PRNC ~ 189 PUERTO RICO NUCLEAR CENTER PUNTA VERRACO ENVIRONMENTAL STUDIES Prepared for the Puerto Rico Water Resources Authority By the Staff of Puerto Rico Nuclear Center of the University of Puerto Rico June 1, 1975 OPERATED BY UNIVERSITY OF PUERTO RICO UNDER CONTRACT NO. (40:1)1838 POR US ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION ---Page Break--- ---Page Break--- PUNTA VERRACO ENVIRONMENTAL STUDIES by E.D. Wood, M.J. Youngbluth, P. Yoshioka and M. Canoy ---Page Break--- PREFACE This report stems from investigations carried out by the Puerto Rico Nuclear Center. The studies were designed to provide data upon which to judge the suitability of a site for the construction of power generating facilities and to allow the determination of the impact of such construction and operation upon the environment. The report represents the combined effort of the scientists, technicians, and support staff of the Site Selection Survey Project. The authors who contributed to the Punta Verraco Site Selection Survey are: E.D. Wood, Project Leader Physical, Chemical and Geological Parameters Marsh J. Youngbluth Zooplankton Studies Paul Yoshioka Benthic Invertebrates and Fish Studies Michael J. Canoy Plant Associations Report Coordinator E.D. Wood Technical Editor Forne Galantai Project Secretary Pauline Ortega de Cabassa Data Processing: Rosa Asencio ---Page Break--- TABLE OF CONTENTS ---Page Break--- ---Page Break--- 1.1 INTRODUCTION ‘The Puerto Rico Nuclear Center of the University of Puerto Rico has been under contract to the Puerto Rico Water Resources Authority since 1972 to conduct site selection surveys and environmental research studies of seven coastal sites. Experience gained from these investigations will add to the knowledge about these areas, and provide useful data which will aid in the assessment of the desirability and practicability of locating power generating plants on one or more of these sites. Puerto Rico Nuclear Center scientists have studied the physical, chemical and geological parameters of the sites, and the ecological parameters of zooplankton, benthic invertebrate and fish communities. Plant associations, except for the Cabo Rojo Matform site, have been included. The sites chosen for study were: Tortuguero Bay, Punta Manati, Punta Higuero, Cabo Rojo Platform, Punta Verraco and Cabo Mala Pascua (see Figure T.1-FI). The seventh site, Barrio Islote, was studied and reported under a separate contract. The reports in order of their dates of completion are: ‘Tortuguero Bay Environmental Studies April 1, 1975 Punta Manati Environmental Studies April 15, 1975 Punta Higuero Environmental Studies May 1, 1975 Cabo Rojo Matform Environmental Studies May 15, 1975 Previous studies of Punta Higuero, also referred to as “Rincon” or "the BONUS site," have been reported in "Punta Higuero Power Plant Environmental Studies 1975-1974" (Wood et al., 1974). This report covers the Punta Verraco study site. A final report of this series, to be entitled "Cabo Mala Pascua Environmental Studies," will be completed on June 15, 1975. ---Page Break--- 2.1 PHYSICAL AND CHEMICAL PARAMETERS AT PUNTA VERRACO by E.D. Wood 2.1.1 INTRODUCTION Punta Verraco is an inward curving point which forms the western margin of the entrance to Bahia de Guayanilla on the south coast of

Puerto Rico, as shown in Figure 2.1-F1 (Beck, 1972), connects to the mainland at its western end, is bounded on the north by a shallow arm of Bahia de Guayanilla, and its curving south and east-facing coast presents low (15-28) cliffs to the Caribbean Sea. The Puerto Rico Nuclear Center carried out environmental studies of this region over a period of three years, 1972-1974. The coastal and nearshore currents have been measured on several occasions. The factors affecting nearshore currents, such as winds, tides, bathymetry, and density structure of the water column, are discussed in the following sections.

2.1.2 TIDES

The tidal waves that affect the south coast of Puerto Rico have their amphidromic point in the eastern Caribbean Sea. The waves move in a counterclockwise direction (Anikouchine and Sternberg, 1973), that is, from east to west past Punta Verraco. The south coast tides are diurnal. Two waves exist, but one is dominant for about ten days, followed by about four days of neap tide conditions as one wave decreases in amplitude and the second wave builds. Then, the second wave is dominant for about ten days. Predicted tides for the south coast are shown in Figure 2.1-F2. These predictions were made from the National Oceanic Survey (1972). The tidal excursion is about 20-15 cm. The tidal plot in Figure 2.1-F2 is for the period May 9-11, 1972, covering a period of current measurements using dye markers discussed below.

2.1.3 CURRENTS

Ocean currents in the Caribbean Sea flow generally to the west northwest with velocities at times in excess of 1 knot (30.83 cm/sec). The current near the south coast of Puerto Rico rarely exceeds 0.5 knots (25 cm/sec).

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Pip. 21-1 Punta Verraco site with depth contour lines and hydrographic sampling at three stations.

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24 2 24 TIME HR 12 Q ° 3 ° 9 8 g 2 2 b-OwW Suw>w4 tides at Punta Vernaco covering one of the periods of

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The current pattern near Punta Verraco and Guayanilla Bay is affected by wind, tide, and industrial.

discharges. The wind is usually from the east (Wood, 1975a). The wind rises in the northeast in the morning, shifts to the southeast during the mid-day with velocities of about 7 m/sec (14 knots), then returns to northeast with reduced velocity by evening. Guayanilla Bay is shallow, especially in that region north of Punta Verraco. With a surface area of just over 3 km south to Station PVE-6A, and a depth of 20 cm, there would be a tidal exchange of 6.5×10^6 m^3 daily or about 5% of the volume of the bay. The combined effect, then, is for water along the coast to flow westward through Tallaboa Bay around Punta Guayanilla and then westward to the head of the bay north of Punta Verraco. The circulation continues as water flows out of the bay to the southwest along the southeast side of Punta Verraco. A large flow of water enters the Corco Refinery complex from Tallaboa Bay and flows out on the south side of Punta Guayanilla carrying thermal, chemical, and sediment wastes. The inner bay circulation is such that upwelling occurs near the intake of the power complex cooling system. The condenser discharge enters a pond on the east side of Guayanilla Bay, then flows out into the mid-bay region spreading over a wide area. The plume characteristics are reported in Wood (1975). "There are several sources of fresh water for the region which are significant seasonally. The Yauco River enters near the head of the bay and numerous ditches drain agricultural, industrial, and municipal wastes. The currents in the vicinity of Punta Guayanilla were measured on three occasions during this study. Observation was reported by Beck (1982) and is summarized briefly here. "Four Savonius rotor type current meters were employed to measure flows at the stations shown in figure 1-F3. The data collection period was about 24 hours at each site. The general trend of the flow is indicated by the vectors in Figure 2.1-F3." The surface currents tended to the southwest with subsurface currents more toward the southeast. The data are summarized in Table 2.1-17.

Dye drops with aerial photography were used May 10, 1972, to measure currents along the seaward side of Punta Verraco once in the morning and again in the afternoon. ---Page Break--- ---Page Break--- ‘Summation of current data at Punta Verraco December 19-20, 1971 STATION DEPTH (n) (hy. Drift) AND SPEED Pe, ° Wat 0.2 - 0.3 knots + 9-24 2 Following high tide, W.S.W at 0.2 - 0.3 knots; remainder of time, S.S.W. at less than 0.1 kt; S.S.M. at 2.10 = 0.2 knots; E.S.S. at 0.3 knots; S.E. at 0.4 knots following low tide; S.W. at 0.2 knots. 20-2 From high to low tide. 2 Following high tide, S.S.W. at 0.3 - 0.4 knots; remainder of time, S.W. at less than 0.1 kt; S.S.W. at 0.3 knots. Following high tide, S.W. at 0.2 knots; remainder of the time, S.W. at less than 0.1 knots. Pv-3 ° S.W. at 0.1 - 0.2 kts. S42 S.B. - E.S.S. at 0.2 knots. Dec. 21-22 A sustained with four hydro Products Model 502 Recorders. The morning drops shown in Figure 2.1-F4 occurred at low tide (Figure 2.1-F2) when the wind was from the east-southeast at 10 kt. The strongest current was at drop No. 7 near the head of the submarine canyon. The flow was to the southwest at 15 cm/sec (0.3 kt). Drop Nos. 3, 4, and 5 started to the southwest, then turned shoreward and finally northward into the bay at about 8 cm/sec (0.1 kt). Drop Nos. 1 and 2 moved around the tip of Punta Verraco into the inner bay region at about 10 cm/sec (0.2 kt). Drop No. 6 was placed in a small channel between Unitas and Guavaniila Reefs. It flowed to the northwest at about 10 cm/sec (0.2 kt), and then dispersed until it was no longer visible. ? ---Page Break--- ---Page Break--- Figure 2.1-F5 shows the afternoon drops which coincided with a rising tide (Figure 2.1-F1). All of the dye drops moved to the north or northwest except No. 7, which went southeast. Drops No. 6 and 7 indicated that an eddy may have existed in the region of Punta Ventana at that time. The current was only 5-8 cm/sec.

in the lee of the reefs, but was about 15 cm/sec going around the tip of Punta Verraco with the combined effect of the wind (from the southeast at 13 kt) and a flood current. While making the dye study on May 10, 1972, it was noticed that considerable oil and solid waste had accumulated in the half-moon bay (Ballena Bay) between Punta Vaquero and Punta Criolla west of Punta Verraco. There was concern that heated water may also be entering the bay. Therefore, another dye study was performed on the afternoon of May 28, 1972. Drops No. 1-4 were made along the shore, as shown in Figure 2:18, and followed for about one and a half hours before drops No. 5-8 were made. Drops No. 3, 7, and 8 flowed past the bay with no indication of entering. It seems that floating material would be carried into the bay especially during periods of strong wind, but that very little surface water actually went into the bay during this period. A study done by the Oceanographic Group, Department of Public Works (1971) showed similar current patterns in this region. Surface currents were to the northwest and deep currents varied with a strong tendency toward the southeast in the vicinity of the reefs. Near Punta Ventana, the surface currents were to the south-southwest with velocities of 8-12 cm/sec and were more variable with depth. The net deep flow was to the southwest. Velocities were 4 to 8 cm/sec. The limited current studies in the region of Punta Verraco indicate that currents in the lee of the reefs are weak and flow into Guayanilla Bay a significant portion of the time. However, currents to the west of the reef area, that is, from the region of the submarine canyon and Punta Ventana, are predominantly to the west with velocities of 8-15 cm/sec. Surface flows into the bay are balanced by deep water flow out. Much of the flow very near shore is from the inner bay as will be shown later in the chemistry section. Therefore, intake and discharge locations should be offshore at least 500 m with the discharge further to the west than

the intake. 2.1.4 BATHYMETRY The Puerto Rico Nuclear Center has undertaken no detailed bathymetry of the Punta Verraco site beyond that done during benthic and hydrographic sampling. The C&G Charts 902 and 928 (National Ocean Survey, 1972) are inadequate especially with regard to the definition of the shelf edge and deep water soundings south of Punta Verraco. Also, there are some discrepancies in the shallow regions caused by coral growth and shifting sediments. The contour lines shown in Figure 2.1-F1 and the depth profiles in Figure 2.1-F7 were drawn using depths shown in the above-mentioned charts and sonic depths obtained during hydrographic work. The region north of Punta Verraco is shallow with a mud bottom. It receives the discharge of the Yauco River and several agricultural drainage ditches. The basin also receives sediments carried in by wind-driven currents. A large basin makes up the central part of Guayanilla Bay immediately east of the tip of Punta Verraco providing anchorage for ocean-going ships that frequent the harbor. The basin leads to the sea through a channel between Punta Guayanilla to the east and the shallow reef area to the west. Two major reefs (Guayanilla and Unitas reefs) and a small island offer protection from the dominant wave and swell action to Punta Verraco. The channel between the reefs and Punta Verraco is shallow but does allow passage to small boats. A submarine canyon marks the abandoned course of the Yauco River just east of the reefs. The canyon starts very near shore (200-300 meters) and tends to the southeast dropping off to the depths between Stations PVE-4B and PVE-5A. The region west of the submarine canyon is generally free of outstanding features. The rugged coastline tends to the southwest past Punta Ventana and Punta Vaquero to Ballena Bay. The 10-meter contour line is about 1 kilometer from shore in this region. The shelf edge drops off very rapidly to about 400.

meters to 1 1/2 kilometers from shore along Punta Verraco as shown by the offset profiles in Figure 2.1-F7. Depths in excess of 300 meters are available about 5 kilometers south of Punta Verraco.

2.1.5 TEMPERATURE, SALINITY AND DENSITY
The physical parameters of temperature and salinity were measured at the Punta Verraco site on seven cruises covering four seasons (Table 2.1-T2).

TABLE 2.4-12 Schedule of hydrographic cruises to Punta Verraco
Winter Spring Summer Fall
PA-005 Dec. 19-29, 1973
PA-023
PA-028 - - Feb 20
May 21-22
PA-029
PA-002
PAR-046
PA-052 Feb 12
Apr 22
Aug 21

Nov 13

Results reported by Beck, 1975.

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7 Bottom profiles along the sampling transects of the Punta Verraco site. Vertical lines indicate relative positions of the hydrographic stations, GUAYAMILLA, GUAYANILLA BAY. VERTICAL EXAGGERATION.

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The hydrographic sampling stations are shown in Figure 2.1-F1; five transects were sampled on most cruises. The transects are nearly normal to the shoreline, each with three stations. The "A" stations were most shoreward, the "B" stations were in excess of 125 meters of water, and the most seaward stations ("C") were in excess of 325 meters. Fourteen depths were sampled on each transect. Temperatures were measured using deep-sea reversing thermometers with readings accurate to 0.003°C. Salinities were determined with an induction salinometer to an accuracy of ± 0.005%. The values are included in a report of hydrographic data for the south coast of Puerto Rico (Wood and Asencio 1975). These data were converted to standard depths and averaged by season and type of stations. The sampling, analytical, and data processing procedures are described in "A Manual for Hydrographic Cruises" (Wood 1975).

Temp: Temperatures were determined using reversing thermometers in pairs, or in triplicate when possible. Although only one temperature is shown on the computer print-out of the data (Wood and Asencio 1975) for each depth, these values are often the average of two or three.

thermometers. Most temperatures below 1.5 meters were measured using both "protected" and "unprotected" reversing thermometers. A thermometer depth, Iz, was then calculated for the sampling depths and correlated quite well with the calculated depth, Cz, obtained from the amount of hydroxide paid out, WZ, and the cosine of the wire angle. A comparison of some of these depths is shown in Figure 2.1-78. The data were averaged by a computer program which first interpolated between the depths sampled to provide temperatures (and other hydrographic parameters) at "standard depths." The averaged standard depth temperatures and salinities are plotted by season in Figure 2.1-F9. The diagonal lines indicate density as a function of depth. Depth is not shown on the plot, but generally increases in the lower right corner of the plot, as density increases with depth. Very little change is seen seasonally where density is greater than 25.5; however, a finite change can be seen in the lower densities (surface waters). The temperature increases between winter and summer, while salinity increases between fall and spring. The averaging for the depth profiles was done first for all stations by season (Figures 2.1-F10, 12, 14, and 16), then by type of station by season (Figures 2.1-F11, 13, 15, and 17). The tabulated data are in Appendix 2.14.

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PVE-C STATIONS

BN ° 100 200 300 (72)

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anna SRA Se Qmno 4 2 3 4 5 6 PO} pa-at P/1x10 PVE-1

Fig. 2.1-F10 Averaged hydrographic parameter (temperature and density) at the Ward depth in

meters for the winter season of 1973 at Punta Verraro.
---Page Break---
1 2 POR pg-at P1 x10 PVE-1 averaged by type of
---Page Break---
3 r4umo 300- a Qmno 1 4 2 3 4 5 6 PO} pa-at P1 x10 PVE-2
2ut-122_ Averaged hydrographic parameter depth profiles for the season of 1973 and 1974 at Punta Vers
19
---Page Break---
ee ee mio. 4 2 3 4 5 6 POA pa-at P1 x10 PVE-2
ri 1 month profiles of hydrology by type of
20
---Page Break---
3 xr4vmo SO ri O 3 4

5 6 ° PO} po at PIIXi0 PVE-3 Averages! hydrographic parameter depth profiles for the summer season of 1978 a ---Page Break--- 300 pm. 4 2 3 4 5 6 POY pg-at PN x10 PVE-3 graphic parameter a by type of ---Page Break--- S%eo 34 35 36 37 THC 416 3 20.0 22 eB 100 r pr E Pp tT 4 - nod m4 2004 4 ! 3004 ! ei min 0 1 2 3 4 5 6 POR pg-at P/XI0 PVE-4 Fig. 24-716 Averaged hydrographic parameter depth profiles for the fall season of 1974. 23 ---Page Break--- 300 oe QomiiO 4 2 3 4 5 6 POY pg-at PI! X10. PVE-4 Fig. 2uicf27 Depth profiles of hydrographic parameters averaged by type of station for the fall season of 197%, 24 ---Page Break--- A comparison of the averaged "C" station standard depth temperature data by season is shown in Figure 2.1-P1@ A sequence of events can be seen from this comparison. Surface temperatures were lowest in the winter (26.1°C). The deepest thermocline (100+m) occurred in the winter and is caused by cooling and deep mixing by winter storms. It persisted into the spring season. This mixing process tends to carry heat to the depths so that the highest temperatures between 100 and 200 meters occur during the winter and spring. This condition is part of a phenomenon one might call "seasonal stage." Little seasonal change was seen below 150 meters except that the fall temperatures were generally lower than the other seasons. There was a steady temperature decrease in the 100 to 120 meter depth interval between winter and fall. The thermocline during summer was 75 meters and in the fall was about 20 meters with a slight temperature inversion existing in the fall as surface cooling occurred. Surface temperatures were at a maximum in the summer (28.1°C). There was an average temperature range of about 1.7° between summer and winter in the nearshore surface water at Punta Verraco. Temperatures increase with distance from shore for all seasons except fall (Figures 2.1-F11, 13, 18 and 17). This increase is due mostly to the large quantities of waste heat discharged from the Corco Refinery complex.

the PRNRA power plants and to a lesser extent the industries dedicated on the north side of Guayanilla Bay (Wood, 1975). Some excess solar heating occurs in the shallow inner bay, but this is minor compared to the industrial contributions. Temperature depth profiles were obtained at all "c" Stations by lowering a bathythermograph to 300 meters. The BT traces are in Appendix 2.1. The sea surface temperatures at Punta Verraco were mapped seasonally by aerial infrared scanning (Kood, 1975). Considerable heated water approaches the eastern side of Punta Verraco from the PRWRA power plant discharges. However, the excess temperatures are usually reduced to less than 15°C by the time the water flows westward along the south side of Punta Verraco past Punta Ventana. Salinity Salinity, psu, is the total salt content of water expressed in parts per thousand. It is used along with temperature to typify ocean water masses. Low salinity usually occurs at the surface and indicates dilution by precipitation, runoff, or fresh water intrusions. High salinities are found in Sub-tropical regions and are the result of high rates of evaporation. The salinities at Punta Verraco were determined using an induction salinometer with the readings good to better than 0.0005 psu. The average seasonal salinity data are shown plotted against depth with the other hydrographic parameters in Figures 2.1-F10 through F17. In general, the salinities increased with depth to about 150 meters then decreased slightly. The layer of high salinity water with a maximum of about 56.9 psu was formed by evaporation in the sub-tropical North Atlantic Ocean. A comparison of the averaged "Cc" station data by season is shown in Figure 2.1-F19. The lowest surface salinities are found in the fall season coinciding with the end of the tropical rainy season.

The highest surface salinities occur in the spring after the winter-spring dry season. The salinity depth profiles are very similar, below 75 meters for all seasons except fall. A sharp pycnocline exists at about 50 meters during the fall where the salinity increases from about 34.3 to 36.7‰ between the depths of 25 and 100 meters. The salinity maximum is shallower for the fall season also. Little seasonal change was noticed below 150 meters where the salinity decreased from 30.8 to about 30.3‰ at 300 meters. Little difference was seen in surface salinities with distance from shore in the winter and summer. However, a slight decrease in surface salinity was seen in the spring due to evaporation in the shallow regions, and a prominent positive salinity gradient occurred in the fall as fresh water runoff diluted the nearshore waters. Water densities were calculated from temperature and salinity data and included with the other parameters as sigma-t, σt. Sigma-t is related to density at the temperature measured, θ, by the following relationship Hs (1) x 10^8 ny (Changes in sigma-t with depth are an indication of the stability of the water column. A small sigma-t gradient indicates a well-mixed or unstable zone, whereas a high gradient is indicative of a very stable portion of the water column. The surface layer usually has a very small density gradient because of wind-induced wave mixing. This layer varies from less than 50 meters in the summer to an excess of 100 meters in the winter. Sigma-t profiles are shown plotted with other parameters in Figures 2.1-F10 through F12. A comparison of the averaged seasonal sigma-t profiles is shown in Figure 2.1-F20. Sigma-t varies from 22.1 to 23.4 in the surface waters and is highest in the winter and spring months due principally to generally cooler surface. ---Page Break--- 3 ° 3 r4um9 200 300 1F SALINITY So 35 36 37 pve Spring 2 Summer 3 Fall 4 9. Averaged seasonal depth profiles of "C" station salinities at Points Varraco for 1973 and 1974. ---Page Break---

DENSITY 20, 22, 24, 26, 28 o+ 100 D € Pp T H m 200 300: Pir. fyenovline water density (sigma-t) profiles of "C" station data plotted by sea: for Punta Verraco, 1973 and 1974 ---Page Break--- temperatures in winter and higher salinities in the spring. The pycnocline occurs at about 125 meters in winter because of the deep storm mixing. The most stable water column occurs in the fall when surface water density decreases because of dilution and fairly warm surface temperatures. Sigma t at the surface decreases from winter through fall. Little seasonal change in density occurs below 150 meters; there is a slight increase in sigma-t with distance from shore for all seasons as shown in Figures 2.1-F11, 15, and to the winter, spring, and summer density gradients are due to high nearshore temperatures, and the fall season low nearshore density is due to low salinity water coming out of Guayanilla Bay. This type of density gradient contributes to a seaward flow. Both wind and the Coriolis effect then cause this flow to turn to the west. 2.2 CHEMISTRY 2.2.1 DISSOLVED OXYGEN amounts of dissolved oxygen, D.O., in the water off a Yerrace were determined by the Winkler titration method (Giefctland and Parsons, 1908) with the analyses usually performed (stated on shipboard within a few hours of sample collection. The titration values are generally good to better than ± 18. Dissolved oxygen data are included with the hydrographic data reported by Mood and Asencio (1978) in mL, mg/L, and % sat. Oxygen saturation is a function of both temperature and salinity. Since neither shift drastically in the tropics, little change in near-surface D.O. is expected nor was it seen. Averaged D.O. values in milliliters per liter are plotted with other hydrographic parameters in Figures 2.1-F10 through F17 by season and type of station. The highest values were in the winter season. Surface values were near saturation. A comparison of seasonal averaged values is shown in Figure 2.52. The oxygen minimum occurred at about 200 meters for all seasons except

spring When it was at about 160 meters. The lowest DO values were about 3.9 mg/L at 200 m during the winter season. Many "A" station D.O. values were only about 20% of saturation due to the high BOD and COD of the Guayanilla Bay waters. 2.2.2 NUTRIENTS Nutrients are important from two aspects. First, nutrients are generally low in the tropical Atlantic Ocean and Caribbean Sea surface waters and limit primary productivity. Second, the discharge of wastes from agricultural, municipal, or industrial sources may contain such high nutrient levels that they cause eutrophication and local ecological degradation. ---Page Break--- DISSOLVED OXYGEN mg/L 3 4 8 6 100 ° E P. H m 200. pve winter Spring Summer 300 Figure 2.2-F1 Averaged dissolved oxygen depth profiles by season at Punta Verraco for 1973 and 1974 ---Page Break--- Reactive phosphate can be determined quickly and accurately with the Murphy and Riley molybdate blue complex method (Strickland and Parsons, 1948) and is a good indicator of pollution. Limited number of nitrate analyses were performed on the waters off Punta Verraco. The tropical region around Puerto Rico is generally deficient in surface water nutrients, especially nitrate. Reactive silica is usually not regarded as a pollution problem. Reactive phosphate, the concentration of reactive phosphate was generally low (ca 0.05 µg-at. P/L) in the surface waters off Punta Verraco as seen by the averaged "C" station seasonal phosphate profiles shown in figure 2.2-F2. The phosphate values remained low with depth to near 100 meters before increasing to about 0.25 µg-at. P/L except for the winter season when the increase started at 100 meters and went to about 0.38 µg-at. P/L. There was very little difference in surface phosphate concentrations with distance from shore seen in the spring and summer. However, the winter and fall seasons saw high surface phosphate values nearshore (ca 0.13 µg-at. P/L). These anomalies coincide with low salinity (runoff) in the fall, but the phosphate source is not obvious for the winter.

Vitrate was determined by the cadmium-copper reduction method. A limited number of samples were taken for nitrate at Punta Yerraco for the summer and fall seasons. The concentration of nitrate was less than 1 µg-at. from the surface to about 75 meters in the summer, and less than 5 µg-at. in the fall, except for a surface value of nearly 2 µg-at. N/E. Nitrate values were higher in the fall than in the summer between 30 and 123 meters. Little seasonal difference existed below 125 meters. The concentration of nitrate increased from about 2 µg-at. N/E at 100 meters to over 18 µg-at. at 300 meters. The only anomalies observed were values of 6 µg-at. N/E at 9.20 at PYF 0A, with significance in the nitrate data of 2.88 at PVE-#8. High nitrate values were found in the nearshore stations in the fall: 6.0 µg-at. N/E at PVE-dA, AB, and OA, respectively. These coincided with high phosphate and low salinity values for these stations for the same season.

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REACTIVE PHOSPHATE µg-at. P/i

0 1 2 3 4 5 6 7 8 9 10; 0D 4 eG pf TY wood Mood a pve : ' Winter 1 j Spring 2 : | Summer 3 4

Fig. 2.2-F2 Averaged reactive phosphate depth profiles by season, 1973 and 1974, 35

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NITRATE µg-at. N/i

0 2 4 6 8 10 12 14 16 3 I4vmo 200 300 profiles for the summer and fall season of 1973

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GEOLOGICAL PARAMETERS AT PUNTA VERRACO by E.D. Wood

The geology of the Punta Verraco site was described in an earlier report (Keck, 1972). Portions of that report will be repeated here along with a brief description of the marine sediments. The major portion of Punta Verraco is composed of Tertiary Ponce Limestone, which forms the coastal cliffs (Grossman, 1963), rising abruptly 45-50 meters above the sea around the area where Punta Verraco joins the mainland (Figure 3.1-F1). The rugged coast is broken at two areas by lowlands of Quaternary deposits, the major one (Figure 7.1-B1) being a long abandoned valley of the Río Yauco (Grossman, 1963), which is now...

fronted by low sand dunes stabilized by coconut palms and various forms of ground-covering vegetation. This abandoned valley continues offshore as a submarine canyon having depths of 9 meters within 0.5 kilometers of the shore and 18 meters 1.5 kilometers of the shore (Figure 3.1-F1). However, to protect this channel from even the hose dunes that stayed above water during the flooding of 1928, the highest flood for which data is obtainable, when the flood diverted northeastward into Guayanilla Bay (Fields, 1971). The original diversion of the Rio Yauco from this channel (now long abandoned) is postulated to be due to the presence of a East-West trending strike fault, the San Francisco Fault, which must have occurred after the consolidation of the Ponce Limestone, which it offsets, but before the deposition of the undisturbed Quaternary alluvium which covers it (Grossman, 1963). This makes its age between three and twelve million years (according to the geologic time scale as compiled by Holmes, 1905). There are three general regions along the Punta Verraco site with respect to sediments. First, the shallow regions southward of the reefs out to the shelf edge are high-energy areas because of frequent wave action. Sediments here are coarse and sparse. Numerous attempts retrieved no sediments from the PVE-2A, 3A, or 5A stations. ---Page Break--- ---Page Break--- The second region is associated with the reefs. The sediments are coral sand and often in motion because of the wave action. Storms tend to build temporary islands of sand, especially landward of Unitas Reef. Sand sediments were seen from the air near the reefs and between the reefs and Punta Verraco. There may be considerable sand transport westward along the shore at times. The third type of sediment region is low energy. This type is protected from the effects of wave action and strong currents. The sediment in these areas is very fine and high in organic matter. Two such areas were sampled (PVE-5A and GA). Station PVE-4A is in the middle of the Yauco submarine.

Canyon and PVE-6A are in the main channel into Guayanilla Bay. The sediments from these two stations were air-dried and sieved for size distribution. The PVE-GA sediment was especially troublesome because of its tar-like texture. The results were plotted as cumulative weight percent and weight percent histograms in Figure 3.1-F2. The size analysis statistics are shown in Table 3.1-T1. Table 3 STATISTICS PVE-4A and PVE-6A. The mean size for the two sediments is very similar. However, as shown in Figure 3.1-F2, the standard deviations are quite different. The PVE-4A sediment contains about 17% of grains larger than 0.25 mm (2.6) while the PVE-6A sediment had only about 2.5% of its grains greater than 0.25 mm. Most of the region inside Guayanilla is in the low energy sediment area. Wind-swept currents do resuspend some of the fine sediments and carry them eventually to the southwest along the Punta Verraco shoreline where some of them settle in the Yauco submarine canyon. Most of these fine sediments were carried on down the beach to the west. ---Page Break--- io os} see! arg 2Goj-2 9 Histograms and cumulative weight percent plots of sediments at Stations PVE-4A and PVE-6A are Fig 38 ---Page Break--- at ZOOPLANKTON STUDIES 1975-1974 by Marsh J. Youngbluth INTRODUCTION The following report provides estimates of the abundance and density of zooplankton in the surface waters along the western portion of the south coast of Puerto Rico. These data form one part of an environmental survey conducted by the Puerto Rico Nuclear Center. All collections were gathered in an area adjacent to the region proposed for the siting of a future power plant. Samples were gathered on 7 days during 1978 and 1974—21 February, 22 May, 28 November, 1° February, 22 April, 21 August, and 13 November. 4.1.2 MATERIALS AND METHODS E 1d Proced Zooplankton were collected with a 1/2 meter diameter cylinder-cone shaped nylon net. This net was designed to reduce clogging error (Smith et al., 1968). Mesh size was 3 microns. The net was towed from a 17.

Foot skiff in a circular path through the upper 2 meters: The speed of the vessel ranged from 2 to 3 knots (determined with a Sims yacht speedometer). The duration of a tow was 10 minutes. After each tow, before the cod end was removed, the net was washed with seawater with the aid of a battery-driven pump (12 volt, Jabsco water-puppy). The catch was preserved in 4% seawater formalin buffered to pH 7.6. “All samples were gathered during the daylight hours. The volume of water filtered through the net was estimated with a flowmeter (TSK or General Oceanics Model 2030) suspended off-center in the mouth of the net. The volumes usually ranged from 100 to 150 m^3. The meters were calibrated every 2 months. Calibration factors fell within 8% of the mean. At each site, three tows were made in the area adjacent to the region where a power station may be located. Single tows were taken at the other stations. The regions sampled were chosen in such a way as to collect within and around the area where thermal alteration is likely to occur (Figure 4.1 FT). 39 ---Page Break--- Fig. 4.1-F1 Zooplankton stations at Punta V ---Page Break--- Laboratory Procedures Within 24 hours after samples were collected, the pH was checked and adjusted, if necessary, to 7.6. If a sample contained a noticeable conglomerate of phytoplankton or detritus, the zooplankton were separated from such material by gentle filtration through 20 µm mesh netting. Before estimates of biomass or numbers were made, all organisms larger than 1 cm, usually hydrozoan medusae, were removed. Biomass was calculated as wet volume (Ahstrom and Thraikitl 1962). This estimate is subject to considerable error and should be viewed only as a rough measure of standing stock. The measurements were reproducible but are undoubtedly biased toward higher than actual values by the variable proportion of interstitial water and detritus. The total number of organisms was estimated by volumetric subsampling with replacement (Brinton 1962). Three aliquots from each sample.

were counted. The abundance of major taxonomic groups of holoplankton and microplankton was determined from dilutions of 300 to 500 organisms. Copepods, usually the most numerous of the zooplankters, were identified to species. All biomass and enumeration data were standardized to a per cubic meter basis or multiple thereof. Data were initially reduced with hand calculators (Hewlett Packard Model 48) and more recently with a computer (PDP-11). See Appendix 4 for a listing of the program.

4.1.3 RESULTS

A total of 49 samples were collected from 5 stations (Figure 4.1-F1). The densities of several taxonomic groups of zooplankton at each station have been determined (Tables 4-1-T1-T0-17). These data are arranged to facilitate comparisons between sets of consecutive tows, nearshore tows, and offshore tows. Densities of total zooplankton differed more between catches from different areas than between consecutive samples from one area. This observation is summarized in Table 4-1-T1.

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Geib selects the volume of differences between the highest and lowest density in each period. Values for population dynamics are indicated as follows: 2m depth 1S 2.2 28.

Recreational Tow AB 26 1R4T ye Sbonore owe - ee fone om ur L6 1) Tows aa out tar |e as 82S the degree of variation between samples is expressed as a ratio formed by dividing the largest total number of zooplankton by the smallest within each set. The ratios are similar to those observed in other coastal regions around Puerto Rico (Youngbluth 1975). Another way of judging differences between samples is also presented (Table 4.1-T2). By calculating the variance between consecutive samples, the number of tows needed to detect various levels of difference was determined.

TABLE W172. (Stormed) from 1 outs of replicate DE vopliests tes (n) needed to determine in density i) Indicate bare a7 10 Feb 22 Apt "71 ang 13 Nov Station 2 2 : 2 2 2 3.46762 9.9320 9.72079 2.63569 2.9942 3.6054 9.78090 racRet .80082 3.29954 9.80875 2.65298 3.06165 3.39965 3.34635, 270057 2.75386 4.96473 4.72509

2.94968 3126126 2.96419 rit seo 2a a 2503 ase i 6 1 3 3 20 > i 1 1 4 > 1 i 1 1 2 Wyre (2) fe student's t for the 988 confidence Level (.f.=2), 22's the conple vor ianse haced on replicate tows, and dis the Ratiewitth of the cong idence interval desire 4 nidaiant /nidiay values. a2 ---Page Break--- These data indicate that a large number of replicate tows would he necessary to detect density differences at the St level. However, on the average, differences of 50% can be noted with only' tows. Differences of 70% of more my be revealed with a single tow. Density estimates larger than 208 or more were found within and between nearshore and off shore catches. the range of density values during a sampling period was usually two to four-fold. Seusonal changes in the average abundance of total zoo- Plankton were small, i.e., about 3 t0 SX (Table 41-13). The highest concentrations occurred in November each year. These larger densities, however, probably represent the range of variation anong tropical Zooalankton communities in the coastal waters wround Puerto Rico rather than recurrent sea- sonal pulses since the 95% confidence limits from each station overlap. TAR: 4.1273. Averujw denadty af all zooplankton collected ‘otal ooplankton/a® 1974 28 Now Feb 22 Apr 27 Aug 19 fov Range 863-190 woa-z6my wso-su7e [227-969 2a4-942 350-7185 890-309N Wo vow | sey guetta Mean 044 2528 suo 48027) te poss 42597 8 gun? gan The preceding fluctuations in density refer primarily fg Roleptanktonic organisms since they conposed, in most cases, (89,208 9€ the total zooplankton. Meropiankton were most abundant on 22 May 1975 and 13 November 1974. In proportion te holoplankton they were very numerous during 21 hupase 1994 uhen they formed over 30% of the total zooplankton. in two gccasions at Station 3, on 22 May 1973 and 22 April 1974 30 to 59% of the *ooplankton caught were meroplanktonic forms. {a both instances barnacle nauplii and caridean larvae were abundant, Fish exes were abundant in this area although they usually conposed less than

S¥ of the total zooplankton (Table 4.1-T4). The largest density, 352/m³, was observed at Station 5 on 28 November 1973. Fish eggs were most numerous on February 1, 1971, when they averaged 87/m³ and formed 20% of the total zooplankton. The largest densities were generally found at the offshore stations. Most of the eggs were round, measuring 1 to 2 mm in diameter. Oblong eggs were common. It is not known which groups of fish are represented by most of the sea luminescent fish eggs from the fine sands at Punta Verano. All groups tended to be more numerous in the night samples. The overall density increase was about 5 times the day level; zooplankton were 3X more numerous, and meroplankton about 2X. The bulk of the zooplankton were copepods. Decapod larvae and mysid nauplii dominated the meroplankton. A similarly large nocturnal increase in meroplankton was also noted in a series of diurnal samples gathered at the Tolote and Cabo Santa Pascua sites (Youngbluth 1974). Copepods formed 80 to 90% of the zooplankton community. A total of 3 species were identified. Time did not allow detailed study of species abundances at all stations. Consequently, one sample from Station 2 for each period was selected for analysis. The entire sample was scanned to form a species list and subsampled for quantitative analysis. Using these data, the species most numerous, those commonly observed, and others occasionally found are listed in Table 4.4-15. Species usually most numerous include: Siphonophora spp., T. gracilis, L. torquatus, O. app., and oblong tubinates (B. aculeatus, P. crassinostris, P. parvus). Species commonly present (observed in 8 or more sampling periods) include: Conyciws spp. (C. gibberchti, C. pacificus, C. spretosus). Species occasionally present include: Euchaeta marina (C. pavoninus, C. pavoninus, C. furcatus, C. caribbeanus, C. pavoninus). 5) Soudelafete san Tablincera spp. (T. acotti, B. spp.)

4.1.4 DISCUSSION The variety of zooplankton observed at Punta

Verraco was similar throughout the year. However, the abundance relationships between the more numerous groups fluctuated. The highest total densities were found in August and November. The largest proportion of meroplankton occurred during April. Native fish species were most numerous during February 1974. Planktonic species were also generally more abundant in the shallower limits for the mat. The sampling program was designed to provide quantitative estimates of: 1) the standing stock of zooplankton, 2) the variety of major taxonomic groups, and 3) the diversity and abundance of the more numerous copepod species. The manner of field sampling determined the variety and homes of organisms encountered. The data in this report are based on collections made in the surface waters during the daylight hours; the sampling gear and methods were kept uniform, including net type, mesh, towing speed, and depth range sampled. A small number of replicate tows were gathered at each site to obtain some measure of the variability between samples. To obtain a better understanding of the zooplankton community, more sampling with replication should be done at frequent intervals, at a greater number of stations, at different depths, during the day and night, and during different seasons for several years. Information gathered in these ways will be necessary to interpret fluctuations in standing stock and diversity in relation to environmental changes and biotic interactions. 46 ---Page Break--- ---Page Break--- semoa Keppyu/ausiupr iy nee setter oh sh ove ne 8 yor/tee encore 5 ust ncnozz 8s 1 fn e - exzore * s z va suoyiess wuepsese snoz ea0yes 50 soy ogoyssven usaaquaw) voaxuetdousu go sequnu TPI0L i-th a18vE le ecee | sotr cussoeot — 6nor eazore sive smol 94048540 loroy 5@ aequnu qeaoy @uEty STAVE ears osesuey eaune (,u/as 48 ---Page Break--- ---Page Break--- ---Page Break--- auoysseon 2i79 o9eaae, A e2ung (cto T/ao: e204 a¥i-t'h a4avs ---Page Break--- wl|Shonfe5 3 elseaseen ---Page Break--- 4.2 BENTHIC INVERTEBRATES AND FISH STUDIES by

Paul Yoshioka

4.2.1 INTRODUCTION

The results of benthic studies conducted at the Punta Verraco site from the winter of 1973 through the summer of 1974 are reported. Most of the investigative effort involved the mapping and description of the major benthic communities. Quantitative samples were taken in an attempt to assess the biological structure of selected communities and to provide quantitative baseline information. The qualitative and quantitative descriptions of communities are important aspects of community studies. However, these aspects represent preliminary levels of community investigations and are often insufficient to satisfy the demands of contemporary environmental concerns. It is often necessary to ascertain the direct effect of a pollutant on populations of specific species and also its secondary and tertiary ecological effects upon the entire community. The role of secondary or tertiary ecological effects should not be underestimated. Several studies have demonstrated that the structure and diversity of many natural communities are determined by ecological interactions (Dayton 1971; Paine 1960; Paine and Vadas 1969; Kitching and Ebling 1961; Huffaker 1959; Harper 1969). In such cases, predictions based solely upon the direct effects of physicochemical perturbations on single species populations would be inadequate and misleading if extrapolated to the community level. What is required to predict the effect of an environmental pollutant is an insight into those factors responsible for the ecological organization of communities. Descriptive or structural aspects of communities provide only a static, steady-state outlook upon a community. Species lists provide little insight into the interactions of their component species populations. Diversity indices, derived from the biological structure of communities, are speculative in their origin. Their ecological implications remain a point of controversy (Hedgpeth 1973).
---Page Break---
What is needed is an awareness of the dynamic process responsible.

for 1 community's control and regulation. This entails a knowledge of the functional roles of various species comprising the natural community. With these considerations in mind, a series of preliminary field experiments designed to ascertain the functional roles of the species in selected communities was begun in the spring of 1983. The gorgonian communities were selected as the major object of investigation during the latter phases of this study because the gorgonians represent a dominant feature of the benthic communities of the Punta Verraco site and, as such, deserve major attention; the growth form of gorgonians adds a considerable amount of physical structure and heterogeneity to the benthic environment, and such physical structure greatly influences the remainder of the biological community (Elton et al. 1973). Gorgonians may be useful indicators of such environmental parameters as wave action, currents, and turbidity (Grigg et al. 1983; Goldberg 1973; Kinzie 1975). Clearing experiments were conducted in an attempt to assess the effect of settled gorgonian colonies on the recruitment of new colonies. Permanent observation quadrats were set up as controls.

4.2.2 MATERIALS AND METHODS

Field Procedures

Surveys of the major benthic communities were made by traversing underwater transects and making station dives. A diver propulsion vehicle (DPV) was usually employed for transect work. Notes were taken on dominant or unusual organisms, bottom type and topography, depth, visibility, surge, and other pertinent biological or physical data. Photographs were taken to aid in describing the benthic communities. In the latter stages of the investigation, increasing emphasis was placed on station rather than transect diving in an effort to generate information on the benthic communities at selected locales that would be more appropriate for statistical analysis. Quantitative samples were replicated whenever possible to assess the effect of sampling variability. Samples of the infaunal and smaller epibenthic organisms.

were taken within 4.25 m² quadrat. These samples were placed in a plastic bag held as close to the sampling site as possible to minimize the loss of organisms. Substrate was removed with the aid of a hammer and chisel. A description of the sampling method can be found in Vicente (PRNC=174 1974). ---Page Break--- ---Page Break--- Gorgonians were collected in 3 m² (1 x 5 m) or 10 m² (2 x 5 m) quadrats depending on the density of gorgonians and limitations of bottom diving time. Gorgonian samples were taken in May, August, and November of 1974. Two replicate samples were usually taken. Quadrat (1 x 7 m) observation quadrats were set up in February 1974. The larger sessile organisms in these quadrats were identified to the lowest possible taxonomic category and were monitored both visually and photographically. The gorgonians in a single 3 m² quadrat were tagged and measured. The quadrats which had been cleared of gorgonians in 1974 were observed thereafter to assess the effect of colonies on recruitment of new colonies. Their established growth, and then species. Gorgonian samples were dried for several weeks, weighed, measured, and identified. The more familiar were identified on the basis of external characteristics. Questionable individuals were identified with the aid of spicule preparations. Substrate samples were brought to the laboratory, sorted into phylogenetic groups, and preserved in buffered formalin for later analysis. Organisms were listed in citations and other pertinent information of transects, dives, and beach sites at Punta Verraco are shown in Figure 4.2-F1 and Appendix 4. The following description is based on observations compiled from these dives. Collected or identified at three shore locations are listed in Appendix 4.25. The collections are listed in Appendix 4.26. The inshore areas between Punta Verraco and a sand spit island near the entrance of Guayanilla Bay (Transect T1, Station 31) appear to be dominated by

Thalassia, Syringodium, Caulerpa, and typical seagrass bed species such as Diplanthera urcellana, Tripneustes gigas, and the starfish Deaster tigrinus and the mollusks Vasum muricatum and Pinna were observed there. A small coral fringing reef was encountered about 190 m offshore of Punta Verraco. Organisms observed here included the alga Udotea sp., the corals Siderastrea spp. and Millepora sp., the gorgonians Pseudopterogorgia sp., Erythropodium sp., Palythoa, and the sponge Sphagelospongia ves. Water depth in this area ranged between 1 and 3 meters. On the seaward side of the sand spit island, the substrate appears to be dominated by algae and some sponges (Station 51). Occasional colonies of corals, principally Diploria strigosa, Porites astreoides, and Montastraea annularis, were observed. Siderastrea, Millepora, and Montastraea were much more abundant than the other corals. Coral cover was scarce compared to other reefs and was comprised mostly of two genera, Acropora and Plexaurella. The dusky damselfish Pomacentrus fuscus, the sergeant major Abudefduf saxatilis, the rock beauty Holacanthus tricolor, the bluehead wrasse Thalassoma bifasciatum, the Spanish hogfish Bodianus rufus, the blue tang Acanthurus coeruleus, the doctorfish Acanthurus chirurgus, and grunts Haemulon spp. were observed. Further westward along Punta Verraco (Transect 12), the substrate is comprised mostly of dead coral heads with occasional patches of sand. These coral heads provide much topographic relief, up to 2 meters in places. Only occasional colonies of living corals were observed. Gorgonians were common, algae primarily Sargassum was abundant. Fish were fairly abundant due to the high topographic relief available for cover. Among the species observed were grunts Haemulon spp., the highhat Tetrosomus gibbosus, the bluehead wrasse Thalassoma bifasciatum, the hogfish Lachnolaimus maximus, and the queen triggerfish Balistes vetula. Water depth in this area ranged between 6 meters. The substrate was covered with a

layer of sediment which was probably derived from Guayanilla. A submarine canyon was encountered offshore of the Río Yauco (Cerro Forte). A soft sand-mud mixture dominates the bottom substrate (Transect Ti, Station 83). It is characteristic of such substrate that visually conspicuous organisms are usually rare. However, small patches of algae Ulva lactuca, Typnea musciformes, Gracilaria sp., the fighting conch BUF pits and several bivalves Arca icara, Tellina alternata were observed in this area. To the west of the Cerro Toro submarine canyon, off Punta Vaquero and Punta Ventana, the bottom substrate consists mostly of low relief rock with occasional patches of sand (Transects 74, 15, 6; Stations 88, 85, 87). Areas near shore (Transects 1 to 10) appear to be dominated by algae. Various species of algae Sargassum, Dictyota, and red algae were observed. The hard coral Stiviaitrex Sidera, gorgonians: Pseudopterogorgia and Eunicea; and the sponges Sphacelospongia vesparium, Anthosigmella varians, and Tethya were seen (Stations 87).

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In areas further offshore (Transect T4, Stations 84, 85, 87) hard corals, sponges, and gorgonians become more abundant, the latter being the most visually conspicuous. In general, the faunal characteristics of Stations 84 and 85 are probably representative of this area. Relatively flat, low relief rock dominates the substrate at Stations 84 and 85. Small sand patches cover less than 10% of the bottom. The water column is relatively turbid; during this study visibility never exceeded 7 meters. Macroalgae were conspicuously absent and the sea urchin Diadema was quite common. The hard corals were visually estimated to cover between 1-10% of the bottom substrate. Among the more common corals observed were Montastrea annularis, M. cavernosa, and Diploastrea sp., and at both stations the gorgonians were the most visually conspicuous organisms. Among the genera observed were Eunicea, Muricea, Muriceopsis, and Plexura. Quantitative sampling regarding these organisms was conducted at both stations. The fish

and larger invertebrate species observed at both stations as well as Station SSA are listed in Appendix 4.2D. Fish were observed on two different occasions at Station $4 in an effort to estimate the frequency of occurrence of various species. Of the total of six species identified, only the blue-head wrasse Thalassoma bifasciatum appeared during both periods of observation (12 February 1974 and 21 August 1974). However, of the seven total species observed at Stations $4 and SS on August 1974, five occurred at both stations. This suggests that the fish fauna at both stations are quite similar. Seven of the 13 species of scleractinian corals and 19 of the 24 gorgonian species co-occurred at both stations. Gorgonian colonies collected on 1 December 1974 in an area previously cleared of gorgonians on 5/4 the Height (range) Fry - Eunices laetep: 5 Sargonia ventallina 5 2 2 a variegata + adap lexura st 2 Funte 2 ---Page Break--- Species found in 1/4 m² quadrat substrate samples taken at Stations S1 and S2 are listed in Appendix 4. Noth samples show similar distributions of individuals among species. The 240 individuals were represented by 40 species (excluding stone and colonial organisms) in the S1 sample, and 46 individuals among 27 species in the S2 sample. Both distributions were highly equitable; more than 50% of the species were represented by two or fewer individuals. Large discrepancies appear when the species lists are compared. Of the 58 species found in the samples only nine were found in both. It could not be determined if this discrepancy was caused by habitat differences between the two stations or by sampling variability; therefore, two replicate samples were taken a few meters apart at Station $4. These results are also shown in Appendix 4.21. The number of individuals shows a highly equitable distribution; 17 individuals among 14 species in one replicate; 7 individuals among 23 species in the other. Over 50% of the total number of species (37) were represented by single individuals. However, only four

Snucies occurred in both replicates. The lack of similarity between the two replicates in terms of co-occurrences of species could indicate an inadequacy of the 1/4 x? quadrat in obtaining a representative sample of the infaunal community. This is probably due to distribution patterns as well as the “rarity” of individuals relative to the sampling scale. Gorgonian species and numbers of individuals collected from two 10 a° quadrats at Station $4 are listed in Appendix 4.2F. Overall colony density of the subsamples was very similar, 9 colonies per m². Correlation of the relative abundances was statistically significant (Kendall - tau = +9.46, > 0.05) indicating that the quadrat size was sufficient to representatively sample the gorgonian community. The four most abundant species in decreasing order of abundance were Muriceopsis flavida, Gorgonia ventalina, Plexaura flexuosa, and Muricea muricata. These species accounted for about 781 of the total number of individuals. Gorgonians were found in much higher densities at Station $5, an average of 25 and 30 colonies per m². This corresponded with the general visual impression that gorgonian densities decreased at shallower depths. Relative abundances of gorgonian species in the two subsamples were significantly correlated (Kendall-Tau = +0.06, p < 0.01). The five most abundant species in decreasing order of abundance were Eunicea tourneforti, Junicea laxispica, Muricea muricata, Plexaura exuasa, Dinicens clavigers, and Muriceopsis flavida. These species accounted for about 781 of the total number of colonies. ---Page Break--- No correlation was found between the relative abundances of gorgonians at Stations $4 and $5. The causative factor(s) responsible for the differences in relative abundances are undetermined at present. However, Kinzie (1973), Goldberg (1953), and Opreske (1973) discuss several environmental factors which may influence the abundance of gorgonian species. When revisited on 21 August 1974, the area cleared of yn 2} Apeg? 1874 at Station $4 had an average of (354.

Cut.) newly recruited gorgonian colonies per wed aces quadrats. ALL recruits were less than 5 cm previously, the density of similar sized colonies was only 0.45 colonies per 1/4 m2, the presence of settled colonies inhibits other colonies. Established colonies influence play a regulatory role in the recruitment of new colonies. "The mechanism by which this occurs is unknown, on 1 December 1974 gorgonian colonies were collected from a dome previously cleared of all gorgonians the previous spring. Species collected and their abundances are listed on table." The relative abundances correlated positively but not significantly with the gorgonians collected the previous spring (Kendall-tau, p~.20), suggesting that persistence of gorgonian species occurs in the same order of relative abundance as the natural mature populations. The distribution of colonies in the cleared and controlled areas were also determined by 32 (2x 2m) quadrats. The distribution patterns of colonies for various quadrat sizes of gorgonians in natural areas, however, seem to be more randomly distributed. Listed on Table T.c-T2. Evidently, recruits exhibit an aggregated pattern. Colonies of gorgonian colonies in cleared and natural areas are, for (2) PROB. PATTERN rate 0.001 as aggregated as “silos 9100: aggregated 2am = 7.96 9,008 aggregated as 40.288 139. random pi 48 01001 averaged as Silwe 01072 random 60 ---Page Break--- Growth rates for tagged gorgonian colonies in the observation quadrat between August and December 1974 are listed in table 1.2.13. An apparent trend for higher growth rates for smaller colonies was not significant at the 0.05 level (Tukey Corner Test). Due to limitations of diving bottom time, all the gorgonians were not tagged, therefore natural recruitment and mortality rates could not be determined, TAB 4.278, Growth of tagged gorgonians in the permanent quadrat at Station 54, Punta Verraco SS —SS= 2 as DECEMBER (heights, ea) (esghe en) ee 3 Te 10.8 1 2 2 se 38 40 “0 235 te 4 1 2 a 49

80 (broken) 13.5 18 on a 4.2.4 vIscussz0N The intertidal biota of the Punta Verraco site appears to be representative of this environment along the coasts of Puerto Rico (Glynn 1964). The infaunal populations possess a high species diversity and equitability. This feature has been found to be common to all substrate samples taken at various sites around the island (Tortuguero, Manati, Cabo Mala Pascua). However, due to high sampling variability, the structure of this community cannot be deduced. The greatest abundance of fish life observed at the Punta Verraco site was associated with areas of high topographic relief. This feature is common to several sites around Puerto Rico (Manati, Tortuguero), and is probably related to the shelter provided in such areas (Smith 1973). Repeated observations of fish life at the permanent station indicated that only a small portion of the fish species at a given location are observed at any single given time. oo ---Page Break--- eo road to affeer we gorgonian com Eorent qorgonian communities in sociated vith aespectfig inter- the centro} and Y"saurabie seithing Suitable set" ting pf recruitment rates parte: Rrobahs hie fe teed oF oo 1 colonies 7 Hitment ae wee S38 toons of che ceemat colenies im ft sovonazing stages ody SONS as’ equilibrium wt tesvactions among. fishers 2 yaceur. the pose) beat are strrbuced ee aperamoted der te vhange Sepe oieh egctebity rust cceur . cuerit 7a agereyatsons. Both hace roo Ferponsipie for feacg shew hac this © interactions, Fowever, if 1s nog, evra) rollerica wiht be e biologics: process responsible this cornant-y ---Page Break--- as PLANT ASSOCIATIONS by Michael J, Canoy 4.3.1 INTRONUCT ION res rocoiving. Face, on the south-west coast, is in an arid gas'than $7 inches rainfall per years The cil is spaveard has Tztle or no organics. “In te aren’ in ack of “het points (Punta foro and funta Verrace) there are a Typha svanp and sugar cane fields, The forest on the Sho pouty is"topseal tertiary dry commiry tuccstssenet The terres:rial fauna is not

obviously different from the rest of Puerto Rico's coasts (See Appendix #-5A). The major species are rats, cats, mongoose, cattle, dogs, and a few “pest” birds such as grackles, ani, and pigeons. Pelicans, frigate birds, and Clapper rails were observed, more nesting. There are possible inclusions in the breeding area of rare species, the Puerto Rican Nightjar, due to the proximity of the Guanica forest, and a large number of bats which issue from several caves and a large sinkhole in the point. The existence of extensive caves in the point may make the area unsuitable for heavy construction. The forest association is one of the less disturbed dry forests in Puerto Rico. It easily ranks with the Guanica forests; the banks and cliffs rise rapidly. There is very little beach to the forests. Among the more seaward plants are Ipomea, Canavalia, and Sperobelus. Opuntia species begin near the sea and continue through the forest. These seaward associations are vagrant and often washed away only to reappear later.

TALS AND METHODS

The Punta Verraco site represents an anomalous ecological assemblage. It consists of parts of a dry forest, a beach community, a Typha swamp, and a fringing mangrove forest. Therefore, it was necessary to establish one long transect roughly northeast by southwest (Figure 4.3-F1) and three small perpendicular transects on Punta Ventana, the old river mouth, and Punta Verraco. The long transect was roughly 1 km in length while the smaller transects were 10 m. One meter plots were examined for wrasses and ichthyofauna at the juncture of the transects and at the distal end of each 10 m transect. This gave six 1 meter plots. All unknown specimens were removed to the laboratory for identification.

The tertiary successional forest of the hills is more complex than it appears. The xerophytic nature of these tertiary limestone hills is deceptive; to the untrained eye, many species appear as one. One feature of the forest is the

number of sent. The succulents Cephalocereus A cons succulents and Toyeni, Leptocereus quadricostatus, and cacti Opuntia species, and the Cyngpre creer “Sema. The S" trisomus ate eeens can ang the cactus Cactus intortus are Bey crow to 3 to 6 liters, towering over acti near the shore are covered agave Agave conspicuous the surrounding with epiphytes. + end one orchid Encyclia Paptionscea, The s| Burserea, and Anyris are dense. of tree Size, Occasional The Larger Puri RTe5: are found here. Behind the is a Typha skamp which white mangroves. distances up the hit? t Ponta Verraco, but not on the site, rainy to a mangrove fringed say. Black Suncularia and Avicennia stray short ---Page Break--- REFERENCES Ahlstrom, D.H. and J.R. Thraikill, 1962. Plankton volume loss with time of preservation. CALCOFI Rept. 9:57-73. Alny, C.C., Jr. and C. Carrion-Torres, 1963. Shallow-water Stony Corals of Puerto Rico, Carib. J. Sci. 3(263):133-162. Anikouchine, W.A. and R.W. Sternberg, 1973. The World Ocean: An Introduction to Oceanography, Prentice-Hall, Inc., Englewood Cliffs, N.J. Bailey, R.M. (Chairman), 1970. A List of Common and Scientific Names of Fishes from the United States and Canada (Third Edition Amer. Fish. Soc. Publ.) No. 6:1-149. Bayer, F.M., 1961. The Shallow-water Octocorallia of the West Indian Region! Martinus Nijhoff, The Hague, Netherlands. Beck, 3.F., 1972. Preliminary report on the proposed Punta Verracas power plant site. Submitted to PRWRA Feb. 1, 1972. PRNC, Mayaguez Bigelow, H.B. and N.C. Schroeder, 1953. Fishes of the Gulf of Maine. Fish and Wildl. Serv, Fish Bull. 4, Vol. 53, U.S. Dept. of the Interior, GOP, Washington, D.C. Bohike, J.E. and C.C.G. Chaplin, 1968. Fishes of the Bahama and Adjacent Tropical Waters, Acad. of Nat. Sci. of Phila., Livingston Publ. Co., Wynnewood, Pa. Breder, C.M., Jr., 1948. Field Book of Marine Fishes of the Atlantic Coast, G.M. Putnam's Sons, New York. ps, BPs and J.P. Akevs, 1962. Hydrogeologic map of Puerto Rico and adjacent islands. Atlas NA-197, U.S. Geological

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sransect TH Location: perpendicular to shore off Punta Verraco Depth 1-7 m Date: 22 April 1974 Investigator: P. Mt. Yoshioka Transect 75 Location: perpendicular to shore near Punta Vernaco Depth: 80 m Date: 21 May 1973 Investigator: V.P. Vicente Transect T6 Location: perpendicular to shore off Punta Verraco Depth: 80 m Date: 23 May 1973 Investigator: V.P. Vicente Location: reef outside of sand spit off Punta Verraco Depth: 0 m Date: 5 March 1973 Investigator: A. Smmant-Froelich Station 2 Location: between sand spit and Punta Verraco Depth on Date: 21 May 1973 Investigator: V.P. Vicente Station 2 Location: canyon off Cerro Toro Depth 26 m Date: 6 March 1973 Investigator: V.P. Vicente ---Page Break--- APPENDIX 4.28 (continued) Station 4 Location: Permanent station Investigator: Station 5 Location: Depth: Date: Investigator: Station 58 Location: Investigator: Station 7 Investigator: 1 Location: Date: Investigator: 22 Location Date Investigator: 33 Location: Date: Investigator: off Punta Ventana on 12 Feb, 1974, 22 May 1974, 24 August 1974, 18 November 1974 P.M. Yoshioka off Punta Ventana - offshore of Station 4 on 24 August 1976 P.M. Yoshioka, off Punta Ventana - offshore of Stations #4 and 5 on 13 November 1974 P.M. Yoshioka off Punta Ventana on 21 March 1973 P.M. Yoshioka off Punta Vaquero on 6

March 1973 V.P. Vicente sand spit off Punta Verraco March 1973 W.F. Vicente Cerro Toro beach 28 February 1973 V.P. Vicente Punta Vaquero 26 February 1973, V.P. Vicente ---Page Break--- ---Page Break--- Punta Verraco Island Shore sand spit 0 - 4 m off Vaquero Shore sand spit: 228/73, 2028/73 VT ---Page Break--- ---Page Break--- ‘roy, e399 eusez/e (ponupsucs) az*h xIONIEEY ---Page Break--- ---Page Break--- ---Page Break--- ---Page Break--- APPENDIX 4.20 (continued) sien ‘cOBrIDAE, Bathygobius curacao Euclycobothrus Soponator 26 Drooconidae Diodon holocanthus 1/72 s/s0/72 12/11/72 2/14/73 ar ae from shore tr 298 9/30/73, ---Page Break--- ---Page Break--- APPENDIX 4.20 (continued) Permanent Station ras 21/8/78 ---Page Break--- ---Page

Break--- APPENDIX 4.26 Species occurring in 1/4 m quadrat substrate samples at Punta Verraco, Stations 1, 6, and 7 (Replicates 7 and 8), (Permanent station) Phylum Phacophyta Dictyopteris delicatula ° ° ° Sapasmene peleerecran ° ° : Phylum Chlorophyta Phylum Rhodophyta Amphiroa fragilissima ° ° ° Spatogorgia pisce ° ° ° Hypnea estuarii ° ° : Phylum Porifera Acropora sp. ° ° ° Setar esereTetace ° ° ° Erythra te ° ° ° Dysidea sponge ° ° * Phylum Coelenterata Astrangia solitans ° ° 2 Phylum Echinodermata Untd, neenertean ° ° 1 6 ---Page Break--- APPENDIX 4.28 (continued) Phylum Annelida Class Polychaeta Arabella Gniee naa Euplectella undulans Eunice =p Euclymenia conplanata Terebellides branchiatus ‘Gibberichia fibritabia Capitella variabilis ome igre cating Rstafon Mnbere’s Welafon Pe Hieamhves 2p. Fapndothey conjuaca Polychaeta sp. Fentogents oe ma sat : ia SP Hianeiaie sp. ‘Siphonodentis glabra Siuppeniee Terebellum sp. Oal®. Flabellinae Vaid: Lysidicean Unid. serpulidae Uni. sylidae a0 Phylum Sipunculoidea SESE op. Sipunculus sp. Phylum Arthropoda Class Crustacea Order Pericarida ‘Suborder Isopoda (Permanent Station) Rep. 5 repl. & su st s6 ---Page Break--- DTK 8.7% Continued) Class Bivalvia Barbatia donati Brachidontes exustus Gastrochaena hirsuta Gregaritinia covalliophaga Geissothrissa sieuctata Tees Spec Sthoskens Deltves equinistr's Pericots Tapetina ‘Spengler/« roar Phylum Echinodermata Class Ophiuroidea Ophiocoma aiigocantha oo S Echinodermata Iucunter Ord. echinoderms Phylum Chordata Class Ascidacea Microcosmus helenae (Permanent Station) ‘A Rep. B Rep. se st se ---Page Break--- Phylum Arthropoda (cont) Eagurus Brewidactylus ectothenes qatachinus Beachysna pinpiea Mithniy pleare= class Scaphopoda Dent ab Jara Class Gastropoda Bolinus striata oral Tapatia caribaea Space 3B. Tatgnone FRITS (Permanent Station) Rep. Repl. st 56 ---Page Break--- APPENDIX 4.27 species and numbers of individuals recorded from Stations 54 and 53, Station 54 Station 55 Replicate B/replicate ° a yan ayia 1 ° 0 3 3 Kt 2 0 ---Page Break--- ---Page Break---