrainment of heated water on the size of the 4°F isotherm and the effect of deflection and subsequent re-entrainment of heated water impinging on the Cayos on its temperature. All calculations are for the case of two fossil plants.

CALCULATIONS FOR TABLES III-2 AND III-3

of

AGUIRRE POWER PLANT COMPLEX ENVIRONMENTAL REPORT

1. Basic Data and Unit Conversion:

a) From p. 62, Ref. [1]:

	Flow	Condenser Excess Temp.	Power
Fossil:	Q_f = 226,000gpm	θ_{ef} = 18.74°F	P_f = 460MWe
Nuclear:	Q_n = 555,000gpm	θ_{en} = 14.80°F	P_u = 600MWe

b) From pp 3204 & 3209, Ref. [6]:

1 US gal. = 0.13368 ft^3

1 acre = 4.3560×10^4 ft^2

c) Converted Flow Data and Approximation

Fossil: Q_f = 226,000gmp = 503.528 ft 3/sec ~ 505cfs

Nuclear: Q_n = 555,000gpm = 1236.54 ft 3/sec ~ 1250cfs

2. Equations for Computation of Table III-2:

Let: N_f = Number of Fossil Plants

N_n = Number of Nuclear Plants

a) Power Production

$$P_{tot} = P_f \cdot N_f + P_n \cdot N_n$$

b) Flow Rate

$$Q_{tot} = Q_f \cdot N_f + Q_n \cdot N_n$$

c) Condenser Excess Temperature

$$\theta_{ctot} = (\theta_{cf} \cdot Q_f \cdot N_f + \theta_{cn} \cdot Q_n \cdot N_n) / Q_{tot}$$

d) Discharge Nozzle Dimensions (Triangular)

u_o = exit velocity

2. d) cont.

h_o = exit depth

b_o = exit width

$$b_o = \frac{2Q_{tot}}{u_o\ h_o}$$

e) "Normalized" Nozzle

For equal area and centroid, equivalent rectangle defined by

$$h_o^* = \frac{2}{3}\ h_o$$

$$b_o^* = \frac{3}{4}\ b_o$$

3. Recomputed Values for Table III-2:

a) Data:

Q_f = 505cfs P_f = 460MWe θ_{cf} = 18.74°F

Q_n = 1250cfs P_n = 600MWe θ_{cf} = 14.80°F

U_o = 6ft/sec

b) Table Values:

N_f	N_n	P_{tot} MWe	Q_{tot} cfs	θ_{ctot} °F	Triangle		Normalized	
					b_o ft	h_o ft	b_o^* ft	h_o^* ft
1	0	460	505	18.74	16.83	10	12.62	6.67
2	0	920	1010	18.74	33.67	10	25.25	6.67
2	1	1520	2260	16.56	37.67	20	28.25	13.33
2	2	2120	3510	15.93	58.50	20	43.88	13.33

4. Equations for Computation of Table III-3:

From Ref. [1], [2], [5]:

$$(\xi_\Theta/\xi_V) = (\Theta/\Theta_o)^{-2}, \quad \xi_V = 6\, b_o^*$$

$$A = 0.215\, \xi_\Theta^2$$

NOTE: Θ_o = Excess temperature at discharge orifice.

5. Recomputed Values for Table III-3:

NOTE: Assumption of no cooling in discharge canal, $\Theta_o = \Theta_{ctot}$, is made. For cooling in canal and resulting changes in Table III-3, see items 6, 7 and 8.

P_{tot}	460 MWe		920 MWe		1520 MWe		2120 MWe	
Θ_o	18.74°F		18.74°F		16.56°F		15.93°F	
b_o^*	12.62 ft		25.25 ft		28.25 ft		43.88 ft	
Θ °F	ξ_Θ ft	A_Θ acres	ξ_Θ	A_Θ	ξ_Θ	A_Θ	ξ_Θ	A_Θ
12	185	0.17	369	0.67	323	0.51	464	1.06
10	266	0.35	532	1.40	465	1.07	668	2.20
8	415	0.85	831	3.41	726	2.60	1044	5.38
6	739	2.69	1478	10.78	1291	8.23	1856	17.00
4	1662	13.63	3325	54.58	2905	41.66	4176	86.06

6. Equations and Parameters for Surface Cooling in Canal:

a) Equation for temperature change - Ref. [2]:

$$\Delta\Theta = \frac{\mu A \Theta}{\rho c Q} \qquad \Theta_o \sim \Theta_c - \Delta\Theta$$

b) Canal Area A - Ref. [1], pp. 62, 63:

$L = 7900$ ft, $w = 156.5$ ft, $A = 1.24 \times 10^6$ ft^2

c) Surface Heat Loss Coefficient μ

i From Ref. [4]

for wind = 12 mph

dew pt. = 70°F

water surface temp. = 80°F

$$\mu_1 = 2.1991 \times 10^{-3} \ \frac{\text{Btu}}{\text{ft}^2\,^\circ\text{F sec}}$$

ii From Ref. [5]

for wind = 10 mph

water surface temp. = 80°F

excess temperature = 18°F

$$\mu_2 = 2.5361 \times 10^{-3} \ \frac{\text{Btu}}{\text{ft}^2\,^\circ\text{F sec}}$$

iii For computations use average value

$$\mu = \frac{1}{2}(\mu_1 + \mu_2) = 2.3676 \times 10^{-3} \sim 2.4 \times 10^{-3} \ \frac{\text{Btu}}{\text{ft}^2\,^\circ\text{F sec}}$$

d) Heat capacity of water - Ref. [4]:

$$\rho c = 64 \ \frac{\text{Btu}}{\text{ft}^3\,^\circ\text{F}}$$

7. Surface Cooling in Canal:

N_f	N_n	P_{tot}	Q_{tot}	Θ_{ctot}	$\Delta\Theta$	Θ_o
1	0	460	505	18.74	1.73	17.01
2	0	920	1010	18.74	0.86	17.88
2	1	1520	2260	16.56	0.34	16.22
2	2	2120	3510	15.93	0.21	15.72

8. Modified Values for Table III-3:

P_{tot}-MWe	460		920		1520		2120	
Θ_o -°F	17.01		17.88		16.22		15.72	
b_o^* -ft	12.62		25.25		28.25		43.88	
Θ -°F	ξ_Θ-ft	A_Θ-acres	ξ_Θ	A_Θ	ξ_Θ	A_Θ	ξ_Θ	A_Θ
12	152	0.11	366	0.56	310	0.47	452	1.01
10	219	0.24	484	1.16	446	0.98	651	2.09
8	342	0.58	757	2.83	697	2.40	1017	5.10
6	609	1.83	1345	8.93	1239	7.57	1807	16.12
4	1369	9.25	3027	45.23	2787	38.34	4066	81.61

9. Equations for Plume Distortion - Ref. [3]:

$$\bar{\xi} = \xi + \xi_V \frac{U}{u_o} \left[\frac{2}{3}(\xi/\xi_V)^{3/2} + \frac{1}{3}\right] \; ; \quad \xi > \xi_V = 6b_o^*$$

$$\bar{n} = \xi_V \frac{V}{u_o} \left[\frac{2}{3}(\xi/\xi_V)^{3/2} + \frac{1}{3}\right]$$

10. Plume Distortion:

Data: Exit velocity u_o = 6 ft/sec

Current: 0.5 ft/sec at 45°, consequently

$U = 0.5 \cos 45° = \frac{1}{2\sqrt{2}}$

$V = 0.5 \sin 45° = \frac{1}{2\sqrt{2}}$

Values of b_o^* and ξ_o correspond to those given in items 5 and 8.

a) Values corresponding to item 5 (no canal cooling)

P_{tot}	460 MWe		920 MWe		1520 MWe		2120 MWe	
b_o^*	12.62		25.25		28.25		43.88	
Θ_o	18.74		18.74		16.56		15.93	
Θ	$\bar{\xi}$-ft	$\bar{\eta}$-ft	$\bar{\xi}$	$\bar{\eta}$	$\bar{\xi}$	$\bar{\eta}$	$\bar{\xi}$	$\bar{\eta}$
12	198	13	395	26	344	21	493	29
10	287	21	574	42	499	34	715	47
8	454	40	910	79	788	62	1131	87
6	831	92	1662	184	1434	143	2055	199
4	1969	307	3940	615	3380	476	4835	659

b) Values corresponding to item 8 (with canal surface cooling)

P_{tot}	460 MWe		920 MWe		1520 MWe		2120 MWe	
b_o^*	12.62		25.25		28.25		43.88	
Θ_o	17.01		17.88		16.56		15.72	
Θ	$\bar{\xi}$	$\bar{\eta}$	$\bar{\xi}$	$\bar{\eta}$	$\bar{\xi}$	$\bar{\eta}$	$\bar{\xi}$	$\bar{\eta}$
12	162	10	359	23	330	20	480	28
10	235	16	521	37	478	32	696	45
8	372	30	826	69	756	59	1101	84
6	678	69	1505	160	1374	135	1998	191
4	1599	230	3562	535	3234	447	4699	633

REFERENCES:

1. Aguirre Power Plant Complex Environmental Report - Puerto Rico Water Resources Authority, Report No. WRA E.S. -8 (1972)

2. April 12, 1971 Progress Report - Appendix E, Puerto Rico Nuclear Center

3. Kovarna - Distortion of Plume Centerline, Puerto Rico Nuclear Center Note (Nov. 1972)

4. Harleman and Stolzenbach - "Preliminary Investigation of Thermal Effects in the Bahia de Jobos..." Report to Jackson and Moreland (October 23, 1970)

5. Pritchard - "Design and Siting Criteria for Once-Through Cooling Systems". Chesapeake Bay Institute. Page No. 26c (1971)

6. Handbook of Chemistry and Physics (43rd Ed.)

I. Basic Jet Model:

The basic, two-dimensional jet model is defined by Eq. (16) of Ref. [1].

$$b=b_o\ (\xi/\xi_v)\ ,\quad \xi v = 6b_o\ ;\quad \xi \geqslant \xi v \qquad (1)$$

This variation of width leads to the velocity distribution

$$u = u_o\ (\xi_v/\xi)^{1/2} \qquad (2)$$

If Q_o is the discharge rate from the orifice and $Q(\xi)$ the flow across a section of the jet, then

$$Q = Q_o\ (\xi/\xi_v)^{1/2} \qquad (3)$$

and the entrainment flow is

$$Q_e = Q - Q_o = Q_o\left[(\xi/\xi_v)^{1/2}-1\right] \qquad (4)$$

Finally, defining

θ_o = orifice excess temperature

θ_e = entrained water excess temperature

θ = excess temperature in the jet at ξ_θ

one obtains

$$\xi_\theta/\xi_v = \left(\frac{\theta_o-\theta_e}{\theta-\theta_e}\right)^2 \qquad (5)$$

II. Rate of Entrainment - Two Fossil Plants

Assume that entrainment occurs over the entire length of the plume (approximately 5500 ft) until it exits from the cayos. For two fossil plants with a discharge rate $Q_o = 1010$ ft^3/sec and a triangular exit orifice of width $b_o = 33.67$ ft. the virtual distance of jet establishment is

$$\xi_v = 6b_o^* = 6\left(\frac{3b_o}{4}\right) = 151.5 \text{ ft}$$

The rate of entrainment for the entire plume is

$$Q_e = Q_o\left[(\xi/\xi_v)^{1/2}-1\right] = 1010\left[\left(\frac{5500}{151.5}\right)^{1/2}-1\right] =$$

$$5075 \text{ ft}^3/\text{sec}.$$

This compares well with the natural flow of approximately 11000 ft^3/sec across a section of the Aguirre Canal (Note that only one half of the entrained water comes from one side, so that the comparison is between 2538 ft^3/sec and 1100).

More to the point, the momentum jet model does not depend on ambient cross flow for entrainment. The question is rather if enough water (i.e. 2538 ft^3/sec) can be withdrawn from the area east of the plume. If it is assumed that all entrainment water must be drawn in between the cayos and through the Boca del Infierno, then the induced velocity is an indicator of the availability of entrainment water. The sectional flow area of the cayos is approximately 1250 m^2 and of the Boca del Infierno 1100 m^2 giving a total area of approximately 25300 ft^2. The induced velocity is therefore

$$u = \frac{1/2 Q_e}{A} = \frac{2538}{25300} \sim 0.1 \text{ ft/sec}$$

III. Effect of Entrained Excess Temperatures:

If the entrained water is not at ambient temperature, but has an excess temperature of θ_e the centerline isotherm distance is given by Eq. (5).

For the case of the two fossil plants and the 4°F. excess temperature isotherm:

$$\xi_v = 151.5 \text{ ft}, \quad \theta_o = 17.9°\text{F.}, \quad \theta = 4°\text{F.}$$

the effect of θ_e is illustrated below:

θ_e °F	ξ_4 ft	A_4 acres
0	3034	45
0.5	3745	69
1.0	4808	114
1.5	6520	210
2.0	9576	453
2.5	15970	1259
3.0	33637	5585
3.5	125673	77953

NOTE: The values given above are computed on the basis of momentum jet only. Surface cooling and diffusion are neglected.

IV. Modification for Reentrainment:

To obtain a first estimate of the effect of reentrainment, the model shown schematically in Fig. 1 is assumed.

The portion of the plume $\xi_v \leq \xi \leq \xi_2$ only is of interest. At $\xi = \xi_2$ the flow rate Q_2 is partially reentrained, the reentrained porition being αQ_2. Reentrainment is assumed to occur only over the section $\xi_1 \leq \xi \leq \xi_2$ and complete mixing of the reentrained water with ambient is also assumed.

If the parameter β is defined as

$$\beta = \xi_1 / \xi_2 \tag{6}$$

then Q_1 and Q_2 are obtained from Eq.(3).

$$Q_1 = Q_o(\xi_1/\xi_v)^{1/2} = Q_o\, \beta^{1/2}(\xi_2/\xi_v),\ Q_2 = Q_o(\xi_2/\xi_v)^{1/2} \tag{7}$$

Since there is no reentrainment on $\xi_v \leq \xi \leq \xi_1$, the excess temperature θ_1 becomes

$$\theta_1 = \theta_o\,(\xi_v/\xi_1)^{1/2} = \frac{\theta_o}{\beta_{1/2}}\,(\xi_v/\xi_2)^{1/2} \tag{8}$$

For total mixing in the jet

$$Q_2\theta_2 = Q_1\theta_1 + Q_{e2}\theta_{e2} \tag{9}$$

and for total mixing of reentrained water

$$Q_{e2}\theta_{e2} = \alpha Q_2\theta_2 + 0\,(Q_{e2}-Q_2) = \alpha Q_2\theta_2 \tag{10}$$

Substitution of Eq. (10) into (9) gives

$$\theta_2 = \frac{\theta_1}{1-\alpha} \frac{Q_1}{Q_2} \tag{11}$$

and finally, use of (7) and (8) yields

$$\theta_2 = \frac{\theta_o}{1-\alpha} \left(\frac{\xi_v}{\xi_2}\right)^{1/2} \tag{12}$$

Note that the temperature θ_2 is independent of the parameter β, that is of the ratio ξ_1/ξ_2. This is a natural consequence of the assumed total mixing. The temperature distribution in the plume is, however, dependent on β. The parameters α and β are not independent, since for steady state it is necessary that

$$\alpha Q_2 \leq Q_{e2} = Q_2 - Q_1 \tag{13}$$

which gives the restriction

$$\alpha \leq 1-\beta^{1/2} \tag{14}$$

Tables I and II summarize results for the case of two fossil plants at Aguirre with the following values of the parameters

ξ_v = 151.5 ft.

ξ_2 = 5500 ft.

θ_o = 17.90 °F.

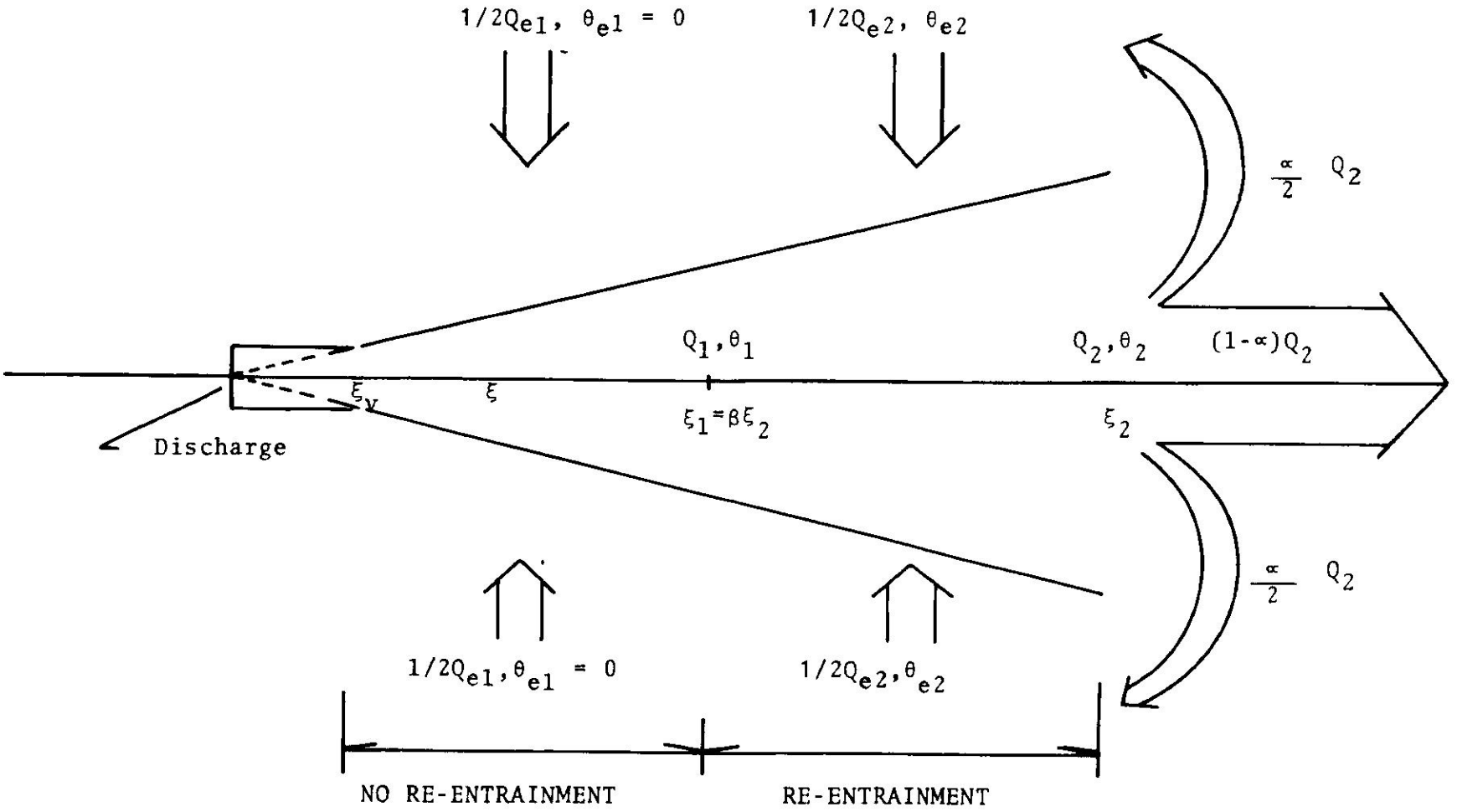
Table I show the variation of ξ_1, θ_1 and α max with β .

Table II gives the variation of θ_2 with α .

It should be noted that the present approximation does not include surface cooling and will necessarily overestimate θ_2.

Reference:

1. Pritchard, - "Design and Siting Criteria for Once-Through Cooling Systems." Chesapeake Bay Institute Paper No. 26c (1971)



SCHEMATIC OF RE-ENTRAINMENT MODEL

TABLE - I

β	ξ_1 ft	θ_1 °F	α max
.03	165	17.15	0.826
.25	1375	5.94	0.500
.50	2750	4.20	0.293
.75	4125	3.43	0.134
1.00	5500	2.97	0

TABLE - II

α	0.827	0.75	0.50	0.25	0.10	0
θ_2 °F	17.07	11.88	5.94	3.96	3.30	2.97

NOTICE