

PRNC - 1620 Poem 27. PUERTO RICO NUCLEAR CENTER Dr. Artur M28. Block University of Foro Ro Cont oe Ener samen Revere Gorsre Heights Station Rio ious Sin hon, Pe Aguirre Power Project Environmental Studies 1972 Annual Report APPENDIX. (OPERATED BY THE UNIVERSITY OF PUERTO RICO UNDER CONTRACT 1833 FOR US ATOMIC ENERGY COMMISSION ---Page Break--- ---Page Break--- PRNC - 162 PUERTO RICO NUCLEAR CENTER AGUIRRE POWER PROJECT ENVIRONMENTAL STUDIES 1972 ANNUAL REPORT Prepared for Puerto Rico Water Resources Authority By the Staff of Puerto Rico Nuclear Center of the University of Puerto Rico - March 1973 Operated By IVE flico\_ woeR Ctaseser WO. At b-1S-1838 For US ATOMIC ENERGY COMMISSION ---Page Break--- ---Page Break--- APPENDIX A ---Page Break--- ---Page Break--- MACROZOOPLANKTON OF JOBOS AND GUAYANILLA BAYS, SOUTHERN PUERTO RICO, AND ITS FLUCTUATIONS UNDER SPECIAL CONDITIONS by bro and Edward A. Shearls Puerto Nuclear Center José A. Suarez-C: Puerto 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 Rowran (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-Caballero (1959), Suarez-Caballero and Madruga (1964), Legare (1961), Zoppi (1961),

Cuzen du est (1968), Reeve (1964, 1970), Suarer-Caabro and Gone: Aguirre (1965), Noryakova and Campos (1966), Cwre and Foy (1967) and Bowman and McCain (1971). An extensive bibliography on general plankton and the main groups of the area can be found in Rjdrnhers (1971). 'The main objectives of this study were to establish the main components of the macrozooplankton in Jobos and Cuayanilla Rays, and their abundance and distribution over a relatively short period of time as a baseline for understanding their future fluctuations with environmental changes. ---Page Break--- 259 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 Cuayanilla Rays 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 Muerto 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 is located in the southeastern part of Puerto Rico (Fig. 1) 20 nautical miles westward of Punta Tuna Light (approximately 17° 55' 00" N and 66° 10' 00" W). Jobos Bay is one of the few natural harbors on 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 easternmost part of Puerto Jobos, is approximately 7 nautical miles (Fig. 2). The widest area is 2-2 nautical miles from Central Aguirre to Roca del Infierno. The bay is divided into three different zones: Inner Bay,

Mid Bay and Aguirre Navigational Channel. The Inner Bay is the easternmost 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 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 Vorrillo, and Cayos de Pajaros, which channels are about 15 m deep. On the east, there is a 4-meter deep channel called Roca 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 Roca del Infierno, and the hydrostatic head that pushes waves.

over the fringing reef and through the mangrove channels between the keys in Cayos de Rarea 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 cm 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). ---Page Break---

261 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 389 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 +1° C within 109 m from the mouth of the discharge canal with a further decrease to +5° C toward the mouth of the cove. There was a 0.1 - 0.5 knot steady surface current flowing out of the cove and a 0.02 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 4.5 m. The discharge cove is more uniform, varying from 2 to 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 nets that were provided with small flowmeters. Most of the samples were collected with a macroplankton net of mesh opening size 380 µm, ten stations were sampled using a net of mesh opening size of 60 µm and three samples were obtained with a net of mesh opening size of 300 µm. 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 holo-planktonic forms in Jobos Bay. Among the calanoids *Acartia tonsa* Dana was found.

in every area sampled (Fig. 2). *E. Weltjeborgii* 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* (Fisher) was present in areas 2, 3, and 4, and *Acartia tonsa* (Lilljeborg) in area 5 only. *Tenora turbinata* (Nana) was the second most common calanoid. It was recorded for all areas except number 3. *Pseudodiaptomus cokeri* Gonzalez and Bowman occurred in area 5; *Samia* in the western part of the bay. Other calanoid species which appeared less common were *Calanopia americana* (F. Nahi), *Clausocalanus furcatus* (Bradley), *Paracalanus crassifloris* (Fe Dahl), *Taranacanthus aculeatus* (Giesbrecht), *Paracalanus* spp., *Labidocera scotti* (Giesbrecht) and *Labidocera* spp. The Cyclopoid copepods *Oithona helix* (Giesbrecht), *Oithona nana* (Giesbrecht) and the harpacticoid *Tisbe acutifrons* (Dana) also occurred in the bay. All those species of copepods except the 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, 1971; Woodmansee, 1983; and Mavis, 1950). *A. longirenis* is not previously reported in Puerto Rico, but it is recorded in Cuban waters by Suarez-Castro (1955). *Lucifer faxoni* was present in all areas of Jobos Bay. Juveniles of this species are reported in area 5 located at the mouth of the bay. Among the larvaceans, *Oikopleura (exiliaria) dioica* (Toll) and *Oikopleura (Vexillaria) pacifica* (Lohmann), *Oikopleura (Cloacarina) tonicauda* (Vea) and *Oikopleura (Caecarta) fusiformis* (Pe) 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 *Krohnites smelis* (Grassi) were also found in the bay. A cladoceran, *Daphnia* 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 Siphonophores were present in those entrances. Two species of mysids were identified. *Siriella chierchiaie* (Costa) was taken in areas near the Hee anes area 6 during the day. "Mysidopsis sp. (identified by Br. Arattegard as a new species 'Mysidopsis' found in Colombian coastal waters in 1971 and called 'Mysidopsis' was taken during a daytime tow in area 4. Among

the Hyperiid amphipods, the genus *Hirachyscelus* was identified in area 2. Also, a Gammarid 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. Other less common species were *Luterpina acutifrons*, *Microsetella norvegica* (Boeck) and juveniles of *Taeniocalanus*. Copepod Sessile tonsene The harpacticoid copepods were also present. ---Page Break--- 264 All those species were previously reported for Bahia Fosforescente and adjacent waters, southern Puerto Rico, either by Gonzalez and Rowman (1965) or Coker and Gonzalez (1960). Most of the species mentioned above are recorded for similar areas by Davis (1950), Davis and Williams (1950), Noodmansee (1958), Suarez-Cabaro (1959) and Peave (1964, 1970). A sergestid, *Lucifer faxoni*, 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 (Rowman and McCain, 1967; and Noodmansee, 1968). *S. tenuis* is a typical neritic species (Suarez-Cabaro, 1958; and Alvarino, 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.

tuayantiTa tay. Among the larvaceans, *Dikopleura (Vexillaria) dieica*, 0. (*Cocearia*) *longicauda*, 0 (*extTiaria*) *rufescens* Tol, *Fritillaria (iryera\ eereis) petealis* T. *sargasst (Cehnatn) and'F.~ (hurycereus) peTiucids (hisch)* were recorded. in the hay. "Al these species of larvaceans are reported for Puerto Rico for the first time, to the author's know- ledge. They were found in Cuban waters by Tokioka and Suareg-Caahro (1956) and in Trinidad Island, brazil, by bjSrnborg and Forneris (1955). Also, Flores (1965) re~ ported these species of the senus *Oikepteura* for the coastal waters of Veracruz, 'lexicos The mysid *Mysidium columbiae* (Zimmer) was taken during May in area T. A large school was taken with a band act at the surface near a mangrove stand. DISTRIBUTION OF THE MACROZOOPLANKTON Jobos Kay Jobos Ray 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 ---Page Break--- effect there. Most of the sampling effort has gone into area 2 (the intake area) and area § (the outfall area), Area 4, fioca del Infierno and the area sheltered hy Cayos Carihe'and Cayos Rarca should he indicative of recrulencat potential provided to the coastal arcas directly adjacent fo the power plant complex, Area 3 was sampled only in November 1971, and then oniy because it is a break point for surface waters coming through ?oca del Infierno, This area is probably the most unstable environment, hut at che Same tine the richest jn the hay. Area 6 was sampled to determine a possible trend toward seaward drift from area § and to estimate recruitment problems associated with wetrinental effects the heated effluent might have. Table 1 is a complete tabulation of plankton hauls analyzed to gate. It shows the location, date, tine and other paran- eters of the sampling. Tables 2 through > list plankton concentrations according toz (A) number taken per cubic meter of water sampled (¥/m<sup>3</sup>)

and (B) percentage of total catch that each plankton category constitutes (1 total catch). As stated before, the Inner Bay (area 1) has been sampled scantily. Zooplanktonic forms caught in this area reached 30.4% in December 1971 (Table 2). The main groups were copepods (43.8%), fish eggs (2.0%), anchovy eggs (0.5%), siphonophores (0.4%) and appendicularia (0.03%). *Lucifer faxoni* accounted for 4.0% in this area. Siphonophores 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 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 zoeae (28.0%), cirripede nauplii (8.4%) and penaeid larvae (4.1%). Copepods were the most abundant group among all plankton in area 2 (Table 3). From mid-December 1971 to the end of January and early February 1972, accounting for 76.4%, 74.4% and 64.5% respectively. Permanent mention in December included, in addition to copepods, appendicularia (0.27%) and *L. faxoni* (1.24%). Chaetognaths (0.6%), appendicularia (8.4%), medusae (1.1%) and very few *L. faxoni* (0.1%) were present at the end of January. Chaetognaths decreased to 0.93%; appendicularia increased to 9.1%; medusae decreased to 6.2%; and *L. faxoni* disappeared, but nemertineans (0.24%) were reported for the first time in area 2. It is interesting to note that copepods decreased, but cirripede nauplii increased to area 3 (Table 4) in early November were predominantly holo-planktonic. 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%, 0.55%); and *L. faxoni* (9.1%, 11.4%). Nauplius larvae (0.126), pluteus larvae (0.71) and porcellanid

larvae (1.6%) were present only during the day station. Area 4 (Table 5) in early November was also holoplanktonic (56.45), but appendicularia (19.24), chaetognaths (8.0%), cladocerans (9.0%), medusae (1.0%) and siphonophores (2.08) 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 JR-7, JB-8 and JR-10) in early December was typically meroplanktonic. Brachyuran larvae (161), decapod larvae (163), fish eggs (20%), fish larvae (0.88), nauplius larvae (124), polychaete larvae (0.14) 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 821 in area 5. Area 6 (Table 7), same as areas 5 and 4, was predominately holoplanktonic in early November. Copepods (54.50), chaetognaths (29.24), appendicularia (3.3%), cladocerans (118) and siphonophores (0.8%) reached a total of 99.9% of the whole plankton community. Meroplankton accounted for 41.1%, consisting of brachyuran larvae (10.3%), decapod larvae (12.34), fish eggs (3.04) and others (4.64). In early December and February copepod peaks of 67.3% and 93.4% were found, respectively. In February larvae had decreased to a total of only 3.5%. Cayeyilla Bay The area of sampling in Cayeyilla 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<sup>3</sup>) and (B) percentage of total catch that each plankter category constituted (1 total catch). Area 1 (Table 9) in early December was predominately holoplanktonic (99.5% of all plankters captured). Copepods and their nauplii accounted for 76.7% and 7.1% respectively, polychaetes for 6.4%, chaetognaths for

1.34. The only major meroplankters were cirripede nauplii (5.28). In early December (GR-A, GN-B), holoplankton had decreased to 691 of the plankton community (66.8% copepods, 2.1% chaetognaths, 1.1% polychaetes). Of the meroplankton, 4% were brachyuran larvae (2/3 of which were porcellanid zoeas), caridean larvae accounted for 3.2%, penaeid larvae for 2.3%, 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), 90.2% of the community was holo-planktonic 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, 19.3% 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 µm nets, later samples with 380 and 390 µm nets; therefore, the decrease in the number of copepods may have been due to smaller copepods not being caught.) In early March, bivalves occurred (St) 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 (0.038%) during November. Neritaceans occurred in both November and March (0.03% and 9.2% respectively). It is interesting that brachyurans 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 (8.1%). Copepod nauplii peaked in

November (where they paid up most of the €61), and early March (21.4%), and disappeared (for all practical purposes) in ---Page Break--- late March. Cirripede nauplii were also more abundant (3%) in early than late March (2%), but also peaked in December (4.68). In area 3 (Table 11) holoplankton accounted for 61.6% of the community during November, 84.91% in December, and 60.5% in March. A high meroplankton percentage in November was primarily a function of fish egg production (16.2%), gastropod reproduction (1.8%), and appearance of tintinnids (5.78) and foraminifers (3.54). The latter two were absent in other periods. It should be noted was also the only time appendicularia (0.6%) and chaetes (0.3%) appeared in area 3. The 59.58% meroplankton concentration in March was a function of a brachyuran breeding period (37%), a nurse of cirripede nauplii (4.04), and a healthy concentration of caridean larvae (4.55) and penaeid larvae. The latter two appeared in areas only in March. Note that the concentration of brachyuran zooplankton was greater than the combined total for copepod adults and nauplii for 94%. Apparently cirripede reproduction occurred both in November (1.14) 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 (40.54) and March (7.18). Larvae, absent in November, were found in small quantities in December and March. December was the only period planktonic larvae (9.6%) and bivalve larvae (0.6%) were found in area 3. Shallow concentrations of mysid and siphonophores occurred solely in spring. 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 1.8% (6.7% porcellanid) and as little as 3.64% within a two-period toward the end of the month. Cirripede nauplii constituted 5.8%, penaeid larvae 2.1%. Caridean

larvae dropped from 3.44 to 1.24 within a matter of hours. Discussion The plankton at Jobos and Guayanilla Bays was fundamentally neritic. However, it could be that some oceanic forms entered occasionally into the bays with tides ---Page Break--- 269 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 of sand. 5 in Jobos Bay. Another calanoid, *Tenora 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. Similarly to *A. tonsa*, a sergestid, *Lucifer faxon* 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. Scyphapids, *S. tenuis* and *S. inflata* were identified when mature specimens appeared. Few appendicularians such as *Oikopleura (Vexillaria) dioica* and *O. (Coccolithophora) longicanda* were 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. Echinoderm 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 two 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 richer than Jobos 1. For total zooplankton, area 5 at Jobos (12.4/m<sup>3</sup>) 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: ---Page Break--- 270 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. ---Page Break--- LITERATURE CITED Alvarino, A. 1965. Chaetognaths. *Oceanogr. Mar. Biol. Annu. Rev.*, 3:115-194. Rydberg, T. K. S. 1971. Distribution of Plankton Relative to the General Circulation System in the Area of the Caribbean Sea and Adjacent Regions. *Symp. Inv. Res. Carib. Sea Adj. Rep.*, UNESCO, pp. 343-356. Rydberg, T. K. S. and L. Forneris. 1955. Resultados Científicos do Cruzeiro do "Raenend" e do "Vega" a Ilha de Trindade. *Copelata I. Cont. Avul. Inst. Oceanogr.* 11, Sao Paulo (1):1-63, pls. I-XVII. Bowman, T. F. and J. C. McCain. 1967. Distribution of the planktonic shrimp, *Lucifer*, in the Western North Atlantic. *Bull. Mar. Sci.* 17(3) 2600-671. Bowman, T. F. and J. C. McCain. 1971, Distribution of Plankton relative to the general circulation system in the area of the Caribbean Sea and the adjacent regions. *Symp. Inv. Res. Carib. Sea Adj. Report UNESCO*, 14 pp. Coker, R. F. and Gonzalez. 1960. Limnetic copepod populations of Bahia Fosforescente and adjacent waters, Puerto Rico. *J. Fish. Mitchell Sci. Soc.* ZAC 28-28. Cuzon du Rest, R. P. 1963. Distribution of the Zooplankton in the salt marshes of Southeastern Louisiana. *Publis. Inst. Mar. Sci.*

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sogor\_B YTMAND Oold OLNAND 4 ANVTd U3MOd ---Page Break--- ---Page Break--- ---Page  
Break--- 269 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-20 were taken on June 10, 1972.  
Samples were taken with a Phieger corer of about 10 cm? 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-3k 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. 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-Ammonbaculites* and *Ammonia-Fursenkoin*. The map  
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 "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*.

*Quinqueloculina-Ammonbaculites* Biofacies 'This biofacies covers the shallowest part of the study  
area (the stations range from 1m 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 CSE 4 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 present in Station G-9. 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 Fursenkoin Biofacies This biofacies includes the stations from 8.5 to 17.0 meters of water depth, Stations 6-24 to 6-29. The dominant species is Ammonia catesbyana tepida and the second in abundance is

Fursenkoina pontoni. Fursenkoin: Armonia Biofacies This biofacies corresponds to water depths from 17.5 to 18.5 meters (Stations G-22 to G-23). Ammonia catesbyana forma tepida F. pontoni is the dominant species and A '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 constitutes 10% as mean value of the total population of this species in the stations in which it occurs. Fursenkoina pontoni is second in number, but the percentage of "pyritized" specimens is only 7% as mean value of the total living populations of this species. ---Page Break--- 202 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 the information function is used by 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  $N = \sum(p_i \log p_i)$  where N is the total number of species in the sample and  $p_i$ , the proportion between the number of specimens of the ith 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 (2-5 cm). Distortion of the surface may increase the number of...

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 Cuayanilla Bay and Mayaguez Bay are constituted mostly by A. catenulata tepida, while most of Jobos Bay populations are constituted by A. catenulata catenulata. Some faunas of Jobos Bay are deformed and it is difficult to include them in a subspecies. The Pteroceras Central Lagoon contains large populations of A. catenulata tepida under conditions of thermal pollution. The most abundant foraminifers in most of Mayaguez Bay are, in order of abundance, Foraminifera pontona and Florilus rateloupuii, while in Guayanilla the most abundant species are Ammonia catenulata tepida and Foraminifera pontona. The occurrence of Florilus rateloupuii in Guayanilla Bay suggests that this species is important to chemical pollutants. The dominance of Ammonia catenulata tepida, at depths in which Foraminifera pontona is dominant in Mayaguez Bay, suggests that this species is more resistant than F. pontona to chemical stress.

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seomtertum of en et ete ote or i os a 1 3 » r 2 i 1 1 woo 1 1 5 1 4 ? » 3 ---Page Break--- 302 TARE  
4 (COM) » FORAMINIFERAL POPULATIONS PER SAMPLE TX GUAYANILIA BAY 25 O26 G26  
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'onfertant ef omHlisie safe, ---Page Break--- Table No. 5, "Pyritized" Living foraminifers at the  
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Table Wo. 6, Speckfie diversity by Aoformition function, #. Station Station GA, Oe em, 1.26 6-23, O61 em. 2.07 GM, leew. 113 6-24, OL em. 1.86 GHA, 2-3 cm, 0.68, 6-26, 162 em. 1.37 GBA, Ont em, 1.26 25, Ont cm, 1.99 6A, Oot em. 1.31 6-26, Ont cm. 1.36 Goh, OL em. 1.56 6-26, 1-2 em, 0.76 GTA, 1-2 om, 0.93 0-27, Ort em. 1.58 GOA, OL em, 1.45 6-28, Onl em. 1.60 6-29, O-1 em, 2.03 n22, Olea, 1.72 1 ---Page Break--- 304 Study of the effect of Heated Water on Turtle Grass, 'Thalassia testudinum Konig, in Guayanilla Bay by Peter Schroeder ---Page Break--- 305

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 from 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) has been recorded as well as the total weight of plant material. After dry weight was recorded, the plant material was ground with a 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 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 the 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? PLANT BOX FOR GROWING THALASSIA (# waT6® Level Station Date collected Br Ws/ie Growing tips 3 ioots rhizomes vertical (short) shoots new leaves old leaves old

sheathing leaves Total Grams per meter square 3a Growing tape 8 roots Rhizomes: vertical (short) shoots new leaves 02d leaves old sheathing leaves Total Grams per meter square 309 Wet weight Dry weight (grams) 5a +7596 8.8 2.9433 14 +3379 2.1901 342343 Te +7890 66.5 8.254 3.276 406.6 39.4952 3.8410 27.8235 5.5819 8.6453 2.0720 28.9616 346130 32.4598 3.5705 --- 2.8814

157.4558 21.5658 1.756 1062.4 ---Page Break--- Station Date collected 4a Ws/te Growing tips 19  
Roots rhizomes vertical (short) shoots old sheathing leaves Total Grams per meter square BA 5/12  
Growing tips 8 roots rhizomes vertical (short) shoots new leaves old leaves old sheathing leaves  
Total Grams per meter square Wet weight 52.5 25.6 2.5 11.6 49.7 30.0 172.9 8468. 310 Dry weight  
(grams) 6.3063 6.9540 2.2959 2.3040 4.9123 2.4976 25.2701 1244.8 4.3672 +4340 +3395 1.7307  
546310 2.5356 25.0979 143.7 ---Page Break--- Station Date collected wet weight Dry weight  
(grams) 38 Use Growing tips 0 roots 6.0252 rhizome 346636 Vertical shoots +3313 New leaves  
2.6558 Old leaves 4.7482 Sheathing 2.4386 Total 37.8423 Grams per meter square 878.3 3 size  
Growing tips 5 roots 92.1 9.7106 rhizome 10.2325 Vertical shoots 36 +4382 New leaves 23.7  
2.4897 Old leaves 70.6 6.7504 Sheathing 50.3 4.8225 Total 302.0 33.5038 Grams per meter  
square 14.832 2650.2 38 Use Roots 69.3 6.0076 rhizome 27.8 3.9867 Vertical shoots 2.3280 New  
leaves 16.0 1.9849 Old leaves 43.7 440320 Sheathing 35.4 2.1054 Total 203.3 20.5036 Grams per  
meter square 10310. 1009.8 ---Page Break--- Station Date collected aA Ts/re Growing tips 3 Roots  
Rhizome vertical shoots New leaves Old leaves Sheathing Total Grams per meter square 2a  
Ws/T2 Growing tips 6 Roots rhizome Vertical shoots New leaves Old leaves Sheathing Total  
Grams per meter square 3 Tas/Te Growing tips 3 roots rhizome Vertical shoots New leaves Old  
leaves Sheathing Total Grams per meter square 32 Wet weight Dry Weight (grams) +5384 2.1910  
=3226 1652 +8012 1.0447 420320 198.6 42.9 4.6713 26.0 4.7439 10.0 12.2880 2.2577 45.3  
444390

14.2 2.3285, 150, 27.7284 7399. 873.4 3964 3.9966 47.4 7.6478 20.2 1.5865 21.3 2.6354 63.5  
6.5108 22.2 2.2224 204.0 24.5999 10049 1222.8 ---Page Break--- Station Date collected 8 1/s/Te  
Growing tips 12 Hoots Rhizome Vertical shoots New leaves 014 leaves sheathing Total Grams per  
meter square 13 1/9/12 Growing tips © Hoots Vertical Shoots New leaves: 014 Leaves Sheathing  
total Grams per meter square ea 1/3/12 Growing tips 4 roots Vertical Shoots New Leaves 014  
Leaves Sheathing, Grams per meter square Wet weight 30.0 17.3 63.9 23.9 46.7 127 206.2 10253  
33.20 22.10 3.20 1.7 88 14.2 82.9 4084 33 Dry weight (grams) 4.8821 4.6692 7.6637 444300  
4.7482 2.2363 28.3295 2395.5, +9686 1.7347 1.0090 +4902, 6.6416 141680 212.0120 591.7  
3.2841 1.9203 +3530 2.5469 +8289 2.4334 10. 3666 510.7 ---Page Break--- Station Date collected  
3B ans/ie Growing tips 4 Hoots Rhizome Vertical Shoots New leaves Old leaves Sheathing 'Total  
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shoots New leaves 014 leaves Sheathing Total Grams per meter square Wet weight 53.6 45.2 3.9  
ws 50.5 40.2 210.8 10384 49.00 18.0 2. 21.3 63.5 21.3 178.2 e778. 219.4 33.9 15.0 32.0 79.8 66.0  
34542 17043 314 Dry weight (grams) 5.0299 7.2897 1.4022 2.1856 8.8149 3.7725 27.4937 1396.4  
5.6480 3.3848 +8900 2.6417 6.0376 1.9040 20.5662 1013.1 12.2036 5.3456 2.5230 3.9680 7.9486  
6.2230 3362338 1637.1 ---Page Break--- Station Date collected a asta Growing tips 0 roots  
Rhizome Vertical Shoots New leaves Old leaves Sheathing 'Total Grams per meter square 2a,  
ea/Te Growing tips 6 roots Vertical shoots New leaves 014 leaves Sheathing Total Grams per  
meter square 3a 8/3/72 Roots Rhizome Vertical shoots New Leaves 02a leaves Sheathing Total  
Grams per meter square Wet weight 1.0 42 2.0 6.0 3.4 3.0 18.6 96 45.3 3064 25.8 9.6 22.2 26.0  
199.2 7842 216 20.2 21.0 as 375 50.0 167.8 8266 35 Dry weight (grams) +0572 +5827 +1329  
+4680 +2597 +2165 1.7260 84.5

4.6880 547043 4.3285 2.0026 2.0432 2.3293 20.0959 983.9 2.8075 3.8406 2.0002 2.4467 542826  
5.0420 22.4186 1055.1 ---Page Break--- Station Date collected 4h 8/9/72 Growing tips 3 Shoots  
Rhizome Vertical shoots New leaves Old leaves Sheathing Total Grams per meter square 1B 89/72  
Growing tips 0 Roots Rhizome Vertical shoots New leaves Old leaves Sheathing Total Grams per

meter square 2B 8/9/72 Growing tips 2 Shoots Rhizome Vertical shoots New leaves Old leaves Sheathing Total Grams per meter square Wet weight 59.0 25.0 17.0 23.0 63.4 35.7 223.1 10390 2.7 5.0 22 2.0 9.2 1.0 21.9 1374 21.3 13.2 15.7 9.0 21.7 12 210.2 5424 Dry weight (grams) 5.7621 3.9234 2.5309 2.4296 6.5342 344082 24.5782 1210.7 2780 +8426 +3334 +1638 +9355 No 2.5523 125.7 2.9340 243580 2.1389 +6617 2.1294 2.4950 22.7170 626.5 316 ---Page Break--- Station Date collected 33 a/a/te Growing tips 0 Roots Rhizome Vertical shoots New leaves Old leaves Sheathing Total Grams per meter square 45 a/s/72 Growing tips 3 Shoots Rhizome Vertical shoots New leaves Old leaves Sheathing Total Grams per meter square 5B ea/re Growing tips 3 Shoots Vertical shoots New leaves Old leaves Sheathing Total Grams per meter square Wet weight 35.2 28.4 10.0 12.6 36.0 22.6 143.8 7084 1563 28.1 16.5 61.0 45.0 245.2 12079 223.0 25.4 18.0 29.2 13.2 61.2 342.0 16847 Dry weight (grams) 3.2940 543607 1.5805 1.4264 4.2980 4.9496 19.3892 995.2 744103 4.8020 1.7390 2.4201 6.0315 4.1425 26.5456 1307.7 11.3560 4.5698 344536 3.0232 6.8974 5.7636 5.7636 2726.8 7 ---Page Break--- 318 Station Date collected Wet weight Dry weight (grams) a 6/20/72 Growing tips 4 Roots 22.2 2.4209 Rhizome 22.2 345903 Vertical shoots 24 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 111 MEAN WEIGHTS (GRAMS PER METER SQUARE) Station Wet Weight Dry Weight 1 2638 g/m<sup>2</sup> 360.7 g/m<sup>2</sup> 2 6187 g/m<sup>2</sup> 1506.1 g/m<sup>2</sup> 3 8440 g/m<sup>2</sup> 1086.2 g/m<sup>2</sup> 4 22277 g/m<sup>2</sup> 1285.3 g/m<sup>2</sup> 12565 g/m<sup>2</sup> 2130246 g/m<sup>2</sup> ---Page Break--- 319 Tomlinson, P.3. and 7. 2. Vargo (1966).

On the Morphology and Anatomy of Turtle Grass *Thalassia Testudinum* (Hydrocharitaceae). Vegetative Morphology, Sul. lar, Sei, 16(4). Grow (1972), Composition of *Thalassia Testudinum* and *Jussiaea* Waritima, Pla, Acad. Zieman, J.C. (1968) of the Sea-grass, *Thalassia Testudinum*, Thesis, Univ. Wiama. A Study of the Growth and Decomposition. Coral Gables. ---Page Break--- 320 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 (Sader 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 1987. In the spring of 1992, the output of the plant was 310 kW. Now the plant produces 710 kW. The ecosystems around the discharge area of the cooling water resemble those in the Aguirre Navigational channels 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. ---Page Break--- 321 '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 190 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<sup>3</sup>/min (188,000 gal/min), and after a new 400 MW unit was added, the output was raised to 1510 m<sup>3</sup>/min (398,000 gal/min), the rate 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 seawater and the resident marine organisms. The power plant uses chlorine treatment against fouling organisms in the condensers and chromates as an anti-corrosive. Free chlorine disappears quite fast, however, in the discharge canal. Part of the free chlorine could have been associated with dissolved organic compounds, many of which 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 Pittsburgh Plate Glass, Inc. (PPG). These fish kills are attributed to the 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 ---Page Break--- 322 Figure 1. East side of Guayanilla Bay showing the location of the power Plant and the sampling stations ---Page Break--- 323 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, 18 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. Net weight - dry weight ratios of the species are being determined presently. Residual 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. 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 - IV). At the mouth of the discharge canal a rapid entrainment was observed. The temperature decreased over 2.5°C within a distance of 100m. From this distance toward the mouth of the cove ---Page Break --- 324 of we pyoe ot fom smn wom mu mong E02 vOHeIS HO] 46 seuoN mM \$3901.00 waenaia3s snow ane sen MAS ARTO S Wort s SOTO AHO Ss RoZiAs BEES ere emer re eT TT ---Page Break --- sce temperature on Jan '3, 1972. Soundings are in feet. ---Page Break --- 326 Power Plant Z Figure 4. Surface temperatures on October 9, 1972 Distribution of mangroves also shown. ---Page Break --- Power Plant S JN oO \ Discharge Canal \ \ PLATE IA, Water temperature on the surface - October 20, 1972 ---Page Break --- PLATE IB, Water temperature at one meter's depth, October 20, 1972 328 ---Page Break --- PLATE IC. Water temperature at 2 meters depth, October 20, 1972 329 ---Page Break --- Po Power Plant OB, wis "A \ \ Discharge Canal y \ PLATE ID. Water temperature at 3 meters depth, October 20, 1972, ---Page Break --- PLATE IE. Power Plant ' \ discharge Canal Water temperature at 4 meters depth, October 20, 1972, 331 ---Page Break --- 332 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 the 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, the 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 at 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<sup>3</sup>/min. was needed to entrain 750 m<sup>3</sup>/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 laminar 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<sup>3</sup>/min.

entrainment water was needed to lower 1510 m<sup>3</sup>/min. from 1n 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. ---Page Break--- \*|puDo efsDyos}p ey Jo YiNoW ey UI ouiNid us UI esnyoredusey 50 suounquisip [D2HleA "ç eundi4 foup> e6s04Ds1q wWo4y sDUDIsIC ool saieW ul yideg ---Page Break--- "AOD 04s 40 Yinow ous 4© euinid ous u| eunjosedwes Jo UoUNaulsIP jDoHJeA —"g ound oA0D @y4 40 YINOW ays wos} soUDIEIG \$4019W 009 oO v 3 z 3 5 5 092 3 gr ode 8S ze 20k tle ---Page Break--- ---Page Break--- Figure 8. Surface water currents in the cove in summer 1972. ---Page Break--- 337 The turbulences 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<sub>2</sub>/l. 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, 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 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 8, but this was not due to the temperature, but rather to the current which was eroding the sediment from

around the roots of mangroves to 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 healthy.

Mangrove Root Communities Species composition: Mangrove root communities in the site Shacoutsiae verioct 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:

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338 STATIONS. Control 1 Temp. °C. 30.0 31.2 Spp. Algae 6 5 5 Rk 7 4 5 5 Spp. Invertebrates 90 45 69 67 58 25 21 10 Total Spp. 96 48 74 75 65 29 2815

The number of invertebrate species at control station is 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 Bay 1972 Annual Report), and no two areas are exactly alike. A 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. Species were not as numerous in Guayanilla as in Jobos Bay. "Mollusks had the most species at Control ---Page Break---

TABLE 1 NUMBER OF SPECIES IN DIFFERENT PHYLA ON

THE MANGROVE ROOTS On (OK OCTOBER 9, 1971) PRY cyanophyta, chlorophyta, Phaeophyta, Rhodophyta, Porifera, Coelenterata, Annelida, Stipunculida, Mollusca, Arthropoda, Echinodermata, Chordata (Asciacea), algae, Invertebrates, Total Control 27 25 45 48 203 4 6 1 13 14 7 6 3 12 46 5 8 7 67 10 18 38 65 25 29 2 26 10 15 339 ---Page Break--- 340 station and at station 3, but arthropods were the most numerous at most stations. "At station 1, ascidians had the most species of all phyla. Annelids, mollusks, 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 counter-current 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	3	4	5	6	7
Temperature °C	25.5	26.0	26.4	27.2	28.9	31.5
# Species	94	45	74	78	85	88

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 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. Blue-green algae, an encrusting sponge (*Haliarcarca* sp.), a calcareous tube-dwelling polychaete (*Tonnastetes jtelzatua*), tree oyster, (*Cognianus seuss*), a periwinkle (*Littorina angulifera*), two *Fatania* species and two crabs (*Kratus pisonii* and *Pachygrapsus transversus*) were the more hardy species. Macroalgae, coelenterates, echinoderms, and ascidians were the most sensitive species. ---Page Break--- ---Page Break--- Stations 'TABLE 2 (cont'd.) Rhodophyta *Loventeria* sp. *Polysiphonia* sp. [INVERTEBRATES ---Page Break--- 343 ---Page Break--- Gastropoda *Bivalvia* ---Page Break--- ---Page Break--- ---Page Break--- ---Page Break--- Stato ---Page Break--- 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 amphitrite* var. *reginae*, which had a lower biomass than the station five beach 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, 5, and 6, molluscs were the dominant group, while at station 2, ascidians; at station 4, Qigae; 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 stations outside the cove. After the new power generating unit was fired, the biomass from 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 blue-green 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 ascidian decreased. The biomass and the temperatures of five stations on 20 September 1972 are given below. 349 ---Page Break--- 350 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, ---Page Break--- ---Page Break--- ANNEDILIA Polychaeta ---Page Break--- ---Page Break--- Teopode ---Page Break--- ---Page Break--- 3 ---Page Break--- 357 TABLE 4 Vertical Distribution of the Number of Species and the Biomass (Wet Weight) Calculated for All Stations on 9 October 1971

Depth, cm	Total	0-9	3	0.8	19	10	8.6	20	- 29	20	22.2	30	= 39	22.5	21.9	40	- 49	20	16.5
so	- 59	n																	

12.2 60 - 69 7 10.5 70 - 79 3.5 5.6 80 - 89 1.6 ---Page Break--- 358 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 ROOTS 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 plants 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 *Terebralia palustris*, which lives in the lower part of the intertidal zone and deeper. A polychaete, *Pomatostegus stellatus*, that lives ---Page Break --- 359 TABLE 5 Maximum Daily Temperatures that the Following Species have been found in Guayanilla Bay. PLANTS cyanophyta 40 40 40 Chlorophyta *Enteromorpha* sp. *Gaulerpa verticillata* 36 *C. fastigiata* 35 *C. sertularioides* 35 *C. zacosmosus* 35 Phacophyta *Dictyota diversifolia* 34 Rhodophyta *Acanthophora spicifera* 35 *Hypnea acanthocladus* 4. Tecticheophyte *Rhizophora mangle* 40 *Avicennia nitida* 40 *Laguncularia racemosa* 40 ANIMALS Porifera 36 35 35 34 33 Annelida *Pomatostegus stellatus* 38 *Syllis* 3 *Phyllochaetopsis clapedii* 36 *Eudorellopsis rubra* 36 *Sabella welanostigma* 35 *S. algal* 35 *Nereis*

duportii 35 *Limnodrilus maculatus* 35 ---Page Break--- 358 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 from 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, *Terebralia palustris*, which lives in the lower part of the intertidal zone and deeper. A polychaete, *Pomatostegus stellatus*, that lives ---Page Break--- 359 TABLE 5 Maximum Daily Temperatures that the Following Species have been found in Guayanilla Bay. Plants Cyanophyta *Microcystis* sp. 40 °C, *Synechococcus* sp. 40 °C, *Oscillatoria* sp. 40 °C, *Lyngbya* sp. 40 °C Chlorophyta *Enteromorpha* sp. 39 °C, *Caulerpa verticillata* 36 °C, *E. fastigiata* 35 °C, *E. sertulariodes* 35 °C, *C. racemosa* 33 °C Phaeophyta *Dictyota divaricata* 36 °C Rhodophyta *Acanthophora spicifera* 35 °C, *Euclima acanthocladus* 35 °C, *Thalassia testudinum* 35 °C Tracheophyta *Rhizophora mangle* 40 °C, *Avicennia nitida* 40 °C, *Laguncularia racemosa* 40 °C ANIMALS Porifera *Clathrina* sp. 2 °C, *Gallyspongia* sp. 36 °C, *Mycale* sp. 35 °C, *Halichondria* 35 °C, *Tedania ignis* 34 °C Coelenterata *Euthalia angulata* 34 °C, *Erythropodium caribaeorum* 33 °C Annelida *Pomatostegus stellatus* 28 °C, *Syllis* sp. 37 °C, *Phyllochaetopterus claparedii* 36 °C, *Eudorella rubra* 36 °C, *Sabella selanostigma* 36 °C

---Page Break--- Annelida, Arthropods, Bryozoa, Echinodermata, Chordata, *Texebelja annulicilis*, *Sabellastarte magnifica*, *Littorina angulifera*, *Brachidontes exustus*, *Nassarius vibex*, *Crassostrea rhizophorae*, Great Isopod, *Veppaceus*, *Ostrea equestris*, *Betalocochos signatus*, *Hainoea elegans*, *Pododesmus rudis*, *Balanus amphitrite* var. *pallidus*, *Chrysanthes*, *Hratus plsonit*, *Gontopeltis cruentata*, *Clibanarius cubicus*, Hexapodidae, *Caribbacus*, *Panopeus bermudensis*, *Eanopeus*, *Rarecat*, *Crosspolite*, *Excoristians sudeticornis*, *Gythansiae*, Fauna, *Eorophiae* sp., *Synuiphenes*, *Fritzmitters*, *Wetopheys*, *Scorinstue*, *Crisia* sp., *Ophiocoma angulata*, *Rotrylloées nigricun*, *Distaphia bermudensis*, *Polyclinus constellatus*, *Pipilosons sidonatus*, *Perophorus viridis*, *Seyela pare: setéie aigrs* 34 33 3 RORERRRESS ---Page Break--- Chordata, *Clavelina picta*, *Polycerotidae*, 4 3% 3 33 33 361 ---Page Break--- 362 in the intertidal zone and below the intertidal

zone was associated with the former species in temperatures up to 38°C. (Table S). All these species have adapted to 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 of 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 (halimeda) until they died. An encrusting sponge (*Ligulicella* 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 excessively high temperatures. One species of snail, periwinkle (*Littorina angulifera*), and two species of crabs (*Aratus pisonii* and *Pachygrapsus transversus*) were found at Station 7, as well as *Balanus amphitrite* var. *pallidus*. Periwinkle and

the two Erabs were capable of climbing above the surface to avoid water that was too hot. Bluegreen algae were found as a thick 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 37.8° and 39.7° C, the biomass of bluegreen algae 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 the water had flakes of bluegreen algae floating. *Frateromorpha* and *Ulothrix* were the only algae besides bluegreens found in the cove in October 1972. Three other polychaetes (*Syllis* sp., *Leodice* sp., and *Narphysa regalis*) besides *Ponostegus* were found in the cove above 7. Two molluscs (*Erachidontes exustus* and *Sovatovos vibex*) were dying in the cove in summer, too. Two isopods (*Sphacrosoma walkeri* and *Cirolana parva*) and several crabs (*Libinia emarginata*, *Sesarma reticulatum*, *Goniopsis cruentata*, *Callinectes sapidus*, and *Vanopeus bermudensis*) were found in the cove in September. Bryozoa (*Crisia* sp.) lived in temperatures up to 38° C. Five species of ascidians (*Distaplia bermudensis*, *Polyclinum constellatum*, *Didemnum candidum*, *Diplosoma listerianum*) were found living in temperatures above 35° C. About 3/4 of all species were found living in temperatures above 38° C. The rest may very well be able to live at those high temperatures, but there may have been some other biological 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 adversely affected in temperatures below 34° C. Between 34° C 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, during which 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 distinct thermal limits of the most important species found in Guayanilla Bay. A population of the snail, *Nassarius tibicen*, was found at 36° C in Guayanilla Bay, while Thorhaug et al. reported 37.5° 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° C for a similar species, *Poriclimenes 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 temperatures. 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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water column, (2) rooted sea grasses (primarily *Thalassia*) and their algal epiphytes, (3) benthic algae, allochthonous 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 allochthonous 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. Hargreaves 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 "Feology 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, 1989; Jones, 1968). It is difficult to guess their importance in the extensive shallows of the Inner Bay (< 1m 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 1% 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 the 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 Var Verpro 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 6 and 7



(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. ---Page Break--- 369, Burkholder, P.R., L. Burkholder and L.R. Almodovar, 1967. Carbon assimilation of marine flagellate blooms in neritic waters of southern Puerto Rico, Bull. Mar. Sci, 17:1-15. Hargraves, P.E., R. W. Brody and P. R. Burkholder. 1970, A Study Of phytoplankton in the Lesser Antilles region. Bull. Mar. Sci. 20:331-349. Jones, J. A. 1968. Primary productivity by the tropical marine turtle grass, *Thalassia testudinum* König, and its epiphytes. Unpublished PhD thesis, Univ. Miami. Pomeroy, L. R. 1959. Algal productivity in salt marshes of Georgia. Limnology and Oceanography 4:386-397. Pomeroy, L. R.

1960. Primary productivity of Boca Ciega Bay, Florida," Bull. Mar. Sci. Gulf Carib. 101-10, ---Page Break--- ---Page Break--- 37 so a sogor jo e1i0d widep wnwyew eur so 18K fo UROUS 840 Ai tuojois Suyduioe yo won0201 eu, "ko@ sogor ---Page Break--- 372 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. 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). 1. 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 For further details and discussion of analytical procedures, see Strickland and Parsons (1968), ---Page Break--- 373 plastic container." Measure surface irradiance and irradiance at the depth of the center of the sample. Measure temperature and oxygen concentration of the Bay water using the surface oxygen meter. Measure salinity using the AO

Refraction Salinometer. Fill a clean 2-1/2 gallon cubitainer with water from just below the surface. 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. 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 POD 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 sulfate 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 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 "LAY". Do the same with the 2 opaque bottles and label them "DR". Wire stoppers on tight using stainless steel or chrome-nickel wire and put all LB and DR 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, X, recover the LB and DR bottles from the bay, remove stoppers and add manganous sulfate and alkaline iodide in the same way as for the IB bottles. Shake well twice and store with the IB bottles. Record incubation time. To the remainder of the 1 gal. surface sample add about.

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 DR 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, sprinkle a few drops of lit on the 375 filter paper. 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, 0.45 (HA) Millipore filter. Record the quantity of water filtered. 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 IR, DB and TR bottles: Take bottle from storage without shaking and remove stopper. Add 1.0 ml of concentrated (specific gravity 1.84) sulfuric acid to the sample, placing the tip of the pipette just below the surface of the water. Re-stopper and shake.

thoroughly until the precipitate dissolves fully. Do not permit air to become trapped in the bottle. Keep out of direct sunlight. 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. ---Page Break--- 316 Within a few hours, transfer 50.0 ml of the solution into a clean 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 were prepared, subtract it from this number of ml. The result is called V, i.e.,  $V_j V_{pg}$  of  $V_{ig}$ . Obtain the value of £ supplied with the reagents. € fs Calculate the dissolved oxygen, O, in the bottle and record  $O = 1.6096 \times xv$  where O is in mg O<sub>2</sub>/liter. Calculate the productivity values for the sample as follows, and record: Gross photosynthesis, mg carbon/m<sup>2</sup> - hr =  $sosst \times zy - vps$ ] Net photosynthesis, mg carbon/m<sup>2</sup> - hr =  $sosxex [Wy - V, Nx 1.2 S$  Manganous sulfate and alkaline iodide. ---Page Break--- 377 Respiration, mg carbon/m<sup>3</sup> - hr =  $eos \times x [Vie - Von]$  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 Dil spectrophotometer sample cell having a path length of 10 cm and volume of about 30 ml. Immediately measure the extinction, T, of the solution in

the spectrophotometer against a reference cell filled with 90% acetone only. Measure at wavelengths: 7500, 6650, 6450, 6300, and 4800 Å. Record values to the nearest 0.001 unit in the range 0 - 9.4 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 wavelengths. This gives a cell-to-cell blank correction,  $F_{750}$ . Calculate the corrected extinctions at each wavelength as follows:

$$E_{6650} = F_{6650} \text{ (as measured)} - F_{750} \text{ (as measured)} + k$$

$$E_{6450} = F_{6450} \text{ (as measured)} - F_{750} \text{ (as measured)} + F_{ee}$$

$$E_{6300} = F_{6300} \text{ (as measured)} - F_{750} \text{ (as measured)} + F_{ee}$$

$$E_{4800} = E_{4800} \text{ (as measured)} - 3 \times E_{750} \text{ (as measured)} + F_{ee}$$

The sign for  $F_{ee}$  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:

$$C = (E_{6450} - 0.14 \times E_{6300}) / V_w$$

where  $V_w$  is the volume, in liters, of water passed through the Millipore filter.  $C$  is in mg pigment/liter water. Or get  $C$  value from the nomograph supplied, using the corrected  $E$  values.

Doty, M.S., J. Newhouse, and R.T. Tsuda. 1967. Daily phytoplankton primary productivity relative to hourly fates: 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, (cog, Welie and Wer iss 1971) appear applicable almost unchanged, and equipment of this sort would be assembled for the purposes. 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 - ---Page Break--- 381 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 continuously 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. ---Page Break--- 382 Doty, M. S., J. Newhouse and R. T. Tsuda, 1967. Daily phytoplankton primary productivity relative to hourly fates. 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. L. Nelles. 1971. Photosynthesis in coral-algal associations. In Scientists-in-the-Sea (J. W. Miller, J. G. Van Nerwalker and R. A. Waller, eds.). U.S. Dept. of the Interior, ---Page Break--- 383 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 the 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 the 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 the 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 the growth of visible green leaf blades (Jones, 1968). Measurement of the 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 the 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 the 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. Fleman's results (Fleman, 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. ---Page Break--- 385, 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 seagrasses 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. Siam. ---Page Break--- 386 PHYSICAL OCEANOGRAPHIC METHODS ---Page Break--- ---Page Break--- 387 CURRENT STUDIES by E. D. Woop 1, Meters - Hydro products Model 503 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 pool's circulating pumps were off for several hours before and during calibration. Calibration was done at velocities of: +2, 15, and .8 kt. The velocities shown by the meters were all lower than measured and the correction factors determined were Meter # Factor S 2 9 The meters are checked periodically in the electronics shop; and adjustments to the read-out circuitry are made as required. Current meter placement. The current meters have been installed by two different methods. (4) 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 3 m 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 occasionally marked with a small buoy anchored separately. ---Page Break--- 368 (ii) Group anchored meters are suspended from a platform, either a raft, buoy, 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 (0.18), 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. 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 ensure that they are functioning properly. 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<sup>-1</sup>. 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, & 6m then the depths of the sections are 0-1, 1-3, 5-5, 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 ---Page Break --- 389 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 equipped 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. Dye Studies. Pe 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/l. 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 delineate 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. Continuous Dye Releases. Soluble rhodamine-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 for a period

of 390 (3d) time. The dye plume was photographed from the air at three different times a day. Transects of the dye plume were made to map the extent of 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 fluorometer 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 a 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 3m, ---Page Break--- 391 COLLECTION AND PREPARATIVE METHODS ---Page Break--- ---Page Break--- 392 COLLECTING METHODS FOR FISHES F. D. MARTIN fish are collected for our studies by a number of methods including gill nets, seines, cast nets, dip nets, hand lines, toxins, spear guns, and traps. The methods most commonly used are gill nets, seines! and fish trawls. 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 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 ottom. 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 downwind 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 labeled containers. Techniques of removal depend on the fish, the mesh size of the net, and the 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. Sunlight breaks

down nylon and must be

avoided as much 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), 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; 3.) when jumping fish which can go over the net and can force their way through the mesh (e.g. 's and needlefish). The other common method used in collecting fish is fish toxins. The toxin we use is Pro-Noxfisi®, 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 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 then to make a 33' by 33' square. Otherwise, four poles are driven into the bottom to make a 25' x 25' square, and the net is pulled around then. 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 is poured into a 2-gallon bucket containing 1 1/2 gallons of seawater. 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 feasible. 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 not 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 that 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 winners frequently leave the area during the setting up process and for this reason the setup 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 fish 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 occasion sharks come into the general area to feed on the incapacitated fish. In the event that this happens (and this practically 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. ---Page Break--- 396 The one remaining point of discussion is the criteria for deciding on sampling areas. First priority is placed on establishing baseline areas which should be directly affected 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 1/3 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. ---Page Break--- 397 THE THALASSIA BEDS Sampling Methods: The sampling biomass of plants and benthic invertebrates was done with a special core sampler that was designed by ME Peter Schroeder. This sampler consists of a stainless steel pipe (16.1 cm) with a crank. (Figure 1 in the Section on Thalassia beds in Guayanilla Bay). It samples an area of 20 cm<sup>2</sup>. 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 into 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. ---Page Break--- THALASSIA SAMPLER 0203

METER? ---Page Break--- 399 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: 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. 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<sup>2</sup> 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, dominance, and species diversity among the major encrusting organisms. Collected Quadrats: 1/4 m<sup>2</sup> 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 WOSS map, cutting out and weighing the tracings, and multiplying the estimated area by the average of the biomass estimates computed from the collected quadrat 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.

OP CUBITAINERS Jaw #1 Label everything with date and station number. 1. 2 3. 4 Rinse with tap water. Rinse with 4 N Nitric acid. Rinse with distilled water. Put on cap and put a piece of masking tape labeled "Prep." on the cubitainer so it won't be confused with dirty ones, ---Page Break--- 3 a 402 COLLECTING OF Samples Wa! On station rinse the cubitainer with a little of the seawater you will be sampling. Avoid cubitainers that may contain paint residue from the boat and motor gas and oil. Add 10 ml (cc) of concentrated HCl (hydrochloric acid). 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 a plastic bag. ---Page Break--- 403 METHODS MANGROVE ROOTS Sampling. The

mangrove root communities in Jobos Bay show enormous variations in the species composition and biomass. The reasons for this are by and 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 #1 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 the 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 was stopped, this area was anoxic on the bottom and producing HS 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 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 and well oxygenated. There was a weak southerly current passing by the station. At times of strong winds, water was silty. Water temperatures rose up to 31 °C in summer. Water at this station was 0.7 meters deep and the sediments were 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 polyethylene bags and transported into the laboratory in an ice chest. In the laboratory, the roots were cut into 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. ---Page Break--- ---Page Break--- PREPARATION OF SAMPLES FOR ANALYSIS 405 ---Page Break--- ---Page Break--- 406 PREPARATION OF BIOLOGICAL SAMPLES FOR AAS Grind the dried sample to a fine powder. Weigh out about 2 g of the sample in a 125 ml Erlenmeyer. Add drop by drop about 25 ml of aqua regia. Place on the hot plate, digest for about 20 minutes at very low heat. Bring to near dryness. Dissolve with double distilled water (DDW). Filter through pre-washed glass filters. Dilute with MDW to 50 ml. Put in screw cap plastic bottles. Pipette out three 17 ml aliquots into small plastic bottles. Add proper standards of different concentrations of each element to each one. (Standard addition technique)

Run at AAS, by plotting each sample on the graph, find out concentrations of the samples. Report the result in milligrams per gram. ---Page Break--- 407 BIOLOGICAL SAMPLE COLLECTION AND PREPARATION FOR TRACE ELEMENT, NUTRIENT, AND CHIN 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. Collected from three habitats: the coral reef, seagrass 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 seawater 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 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 ---Page Break --- 408 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 gram subsamples were dissolved for trace element analysis and one gram subsamples were used for CIN 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. ---Page Break--- ---Page Break--- 409 TREATMENT OF WATER AND BIOLOGICAL SAMPLES FOR TRACE ELEMENT AND NUTRIENT ANALYSIS Water: Water samples should be filtered with 0.45 µm filters as soon as possible after collecting. After 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 requires 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(III) to pre-concentrate Na, Mg, Co, Cu, Ni, Pb, Zn, Cd, Cr, Ca, and Sr for analysis by atomic absorption spectroscopy. Biological Samples: After collecting, all specimens are

cleaned of silt and dirt, specimens of the same species are 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 lipid analysis. Dried samples are cooled in a desiccator, 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 the aqua regia wet digestion 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 spectrophotometry. ---Page Break--- ---Page Break--- 410 LABORATORY METHODS ---Page Break--- ---Page Break--- 2) 3) 4) 8) 6) ” CLEANING GLASSWARE Rinse out all biological or chemical matter with tap water. Wash using cleaner provided. Rinse in tap water. If biological material adheres to glassware, soak in NaOH solution. Rinse. Rinse

glassware with 6N HCl. Rinse two times with distilled water. Dry glassware in low-heat oven. ---Page Break--- 42 LAB PREPARATION OF WATER SAMPLES If the water has not been pre-filtered, do so. Save for counting. Ferric Hydroxide Precipitation: a. Lower the pH of the seawater to 2.0. b. Add 10 ml of Ferric Chloride and mix well. c. Add slowly, 6N NH<sub>4</sub>OH 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. Put the precipitate in 250 ml plastic bottles. Centrifuge. g. Put the precipitate in 150 ml beakers and boil until nearly dry. Put pre-cut filters into 1N HCl and leave for 20 minutes. Wash filters with distilled water and let sit for 15 minutes. Filter what is left of the precipitate and put into 25 ml plastic bottles for Atomic Absorption. ---Page Break--- NAA for TRACE METALS IN SUSPENDED PARTICLES IN SEA WATER Cut to pieces a known weight of the filter and place the pieces in a 25 ml beaker. Add 5 ml conc. H<sub>2</sub>SO<sub>4</sub> and approximately 3 drops HNO<sub>3</sub>, cover beaker loosely. Heat slowly to a boil. Evaporate to dryness. Wash beaker out 3 times with 3 ml aliquots of distilled water. Place washings in a 10 ml polyethylene vial. Place in a vacuum desiccator and evaporate to dryness. Heat-seal vials under vacuum. Irradiate for 5 minutes and allow 3 minutes for decay. Count 400 seconds live-time (Al, S, Ca, Ti, V, Cu) then count 1000 seconds live-time starting 5 minutes after (Na, Mg, Cl, Mn, Br, In, I). The same sample, or another portion of the same air filter, processed as above, should then be irradiated for 2-3 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. Run blanks using "clean" filters and standard reagents. 413 ---Page Break--- ---Page Break--- and DETERMINATION OF REACTIVE PHOSPHORUS Introduction: All methods for phosphate in seawater rely on the formation of a phosphonolybdate.

complex and its subsequent reduction to highly colored blue compounds. Methods using stannous chloride as a reductant at room temperature have been favored 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 seawater 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: 0.3/n!2 µg-at/liter. Mean of n determinations + 2. Precision at the 0.3 µg-at/liter LEVEL The correct value lies in the range: Mean of n determinations + 0.02/n!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.

---Page Break--- 415 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. 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 885 nm. Special Apparatus and Equipment 130-1 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 was sealed in either quartz ampoules or in medical-grade polyethylene tubing. A number (10-20) of samples with appropriate standards were packaged in polyethylene containers and irradiated in a TRIGA reactor. An integrated flux of about  $10^{18}$  n/cm<sup>2</sup> 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 31 Ge (Li) detector. The analyzer was calibrated using radioactive standards. Three absorbers, cadmium sheets each about 1 cm in thickness, were placed between the sample and the detector to reduce the low energy contribution and Bremsstrahlung. 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 <sup>28</sup>Ni (n,p) <sup>28</sup>Co reaction and the thermal flux from the <sup>59</sup>Co (n,y) <sup>60</sup>Co reaction. Inorganic standards were included: Fe-55, Co-60, 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 380 $\mu$ , 300 $\mu$ , 202 $\mu$ , and 60 $\mu$ , pulled behind 13 to 17 feet dories for 15 to 30 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 380 $\mu$  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 60 mesh 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 202  $\mu$ m mesh net, animals (and incidental trash, phyto- and manoplankton) transferred to bottles that were placed, without preservative, into an ice chest. Wet weights were determined as explained in the following. Phytoplankton and manoplankton were sampled by using 2-quart buckets to fill a 45-gallon cubitainer. This was then first filtered through a 60  $\mu$ m mesh sieve, with frequent washing off of captured material to eliminate clogging, to separate phytoplankton and then filtered through 0.45  $\mu$ m membrane filters to separate manoplankton. 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 subjected 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 (65  $\mu\text{m}$  and 200  $\mu\text{m}$  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.) Samples 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 the plankton sample. 3.) Collected plankton should be put into a large plastic container. Then add 2 L of fresh seawater (Take fresh seawater from the front or sides of the boat). 4.) Filter plankton through a funnel fixed with the same mesh size filter as the tow, using low vacuum suction (to avoid breaking cells of plankton). 5.) After filtering, put the plankton sample into small plastic bags and heat seal to avoid contamination. Put the plastic bag filled with the plankton sample in plastic jars. The opening of the jars should be the same size as the rest of the container. 7.) Freeze the sample immediately. 4g ---Page Break---

NITRATE AND NITRITE IN SEA WATER The procedure used for the analysis of nitrate plus nitrite in seawater is described in Industrial Method 43-69W, Technicon Instruments Corporation, Tarrytown, New York 10591. Millipore filtered aged seawater, in place of synthetic seawater, was used in the preparation of standard solutions and as a system wash. Air scrubbers were used in the color reagent line. Instructions for the operation of the Auto Analyzer can be found in the General Operating Instruction manual with the instrument. ---Page Break---

421 THERMAL NEUTRON ACTIVATION ANALYSIS OF AIRBORNE PARTICULATE MATTER IN THE SOUTH COASTAL AREA OF PUERTO RICO By Tin Mo ---Page Break---

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422 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 from modern industry that might be injurious to the public's health. The presence of "smoke", sulfates, and fallout in the 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 product: 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 one 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 establish the conditions and procedures for airborne particulate matter by means of neutron activation analysis and Ge(II) techniques (Dans et al. 1971, Dam et al., 1970, Tuttle, Vogt, Parkinson, 1971).

Computer techniques for multinuclide gamma-ray spectrometry will be applied for data reduction (Dane et al., 1970). The measurement sensitivity for many induced nuclides should be more than adequate when the Puerto Rico Muegenr Center high flux Triga Mark reactor (1-3'x 10^m. eares sect) ---Page Break--- 423 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 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 the Environmental Science Division of Bendix Corporation) sampled approximately 12,260 cubic meters of air through a 1.27 cm<sup>2</sup> 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. ---Page Break--- 424

**PREPARATION FOR IRRADIATION** The procedure to be followed for the 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 is given below.

1. Using plastic gloves and a clean glass slide (or a sharp Teflon or polyethylene knife), tear off 4 pieces of paper of 1 cm<sup>2</sup> 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 desiccator and weigh. Roll up and put inside a 1 cc polyethylene snap-top 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. Cut off five 1 cm 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 mg/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 desiccator. Heat seal under vacuum each sample inside a 1 cc polyethylene snap-top irradiation vessel.

**IRRADIATION AND COUNTING PROCEDURES** Since some of the induced nuclides like <sup>52</sup>V have "short" half-lives, the samples would be irradiated for a period of 1-2 minutes in 1.5 x 10<sup>13</sup> cm<sup>-2</sup> sec<sup>-1</sup> 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 In standard wire will be used as a flux monitor. This 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 nuclide about 3 minutes means of the Canberra (Ge(I)) detector coupled to a 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 long-lived nuclides. For the long irradiation, all samples are in polyethylenes 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,  $^{60}\text{Ni} (n, p) ^{60}\text{Co}$ . The ratio of thermal to fast neutron flux will be determined at both irradiation sites using the reactions  $^3\text{He} (n, p) ^3\text{He}$  and  $^{99}\text{S} (n, p) ^{99}\text{S}$ . Interferences by threshold reactions will be checked experimentally. ---Page Break--- 426 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 judgment should still be involved 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. ---Page Break--- 427 REFERENCES Dams, R, et al 1971. Nondestructive multielement neutron activation analysis of air pollution particulates. Nuclear Methods in Environmental Research. pp. 6 — 15.

Proceedings of American Nuclear Society Topical Meeting, August 23–24 (1971). Dams, R. et al. 1970. Nondestructive neutron activation analysis of air pollution particulates. Anal. Chem. 42: pp. 861-867. Tuttle, R., Fey, J., Ry Vogt, and J. P. Parkinson 1971. Neutron activation analysis of trace elements in airborne particulates. Nuclear Techniques in Environmental Pollution. pp. 119-137. Vienna, TABA. ---Page Break--- 428 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 seawater which contains about 1 µg chlorophyll a. Filter (Note b) through a filter (Note c) covered by a layer of  $\text{MgCO}_3$  (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 for 1 min at about 500 Pa. 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 4000-8000 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 a ceramic mortar and pestle with some quantity of distilled water. Wash mortar

and pestle with acetone so final solution is 80% acetone. Keep 10 min in the dark at room temperature then centrifuge for 10 min. Pour off supernatant and read absorption on a Beckman DU spectrophotometer. Re-extract precipitate with acetone to determine efficiency ---Page Break--- 429 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 bandwidth of 30 nm or less, and cells with a light path of 4-10 cm (Note i). Read the extinction (optical density, absorbance) at 750 nm (Note j), 663 nm, 645 nm, and 630 nm against a 90% acetone blank. Calculation: Subtract the extinction at 750 nm from the extinctions at 663 nm, 645 nm, and 630 nm. Divide the answers by the light path of the cells in centimeters. These corrected extinctions are F and E, the concentrations of chlorophylls. 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 chlorophyll in the seawater is obtained as  $\mu\text{g/liter}$  ( $\text{mg/m}^3$ ). NOTES: (a) The amount of chlorophyll a should be less than 10  $\mu\text{g}$ ; 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  $\mu\text{m}$  pore size); the filter should be 30-60 mm in diameter. If these filters clog with inorganic detritus, use Schleicher & Schuell 575. (d) Add about 10 mg  $\text{MgCO}_3$  to the filter surface, either as 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, (3) If the 7500 A reading is greater than 0.005/em Light path, reduce the turbidity as in Note g. ---Page Break--- 431 TRACE METALS AND MAJOR

#### CATIONS IX 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: ---Page Break--- 432 1. Grind to a fine powder. Weigh out a one gram sample, record weight to the nearest ten-thousandth place. Dissolve in a 50 ml beaker containing aqua regia (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 percent standard deviation of identically prepared samples: Element Detection Limit - Deviation ca 0.026 ppm 5 ppm level cu 0.208 50 ppm level Fe 0.4 300 ppm level Ni 0.23 20 ppm level Zn 0.02 300 ppm level co 0.118 10 ppm level Mathematical Calculation: 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:  $(eR = m/er. (ppt) P = \text{Readings from standard curve } B = \text{Blank } V = \text{Volume of the dissolved } W = \text{Weight of sample}$  ---Page Break--- 433 The standards are currently made from inorganic salts. 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. For ---Page Break--- 434

HS £000" Loo" S00; L\$ 800, RTO 89EO" RL", TSZ"S, EL50" 6z007, aK 41000; COTO "S00; 0z00"«L\_— 800" XO OTME" NEY" MIRO" 9200" as C0004. 0600" 0500; \$200%, 0900% \$600; <elO; sot; Uz"Z\_~—Ttoy zB}, C00; BY a sd aH > mm "sauaus]> 3800 307 3809 94 02 panoad sen eyS0x eMby \*SdOHLaR TALivUVaTE XTS ONTSN (244) suorZveuNEONOD 1 nav ---Page Break--- ---Page Break--- 435 PROCEDURE. FOR ESTIMATING DISSOLVED OXYGEN 5 ML WINKLER METHOD Introductions '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:  $1 + 2Hn(OH) 2 2Mn (OH) 2 + 0 + 1/2 O2 = 2Mn (OH) 2MnCl2 + 4NaOH = 4Ni 2Mn (OH) + 2KI + GUICL = 212 + 2KCL + 6H2O + 1$  '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. ipnent\_and Reagents Reaction syringe - 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 covering it with a piece of capillary glass. The titration should be done on a white background with fluorescent lighting. Reagents - 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<sub>3</sub> and dissolve in 1 liter of distilled water to make a 0.035N solution for standardizing the thiosulfate. Fill a 10 ml burette with the diluted thiosulfate. Pipette accurately 2.0 ml of KIO<sub>3</sub> into the titration vessel and add 1.0 ml of 1% KI. Add 5 drops of concentrated H<sub>3</sub>PO<sub>4</sub> and 2 drops of starch and titrate. Repeat three times. Calculate the normality of the thiosulfate as follows:  $xv = xv \text{ KIO}_3 \text{ KIO}_3 \text{ Na}_2\text{S}_2\text{O}_3 \text{ Na}_2\text{S}_2\text{O}_3 0.05 = N_x$  Note: N/100 Sodium thiosulfate is now commercially available as a standard. 2. MnCl<sub>2</sub> - 40 g/100 ml distilled water. 3. Alkaline Iodide - 32 g NaOH and 10 g KI to 100 ml distilled water. 4. KI - 1.0 g to 100 ml distilled water. 5.

Starch indicator - 1 g is added to 100 ml distilled water and heated slowly to 190° C. Cool and add 0.1 g of salicylic acid. 6. H<sub>2</sub>SO<sub>4</sub> - Concentrated reagent. 'Titration of Sample: 1. Using the 10 ml syringe with nozzle, fill the dead space carefully with MnCl<sub>2</sub>. 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. 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 sit for three minutes for oxygen absorption. 6. Draw in three to four times the dead space volume of concentrated H<sub>2</sub>SO<sub>4</sub>. 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. Rinse the 10 ml syringe thoroughly in tap water and distilled water. When the syringe is again rinsed with MnCl<sub>2</sub>, it is ready to use. ---Page Break---  $438 \text{ Opmi}/1 \text{ (STP)} = n.A, 5600 2A, 5600 n = \text{ml thiosulfate used in the titration}$   $A = \text{normality of thiosulfate}$   $V = \text{volume of the water sample titrated.}$  A correction should be applied for the dissolved oxygen in the reagents (MnCl<sub>2</sub> and the alkaline iodide). It is assumed to be about 3.4 ml O<sub>2</sub>/l. Notice 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.  $\text{Bar.} \times 0.209 \text{ (1000 } \mu) = \text{ml O}_2/1 760$  where Bar. is the barometric pressure and  $\mu$  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. ---Page Break--- 439 Reference: 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. ---Page Break--- ---Page Break--- aay STRONTIUM 89 AND 90 IN MILK AND IODINE - 131 IN MILK by Giiser G. Wood IODINE - 131 in Milk Apparatus: 1. 2.5 liter polyethylene annular counter containers. 1. 248 Trichloroacetic acid. 2. 124 Trichloroacetic acid. 3. 28 NaI Solution (20g AgNO<sub>3</sub>/liter water). 4. 24 AgNO<sub>3</sub> solution (20g AgNO<sub>3</sub>/liter water). Determination 1. Put 2 liters of the whole milk sample into a 5 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 an annular counter container. Add 1 liter water; mix and gamma count (C1). 5. To the remaining sample, add with stirring, 900 ml of 24% trichloroacetic acid solution, and 1 ml of 24 NaI and then 1 ml of 2 AgNO<sub>3</sub> solution. 6. Stir for 30 minutes. Allow the precipitate to settle. ---Page Break--- 4a 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. Transfer the liquid (filtrate and washings) to an annular counter container. Mix well, gamma count (C2). Calculation: The net counting rate of C2 = C1 - The counter efficiency is determined by adding a known standard to a free milk. Decay constant is 0.086 day. Half-life is 8.05 days. Acc A= Age! Reference: Harley, John H. 1967. Manual of Standard Procedures U.S.A.E.C. New York. ---Page Break--- 442 STRONTIUM

89 AND 90 IN MILK: A, By Ion Exchange Preservative: Immediately after the collection of a milk sample, a preservative, formaldehyde (about 3 ml of 37% formaldehyde solution per liter of milk) must be added. The sample must be refrigerated (at 32° - 34° F.) for at least two weeks to allow the Yttrium 90 daughter of Strontium 90 to reach equilibrium with its parent. Reagents Cation-Exchange resin: Dowex 50X-X8 (Na<sup>+</sup> 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 as Sr(NO<sub>3</sub>)<sub>2</sub>: 20 mg Sr<sup>2+</sup> per ml. Citrate Solution: 3N (pH 6.5). Apparatus Ion-exchange column: Dimensions are shown in 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. ---Page Break--- 3. Open stopcock to control flow rate at 1 ml/min. 4. Stop flow when just enough milk remains in the column to cover the resin. Discard effluent milk. 5. Put 300 ml of warm distilled water through the column (about 10 ml/min). 6. Discard the effluent water. Push the resin out of the column into a very small beaker or vial. Dry and gamma count. ---Page Break--- B. By Ashing: Apparatus: Analytical oven, Corningware dish, Muffle furnace. Procedure: 1. Put 2.5 kg evaporated on 5 kg fresh milk into the Corningware dish. ---Page Break--- 2. Dry in the oven at 100°C for 48 hours. Transfer the sample to a muffle furnace and raise the temperature slowly to 550°C. Ash at 550°C for 24 hours. Cool, weigh, and grind the ash to a fine powder. 5. Gamma count or 6. Dissolve in 1 ml of 6 N HNO<sub>3</sub>. 7. Dilute to 25 ml in a volumetric flask. 8. Run at Atomic Absorption. ---Page Break--- ---Page Break--- APPENDIX ---Page Break--- ---Page Break--- MATHEMATICAL SIMULATION OF THERMAL PLUMES ---Page Break--- ---Page Break--- Introductio

material in Appendix C, consisting of two parts, represents a termination section 11{-0-1"}b. (The Blane. Efficient System-Heat environmental influences, pp. 64-68) 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. ---Page Break--- ---Page Break--- 448 CALCULATIONS FOR TABLES III-2 AND III-3 of AGUIRRE POWER PLANT COMPLEX ENVIRONMENTAL REPORT ---Page Break--- ---Page Break--- 449 Basic Data and Unit Conversion: a) From p. 62, Ref. [1]: Flow Condenser Excess Temp. Power Fossil:  $Q_e = 226,000 \text{ gpm}$   $e_g = 18.74^\circ\text{F}$   $P_g = 860 \text{ Mne}$  Nuclear:  $Q_y = 555,000 \text{ gpm}$   $e_n = 14.80^\circ\text{F}$   $P_y = 600 \text{ HNE}$  b) From pp. 3204 & 3209, Ref. [6]: 1 US gal. = 0.13368 ft<sup>3</sup> Acre = 4.3560 x 10<sup>■</sup> ft<sup>2</sup> c) Converted Flow Data and Approximation Fossil:  $Q = 226,000 \text{ gpm} = 503.528 \text{ ft}^3/\text{sec} \sim 503.5 \text{ cfs}$  Nuclear:  $Q_n = 555,000 \text{ gpm} = 1256.54 \text{ ft}^3/\text{sec} \sim 1256.5 \text{ cfs}$  Equations for Computation of Table II Let  $N_g = \text{Number of Fossil Plants}$   $N_y = \text{Number of Nuclear Plants}$  a) Power Production  $P = N_e + N_y$  b) Flow Rate  $Q_{rot} = Q_e$

$N_e + Q_n + \text{©) Condenser Excess Temperature Factor}^{\text{TM}}$  ( $c_e = O_f + N_F * C_{en} = Q_y + 4$ ) Discharge Nozzle Dimensions (Triangular)  $l_o * \text{exit velocity}$  ---Page Break--- 450  $h_g = \text{exit depth}$   $b_g * \text{exit width}$  cc) "Normalized" Nozzle For equal area and centroid, equivalent rectangle defined by Recomputed Values for Table III-2: a) Data  $Q_e = 50 \text{ Scfs}$   $P_p = 460 \text{ NNe}$   $c_g = 18.74^\circ\text{F}$   $Q_n = 1250 \text{ cfs}$   $P_y *$   $GOONK_e = O_{cg} = 14.80^\circ\text{F}$   $U_g = 6 \text{ ft/sec}$  b) Table Values:  $N_e | x_n | P_{eot} | Q_{tr} | \text{Sector} | \text{Triangle} | \text{Normalized uve} \} \text{ cfs} | cr | [bo | bo | bs | hg | i | re | fee | foe | te | 1 | 0 | 400 | sos | 18.74 | 16.83 | 10 | 12.62 | 6.67 | 920 | roto | 18.74 | 33.67 | 10 | 25.25 | 6.67 | 2 | 1 | 1520 | 2260 | 16.56 | 37.67 | 20 | 28.25 | 13.33 | (2 | 2 | fave | sie | 15.98 | 6.50 | 20 | 6.33 | 13.33$  ---Page Break--- 41 Equations for Computation of Table 111-3: From Ref. (1), [2], [5]:  $l_{ey} = o_e \text{ Golty} = (0/0,)^2 \text{ by} = 6 \text{ be} - 2 \text{ Ax} 0.215 62 \text{ NOTE} + \text{Excess temperature at discharge orifice. Recomputed Values for Table III-3: NOTE: Assumption of no cooling in discharge canal } 9 = O_{ctot}, \text{ is made. For cooling in canal and resulting changes in Table III-3, see items 6, and 8. } Proe | 460 \text{ Mite } 920 \text{ Mie } 1520 \text{ MWe } 2120 \text{ Mie } 0g | 18.74^\circ\text{F } 18.78^\circ\text{F } 16.56^\circ\text{F } 15.93^\circ\text{F } bs | 12.62 \text{ ft } 25.25 \text{ ft } 28.25 \text{ ft } 43.88 \text{ ft } e | [co | ae | fo | Ao | co | Ae | Re | ce | ee | acres | 12 | as | [0.17 | 500] 0.07 | 323] 0.31] 605] 1.06 \text{ to } | 266 | 0.35] 532] 1.40] 465] 1.07] 668] 2.20 | 8 | ais | oes] ss] s.ar] 726] 2.60] 1944] 5.38 \text{ © } | 739 | 2.69] 1478] 10.78 | 1291 | 8.23 | 1856] 17.00 | 4 | 1602 | 13.63 | 3325] 54.56 | 2905 | 41.66 | 4176] 86.06 \text{ Equations and Parameters for Surface Cooling in } ---Page Break--- a) \text{ » } ^\circ \text{ a } 482 \text{ Equation for temperature change - Ref. [2]: } no = uae \text{ Por } O_e - 80 \text{ canal Area } A - \text{ Ref. [1], pp 62, 63: } L = 7900 \text{ ft, } w = 156.5 \text{ ft, } A = 1.24 \times 10^8 \text{ ft}^2 \text{ Surface Heat Loss Coefficient } w_i \text{ From Ref. [4] for wind } = 12 \text{ mph dew pt. } = 70^\circ\text{F water surface temp. } = 80^\circ\text{F } 3 \text{ ___ Btw. } v_y 2 2.1991 \times 1073 \text{ Eze See ii From Ref. [5] for wind } = 10 \text{ mph water surface temp. } = 80^\circ\text{F excess temperature } = 18^\circ\text{F uz } \text{© } 2.5361 \times 1073 \text{ Btu } 2^\circ 2 \text{ Fer see iii For computations}$

use average value  $e_{lope} = u_e \times 1073 3 \text{ a Bt we } E(u_y + u_g) \# 2.3676 \times 10^{32} 2.4 \times 10^5 \text{ FEE GES leat capacity of water - Ref. [4]: } \text{ » } 6a \text{ BE ccs } 64 \text{ Fever } ---Page Break--- 453, \text{ Surface Cooling in Car Xen Prot } Q_{tot} = e_{toe} = n 8 1 0 460 \text{ sos, } t_{878} @ \text{ tao } 20 920101878 \text{ ot } 2 1 1520 2260 16.56 0.38 16.22 2 2 21205510 t_{5.93} \text{ ott } t_{5.72} \text{ Modified Values for Table 111-5: Prot } \text{ "tne } 460 920 1520 220 \text{ oF } 1.01 17.88 16.22 1s.72 \text{ bg tt } 12.62 25.25 28.25 43.08 \text{ le tortt } | \text{Agracres} | co | Ao | to | Ae | to do loa tsz_ | 0.11 | 366] 0.56! st0] 0.47] 452) 1.01 | 0 219 | o.2\phi | ase] 1.16) eas | 0.98] 651] 2.09 5 sz | ose | 757] 2.83, 697] 2.40 1017] 5.10 6 609 1.83 1345 | 8.93 1239 | 7.57 | 1807 | 16.12 loa taco | 9.35 | sner [asses a7er | ae.se | anes | arse i L Equations for Plume Distortion - Ref. [3; fect ge a4 Frere t Ben q wet). BER m-yORery ---Page Break--- 454 10. Plume Distortion: bata: Exit velocity  $u_e = 6$$

ft/sec current:  $0.5 \text{ ft/sec}$  at  $45^\circ$ , consequently  $b = 0.5 \cos 45^\circ = 0.354$   $U = 0.5 \cos 45^\circ = 0.354$   $V_v = 0.5 \sin 45^\circ = 0.354$ . WE Values of  $b$  and  $U$  correspond to those given in items 5 and 8. 3) Values corresponding to item 8 (no canal cooling) | Feoe | 460 wwe | 920 wwe | 1520 wwe } 2120 Me fos | taser | 25.25 | e.2s | 43.88 | g | 1.74 18.78 16.56 | 15.93 o feel ael e [a] ela } ela jaz! ae] 1s | sos] 26 | sea] 21] 493] 29 | 8) ase) an oro | 79] 788] 62] 1131] 87 92/1662 | 184 | 1434) 143 | 2055 | 199 so7 3040 | 615 | 5380! 476 | 4835 | 659 ---Page Break--- 455 b) Values corresponding to item 8 (with canal surface cooling) Prot | 460 Me 920 MWe | 1520 MWe | 2120 MWe bs 12.62 25.25 28.25 43.88 & 17.01 17.88 16.56 15.72 2 ela & a = a ela 12} 162] 10} 359} 23] 330 | 20 | aso] 28 to | 235} 16] sar} sz] 47a | 32 | 696] 45 8) 372] 30} 826 | 69} 756 | so | i101) 84 6 | 678} 69] 1505 | 160] 1374] 135 | 1998 | 191 4 | 1599} 230} ssez | 535 | 3234 | 447 | 4699 | 633 | ---Page Break--- 456 Aguirre Power Plant Complex Environmental Report - Puerto Rico Water Resources Authority, Report No. WRA E.S., -8 (1972) April 12, 1971 Progress Report - Appendix E, Puerto Rico Nuclear

Center Kovarna - Distortion of Plume Centerline, Puerto Rico Nuclear Center Note (Nov. 1972) Harleman and Stolzenbach - "Preliminary Investigation of Thermal Effects in the Bahia de Jobos..." Report to Jackson and Moreland (October 23, 1970) Pritchard - "Design and Siting Criteria for Once-Through Cooling Systems". Chesapeake Bay Institute. Page No. 26 (1971) Handbook of Chemistry and Physics (43rd Ed.) ---Page Break--- 457 I. Basic Jet Model: The basic non-dimensional jet model is defined by  $B_j$ . (16 of the  $Y$  Fae Ge) debs (Eley) »  $E_v = 6b, 3 B_{bey} a$  This variation of width leads to the velocity distribution  $u_m u_y (E_y/E)^{1/2} @ L_f Q_0 48$  the discharge rate from the orifice and  $Q(t)$  the flow across a section of the jet, then  $@ = a CEE)? @$  and the entrainment flow is  $G_e = 2 - =a [erp] ro$ ) Finally, defining  $O_5 =$  orifice excess temperature  $\% @ =$  entrained water excess temperature  $@ =$  excess temperature in the jet at  $\text{£}9$  one obtains  $F_{ol} e9f 2 )$  6. ---Page Break--- 458 11, Rate of Entrainment - Two Fossil Plants Assume that entrainment occurs over the entire length of the plume (approximately 500 ft) until it exits from the favos. For two fossil plants with a discharge rate  $\&, = 1010. \text{ ft}^3/\text{sec}$  and a triangular exit orifice of width  $= 6bg = 6(3bo)e \text{ isi. ft we no} le (e/ey)!/2-1] = 1010 [7sso0 y1/2 ae = gfiereo\text{¥} a] 200 (geese so7s \text{ft}^8/\text{sec}$ . This compares well with the natural flow of approximately  $0 \text{ ft}^3/\text{sec}$  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  $2538 \text{ ft}^3/\text{sec}$  and  $3100$ ). More to the point, the momentum jet model does not depend on ambient cross flow for entrainment. The question is rather how much water (i.e.,  $2538 \text{ ft}^4/\text{sec}$ ) 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  $1250 \text{ mi}^2$

of the Boca del Infierno  $1100 \text{ m}^2$  giving a total area of approximately  $25300 \text{ ft}^2$ . The induced velocity is therefore  $u = 1/299 = 2538 - 0.1 \text{ ft/sec}$ . A  $25300$  ---Page Break --- 459 III. Effect of Entrained Excess Temperatures: If the entrained water is not at ambient temperature, but has an excess temperature of  $9$ , the centerline isotherm distance is given by Eq. (5). For the case of the two fossil plants and the  $4^\circ\text{F}$  excess temperature isotherms  $151.5 \text{ ft}, 6, = 17.9^\circ\text{F}, oe aR$ , the effect of  $6$ , is illustrated below:  $ba Ay \text{ ft acres } 3034 45 3745, 68 4808 a4 6520 210 9576 453 15970 1258 35657 5585 125673 77953$  NOTE: The values given above are computed on the basis of momentum jet only. Surface cooling and diffusion are neglected. ---Page Break --- 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 that affects only is of interest. At Peet, the flow rate  $Q_0$  is partially reentrained, the reentrained portion being  $dz$ . Reentrainment is assumed to occur over the section Eicest and complete at  $Rho$ . The retained water with ambient is

also assumed. If the parameter  $\theta$  is defined as  $B_6 y / b y$  (6), then  $Q_1$  and  $Q_2$  are obtained from Eq. (3).  $O_y = ACE ME y / 2 = Q_0 81/2 CE, / E D^4 V_p = Q_0 (EQ/E, I! ? a)$  Since there is no reentrainment on c,sCs, the excess temperature  $\theta$ ; becomes  $1 \theta y, eye = (by/E,) 1/2 (8) \theta 1 y^2$  For total mixing in the jet  $28) = 8] + e282 (9)$  and for total mixing of reentrained water  $er\%e7 \sim 28292 1 F (yz) = 0092 ao) ---Page Break --- 461$  Substitution of Eq. (10) into (9) gives an and finally, use of (7) and (8) yields  $= 8 (ey\W/2 az | 27 8 3)$  Note that the temperature  $\theta$  is independent of the parameter  $\theta$ , that is of the ratio  $\theta, / 2, .$  This is a natural consequence of the assumed total mixing. The temperature distribution in the plume is, however, dependent on  $B y$ . The parameters  $a$  and  $g$  are not independent, since for steady state it is necessary that  $992 \theta oz = 9-0) as)$  which gives the restriction as  $1-8/2 aay$  and

I summarize results for the case of two fossil 't Aguirre with the following values of the parameters  $b y + 151.5 \text{ ft.}, \theta = 5500 \text{ ee.}, \theta = 17.90 \text{ } ^\circ\text{F}$ . Table I shows the variation of  $f_j, \theta$ , and  $a$  max with  $\theta$ . Table II gives the variation of  $\theta$ ) with  $a$ . It should be noted that the present approximation does not include surface cooling and will necessarily overestimate  $a$ . 2 ---Page Break--- Reference Pritchard, - "Design and Cooling Systems." 26c (1971) Siting Criteria for Once-Through Chesapeake Bay Institute Paper No. 462 ---Page Break--- ---Page Break--- ---Page Break--- TABLE - I TABLE - II = VSS v 2 \*Fli7.o7 | iiss | s.94 | 3.96 | 3.30 | 2.97 468 ---Page Break--- ---Page Break--- Notice "The report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission or any of its employees, nor any of the contractors subcontractors, or employees, makes any warranty, express or implied, or assumes any responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights." ---Page Break--- ---Page Break---