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PUNTA VERRACO ENVIRONMENTAL STUDIES

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PUNTA VERRACO ENVIRONMENTAL STUDIES

by

E.D. Wood, M.J. Youngbluth, P. Yoshioka
and M. Canoy

PREFACE

This report stems from investigations carried on 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:

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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 Platform site, have been included.

The sites chosen for study were: Torguguero Bay, Punta Manati, Punta Higuero, Cabo Rojo Platform, Punta Verraco, and Cabo Mala Pascua (see Figure 1.1-F1). 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 Platform 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 1973-1974" (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.

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). It 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 (15-25 m) 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

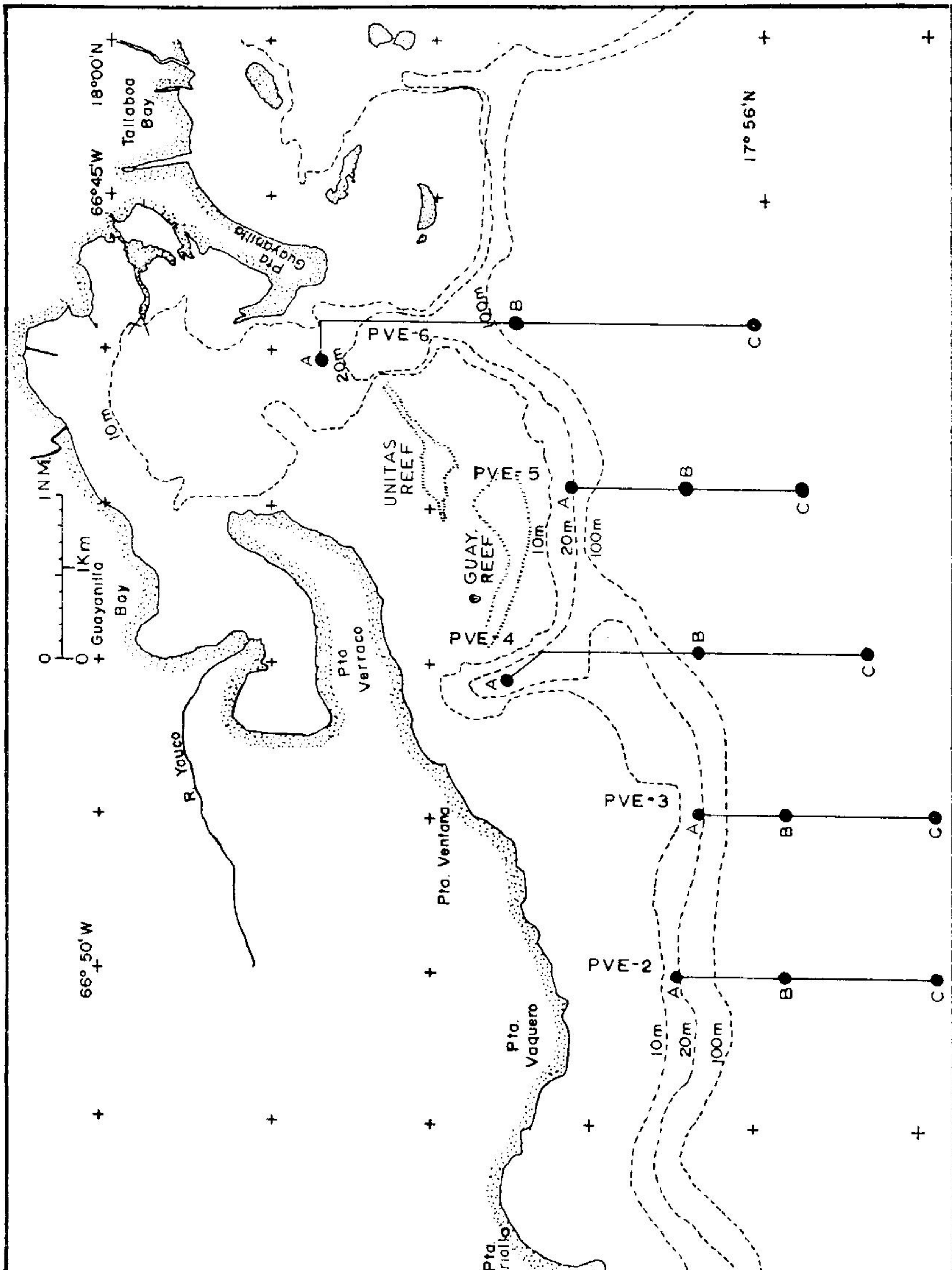
The tidal waves that affect the south coast of Puerto Rico have their amphidromic point in the eastern Caribbean Sea. The waves move in a counterclockwise direction (Anikouchine and Sternberg, 1973), that is, from east to west past Punta Verraco. The south coast tides are diurnal. Two waves exist, but 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 (50.83 cm/sec). The current near the south coast of Puerto Rico rarely exceeds 0.5 knots (25 cm/sec).

Fig. 2.1-F1 Punta Verraco site with depth contour lines and hydrographic sampling transects each with three stations.



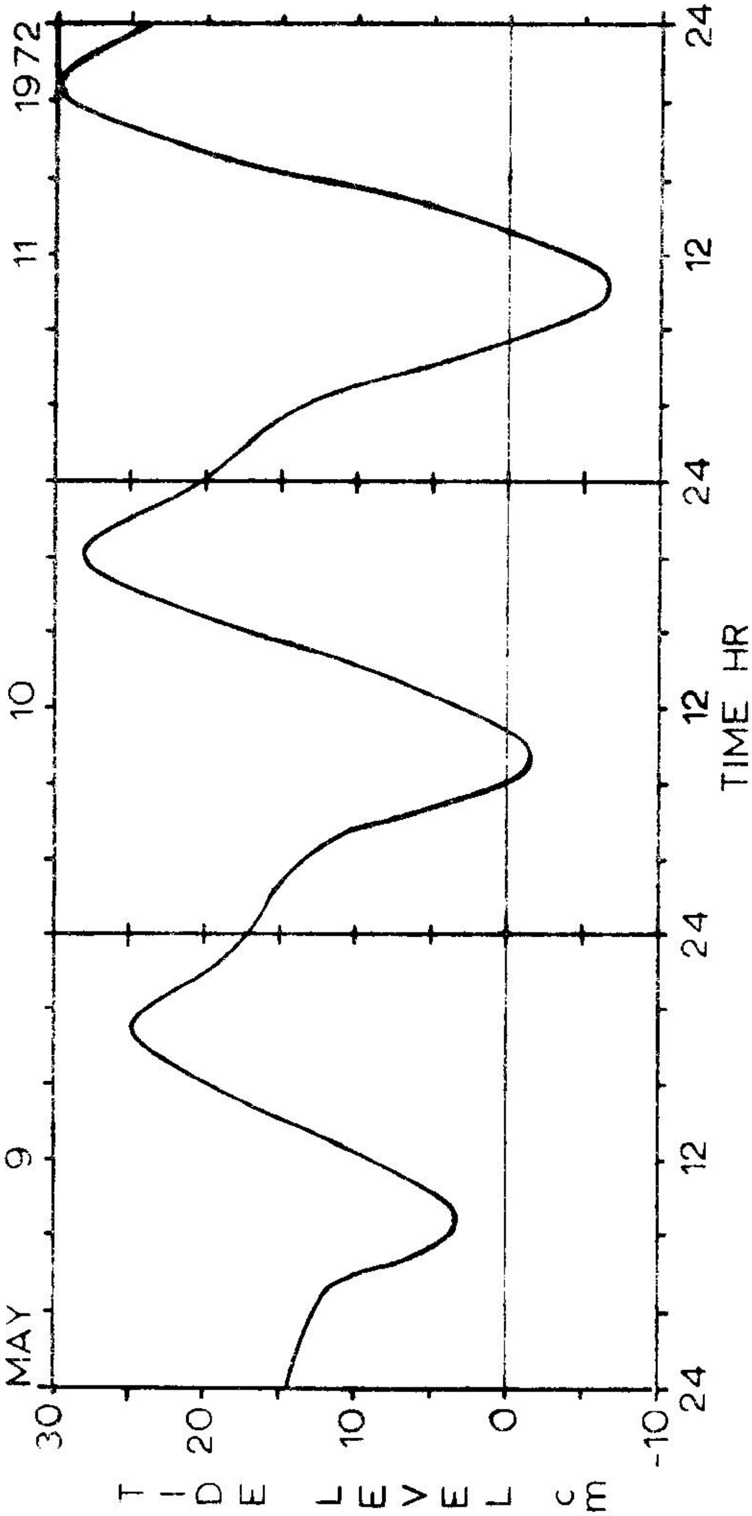


Fig. 2.1-F2 Diurnal tides at Punta Verraco covering one of the periods of current measurements.

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^2 south to Station PVE-6A, and a tide of 20 cm, there would be a tidal exchange of 0.6 x 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 on 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 upswelling 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 (1975b). 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 Verraco were measured on three occasions during this study. The first occasion was reported by Beck (1972) and is summarized briefly here. Four Savonius rotor type current meters were employed to measure flows at the stations shown in Figure 2.1-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 sub-surface currents more toward the southeast. The data are summarized in Table 2.1-T1.

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.

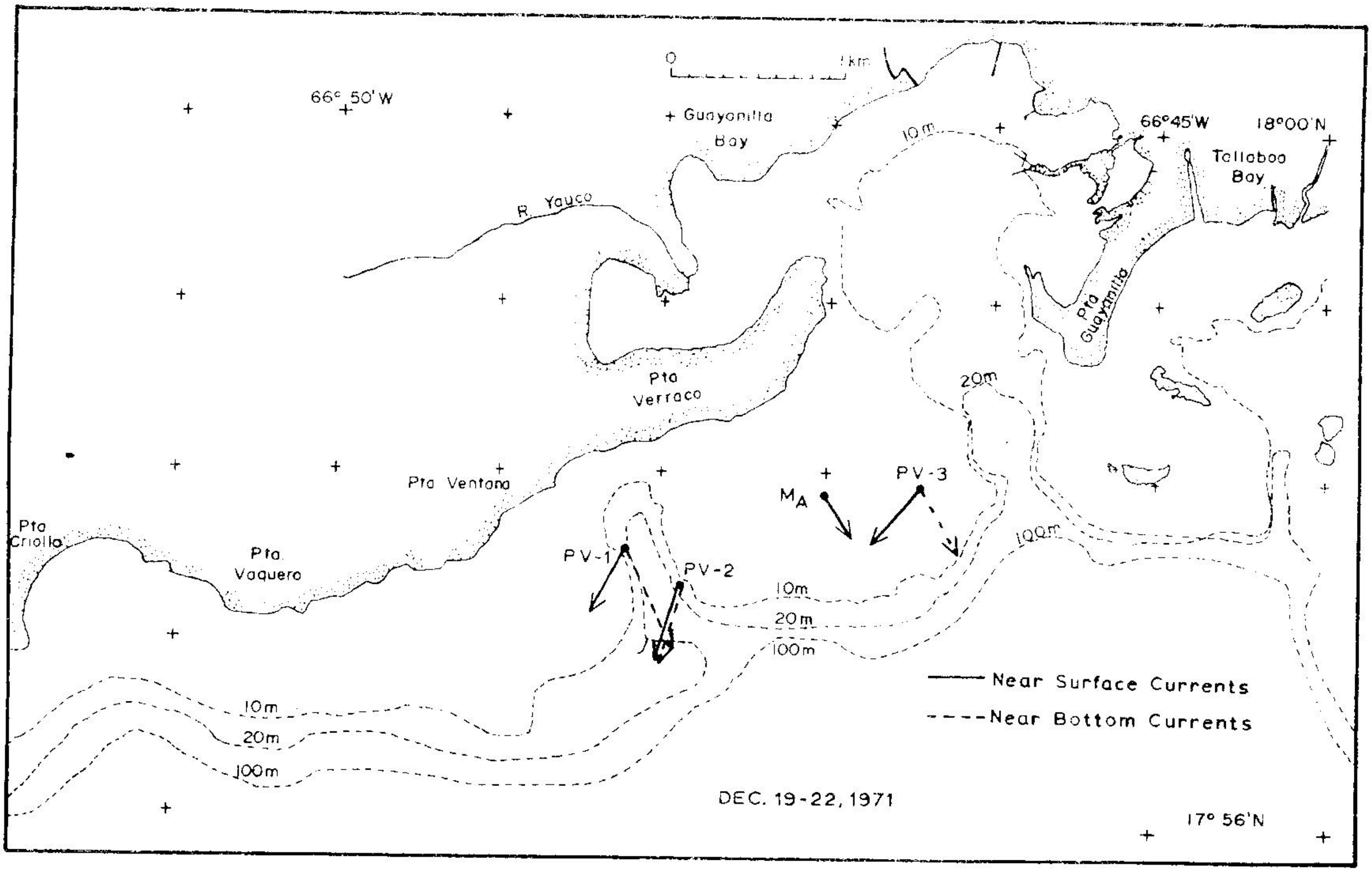


Fig. 2.1-F3 Vectors showing major flow at four stations occupied between December 19 and 22, 1971.

TABLE 2.1-T1	Summation of current data at Punta Verraco December 19-20, 1971*

STATION (Fig. 2.1-F3)	DEPTH(m)	CURRENT DIRECTION AND SPEED
PV-1 Dec. 19-20	0	S.S.W at 0.2 - 0.3 knots
	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.
	4	S.S.W. at 0.15 - 0.2 knots.
	7	E.S.E. at 0.3 knots.
PV-2 Dec. 20-21	0	S.E. at 0.4 knots following low tide; S.W. at 0.4 - 0.2 kts., weakening 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.
	7	S.S.E at 0.3 knots.
	16	Following high tide, S. at 0.2 knots; remainder of the time, S.W. at 0.1 knot.
PV-3 Dec. 21-22	0	S.W. at 0.4 (information incomplete, meter malfunctioned during recording).
	2	S.W. - S.S.W. at 0.1 - 0.2 kts.
	5 1/2	S.E. - E.S.E. at 0.2 knots.
M A Dec. 21-22	2	S.S.E. at 0.1 - 0.2 knots.

*Obtained with four Hydro Products Model 502 Recording current meters.

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 5 cm/sec (0.1 kt). Drop Nos. 1 annd 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 Guayanilla Reefs. It flowed to the northwest at about 10 cm/sec (0.2 kt), and then dispersed until it was no longer visible.

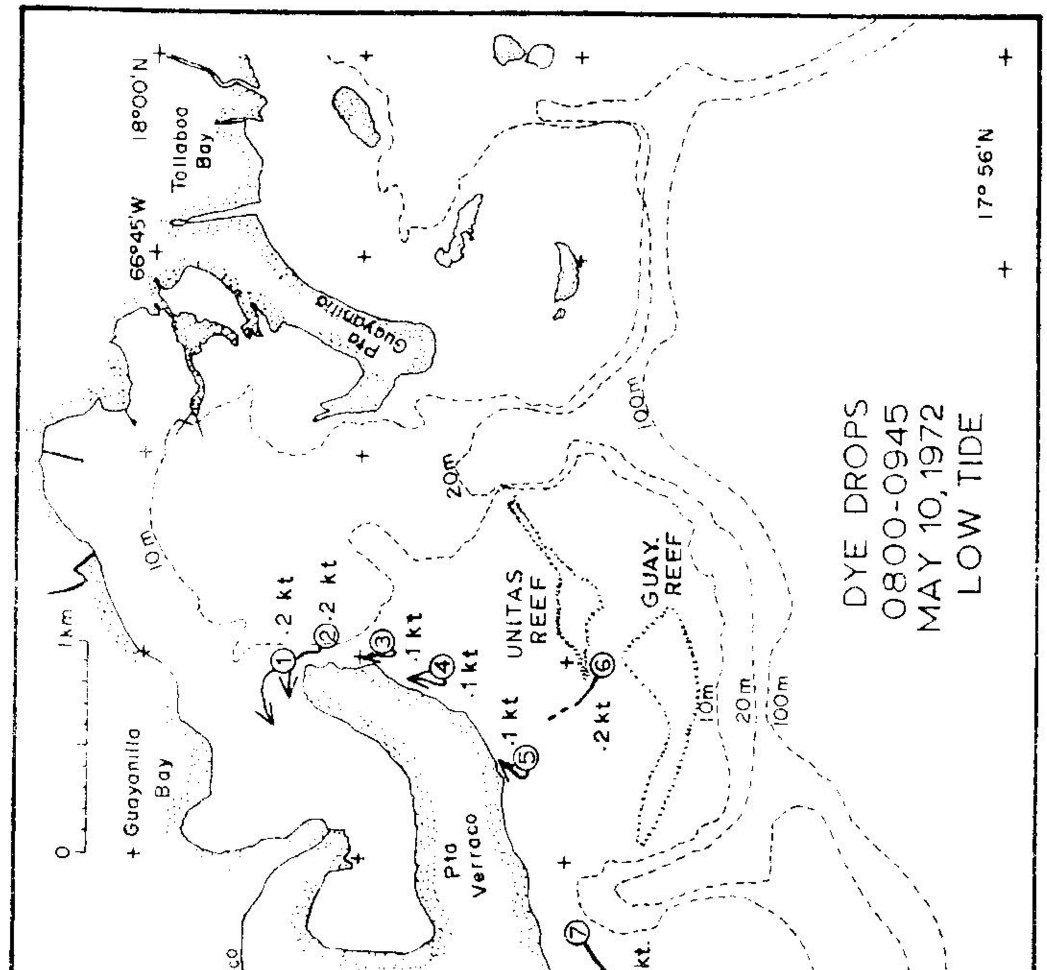


Fig. 2.1-F4 Dye study at Punta Verraco the morning of May 10, 1972.

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 13 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 2.1-F6, and followed for about one and a half hours before drops No. 5-8 were made. Drops No. 3,4,7 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 sub-marine 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

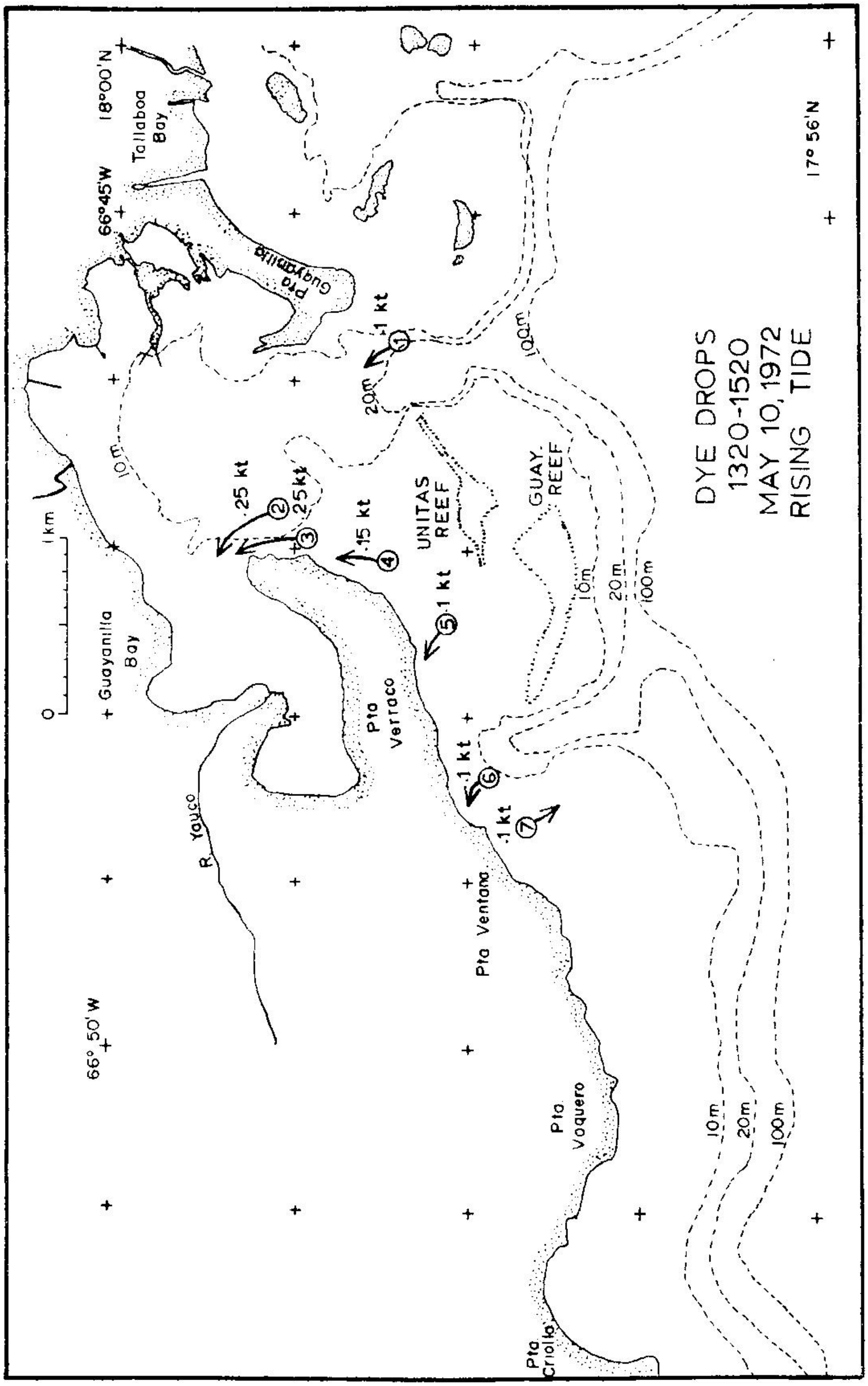


Fig. 2.1-F5 Dye study at Punta Verraco the afternoon of May 10, 1972.

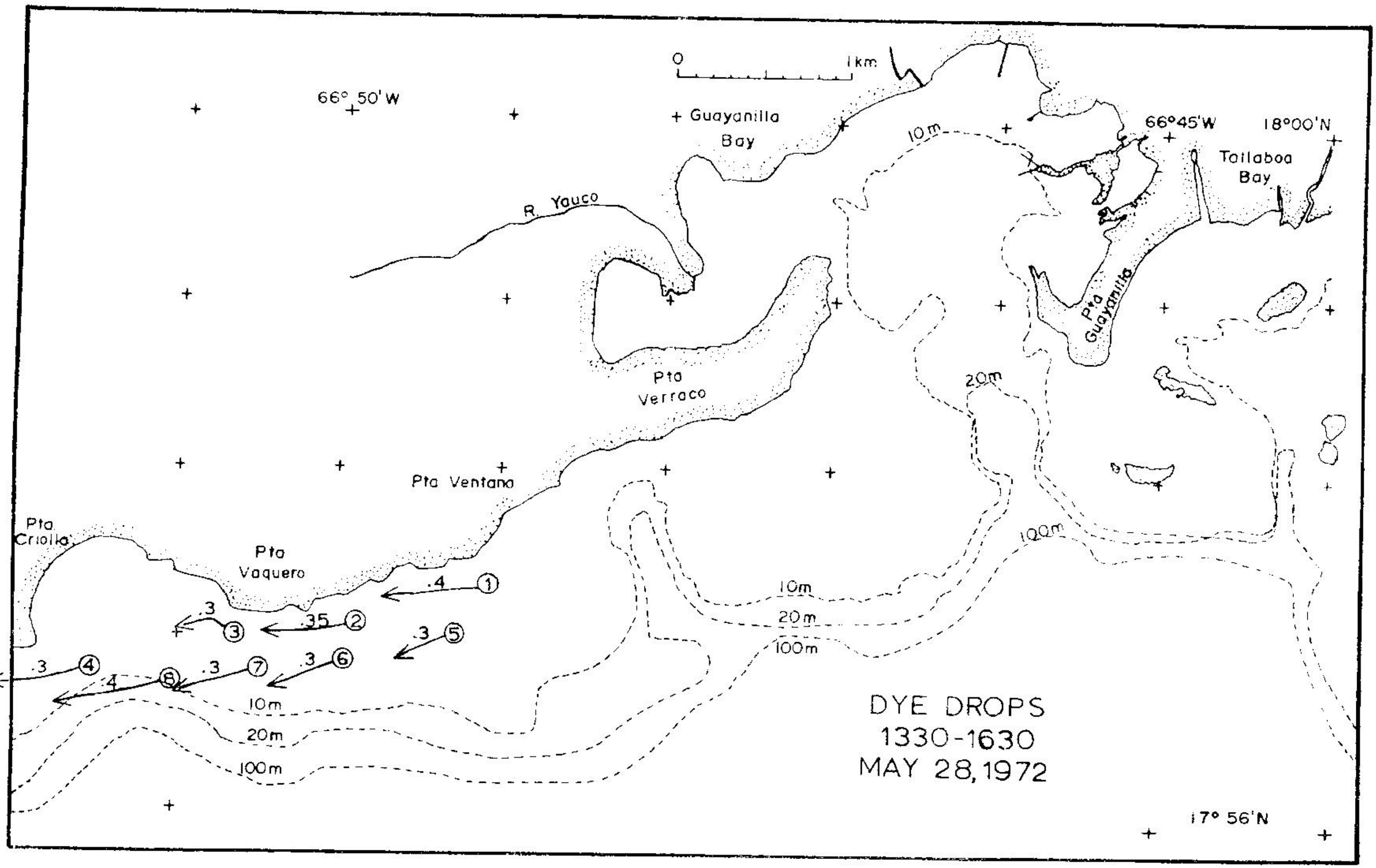


Fig. 2.1-F6 Dye study west of the Punta Verraco site the afternoon of May 28, 1972.

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 west 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 500 meters are available about 5 kilometers south of Punta Verraco.

2.1.5 TEMPERATURE, SALINITY AND DENSITY

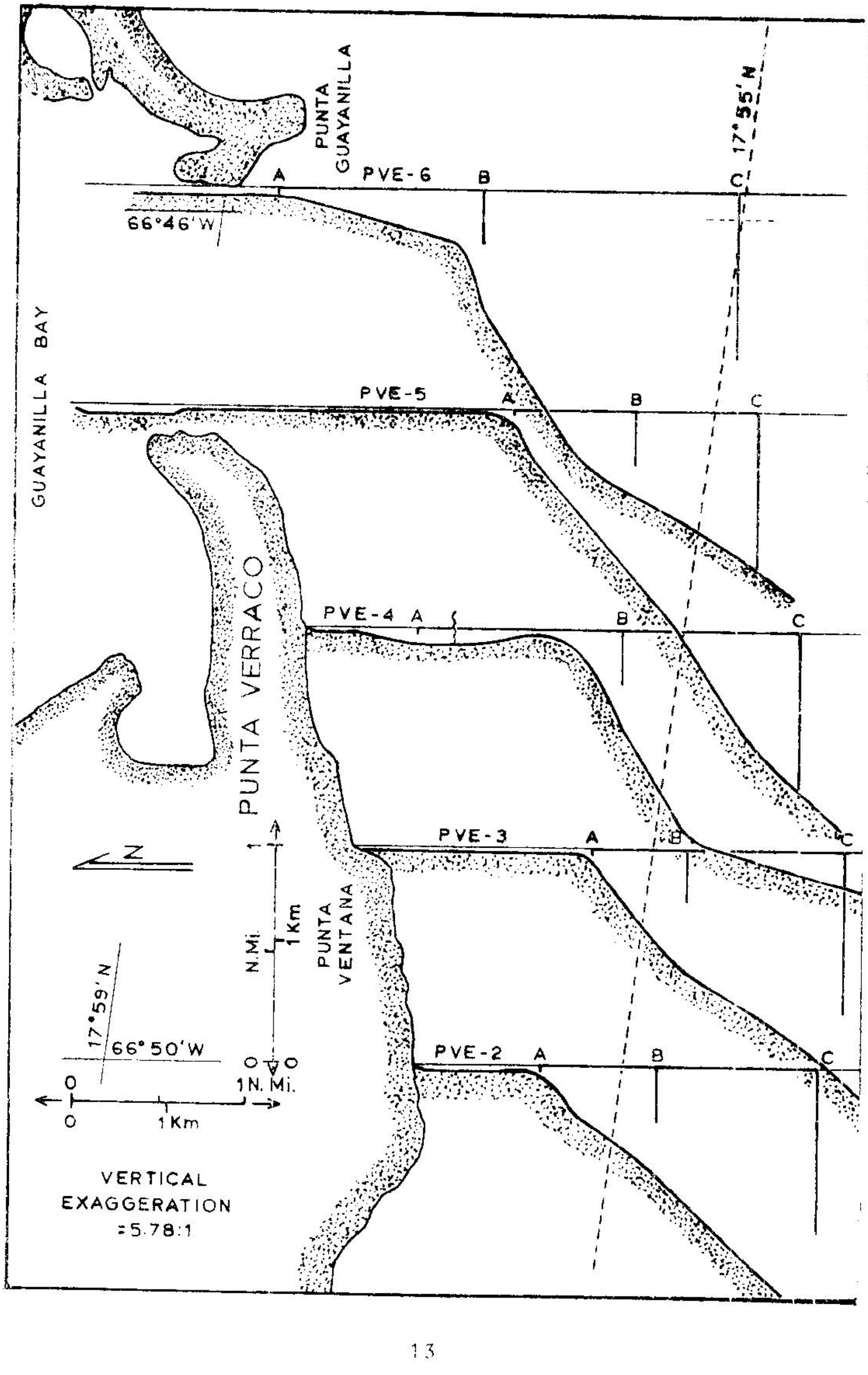
The physical parameters of temperature and salinity were measured at the Punta Verraco site on seven cruises covering four seasons (Table 2.1-T2).

TABLE 2.1-T2 Schedule of hydrographic cruises to Punta Verraco

	Winter	Spring	Summer	Fall
1971	-	-	-	PA-005 Dec. 19-22*
1973	PA-023 Feb 20	PA-029 May 21-22	-	-
1974	PA-039 Feb 12	PA-042 Apr 22	PA-046 Aug 21	PA-052 Nov 13

*Results reported by Beck, 1972.

Fig. 2.1-F7 Bottom profiles along the sampling transects of the Punta Verraco site. Vertical lines indicate relative positions of the hydrographic stations.



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 ± 0.03°C. Salinities were determined with an induction salinometer to an accuracy of ± 0.005°/oo. 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 1975c).

Temperature

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 50 meters were measured using both "protected" and "unprotected" reversing thermometers. A thermometer depth, TZ, was then calculated for the sampling depths and correlated quite well with the calculated depth, CZ, obtained from the amount of hydrowire paid out, WZ, and the cosine of the wire angle, Ø. A comparison of some of these depths is shown in Figure 2.1-F8.

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 sigma-t. Depth is not shown on the plot, but generally increases to the lower right corner of the plot, i.e., density increases with depth. Very little change is seen seasonally where sigma-t is greater than 25.5, however, a definite 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 2.1A.

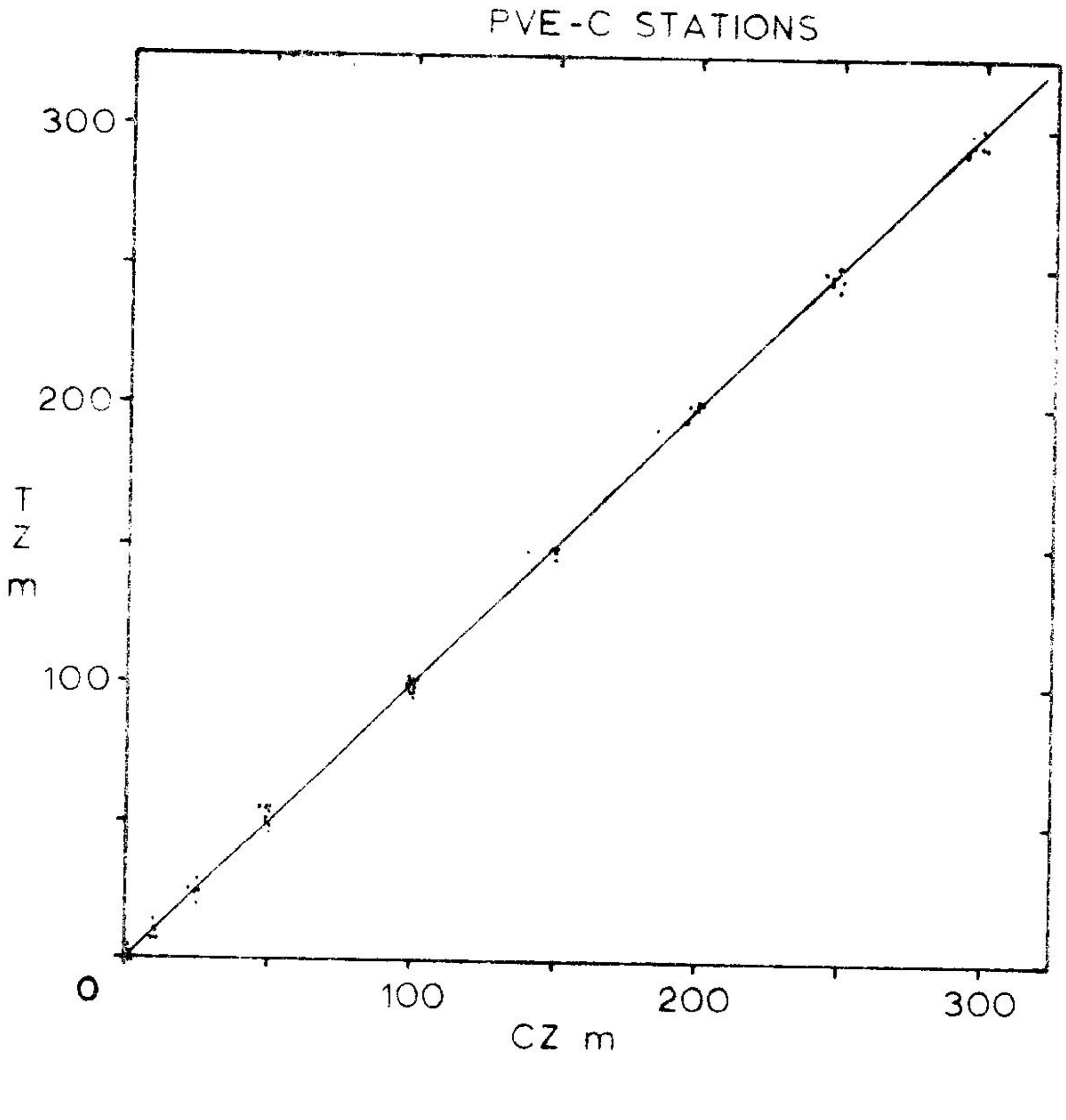


Fig. 2.1-F8 A comparison of sampling depths determined by thermometric (TZ) and wire angle (CZ) calculations.

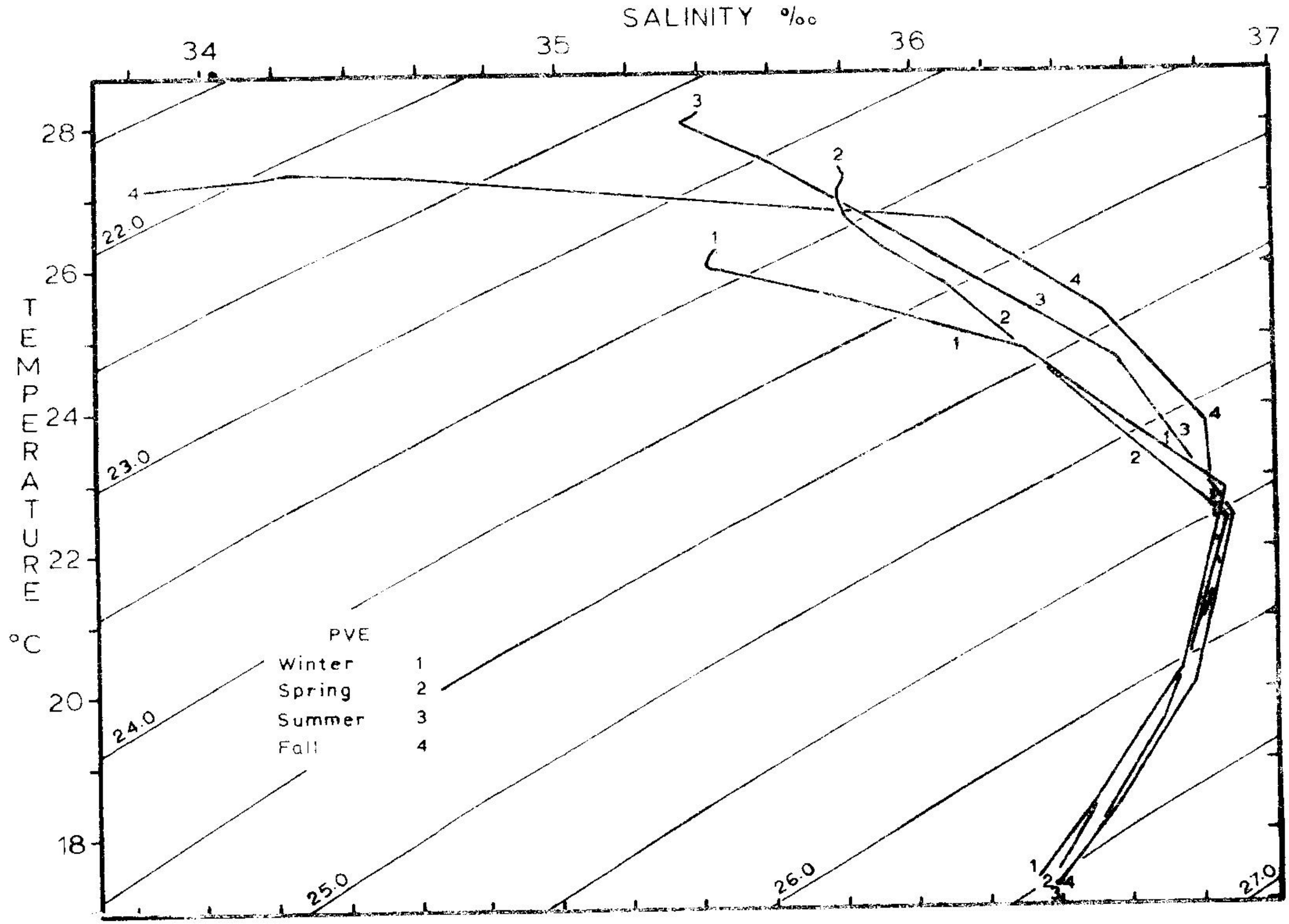


Fig. 2.1-F9 Temperature-salinity diagram of averaged data plotted by season for Punta Verraco, 1973-1974. Diagonal lines indicate density as sigma-t.

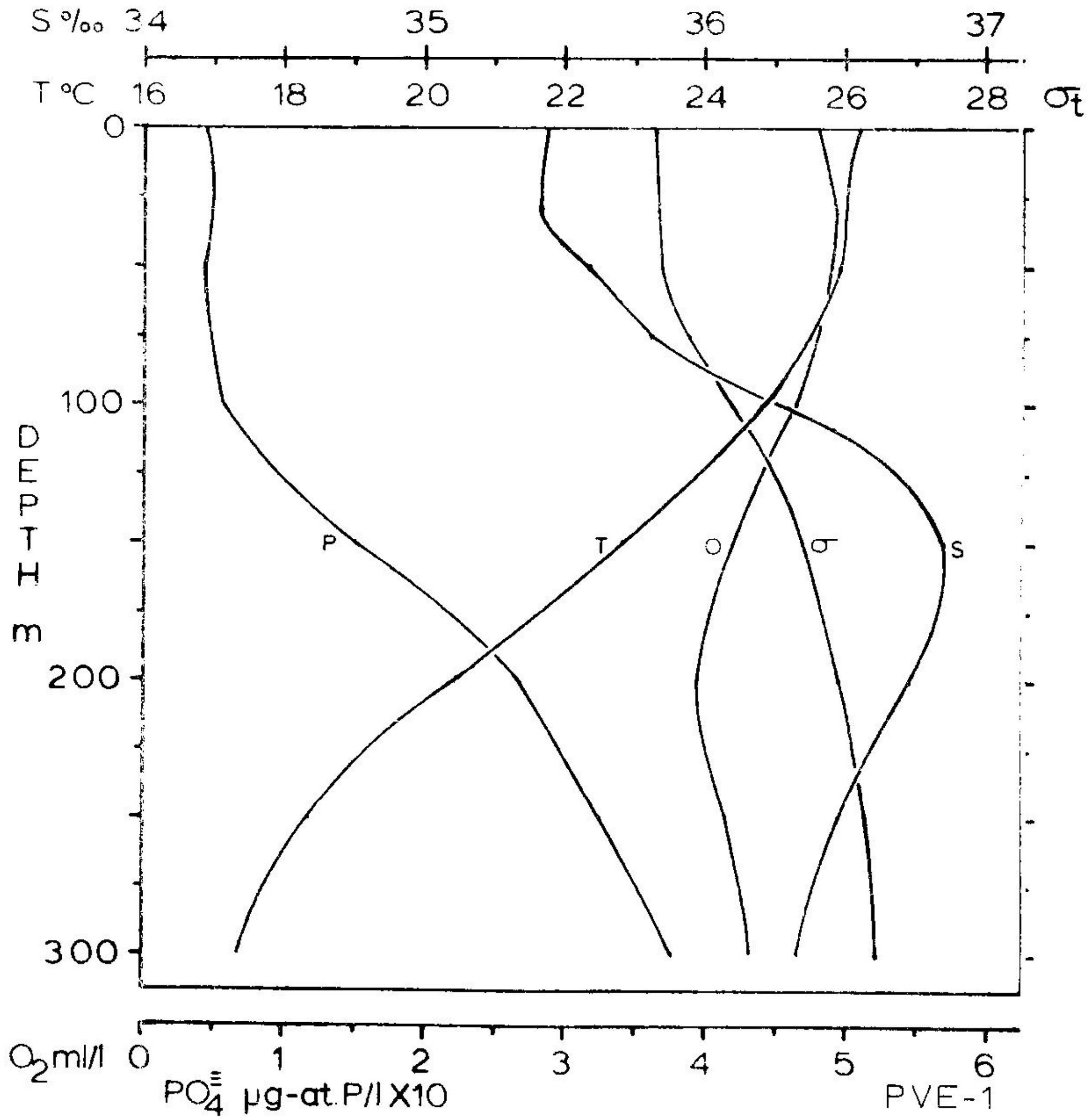


Fig. 2.1-F10 Averaged hydrographic parameter (temperature, T°C; salinity, S°/oo; density, σt; dissolved oxygen, O_2; and reactive phosphate, $PO_4^{\equiv}$) vs. standard depth in meters for the winter season of 1973 and 1974 at Punta Verraco.

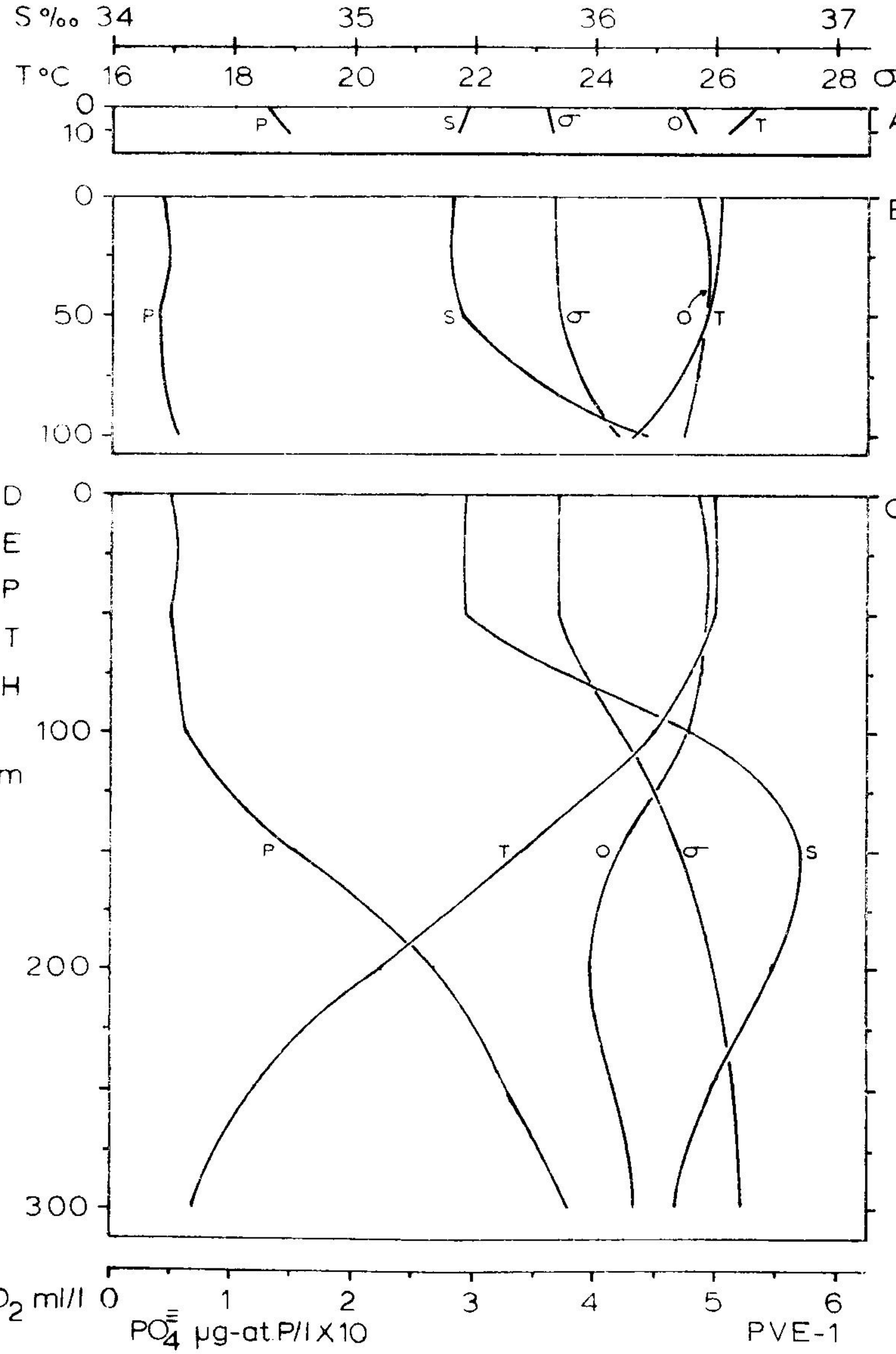


Fig. 2.1-F11 Depth profiles of hydrographic parameters averaged by type of station for the winter season of 1973 and 1974.

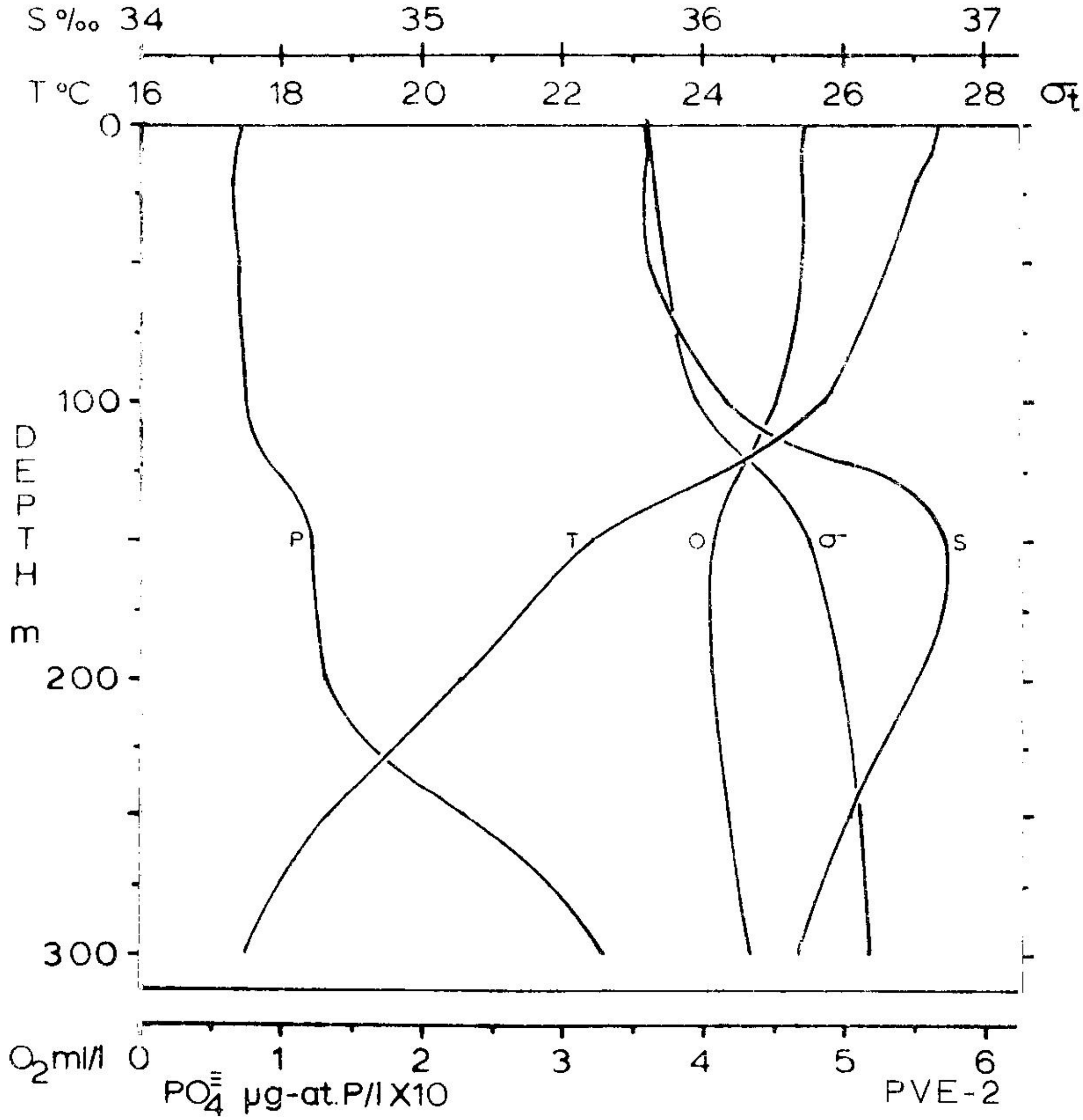


Fig. 2.1-F12 Averaged hydrographic parameter depth profiles for the spring season of 1973 and 1974 at Punta Verraco.

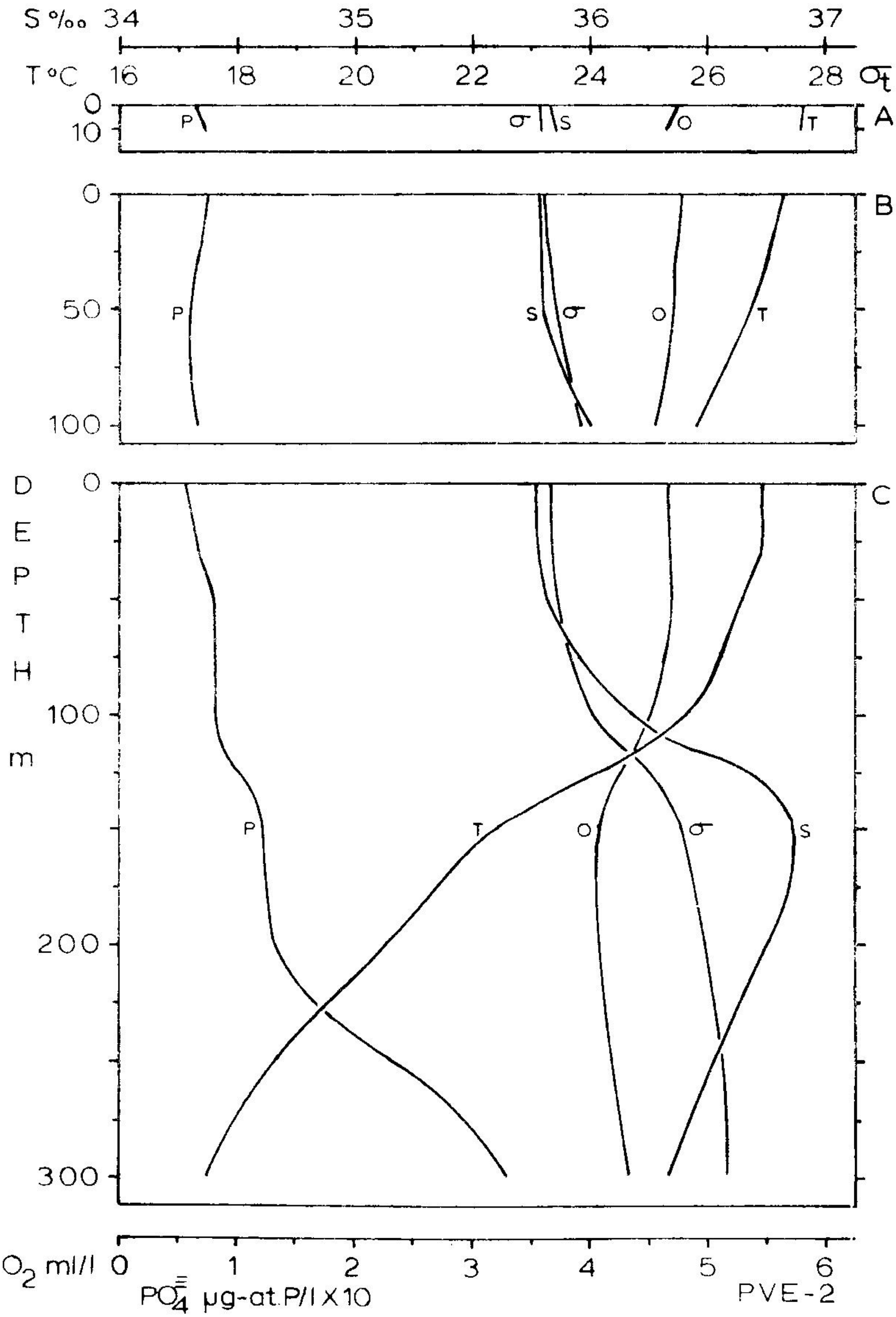


Fig. 2.1-F13 Depth profiles of hydrographic parameters averaged by type of station for the spring season of 1973 and 1974.

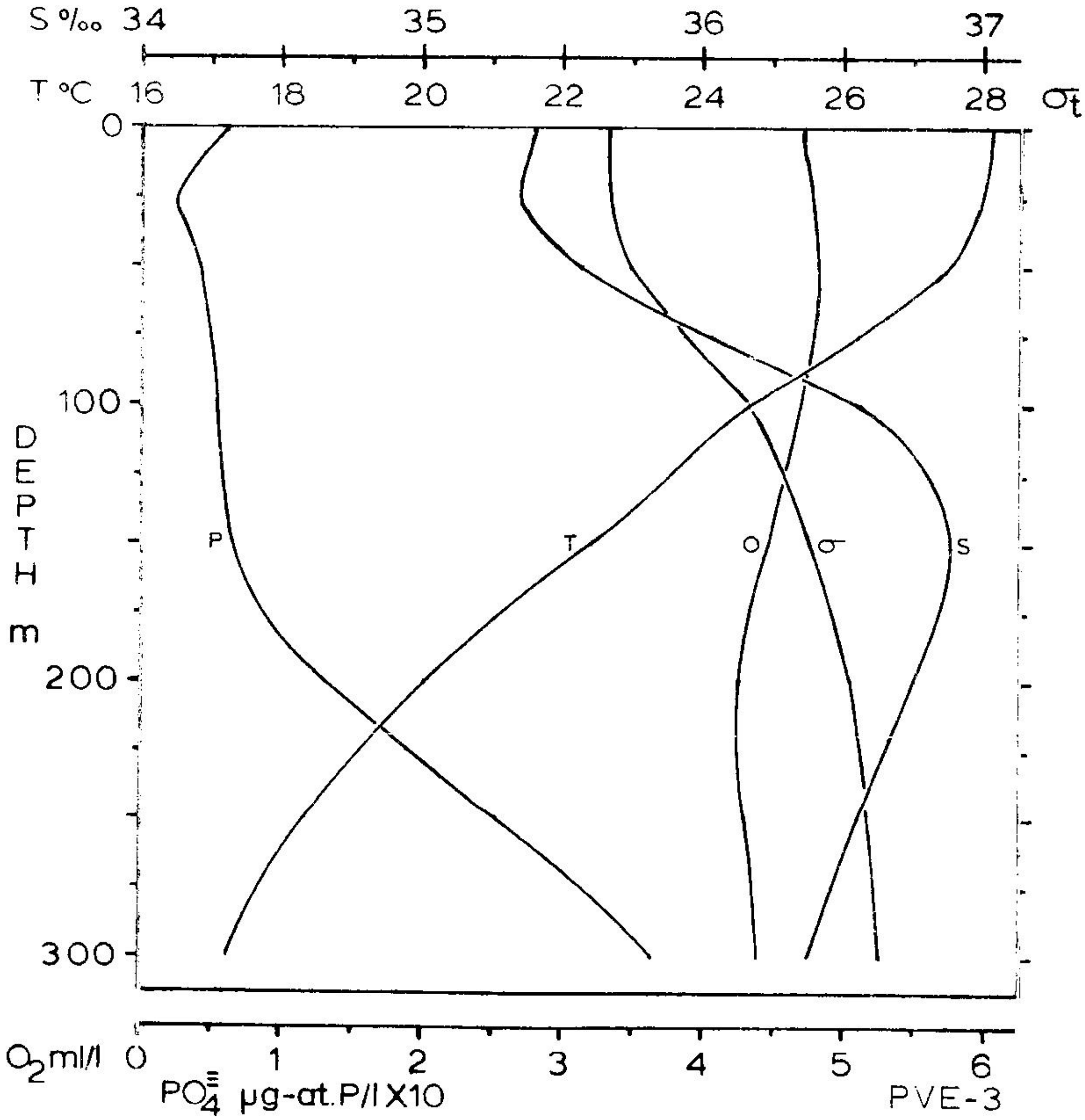


Fig. 2.1-F14 Averaged hydrographic parameter depth profiles for the summer season of 1974.

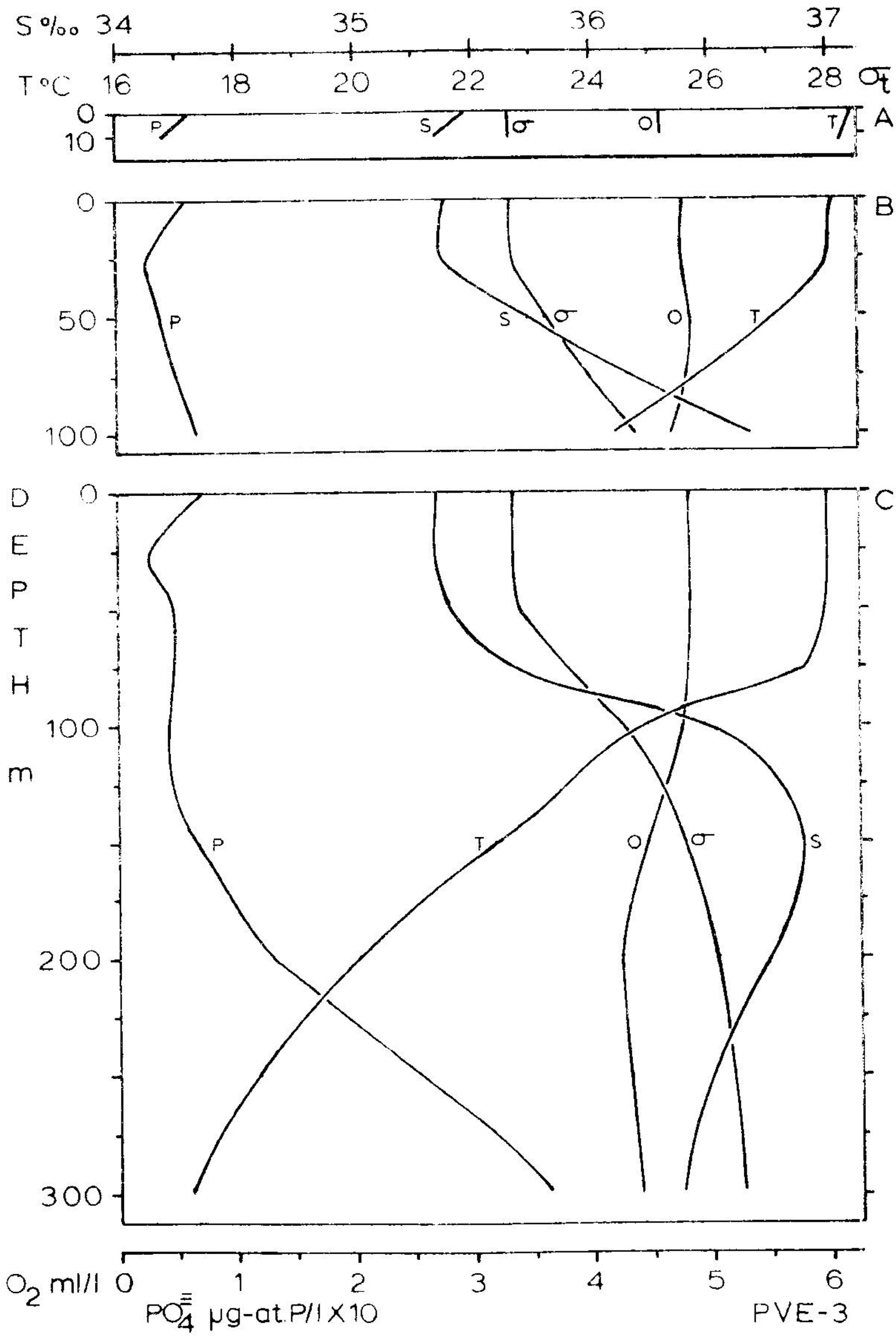


Fig. 2.1-F15 Depth profiles of hydrographic parameters averaged by type of station for the summer season of 1978.

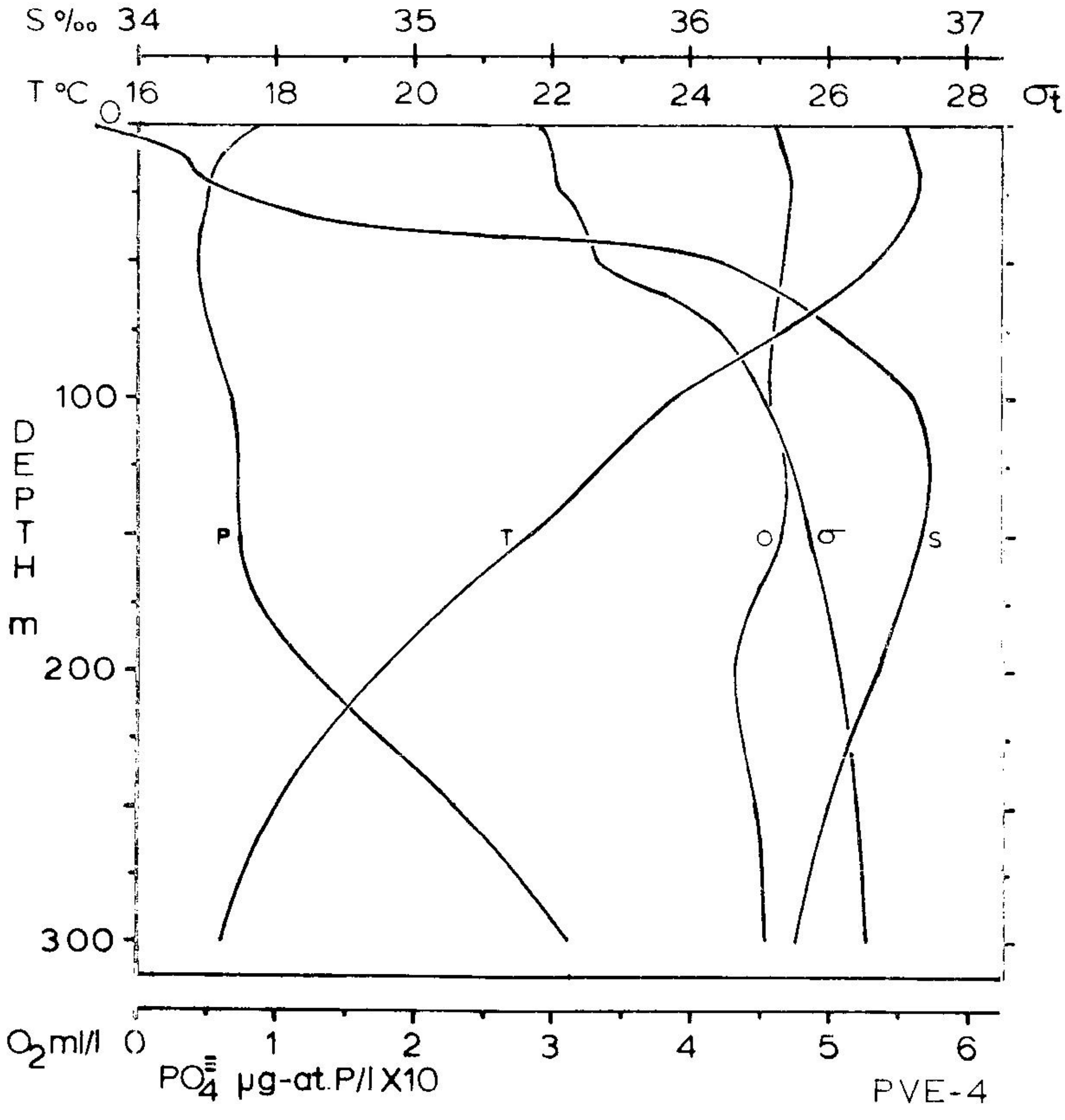


Fig. 2.1-F16 Averaged hydrographic parameter depth profiles for the fall season of 1974.

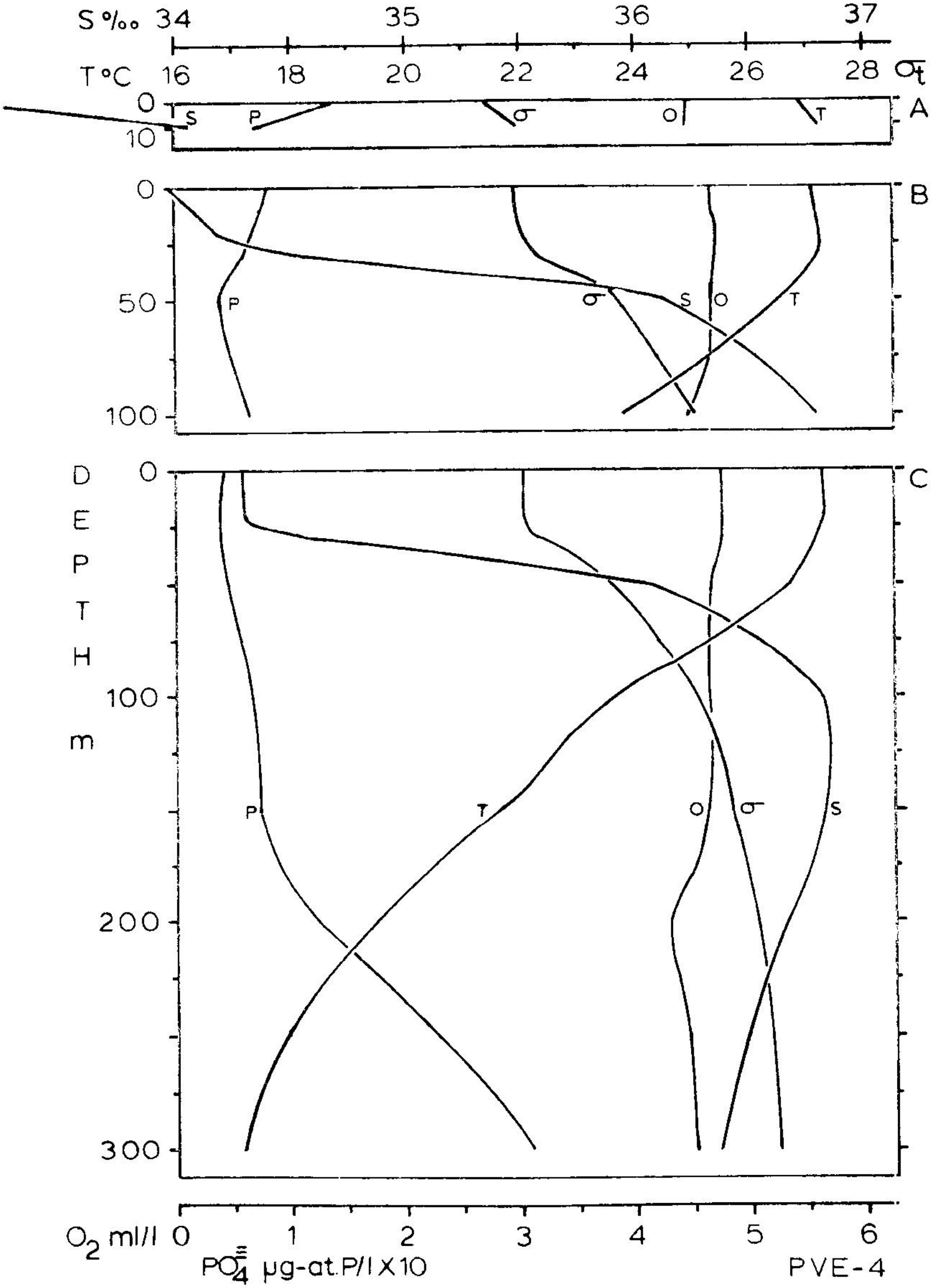


Fig. 2.1-F17 Depth profiles of hydrographic parameters averaged by type of station for the fall season of 1974.

A comparison of the averaged "C" station standard depth temperature data by season is shown in Figure 2.1-F18. 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 lag.") 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 150 meter depth interval between winter and fall. The thermocline during summer was 75 meters and in the fall was about 50 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, 15 and 17). This increase is due mostly from the large quantities of waste heat discharged from the Corco Refinery complex, the PRWRA power plants and to a lesser extent the industries located on the north side of Guayanilla Bay (Wood, 1975b). 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 bathythermography, BT, to 300 meters. The BT traces are in Appendix 2.1B.

The sea surface temperatures at Punta Verraco were mapped seasonally by aerial infrared scanning (Wood, 1975b). 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 1°C by the time the water flows westward along the south side of Punta Verraco past Punta Ventana.

Salinity

Salinity, S°/oo, 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

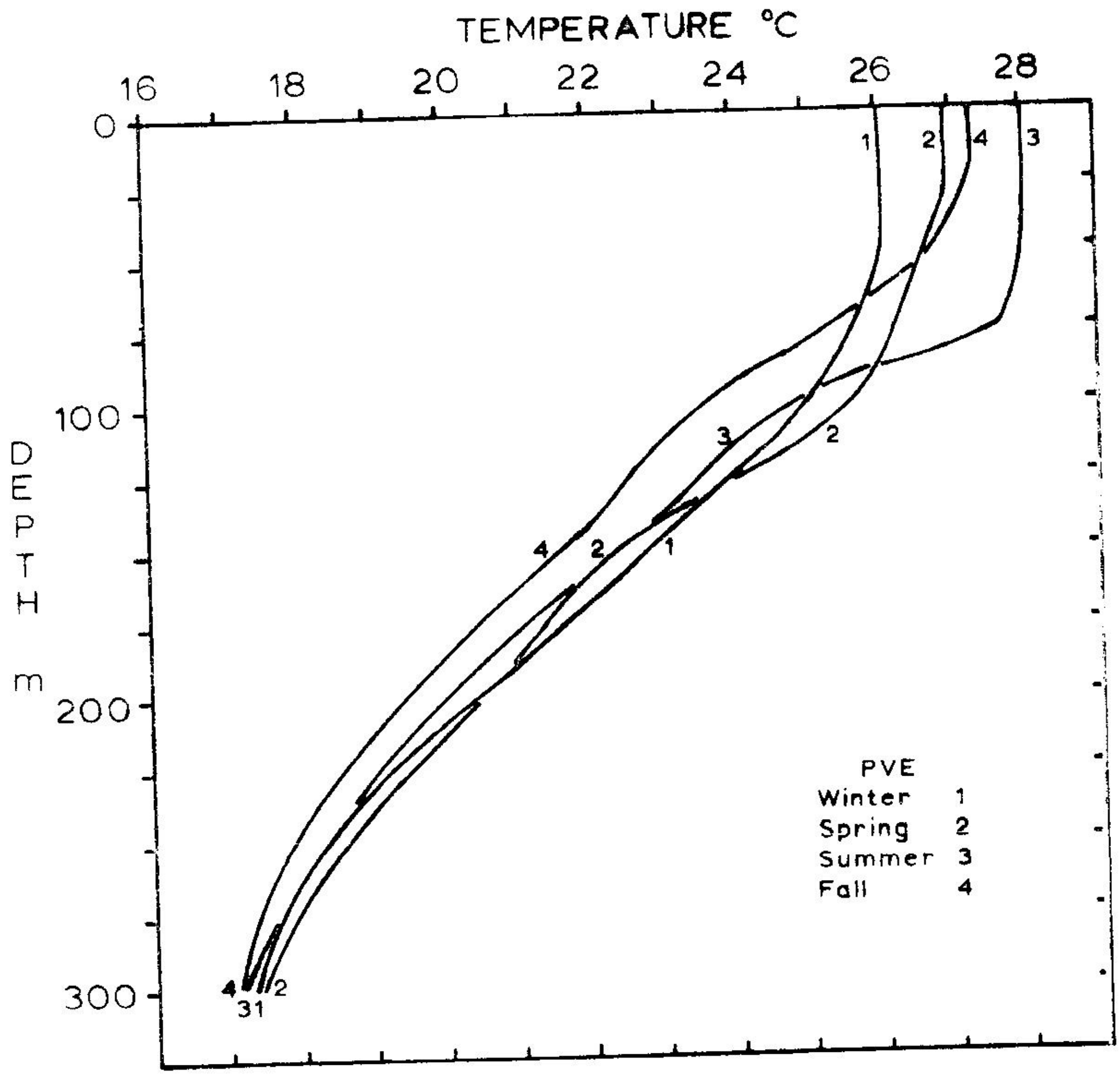


Fig. 2.1-F18 Averaged seasonal depth profiles of "C" station temperatures at Punta Verraco for 1973 and 1974.

evaporation. The salinities at Punta Verraco were determined using an induction salinometer with the readings good to better than ± 0.005°/oo. 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 36.9°/oo was formed by evaporation in the sub-tropical North Atlantic Ocean.

A comparison of the averaged "C" 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°/oo 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 36.8 to about 36.3°/oo 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.

Density

Water densities were calculated from temperature and salinity data and included with the other parameters as sigma-t, σ_t. Sigma-t is related to density at the temperature measured, ρ_t, by the following relationship:

$$\sigma_t - (\rho_t - 1) \times 10^3 \qquad (2.1)$$

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 F17.

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

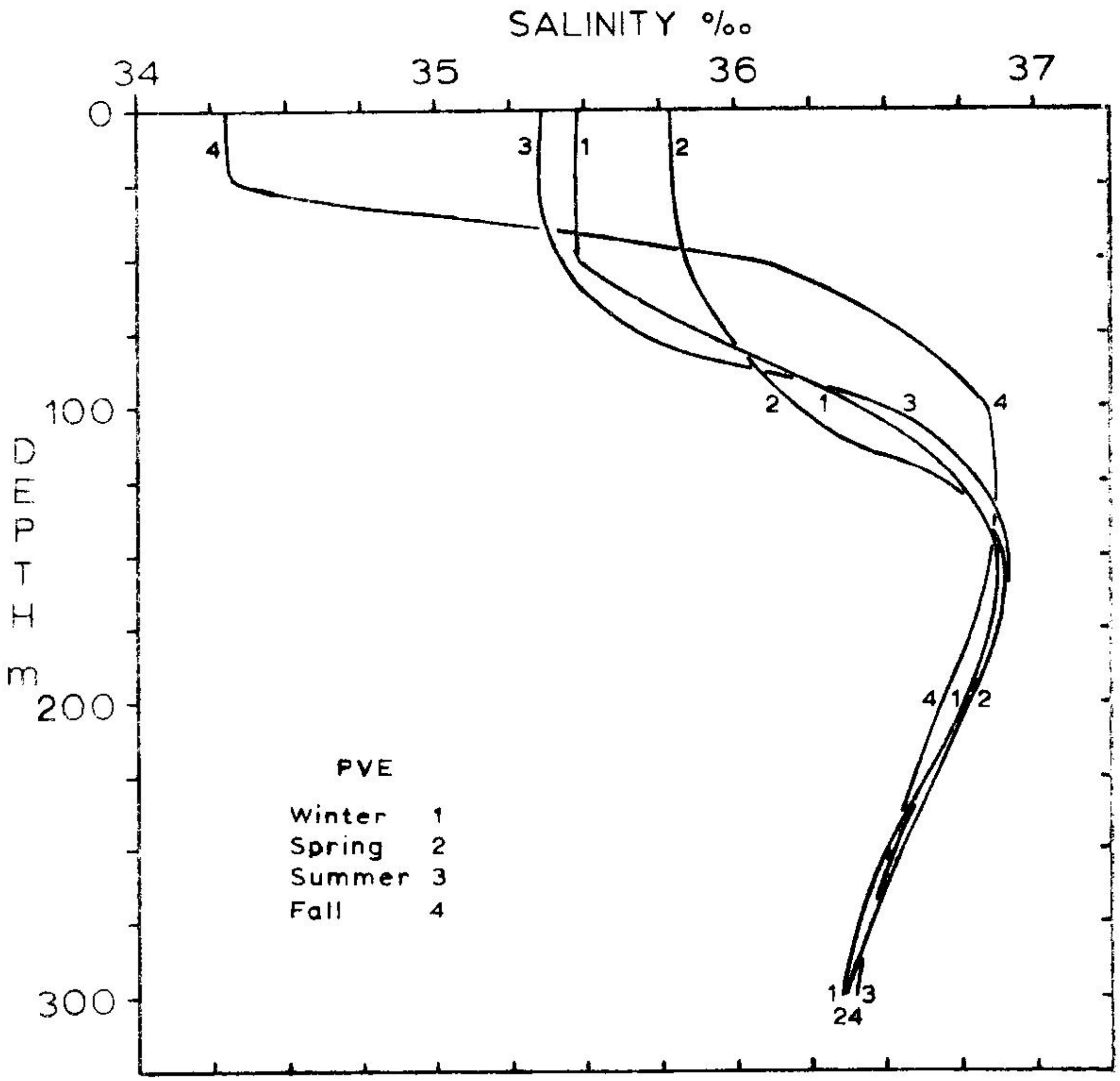


Fig. 2.1-F19 Averaged seasonal depth profiles of "C" station salinities at Punta Verraco for 1973 and 1974.

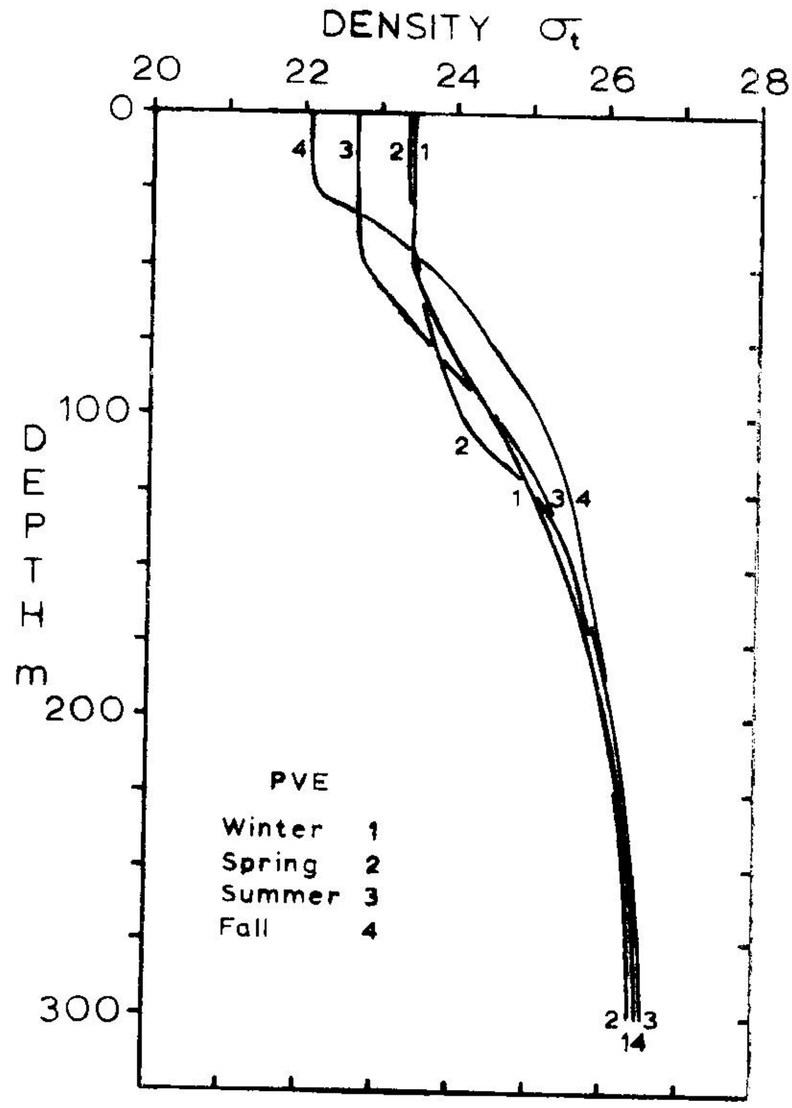


Fig. 2.1-F20 Averaged water density (sigma-t) profiles of "C" station data plotted by season for Punta Verraco, 1973 and 1974.

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, 13, 15 and 17. 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 surface flow. Both wind and the Coriolis effect then cause this flow to turn to the west.

2.2 CHEMISTRY

2.2.1 DISSOLVED OXYGEN

The amounts of dissolved oxygen, D.O., in the water off Punta Verraco were determined by the Winkler titration method (Strickland and Parsons, 1968) with the analyses usually performed on shipboard within a few hours of sample collection. The titration values are generally good to better than ± 1%. Dissolved oxygen data are included with the hydrographic data reported by Wood and Asencio (1975) in mℓ/ℓ, 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 2.2-F1. The oxygen minimum occurred at about 200 meters for all seasons except spring when it was at about 160 meters. The lowest D.O. values were about 3.9 mℓ/ℓ at 200 m during the winter season. Many "A" station D.O. values were only about 90% 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.

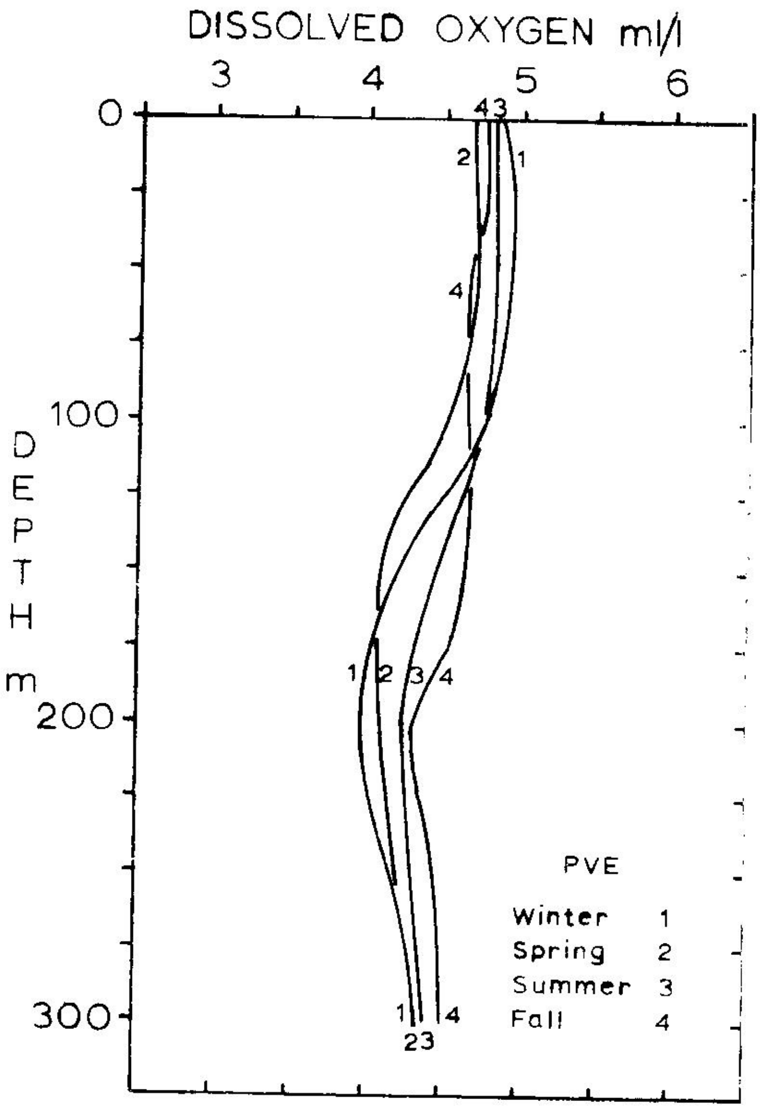


Fig. 2.2-F1 Averaged dissolved oxygen depth profiles by season at Punta Verraco for 1973 and 1974.

Reactive phosphate can be determined quickly and accurately with the Murphy and Riley molybdate blue complex method (Strickland and Parson, 1968) and is a good indicator of pollution. A limited number of nitrate analyses were performed on the waters off Punta Verraco. The tropical regions around Puerto Rico are 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 nearly 200 meters before increasing to about 0.33 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 at 300 meters.

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 coincided with low salinity (runoff) in the fall but the phosphate source is not obvious for the winter season.

Nitrate

Nitrate was determined by the cadmium-copper reduction method (Wood et al., 1967). A limited number of samples were analyzed for nitrate at Punta Verraco for the summer and fall seasons of 1974. The "C" station data were plotted by season in Figure 2.2-F3. The concentration of nitrate was less than 1 μg-at. N/ℓ from the surface to about 75 meters in the summer and less than one to about 35 meters in the fall except for a surface value of nearly 2 μg-at. N/ℓ. Nitrate values were higher in the fall than the summer between 30 and 125 meters. Little seasonal difference existed below 125 meters. The concentration of nitrate increased from about 2 μg-at. N/ℓ at 100 meters to over 13 at 300 meters.

The only anomalies of significance in the nitrate data were values to 6 μg-at. N/ℓ at PVE-4A and 2.88 at PVE-4B and 9.20 at PVE-6A.

High nitrate values were found in the nearshore stations in the fall season: 6.0, 2.9 and 9.2 μg-at. N/ℓ at PVE-4A, 4B and 6A, respectively. This coincided with high phosphate and low salinity values for these stations for the same season.

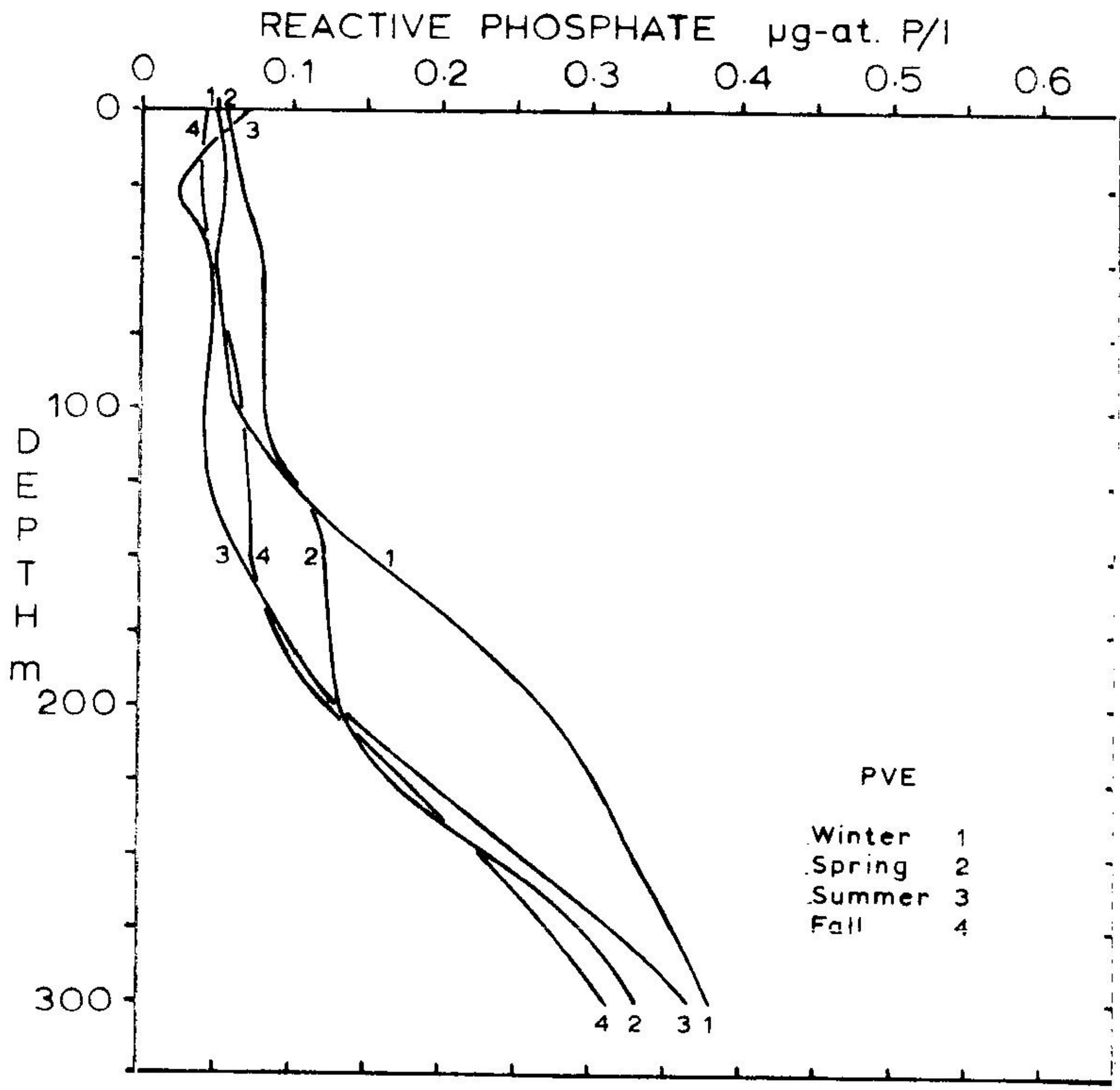


Fig. 2.2-F2 Averaged reactive phosphate depth profiles by season, 1973 and 1974.

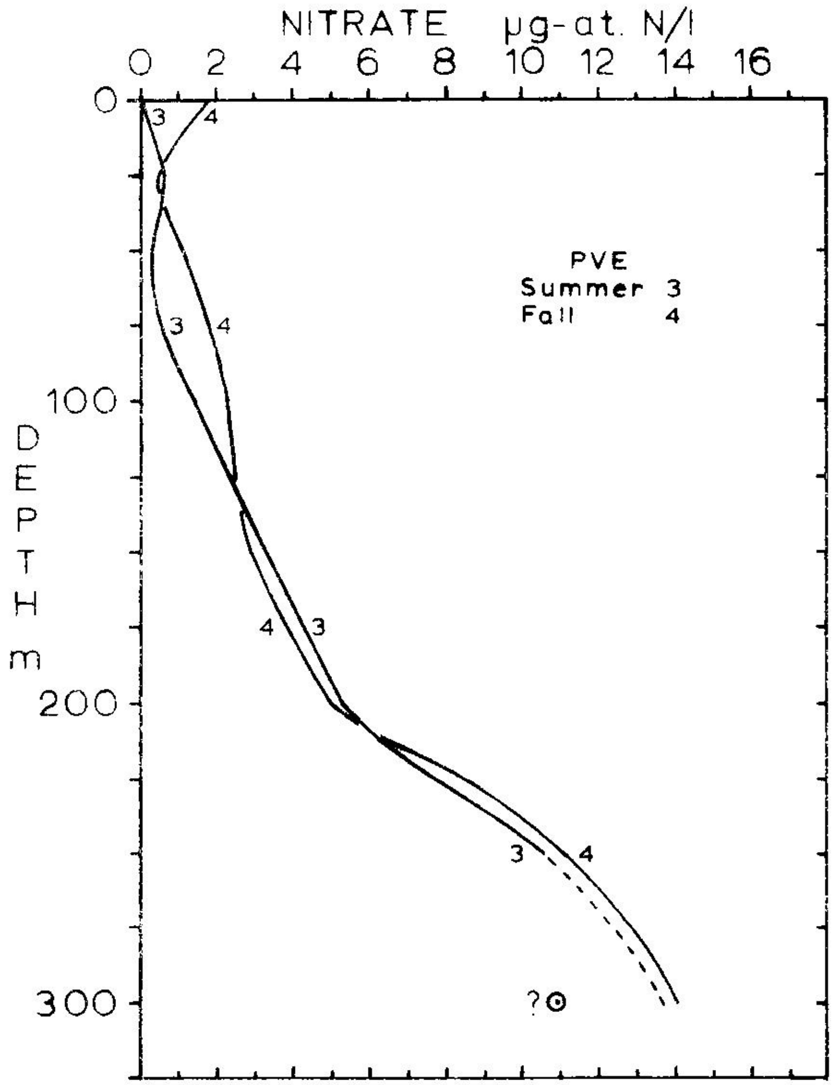


Fig. 2.2-F3 Nitrate depth profiles for the summer and fall seasons of 1974 at Punta Verraco.

3.1 GEOLOGICAL PARAMETERS AT PUNTA VERRACO

by

E.D. Wood

3.1.1 INTRODUCTION

The geology of the Punta Verraco site was described in an earlier report (Beck, 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 3.1-F1) being a long abandoned valley of the Rio 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 within 0.8 kilometers of the shore (Figure 3.1-F1). Coastal dunes, however, protect this channel from even the most major floods; these dunes stayed above water during the disastrous flooding of 1928, the highest flood for which records are 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 an 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, 1965).

<u>Sediments</u>

There are three general regions along the Punta Verraco site with respect to sediments. First, the shallow regions seaward 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.

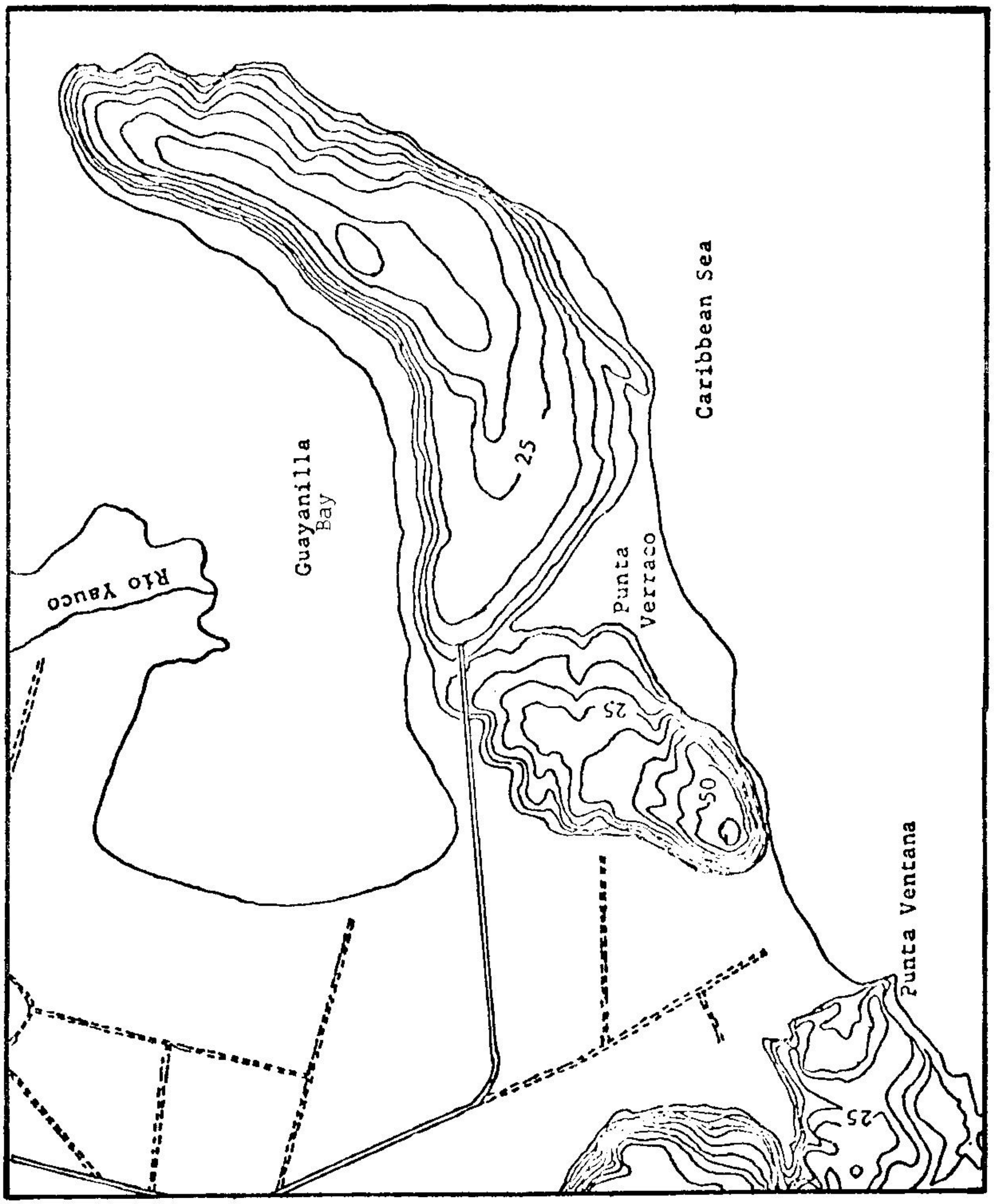


Fig. 3.1-F1 Topographic Map of Punta Verraco Area (from the U.S.G.S. Punta Verraco Quadrangle) Contour interval is 5 meters; this map is approximately 3.6 km. wide.

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 are very fine and high in organic matter. Two such areas were sampled (PVE-4A and 6A). Station PVE-4A is in the middle of the Yauco submarine canyon and PVE-6A is in the main channel into Guayanilla Bay.

The sediments from these two stations were air dried and sieved for size distribution. The PVE-6A 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 3.1-T1 Size analysis statistics for the Punta Verraco sediments

STATIONS	MEDIAN Mdø	MEAN Mø	STD. DEV. σø
PVE-4A	3.5	3.1	1.2
PVE-6A	3.2	3.2	0.7

The mean Mø 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 ø) 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.

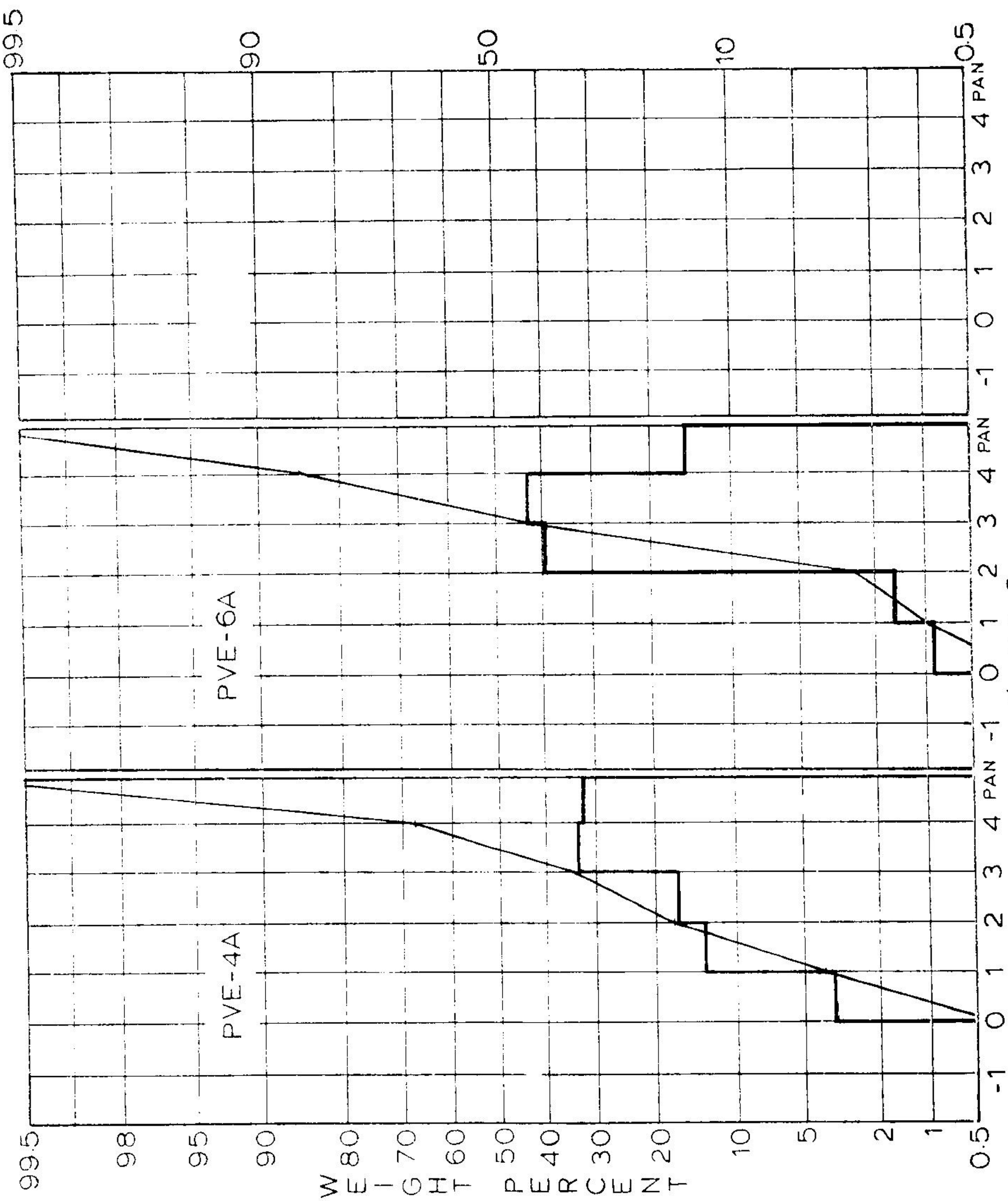


Fig. 3.1-F2 Histograms and cumulative weight percent plots of sediments at Stations PVE-4A and 6A.

4.1 ZOOPLANKTON STUDIES 1973-1974

by

Marsh J. Youngbluth

4.1.1 INTRODUCTION

The following report provides estimates of the abundance and density of zooplankton in the surface waters along a 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 1973 and 1974---21 February, 22 May, 28 November, 12 February, 22 April, 21 August, and 13 November.

4.1.2 MATERIALS AND METHODS

Field Procedures

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 233 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 and 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 sea water with the aid of a battery driven pump (12 volt, Jabsco water-puppy). The catch was preserved in 4% sea water formalin buffered to pH 7.6. All samples were gathered during the daylight hours. The volume of water filtered through a 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-F1).

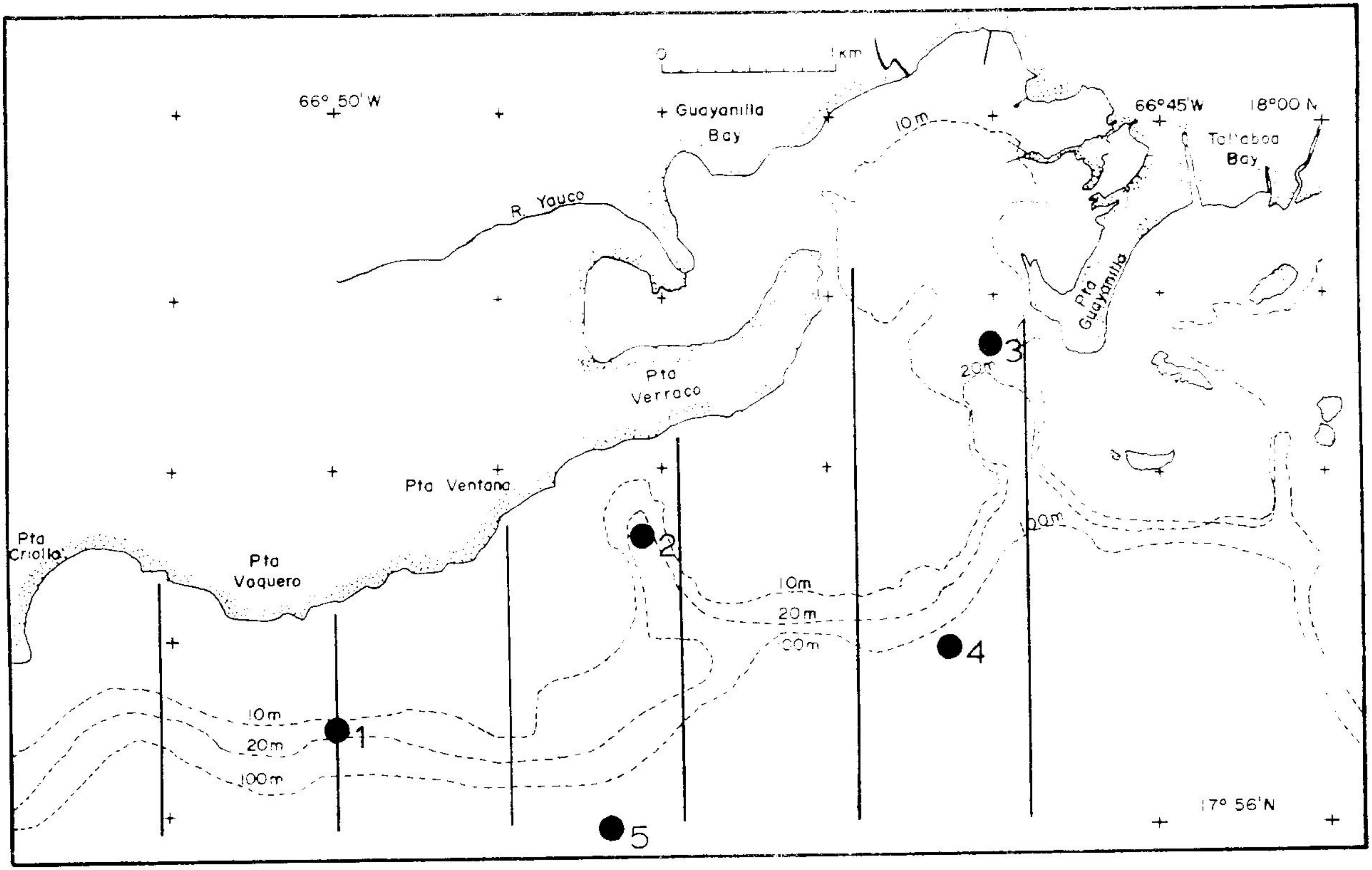


Fig. 4.1-F1 Zooplankton stations at Punta Verraco.

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 202 micron 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 (Ahlstrom and Thraikill 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 meroplankton were 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 45) and more recently with a computer (PDP-10). See Appendix 4.1A 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-T6-17). 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.

TABLE 4.1-T1. Summary of ratios between the highest and lowest density values of total zooplankton during each period.

	1973 21 Feb	1973 22 May	1973 28 Nov	1974 12 Feb	1974 22 Apr	1974 21 Aug	1974 13 Nov
Consecutive Tows	2.6	2.1	1.3	1.5	1.5	2.2/1.5	2.8
Nearshore Tows	3.8	2.3	12.7	2.4	2.8	3.7	3.1
Offshore Tows	---	2.9	5.5	1.5	---	4.7	1.6
All Tows	3.8	3.1	12.7	2.9	3.3	6.2	4.5

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 4.1-T2. Total zooplankton (10 transformed) from 7 sets of replicate tows. The number of replicate tows (n) needed to detect a +5-70% difference in density is indicated.*

Date	1973 21 Feb	1973 22 May	1973 28 Nov	1974 12 Feb	1974 22 Apr	1974 21 Aug	1974 13 Nov
Station	2	2	2	2	2	2	2
	3.16761	3.29380	3.71079	2.83569	2.89432	3.60541 / 2.86864+	3.78490
	2.80082	3.23955	3.80875	2.65228	3.06145	3.33965 / 2.70157	3.34635
	2.75358	2.96473	3.68215	2.72509	2.94988	3.26126 / 2.72754	3.56419
n 5%	380	231	33	125	103	241/60	356
n 30%	11	6	1	3	3	7/2	10
n 50%	4	2	1	1	1	2/1	4
n 70%	2	1	1	1	1	1/1	2

*$n = t^2 \times s^2$ Where (t) is Student's t for the 95% confidence level (d.f.=2), s^2 is the sample variance based on replicate tows, and d is the half-width of the confidence interval desired.
+ midnight/midday values.

These data indicate that a large number of replicate tows would be necessary to detect density differences at the 5% level. However, on the average, differences of 50% can be noted with only 3 tows. Differences of 70% or more may be revealed with a single tow. Density estimates larger than 70% or more were found within and between nearshore and offshore catches. The range of density values during a sampling period was usually two to four-fold.

Seasonal changes in the average abundance of total zooplankton were small, i.e., about 3 to 5X (Table 4.1-T3). The highest concentrations occurred in November each year. These larger densities, however, probably represent the range of variation among tropical zooplankton communities in the coastal waters around Puerto Rico rather than recurrent seasonal pulses since the 95% confidence limits from each station overlap.

TABLE 4.1-T3. Average density of all zooplankton collected

Total Zooplankton/m^3

	1973			1974			
	21 Feb	22 May	28 Nov	12 Feb	22 Apr	27 Aug	13 Nov
Range	463-1980	848-2584	430-3478	227-962	284-942	350-2165	890-3994
Median	890	1541	2632	555	348	1617	1449
Mean	1044	1661	2528	540	480	1272	1861
95% C.L.	±1669	±1032	±2597	±358	±492	±954	±1522

The preceding fluctuations in density refer primarily to holoplanktonic organisms since they composed, in most cases, 70 to 90% of the total zooplankton. Meroplankton were most abundant on 22 May 1973 and 13 November 1974. In proportion to holoplankton they were very numerous during 21 August 1974 when they formed over 30% of the total zooplankton. On two occasions at Station 3, on 22 May 1973 and 22 April 1974, 50 to 59% of the zooplankton caught were meroplanktonic forms. In both instances barnacle nauplii and caridean larvae were abundant.

Fish eggs were abundant in this area although they usually composed less than 5% of the total zooplankton (Table 4.1-T4). The largest density, 552/m, was observed at

Station 5 on 28 November 1973. Fish eggs were most numerous on 12 February 1974 when they averaged $87/m^3$ and formed 20% of all zooplankton. The largest densities were generally found at the offshore stations. Most of the eggs were round and 0.5 to 2 mm in diameter. Oblong eggs were common. It is not known which groups of fish are represented by most of the eggs.

TABLE 4.1-T4. Summary of densities of fish eggs from all stations sampled at Punta Verraco.

	Station					
	1	2	3	4	5	ALL
Range	2-44	7-42	8-148	8-107	33-552	2-552
Median	13	20	13	88	88	33
Mean	20	21	51	73	155	64

All groups tended to be more numerous in the night samples. The overall density increase was about 5 times the day level. Holoplankton were 3X numerous, meroplankton about 8X. The bulk of the holoplankton were copepods. Decapod larvae and cirripede nauplii dominated the meroplankton. A similarly large nocturnal increase in meroplankton was also noted in a series of diurnal samples gathered at the Islote and Cabo Mala Pascua sites (Youngbluth 1974).

Copepods formed 50 to 90% of the zooplankton community. A total of 37 species were identified. Time did not allow a 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 4.1-T5.

TABLE 4.1-T5. Copepod populations observed at Punta Verraco.

Species usually most numerous (5 individuals/m³)
Clausocalanus furcatus
Paracalanus spp. (*P. aculeatus*, *P. crassirostris*, *P. parvus*)
Farranula gracilis
Oithona spp. (*O. plumifera*, *O.* spp.)
Acartia spinata
A. lilljeborgii
Temora turbinata
Species commonly present (observed on 5 or more sampling periods)
Corycaeus spp. (*C. giesbrechti*, *C. pacificus*, *C. speciosus*)
Euterpina acutifrons
Calanopia americana
Undinula vulgaris
Species occasionally present
Euchaeta marina
Corycaeus spp. (*C. pavo*, *C. pavoninus*)
Pseudodiaptomis cokeri
Nannocalanus minor
Calocalanus spp. (*C. pavo*, *C. pavoninus*
Centropages spp. (*C. furcatus*, *C. caribbeanensis*)
Scolecithrix danae
Labidocera spp. (*L. scotti*, *L.* spp.)
Candacia pachydactyla
Mecynocera clausi
Acrocalansu longicornis
Eucalanus spp.
Lucicutia flavicornia
Temora stylifera

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 and May. Fish eggs were most numerous during February 1974. These planktonic eggs were also generally more abundant offshore.

Limitations of the Data

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 biomass 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, i.e., net type, net 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.

TABLE 4.1-T6 Total biomass of zooplankton (ml/m^3) Punta Verraco Site

DATE	Nearshore Replicate Tows Stations			Nearshore Tows Stations			Offshore Tows Stations	
	2a	2b	2c	1	2	3	5	4
210273	.134	.113	.117	.070	.121	.193	-	-
220573	.108	.128	.082	.083	.106	.112	.087	.217
281173	.251	.274	.248	.107	.258	.092	.031	.090
120274	.123	.116	.082	.061	.107	.041	.131	.105
220474	.107	.110	.089	.046	.102	.095	.054	-
210874*	.184/.052	.200/.041	.168/.052	.153	.184/.048	.192	.135	.034
131174	.253	.145	.144	.060	.181	.122	.189	.191

TABLE 4.1-T7 Total number of zooplankton ($number/m^3$)

DATE	Nearshore Replicate Tows Stations			Nearshore Tows Stations			Offshore Tows Stations	
	2a	2b	2c	1	2	3	5	4
210273	1471	632	567	463	890	1780	-	-
220573	1967	1736	922	880	1541	2584	848	2453
281173	5138	6438	4810	2632	5462	430	3478	636
120274	685	449	531	323	555	227	633	962
220474	784	1152	891	364	942	332	284	-
210874*	4031/739	2186/503	1825/534	1617	2681/592	2165	1637	350
131174	6094	2220	3666	1301	3994	1669	890	1449

*Midnight/midday tows.

TABLE 4.1-T8 Total number of holoplankton (number/m^3) Punta Verraco Site

DATE	Nearshore Replicate Tows Stations			Nearshore Tows Stations			Offshore Tows Stations	
	2a	2b	2c	1	2	3	5	4
210273	1392	592	523	387	835	1046	-	-
220573	1553	1296	635	682	1161	1548	705	2147
281173	4994	6292	4672	2546	5319	200	2879	520
120274	478	289	345	251	371	101	465	531
220474	644	972	715	315	777	125	197	-
210874*	1060/455	1212/316	971/360	1049	1080/377	1825	1456	267
131174	499	1842	3137	1106	3323	1333	777	1332

TABLE 4.1-T9 Total number of meroplankton (number/m^3)

DATE	Nearshore Replicate Tows Stations			Nearshore Tows Stations			Offshore Tows Stations	
	2a	2b	2c	1	2	3	5	4
210273	52	27	37	72	39	721	-	-
220573	362	422	248	187	344	971	77	179
281173	46	40	64	40	50	220	41	25
120274	124	75	72	45	90	15	59	24
220474	125	167	167	36	153	197	5	-
210874*	2819/264	931/161	794/161	553	1515/199	173	83	74
131174	1089	384	523	149	665	326	45	49

*Midnight/midday tows.

TABLE 4.1-T10 Total number of copepods (number/m^3) Punta Verraco Site

DATE	Nearshore Replicate Tows Stations 2a	2b	2c	Nearshore Tows Stations 1	2	3	Offshore Tows Stations 5	4
210273	1203	536	460	329	733	859	-	-
220573	1158	1056	458	602	890	1488	563	1849
281173	4795	5971	4435	2394	5067	151	2333	409
120274	402	243	294	230	313	82	430	743
220474	499	675	495	221	556	115	168	-
210874*	988/445	1027/311	851/348	1002	955/368	1641	1318	234
131174	4737	1766	2961	997	3155	1251	693	1266

TABLE 4.1-T11 Total number of chaetognaths (number/10m^3)

DATE	Nearshore Replicate Tows Stations 2a	2b	2c	Nearshore Tows Stations 1	2	3	Offshore Tows Stations 5	4
210273	67	98	95	70	87	134	-	-
220573	26	128	62	18	72	398	77	231
281173	232	334	289	160	285	42	439	131
120274	207	163	89	87	153	56	110	84
220474	107	236	87	23	143	45	98	-
210874*	120/53	152/20	92/15	202	121/29	659	357	100
131174	325	448	882	92	552	292	130	191

*Midnight/midday tows.

TABLE 4.1-T12 Total number of larvaceans (number/10m^3) Punta Verraco Site

DATE	Nearshore Replicate Tows Stations 2a	2b	2c	Nearshore Tows Stations 1	2	3	Offshore Tows Stations 5	4
210273	904	151	230	162	428	267	-	-
220573	2321	588	479	422	1129	50	1079	156
281173	279	200	58	160	179	436	4328	82
120274	98	85	74	15	86	6	25	309
220474	61	+	17	15	26	6	73	-
210874*	80/38	1175/27	611/96	90	622/54	1125	882	172
131174	731	85	63	350	293	146	179	218

TABLE 4.1-T13 Total number of veliger larvae (number/10m^3)

DATE	Nearshore Replicate Tows Stations 2a	2b	2c	Nearshore Tows Stations 1	2	3	Offshore Tows Stations 5	4
210273	921	308	305	348	511	267	-	-
220573	1530	1610	1165	294	1425	149	231	1156
281173	928	1868	1444	935	1413	50	376	65
120274	391	147	311	103	283	108	147	422
220474	1240	2626	2022	838	1962	11	80	-
210874*	1080/365	392/271	168/103	247	546/263	1098	119	238
131174	1381	107	819	497	769	195	110	136

*Midnight/midday tows.

TABLE 4.1-T14 Total number of caridean larvae (number/10m^3) Punta Verraco Site

	Nearshore Replicate Tows Stations			Nearshore Tows Stations			Offshore Tows Stations	
DATE	2a	2b	2c	1	2	3	5	4
210273	218	124	183	417	175	2047	-	-
220573	714	332	395	294	481	3982	193	549
281173	46	133	+	53	60	193	157	147
120274	478	217	267	289	321	62	196	42
220474	321	345	558	53	408	323	18	-
210874*	21714/1216	3046/1216	3085/840	2471	9282/859	357	214	196
131174	8532	2754	4032	552	5106	1217	279	355

TABLE 4.1-T15 Total number of brachyuran larvae (number/10m^3)

	Nearshore Replicate Tows Stations			Nearshore Tows Stations			Offshore Tows Stations	
DATE	2a	2b	2c	1	2	3	5	4
210273	67	92	88	162	82	445	-	-
220573	128	230	42	330	133	149	77	145
281173	+	+	58	160	19	50	+	25
120274	228	194	245	53	222	9	355	42
220474	61	440	401	15	301	28	4	-
210874*	1520/175	631/122	748/44	225	966/114	27	72	69
131174	163	256	126	74	182	49	100	55

*Midnight/midday tows.

TABLE 4.1-T16 Total number of cirripede nauplii (number/10m^3) Punta Verraco Site

DATE	Nearshore Replicate Tows Stations 2a	2b	2c	Nearshore Tows Stations 1	2	3	Offshore Tows Stations 5	4
210273	+	+	+	46	+	4139	-	-
220573	1709	2352	1438	532	1853	4878	193	433
281173	139	+	+	+	46	1827	+	8
120274	402	271	185	30	286	41	+	70
220474	107	126	244	175	159	1575	18	-
210874*	3239/714	4982/664	3742/508	2066	3988/629	220	214	155
131174	1625	641	630	644	965	1752	20	+

TABLE 4.1-T17 Total number of fish eggs (number/m^3)

DATE	Nearshore Replicate Tows Stations 1a	2b	2c	Nearshore Tows Stations 1	2	3	Offshore Tows Stations 5	4
210273	27	14	7	2	16	13	-	-
220573	18	15	35	7	23	60	66	113
281173	97	87	52	40	79	8	552	+
120274	79	81	109	21	90	110	106	107
220474	12	14	7	13	11	9	82	-
210874*	56/14	35/12	53/8	11	48/11	148	93	8
131174	16	2	6	44	8	97	33	49

* Midnight/midday tows.

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 base line 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 1966; 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 on 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; Fager 1972).

What is needed is an awareness of the dynamic processes responsible for a 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 1974.

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 1966); and gorgonians may be useful indicators of such environmental parameters as wave action, currents, and turbidity (Grigg 1972; Opresko 1973; Goldberg 1973; Kinzie 1973).

Clearing experiments were conducted in an attempt to assess the role 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 which 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 a 1/4 m^2 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. Description of the sampling method can be found in Vicente (PRNC-174 1974).

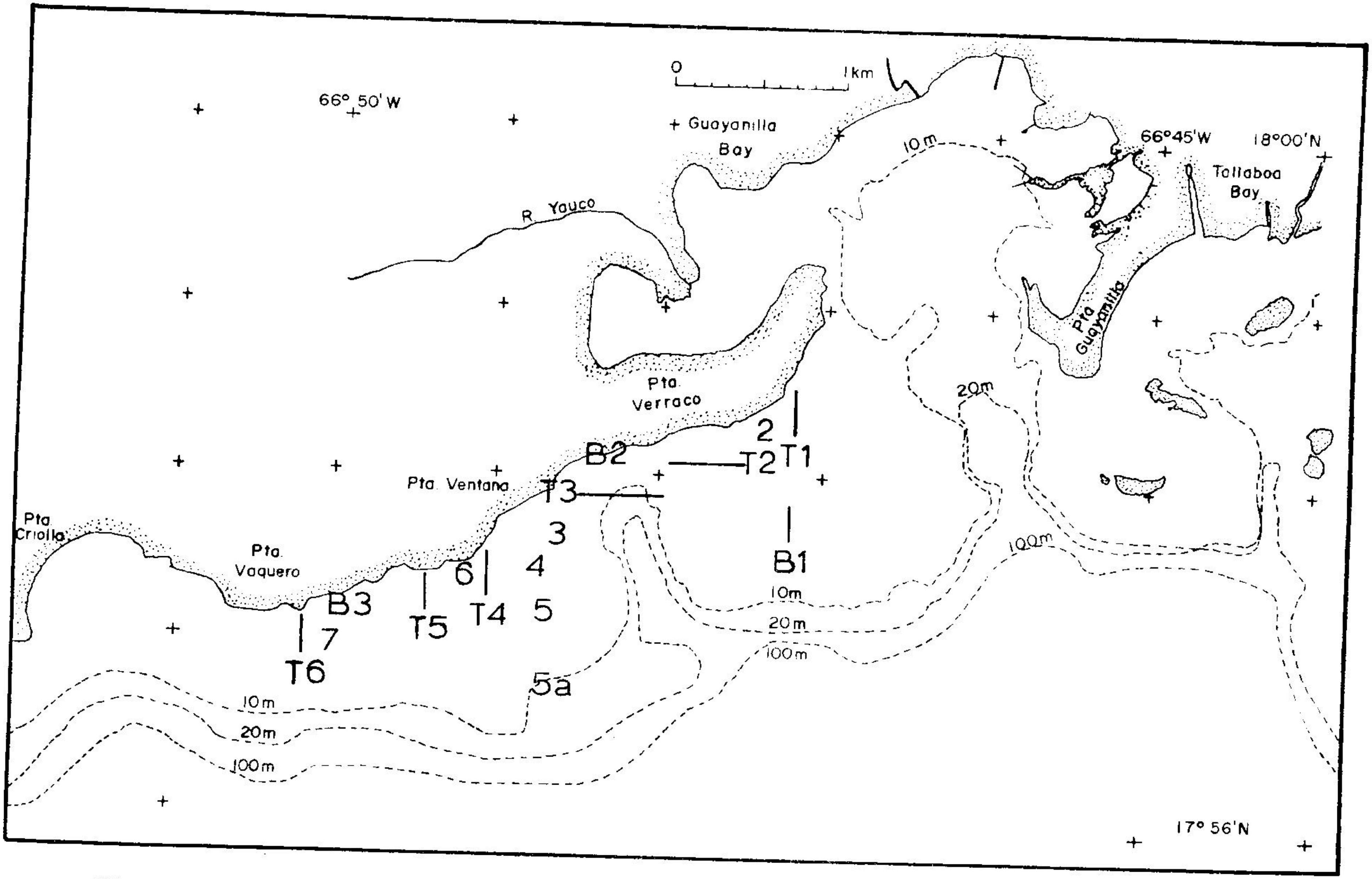


Fig. 4.2-F1 Benthic studies field stations at Punta Verraco.

Gorgonians were collected in 5 m^2 (1 x 5 m) or 10 m^2 (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.

Permanent 1 m^2 (1 x 1 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. In August 1974, the gorgonians in a single 1 m^2 quadrat were tagged and measured.

The quadrats which had been cleared of gorgonians in May 1974 were observed thereafter to assess the effect of established colonies on recruitment of new colonies, their growth, and mortality.

Laboratory Procedures

Gorgonian samples were dried for several weeks, then weighed, measured, and identified. The more familiar species 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 70% ethyl alcohol or 10% buffered formalin for later identification. The samples were often frozen prior to sorting. Taxonomic references used to identify organisms are listed in the bibliography.

4.2.3 RESULTS

Locations and other pertinent information of transects, station dives and beach sites at Punta Verraco are shown in Figure 4.2-F1 and Appendix 4.2A. The following description is based on observations compiled from these dives.

Species collected or identified at three shore locations at the Punta Verraco site are listed in Appendix 4.2B. The results of shoreline fish collections are listed in Appendix 4.2C.

The inshore areas between Punta Verraco and a sand spit island near the entrance of Guayanilla Bay (Transect T1, Station S1) appear to be dominated by Thalassia, Syringodium, Caulerpa, and Diplanthera. Typical Thalassia bed species such as the urchin Tripneustes esculentus and Lytechinus the starfish Oreaster reticulatus, and the molluscs Vasum muricatum and Pinna were observed there. A small coral fringing reef was encountered about 100 m offshore of Punta Verraco. Organisms observed here included the alga Udotea sp., the corals Siderastrea siderea, and Millepora sp., the gorgonians Pseudopterogorgia sp. and Plexaurella sp., the zoanthid Palythoa, and the sponge Sphaeciospongia vesparia. Water depth in this area ranged between 0 and 5 meters.

On the seaward side of the sand spit island the substrate appears to be dominated by algae and some sponges (Station S1). Occasional colonies of corals, principally Diploria strigosa, Porites astreoides and Montastrea annularis were observed. Palythoa, Erythropodium and Millepora were much more abundant than the scleractinian corals. Gorgonians were relatively scarce compared to other reefs and were comprised mostly of two genera, Eunicea and Plexaurella.

The dusky damselfish Pomacentrus fuscus, the sargeant Abedefduf saxatilis, the rock beauty Holocanthus tricolor, the bluehead wrasse Thalassoma bifasciatum, the spanish hogfish Bodianus rufus, the blue tang Acanthurus coerulus, the doctor-fish Acanthurus chirurgus and grunts Haemulon sp. were observed.

Further westward along Punta Verraco (Transect T2) 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 Spyridia was abundant. Fish were fairly abundant, due to the high topographic relief available for cover. Among the species observed were grunts Haemulon sp., the high hat Equetus acuminatus, the bluehead wrasse Thalassoma bifasciatum, the hogfish Lachnolaimus maximus and the queen triggerfish Balistes vetula. Water depth in this area ranged between 5-6 meters. The substrate was covered with a layer of sediment which was probably derived from Guayanilla Bay.

A submarine canyon was encountered offshore of the Río Yauco (Cerro Toro). A soft sand-mud mixture dominates the bottom substrate (Transect T3, Station S3). It is characteristic of such substrate that visually conspicuous organisms are usually rare. However, small patches of algae Ulva lactuca, Hypnea musciformes, Gracilaria sp., the fighting conch Strombus pugilis, and several bivalves Arca zebra, 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 T4, T5, T6; Stations S4, S5, S6, S7). Areas near shore (Transects T5, T6) appear to be dominated by algae. Various species of algae Sargassum, Dictyota, and red algae were observed. The hard coral Siderastrea siderea; gorgonians Pterogorgia and Eunicea; and the sponges Sphaeciospongia vesparia, Anthosigmella varians, and Tethya were also noted.

In areas further offshore (Transect T4, Stations S4, S5, S7) hard corals, sponges and gorgonians become more abundant, the latter being the most visually conspicuous. In general, the faunal characteristics of Stations S4 and S5 are probably representative of this area.

Relatively flat, low relief rock dominates the substrate at Stations S4 and S5. 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. caveronosa and Diploria sp., and at both stations the gorgonians were the most visually conspicuous organisms. Among the genera observed were Eunicea, Muricea, Muriceopsis, and Plexaura. Quantitative samples of gorgonians were taken at both stations.

The fish and larger invertebrate species observed at both stations and also Station S5A are listed in Appendix 4.2D. Fish were observed on two different occasions at Station S4 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 S4 and S5 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.

TABLE 4.2-T1. Recruit gorgonian colonies collected on 11 December 1974 from an area previously cleared of gorgonians on 22 April 1974

SPECIES	#'s/4 m^2	Height(range)
Muriceopsis flavida	13	2-4.4 cm
Eunicea succinea	6	2.2-7.4 cm
Eunicea tourneforti	6	2.9-5.3 cm
Eunicea laxispica	5	2.6-3.1 cm
Gorgonia ventalina	5	2.2-7.0 cm
Muricea atlantica	4	4.7-6.4 cm
Pseudoplexaura porosa	4	2.2-5.3 cm
Pseudopterogorgia acerosa	2	2.3-7.1 cm
Plexaurella dichotoma	2	1.2-2.0 cm
Plexaura flexuosa	1	3 cm
Muricea muricata	1	1.6 cm
Pseudoplexaura sp.	3	3.2-5.1 cm
Eunicea sp.	2	2.4-3.5 cm

Quantitative Samples

Species found in 1/4 m^2 quadrat substrate samples taken at Stations S1 and S6 are listed in Appendix 4.2E. Both samples show similar distributions of individuals among species. The 246 individuals were represented by 80 species (excluding algae and colonial organisms) in the S1 sample, and 46 individuals among 27 species in the S6 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 98 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 S4.

These results are also shown in Appendix 4.2E. The number of individuals shows a highly equitable distribution; 17 individuals among 14 species in one replicate; 75 individuals among 23 species in the other. Over 50% of the total number of species (33) were represented by single individuals. However, only four species occurred in both replicates.

The lack of similarity between the two replicates in terms of co-occurrences of species would indicate an inadequacy of the 1/4 m^2 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 m^2 quadrats at Station S4 are listed in Appendix 4.2F. Overall colony density of the subsamples was very similar, 15.9 and 14.9 colonies per m^2. Correlation of the relative abundances was statistically significant (Kendall - Tau =+0.46, $p = 0.05$) 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 57% of the total number of individuals.

Gorgonians were found in much higher densities at Station S5, an average of 25 and 30 colonies per m^2. 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*, *Eunicea laxispica*, *Muricea muricata*, *Plexaura flexuosa*, *Eunicea clavigera*, and *Muriceopsis flavida*. These species accounted for about 75% of the total number of colonies.

No correlation was found between the relative abundances of gorgonians at Stations S4 and S5. The causative factor(s) responsible for the differences in relative abundances are undetermined at present. However, Kinzie (1973), Goldberg (1973), and Opresko (1973) discuss several environmental factors which may influence the abundance of gorgonian species.

When revisited on 21 August 1974, the area cleared of gorgonians on 21 April 1974 at Station S4 had an average of 2.77 ± 1.22 (95% C.L.) newly recruited gorgonian colonies per 1/4 m^2 based on randomly placed quadrats. All recruits were less than 3 cm tall. When sampled previously, the density of similar sized colonies was only 0.45 colonies per 1/4 m^2, suggesting that the presence of settled colonies inhibits the recruitment of other colonies. Established colonies evidently play a regulatory role in the recruitment of new colonies. The mechanism by which this occurs is unknown.

On 11 December 1974 gorgonian colonies were collected from a 4 m^2 area previously cleared of all gorgonians the previous spring. Species collected and their abundances are listed on Table 1. The relative abundances correlated positively but not significantly with the gorgonians collected the previous spring (Kendall-Tau, $p \sim .20$), suggesting that recruitment 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 in 4 m (2 x 2 m) quadrats. The distribution patterns of the colonies for various quadrat sizes are listed on Table 4.2-T2. Evidently, recruitment of gorgonians occurs on an aggregated pattern. Colonies in natural areas, however, seem to be more randomly distributed.

TABLE 4.2-T2. Index of dispersion of gorgonian colonies on various sampling scales in cleared and natural areas.

AREA		INDEX OF DISPERSION	NORMAL (z)	PROB.	PATTERN
1/64 m^2	"recruit"	2.18	-13.3	0.001	aggregated
1/64 m^2	"natural"	1.45	- 5.08	0.001	aggregated
1/16 m^2	"recruit"	2.41	- 7.96	0.001	aggregated
1/16 m^2	"natural"	0.95	+ 0.283	.39	random
1/4 m^2	"recruit"	2.74	- 4.8	0.001	aggregated
1/4 m^2	"natural"	1.53	- 1.46	0.072	random
1 m^2	"recruit"	1.7	- 0.86	0.19	random
1 m^2	"natural"	[illegible].16	- 1.43	.075	random

Growth rates for tagged gorgonian colonies in the observation quadrat between August and December 1974 are listed in Table 4.2-T3. 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.

TABLE 4.2-T3. Growth of tagged gorgonians in the permanent quadrat at Station S4, Punta Verraco

SPECIES	21 AUGUST (Height, cm)	11 DECEMBER (Height, cm)
E. laxispica	6	10
E. laxispica	10.5	14
E. succinea	23.5	23
E. tourneforti	32	32
E. tourneforti	54	59
E. calyculata	40	40
Eunicea sp.	13.5	16
Muriceopsis sp.	11	10
Muriceopsis sp.	12	11
Muriceopsis sp.	40	30 (broken)
Gorgonia sp.	13.5	15
Pseudopterogorgia sp.	27.0	27
Pseudopterogorgia sp.	27.5	27

4.2.4 DISCUSSION

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.

Several factors were found to affect the gorgonian community at Punta Verraco. Different gorgonian communities in terms of relative abundance were found to be associated with different depths.

Field experiments indicate that interspecific interactions among gorgonians play a role in the control and regulation of this community. The aggregated distribution patterns of the recruit colonies in the cleared areas is probably due to the distribution pattern of suitable settling sites. Based on the Index of Dispersion, suitable settling sites measure about [illegible]. The increase of recruitment rates of gorgonian colonies following the removal of all colonies indicates that the presence of colonies limits the recruitment of other colonies. The mechanism by which this occurs is unknown.

If the distribution patterns of the recruit colonies in the cleared area are interpreted as initial colonizing stages and the distribution of colonies in control areas as equilibrium stages of the gorgonian community, then interactions among gorgonian colonies following recruitment probably occur. The older colonies in the natural areas are randomly distributed while the recruit colonies are aggregated. In order to change an aggregated pattern to a random one high mortality must occur among these recruit colonies occurring in aggregations. Both predation and competition for space could be responsible for such mortality.

Studies of the gorgonians at Punta Verraco show that this community is biologically integrated. Interspecific interactions, either direct or indirect, play an important role in the control and regulation of this community. It is not possible to predict the effect on an environmental perturbation such as thermal pollution on this community at this time. However, it is not unlikely that the ultimate effects of thermal pollution will be manifested through its effect on the biological process responsible for the control and regulation of this community.

4.3

PLANT ASSOCIATIONS

by

Michael J. Canoy

4.3.1 INTRODUCTION

Punta Verraco, on the south-west coast, is in an arid area receiving less than 50 inches rainfall per year. The soil is spare and has little or no organics. In the area in back of the two points (Punta Toro and Punta Verraco) there are a Typha swamp and sugar cane fields. The forest on the two points is typical tertiary dry country successional.

The terrestrial fauna is not obviously different from the rest of Puerto Rico's coasts. (See Appendix 4.3A) The major species are rats, cats, mongoose, cattle, dogs, and a few "pest" birds such as grackles, anis, and pigeons. Pelicans, frigate birds, and clapper rails were observed, none nesting. The major unique features are (a) possible inclusion in the breeding area of a rare species, the Puerto Rican Whippoorwill, due to the proximity of the Guanica forest, (b) a large number of bats which issue from several caves and a large sinkhole in the point.

The evidence 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. There is very little beach area; the banks and cliffs rise rapidly to the forests.

Among the more seaward plants are Ipomea, Canavali, and Sporobolus. Opuntia species begin near the sea and continue through the forest. These seaward associations are vagrant and often get washed away only to reappear later.

4.3.2 MATERIALS AND METHODS

The Punta Verraco site represents an anomolous 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 north-east by southwest (Figure 4.3-F1) and three small perpendicular

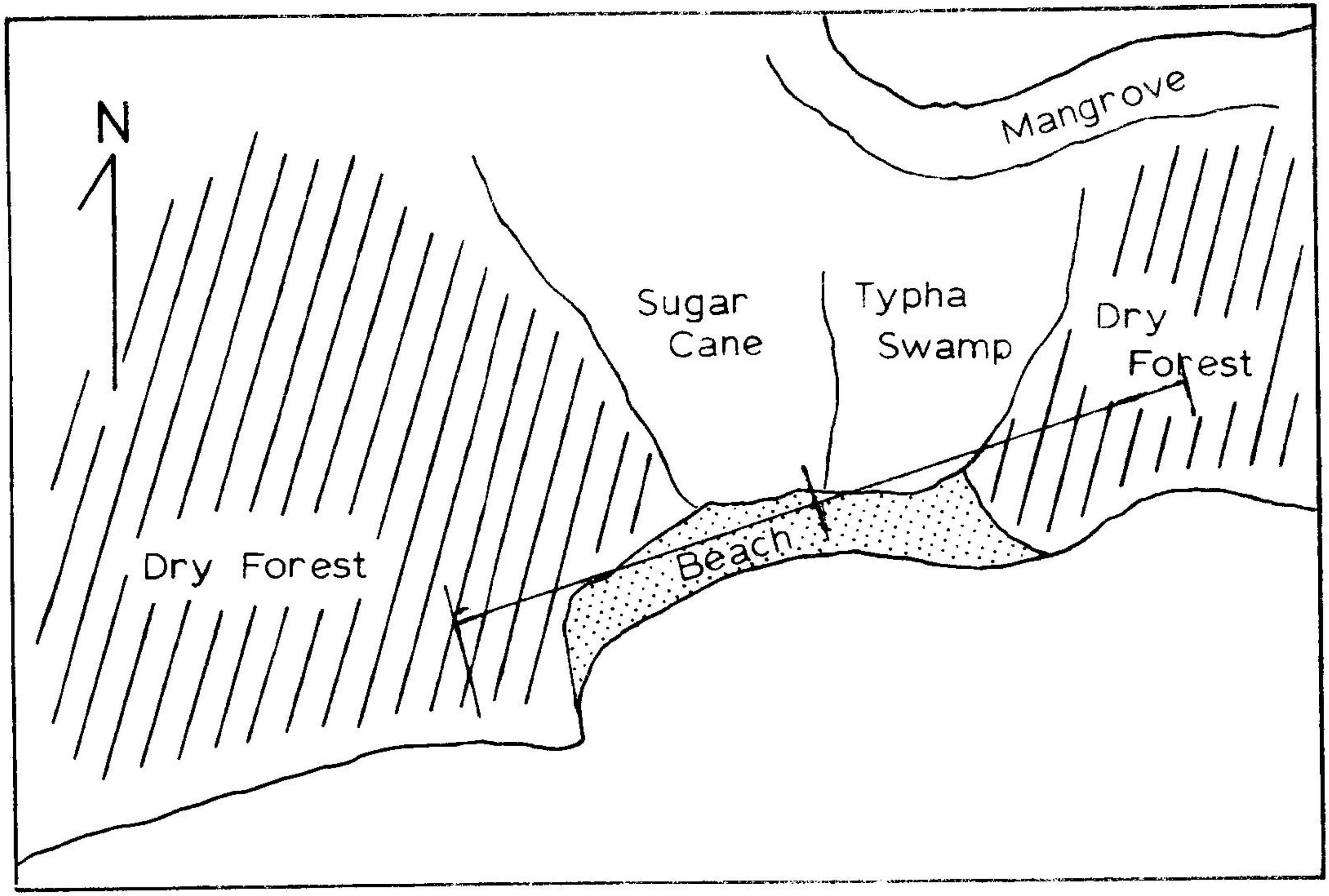


Fig. 4.3-F1 Punta Verraco site surveyed for plant associations.

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^2 plots were examined for grasses and forb at the juncture of the transects and at the distal end of each 10 m transect. This gave six 1 meter^2 plots. All unknown material was removed to the laboratory for identification.

4.3.3 DISCUSSION

The tertiary successional forest of the hills is more complex than it first appears. The xerophytic nature of these tertiary limestone hills is deceptive. To the untrained eye many species appear as one.

A conspicuous feature of the forest is the number of succulents and cacti present. The succulents Cephalocereus royeni, Leptocereus quadricostatus, and cacti; Opuntia species, and the climbing cactus Hylocereus trigomus are common. The agave Agave missionum and the cactus Cactus intortus are conspicuous since they grow to 3 to 6 meters, towering over the surrounding shrubs. The cacti near the shore are covered with epiphytes, bromeliads, Hylocereus, and one orchid Encyclia papilionacea.

The shrubs of Bucida, Burserea, and Amyris are dense. The larger Bucida and Burserea are of tree size. Occasional Erythroxylum (cocaine) trees are found here.

Behind the hills at Punta Verraco, but not on the site, is a Typha swamp which drains to a mangrove fringed bay. Black and white mangroves (Laguncularia and Avicennia) stray short distances up the hill.

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APPENDIX 2.1A

Tabulated Averaged Hydrographic Data

AVERAGE DATA FOR [illegible]23294 THROUGH [illegible]39671 — PUNTA VERRACO - ALL STATIONS- WINTER

DEPTH	TEMPERATURE	SALINITY	SIGMA T	OXYGEN	PHOS	NITROGEN
0	26,243	35,[illegible]	23,31[illegible]	4,[illegible]	[illegible],[illegible]45	2,588
10	26,115	35,432	23,342	4,874	[illegible]	2,419
20	26,034	35,42[illegible]	23,361	4,933	[illegible]	2,269
30	26,010	35,424	23,37[illegible]	4,96[illegible]	[illegible]	2,145
50	25,952	35,459	23,414	4,925	[illegible]	2,[illegible]
75	25,521	35,[illegible]16	23,[illegible]	4,[illegible]29	[illegible]	2,127
100	24,312	36,[illegible]	2[illegible],[illegible]7	4,679	[illegible]97	2,174
150	22,012	36,[illegible]05	2[illegible]	4,225	[illegible],192	2,341
200	20,476	36,[illegible]	2[illegible],976	3,967	[illegible]	2,221
250	18,592	36,[illegible]	2[illegible]	4,179	[illegible],327	2,866
300	17,[illegible]	36,141	26,474	4,34[illegible]	[illegible],37[illegible]	1,790

AVERAGE DATA FOR [illegible] THROUGH [illegible]42734 — PUNTA VERRACO - ALL STATIONS- SPRING

DEPTH	TEMPERATURE	SALINITY	SIGMA T	OXYGEN	PHOS	NITROGEN
0	27,374	35,795	23,212	4,747	,[illegible]72	2,[illegible]
10	27,268	35,[illegible]7	23,256	4,712	,[illegible]67	[illegible]
20	27,347	35,[illegible]	23,312	4,726	,264	[illegible]
30	26,965	35,[illegible]1	2[illegible]	4,722	,[illegible]65	[illegible]
50	26,076	35,[illegible]13	2[illegible]	4,718	,[illegible]69	[illegible]
75	26,272	35,[illegible]17	23,[illegible]	4,[illegible]	[illegible]	[illegible]
100	25,762	36,[illegible]	[illegible]	4,[illegible]44	,[illegible]73	[illegible]
150	22,419	36,[illegible]72	[illegible]	4,[illegible]	,121	[illegible]
200	2[illegible]	36,771	[illegible]	4,[illegible]	,13[illegible]	[illegible]
250	18,658	36,530	26,295	4,189	,229	[illegible]
300	17.484	36,348	26,372	4,332	,329	[illegible]

AVERAGE DATA FOR [illegible] THROUGH [illegible] PUNTA VERRACO - ALL STATIONS- SUMMER

DEPTH	TEMPERATURE	SALINITY	SIGMA T	OXYGEN	PHOS	NITROGEN
[illegible]	[illegible]	[illegible]	22,601	4,738	[illegible]	[illegible]
10	[illegible]	[illegible]	22,464	4,741	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	4,774	[illegible]	0,109
[illegible]	27,964	[illegible]	22,712	[illegible]	[illegible]	0,121
[illegible]	27,329	[illegible]	22,997	4,942	[illegible]	[illegible]
75	26,232	[illegible]	23,762	4,410	[illegible]	0,111
[illegible]	24,634	[illegible]	24,643	4,727	[illegible]	0,282
[illegible]	[illegible]	[illegible]	[illegible]	4,406	[illegible]	[illegible]
[illegible]	[illegible]	36,767	[illegible]	4,265	[illegible]	[illegible]
[illegible]	18,375	[illegible]	26,393	4,314	0,253	2,124
[illegible]	17,215	[illegible]	[illegible]	4,107	[illegible]	2,714

AVERAGE DATA FOR [illegible] THROUGH [illegible] PUNTA VERRACO - ALL STATIONS - FALL

DEPTH	TEMPERATURE	SALINITY	SIGMA T	OXYGEN	PHOS	NITROGEN
[illegible]	27,132	[illegible]	[illegible]	4,639	[illegible]	1,243
[illegible]	27,265	[illegible]	[illegible]	4,692	[illegible]	0,312
[illegible]	27,332	[illegible]	[illegible]	4,752	[illegible]	0,135
[illegible]	27,269	[illegible]	22,341	4,746	[illegible]	[illegible]
[illegible]	26,571	[illegible]	[illegible]	4,691	[illegible]	0,225
75	25,313	[illegible]	[illegible]	4,663	[illegible]	0,345
[illegible]	23,766	[illegible]	[illegible]	[illegible]	[illegible]	0,571
[illegible]	[illegible]	[illegible]	[illegible]	4,659	[illegible]	0,577
[illegible]	[illegible]	[illegible]	26,194	4,331	[illegible]	[illegible]
[illegible]	17,998	[illegible]	[illegible]	4,495	[illegible]	2,238
[illegible]	17,159	[illegible]	[illegible]	4,549	[illegible]	2,845

AVERAGE DATA FOR Ø23294 THROUGH Ø39675 — PUNTA VERRACO - WINTER - "A" STATIONS

DEPTH	TEMPERATURE	SALINITY	SIGMA T	OXYGEN	PHOS	NITROGEN
Ø	26,625	35,474	23,212	4,747	Ø,Ø45	Ø,129
1Ø	26,241	35,43Ø	23,3Ø1	4,819	Ø,Ø52	Ø,144
2Ø	25,641	35,285	23,381	4,887	Ø,Ø6Ø	Ø,ØØØ
3Ø	25,618	35,285	23,388	5,167	Ø,Ø6Ø	Ø,ØØØ

AVERAGE DATA FOR Ø233Ø1 THROUGH Ø39674 — PUNTA VERRACO - WINTER - "B" STATIONS

DEPTH	TEMPERATURE	SALINITY	SIGMA T	OXYGEN	PHOS	NITROGEN
Ø	26,1ØØ	35,4Ø7	23,327	4,862	Ø,Ø41	Ø,217
1Ø	26,Ø9Ø	35,424	23,328	4,9Ø1	Ø,Ø44	Ø,24Ø
2Ø	26,Ø82	35,4ØØ	23,329	4,942	Ø,Ø47	Ø,265
3Ø	26,Ø39	35,4Ø5	23,346	4,957	Ø,Ø47	Ø,248
5Ø	25,892	35,452	23,427	4,925	Ø,Ø39	Ø,112
75	25,443	35,736	23,781	4,867	Ø,Ø42	Ø,151
1ØØ	24,651	36,222	24,39Ø	4,755	Ø,Ø54	Ø,17Ø

AVERAGE DATA FOR Ø233Ø2 THROUGH Ø39671 — PUNTA VERRACO - WINTER - "C" STATIONS

DEPTH	TEMPERATURE	SALINITY	SIGMA T	OXYGEN	PHOS	NITROGEN
Ø	26,ØØ6	35,465	23,4Ø1	4,877	Ø,Ø49	1,419
1Ø	26,Ø15	35,462	23,396	4,9Ø2	Ø,Ø51	Ø,874
2Ø	26,Ø26	35,459	23,39[illegible]	4,929	Ø,Ø53	Ø,3Ø1
3Ø	26,Ø21	35,458	23,392	4,943	Ø,Ø53	Ø,Ø56
5Ø	26,Ø12	35,466	23,4ØØ	4,926	Ø,Ø48	Ø,Ø64
75	25,599	35,896	23,854	4,791	Ø,Ø55	Ø,1Ø3
1ØØ	24,973	36,398	24,425	4,6Ø3	Ø,Ø6Ø	Ø,178
15Ø	22,812	36,665	25,422	4,225	Ø,152	Ø,341
2ØØ	2Ø,478	36,742	25,976	3,967	Ø,266	2,221
25Ø	18,392	36,489	26,33Ø	4,17Ø	Ø,327	2,866
3ØØ	17,36Ø	36,341	26,473	4,34Ø	Ø,378	1,798

AVERAGE DATA FOR 029482 THROUGH 042732 PUNTA VERRACO - SPRING - "A" STATIONS

DEPTH	TEMPERATURE	SALINITY	SIGMA T	OXYGEN	PHOS	NITROGEN
0	27,666	35,831	23,145	4,757	0,064	0,000
10	27,620	35,857	23,180	4,669	0,071	0,000

AVERAGE DATA FOR 029483 THROUGH 042731 PUNTA VERRACO - SPRING- "B" STATIONS

DEPTH	TEMPERATURE	SALINITY	SIGMA T	OXYGEN	PHOS	NITROGEN
0	27,321	35,783	23,221	4,794	0,074	0,000
10	27,225	35,790	23,257	4,777	0,071	0,000
20	27,129	35,797	23,294	4,759	0,068	0,000
30	27,016	35,800	23,333	4,747	0,064	0,000
50	26,740	35,810	23,429	4,729	0,059	0,000
75	26,310	35,882	23,620	4,657	0,060	0,000
100	25,844	36,002	23,857	4,565	0,065	0,000

AVERAGE DATA FOR 029492 THROUGH 042730 PUNTA VERRACO - SPRING - "C" STATIONS

DEPTH	TEMPERATURE	SALINITY	SIGMA T	OXYGEN	PHOS	NITROGEN
0	26,956	35,772	23,331	4,689	0,055	0,000
10	26,962	35,773	23,331	4,691	0,058	0,000
20	26,965	35,775	23,331	4,693	0,061	0,000
30	26,916	35,781	23,351	4,696	0,066	0,000
50	26,611	35,817	23,476	4,706	0,083	0,220
75	26,233	35,952	23,698	4,649	0,080	0,200
100	25,680	36,180	24,043	4,522	0,082	0,420
150	22,419	36,672	25,539	4,082	0,121	0,220
200	20,526	36,771	25,989	4,086	0,130	0,618
250	18,658	36,530	26,295	4,189	0,229	1,072
300	17,484	36,484	26,372	4,332	0,329	1,152

AVERAGE DATA FOR Ø46834 THROUGH Ø46839 — PUNTA VERRACO - SUMMER - "A" STATIONS

DEPTH	TEMPERATURE	SALINITY	SIGMA T	OXYGEN	PHOS	NITROGEN
Ø	28,418	35,474	22,634	4,617	Ø,Ø6Ø	Ø,ØØØ
1Ø	28,292	35,435	22,647	4,631	Ø,Ø38	Ø,ØØØ

AVERAGE DATA FOR Ø46833 THROUGH Ø46838 — PUNTA VERRACO - SUMMER - "B" STATIONS

DEPTH	TEMPERATURE	SALINITY	SIGMA T	OXYGEN	PHOS	NITROGEN
Ø	28,1Ø4	35,384	22,67Ø	4,775	Ø,Ø56	Ø,ØØØ
1Ø	28,Ø91	35,376	22,669	4,77Ø	Ø,Ø43	Ø,Ø44
2Ø	28,Ø8Ø	35,369	22,667	4,763	Ø,Ø29	Ø,Ø91
3Ø	27,939	35,416	22,749	4,776	Ø,Ø25	Ø,Ø98
5Ø	27,154	35,74Ø	23,245	4,847	Ø,Ø36	Ø,Ø5Ø
75	25,856	36,162	23,973	4,8Ø8	Ø,Ø49	Ø,135
1ØØ	24,44Ø	36,672	24,794	4,689	Ø,Ø66	Ø,364

AVERAGE DATA FOR Ø46825 THROUGH Ø46829 — PUNTA VERRACO - FALL - "C" STATIONS

DEPTH	TEMPERATURE	SALINITY	SIGMA T	OXYGEN	PHOS	NITROGEN
Ø	27,974	35,34Ø	22,68Ø	4,82Ø	Ø,Ø68	Ø,ØØØ
1Ø	27,983	35,339	22,676	4,823	Ø,Ø54	Ø,Ø61
2Ø	27,992	35,337	22,671	4,825	Ø,Ø32	Ø,126
3Ø	27,99Ø	35,341	22,675	4,828	Ø,Ø26	Ø,145
5Ø	27,9Ø4	35,4Ø2	22,749	4,837	Ø,Ø46	Ø,Ø72
75	26,6Ø7	35,913	23,552	4,813	Ø,Ø47	Ø,Ø68
1ØØ	24,949	36,476	24,492	4,766	Ø,Ø42	Ø,2ØØ
15Ø	22,429	36,887	25,548	4,486	Ø,Ø55	Ø,644
2ØØ	[illegible]	36,767	26,119	4,265	Ø,129	[illegible]
25Ø	18,375	36,565	26,393	4,314	Ø,253	2,124
3ØØ	17,215	36,385	26,543	4,4Ø7	Ø,364	2,714

AVERAGE DATA FOR 052982 THROUGH 052987 PUNTA VERRACO - FALL - "A" STATIONS

DEPTH	TEMPERATURE	SALINITY	SIGMA T	OXYGEN	PHOS	NITROGEN
0	26,928	33,262	21,455	4,483	0,136	3,040
10	27,232	34,057	21,956	4,611	0,068	0,448

AVERAGE DATA FOR 052981 THROUGH 052986 PUNTA VERRACO - FALL - "B" STATIONS

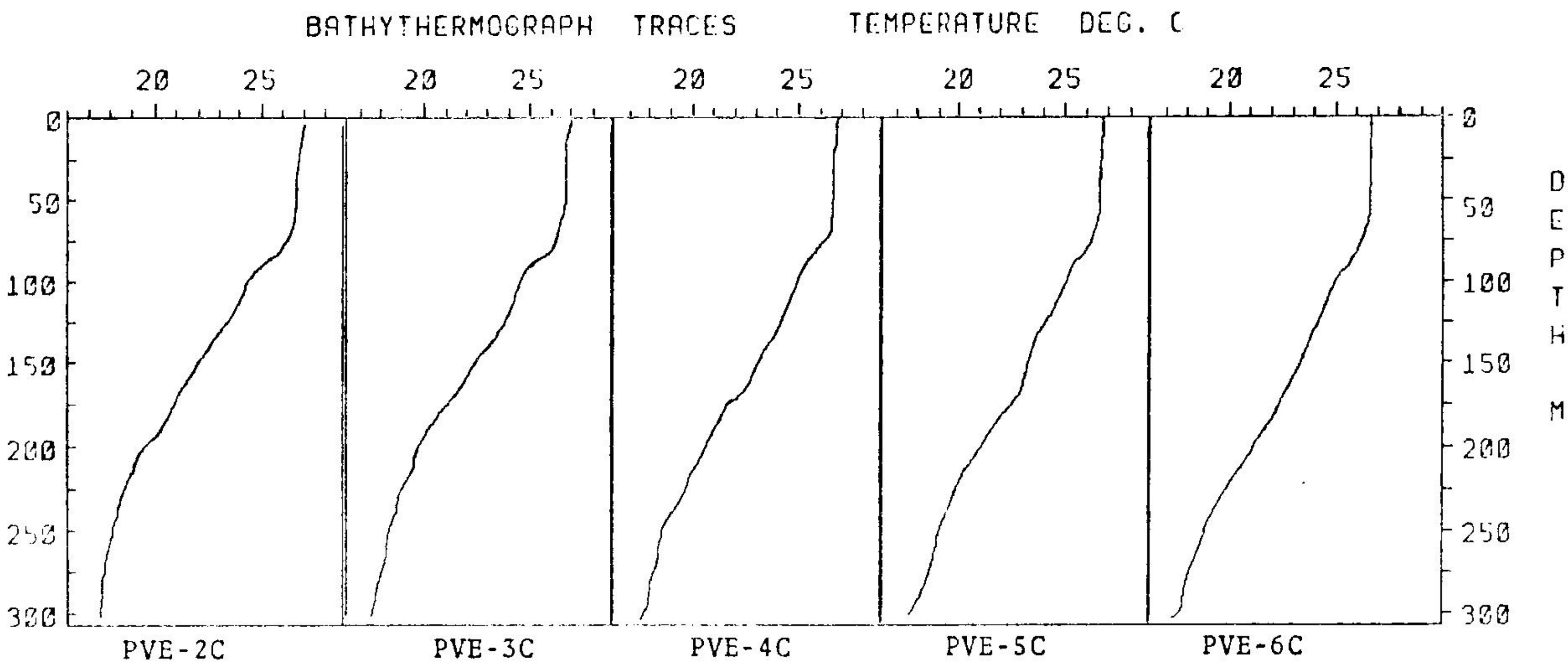
DEPTH	TEMPERATURE	SALINITY	SIGMA T	OXYGEN	PHOS	NITROGEN
0	27,122	33,980	21,933	4,672	0,080	0,576
10	27,200	34,080	21,983	4,697	0,073	0,383
20	27,279	34,180	22,033	4,723	0,066	0,176
30	27,217	34,569	22,346	4,726	0,058	0,108
50	26,551	36,149	23,746	4,683	0,038	0,330
75	25,304	36,536	24,428	4,678	0,048	0,383
100	23,843	36,794	25,065	4,474	0,065	0,639

AVERAGE DATA FOR 052973 THROUGH 052977 PUNTA VERRACO - FALL - "C" STATIONS

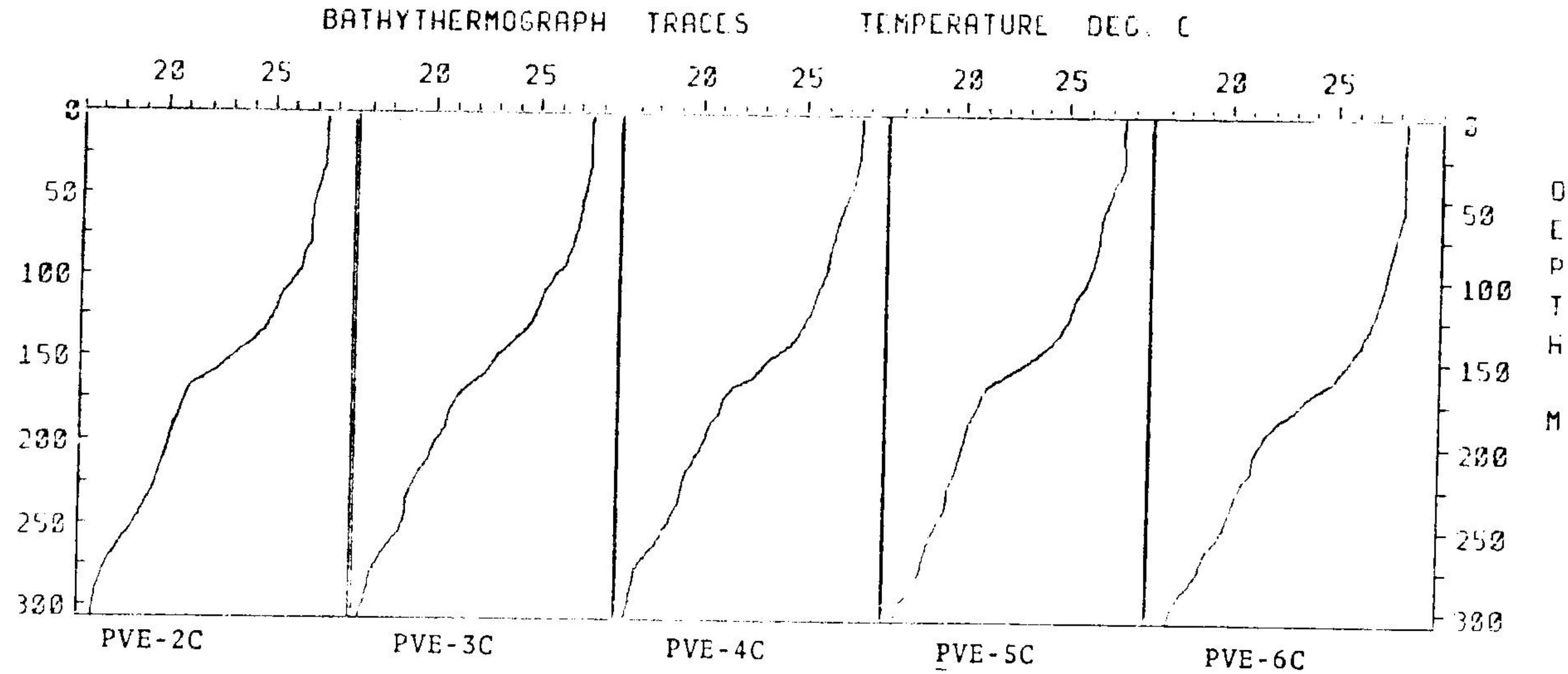
DEPTH	TEMPERATURE	SALINITY	SIGMA T	OXYGEN	PHOS	NITROGEN
0	27,346	34,284	22,090	4,763	0,042	0,112
10	27,364	34,291	22,090	4,769	0,040	0,103
20	27,381	34,299	22,089	4,777	0,039	0,094
30	27,322	34,502	22,337	4,767	0,039	0,090
50	26,791	36,076	23,615	4,699	0,046	0,116
75	25,322	36,545	24,430	4,688	0,057	0,303
100	23,694	36,933	25,139	4,685	0,066	0,503
150	21,666	36,845	25,731	4,659	0,073	0,577
200	19,929	36,686	26,194	4,331	0,124	1,000
250	17,988	36,502	26,442	4,495	0,229	2,238
300	17,169	36,380	26,550	4,549	0,311	2,845

APPENDIX 2.1B

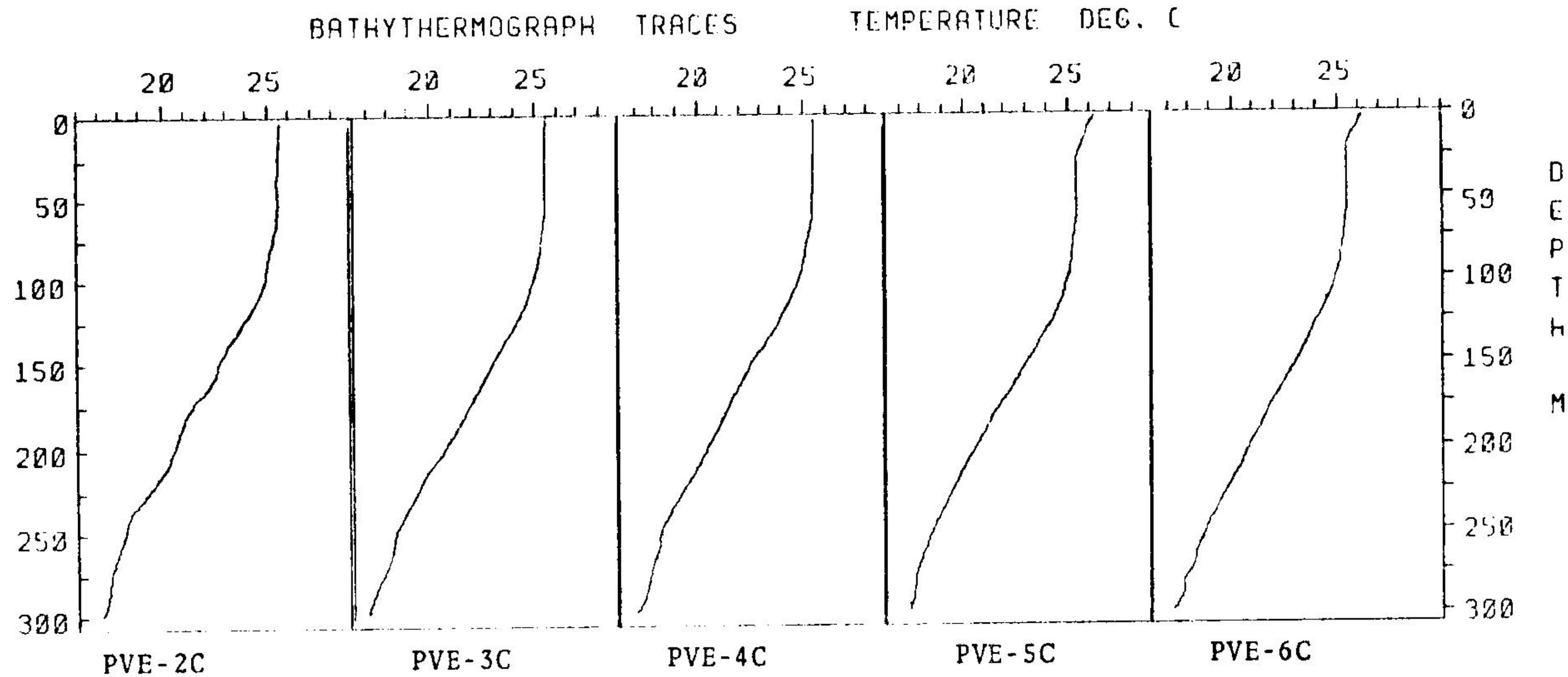
Bathythermograph traces for the
"C" stations at Punta Verraco
quarterly for 1973 and 1974



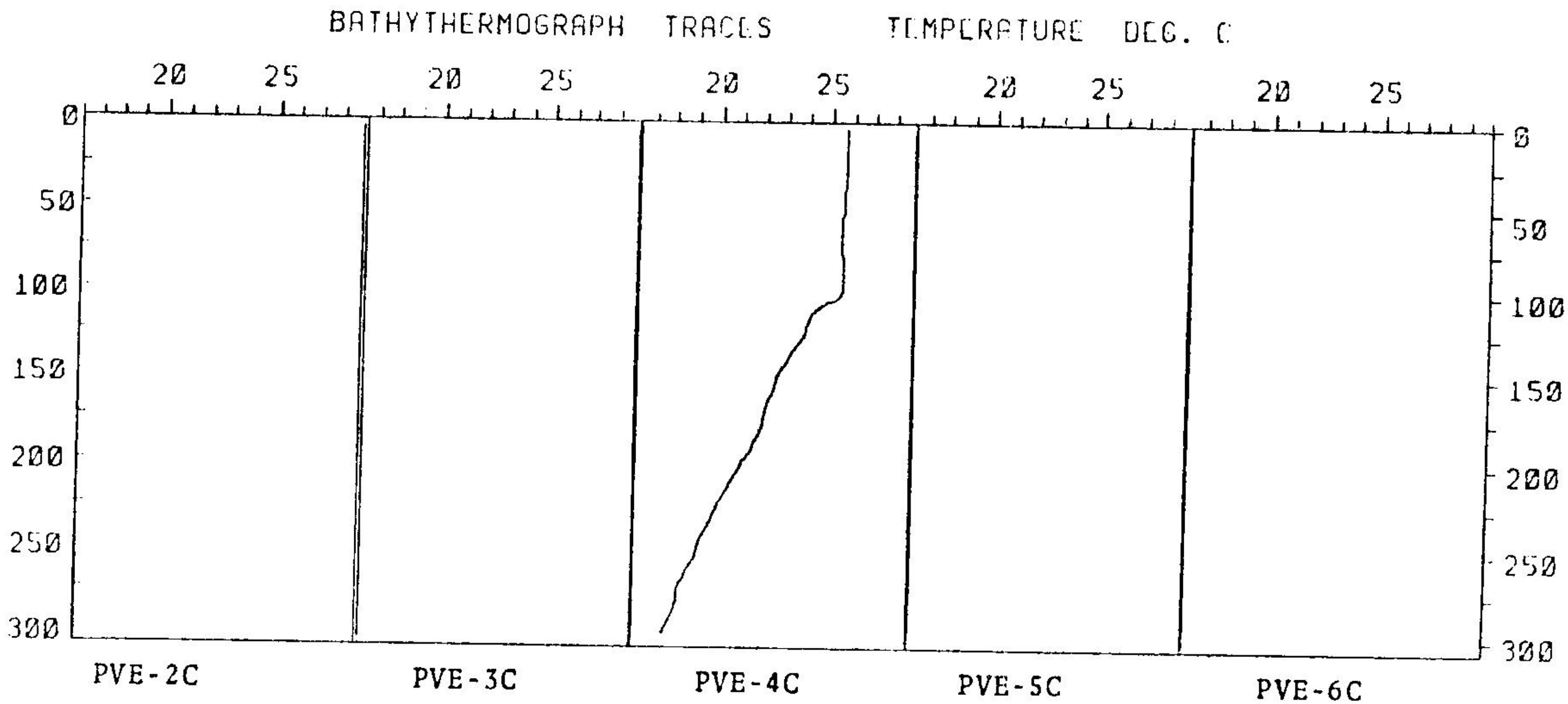
Cruise No. PA023
Feb. 20. 1973



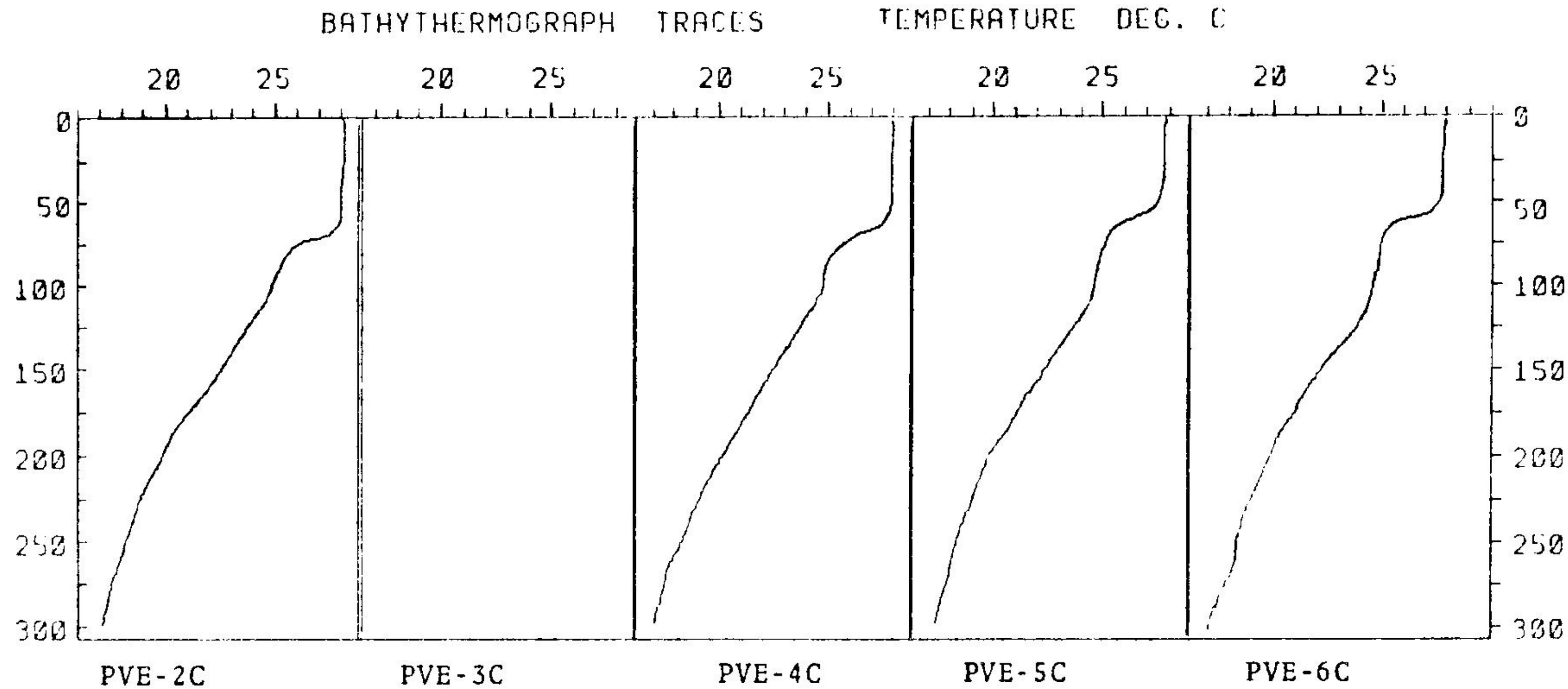
Cruise No. PA029
May 22, 1973



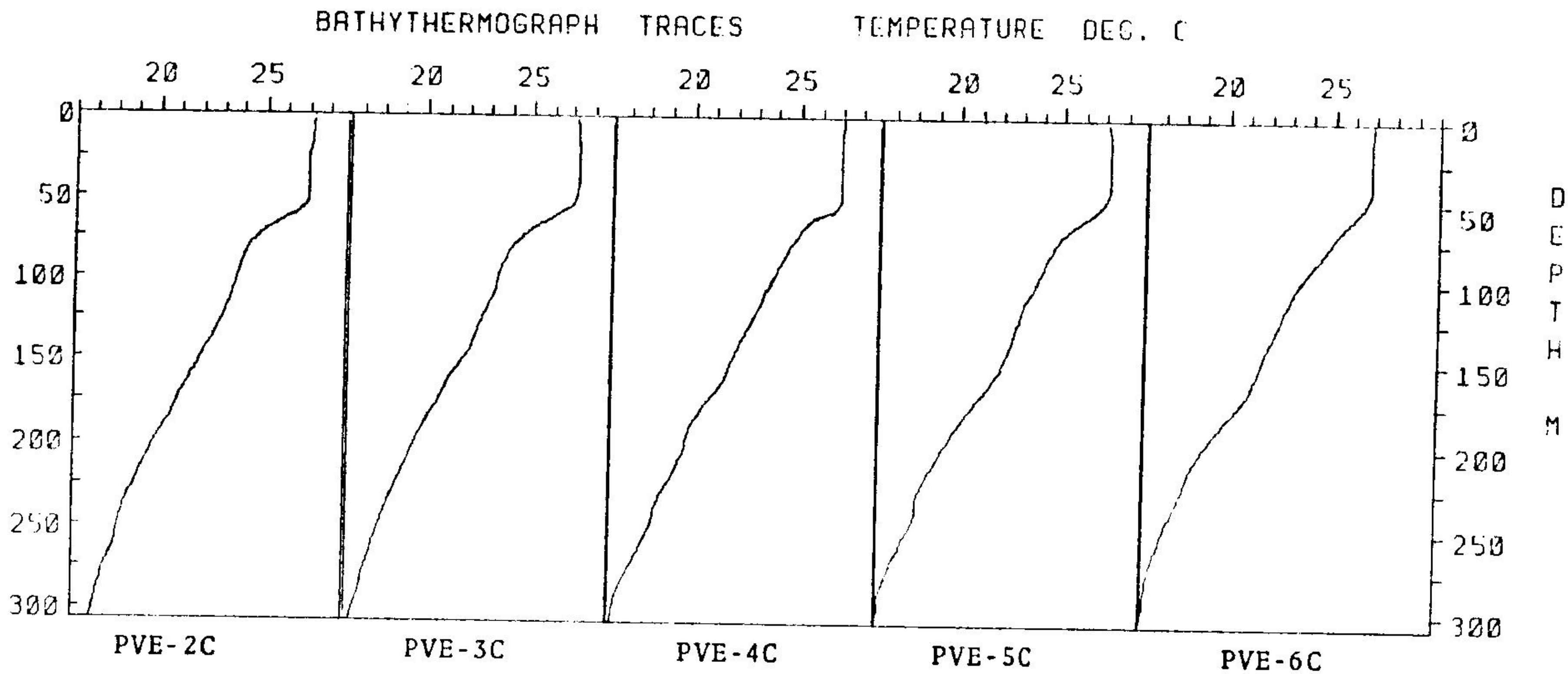
Cruise No. PA039
Feb. 12, 1974



Cruise No. PA042
Apr. 22, 1974



Cruise No. PA046
Aug. 20, 1974



Cruise No. PA052
Nov. 13, 1974

APPENDIX 4.1A

Data Reduction Program-12 Mar '75
TAB

```
      REAL*5 ST,STME
      DIMENSION TABLE(25,10,36),IT(25),ST(10),DATAO(15),DATAN(18)
     1,TITLE(8,34), TITL(16)
  100 FORMAT(I6,9X,A6,5X,F5.0,F5.3,3F10.0,14X,A1,I5)
101   FORMAT(15X,A6,15F4.0)
102   FORMAT(16A5)
103   FORMAT('1',17X,'TABLE',I3,'. ',8A5//20X,16A5///30X,'STATIONS'////
     1 18X,' DATE      ',10A10)
104   FORMAT('0',I23,10F10.3)
105   FORMAT('0',I23,10F10.0)
106   FORMAT('0',I23,10F10.1)
107   FORMAT('0', I6,3X,A6,5X,5F10.3,I10)
108   FORMAT(' ',A6, 15F6.0)
  109 FORMAT('1',16A5)
      DATA DATAN, TABLE/9018*0./
      DATA ((TITLE(I,J),I=1,8),J=1,17) /
     1'TOTAL BIOMASS OF ZOOPLANKTON (ML/100M3) ',
     2'TOTAL NUMBER OF ZOOPLANKTON PER 100M3   ',
     3'TOTAL NUMBER OF COPEPODS PER 100M3      ',
     4'TOTAL NUMBER OF CHAETOGNATHS PER 100M3  ',
     5'TOTAL NUMBER OF LARVACEANS PER 100M3    ',
     6'TOTAL NUMBER OF CLADOCERANS PER 100M3   ',
     7'TOTAL NUMBER OF PTEROPODS PER 100M3     ',
     H'TOTAL NUMBER OF OTHER PER 100M3         ',
     8'TOTAL # OF VELIGER LARVAE PER 100M3     ',
     9'TOTAL # OF CIRRIPEDE NAUPLII PER 100M3  ',
     A'TOTAL # OF CIRRIPEDE CYPRIS PER 100M3   ',
     B'TOTAL # OF PENAEID LARVAE PER 100M3     ',
     C'TOTAL # OF BRACHYURAN LARVAE PER 100M3  ',
     D'TOTAL NUMBER OF OTHER PER 100M3         ',
     E'TOTAL NUMBER OF FISH EGGS PER 100M3     ',
     F'TOTAL NUMBER OF FISH LARVAE PER 100M3   ',
     G'TOTAL NUMBER OF HOLOPLANKTON PER 100M3  '/
      DATA ((TITLE(I,J),I=1,8),J=18,34)/
     1'TOTAL NUMBER OF MEROPLANKTON PER 100M3  ',
     2'PERCENTAGE OF COPEPODS                  ',
     3'PERCENTAGE OF CHAETOGNATHS              ',
     4'PERCENTAGE OF LARVACEANS                ',
     5'PERCENTAGE OF CLADOCERANS               ',
     6'PERCENTAGE OF PTEROPODS                 ',
     H 'PERCENTAGE OF OTHER                    ',
     7'PERCENTAGE OF VELIGER  LARVAE           ',
     8'PERCENTAGE OF CIRRIPEDE NAUPLII         ',
     9'PERCENTAGE OF CIRRIPEDE CYPRIS          ',
     A'PERCENTAGE OF PENAEID LARVAE            ',
     B'PERCENTAGE OF BRACHYURAN LARVAE         ',
     C'PERCENTAGE OF OTHER                     ',
     D'PERCENTAGE OF FISH EGGS                 ',
     E'PERCENTAGE OF FISH LARVAE               ',
     F'PERCENTAGE OF HOLOPLANKTON              ',
     G'PERCENTAGE OF MEROPLANKTON              '/
C         READ TITLE.
1      READ (2,102,END=98) TITL
```

```
      PRINT 1Ø9,TITL
      ITIMF=1
      IS=1
      ISTATN=1
      TABLE (1,1,35)=1.
C        READ FIRST CARD.
      READ 1ØØ,IT(1),ST(1),DILUT,PIR2,REVSPM,REVS,WET, AS,IREP
      DO 5Ø I=1,1ØØØØ
      PRINT 1Ø7,IT(ITIME),ST(ISTATN),DILUT,PIR2,REVSPM,REVS,WET,IREP
      Z=PIR2*REVS/REVSPM/1ØØ.
      DILOZ=DILUT/Z/IREP
      TABLE(ITIME,ISTATN,1)=TABLE(ITIME,ISTATN,1)+WET/Z
      DO 3Ø J=1,IREP
      READ 1Ø1,TOW,DATAO
      PRINT 1Ø8,TOW,DATAO
      DO 28 K=2,16
      DATAN(K)=DATAN(K)+DATAO(K-1)
28    CONTINUE
3Ø    CONTINUE
C        SUM HOLOPLANKTON.
      DO 22 K=2,7
      DATAN(17)=DATAN(K)+DATAN(17)
22    CONTINUE
C        SUM MEROPLANKTON.
      DO 25 K=8,16
      DATAN(18)=DATAN(K)+DATAN(18)
25    CONTINUE
      TABLE(ITIME,ISTATN,36)=TABLE(ITIME,ISTATN,36)+DATAN(2)
      DO 32 K=19,34
      TABLE(ITIME,ISTATN,K)=TABLE(ITIME,ISTATN,K)+DATAN(K-16)
   32 CONTINUE
      DO 31 K=2,18
      TABLE(ITIME,ISTAYN,K)=TABLE(ITIMF,ISTATN,K)+DATAN(K)*DILOZ
      DATAN(K)=Ø.
31    CONTINUE
C        CHECK FOR END OF A DATA SET.
      IF (AS.EQ.1H*) GO TO 99
      READ 1ØØ,IT(ITIME+1),STNEW,DILUT,PIR2,REVSPM,REVS,WET,AS,IREP
      IF(IT(ITIMF+1).NE.IT(ITIME)) ITIME=ITIME+1
      DO 33 ISTATN=1,IS
      IF (STNEW.EQ.ST(ISTATN)) GO TO 34
   33 CONTINUE
C        NEW STATION.
      IS=IS+1
      ISTATN=IS
      ST(IS)=STNEW
   34 TABLE(ITIME,ISTATN,35)=TABLE(ITIME,ISTATN,35)+1.
5Ø    CONTINUE
C        PRINT TITLES.
99    DO 82 I=1,18
      PRINT 1Ø3,I,(TITLE(J,I),J=1,8),TITL,(ST(K),K=1,IS)
      DO 82 J=1,ITIME
      DO 35 K=1,IS
```

```
C          DIVIDE BY NUMBER OF TOWS.
       IF(TABLE(J,K,35).EQ.0.) GO TO 55
       TABLE(J,K,I) =TABLE(J,K,I) /TABLE(J,K,35)
55     CONTINUE
       IF (I.GT.1) GO TO 81
       PRINT 104,IT(J),(TABLE(J,K,I),K=1,IS)
       GO TO 82
81     PRINT 105,IT(J),(TABLE(J,K,I),K=1,IS)
    82 CONTINUE
       DO 84 I=19,34
       PRINT 103,I,(TITLE(J,I),J=1,8),TITL,(ST(K),K=1,IS)
       DO 84 J=1,ITIME
       DO 60 K=1,IS .
C          CONVERT TO PERCENTAGES.
       IF(TABLE(J,K,36).EQ.0.) GO TO 60
       TABLE (J,K,I) =TABLE(J,K,I)/TABLE(J,K,36)*100.
60     CONTINUE
       PRINT 106,IT(J),(TABLE(J,K,I),K=1,IS)
    84 CONTINUE
       DO 90 I=1,36
       DO 90 J=1,ITIME
       DO 90 K=1,IS
       TABLE(J,K,I)=0.
    90 CONTINUE
       GO TO 1
98     CALL EXIT
       END
```

APPENDIX 4.2A

Transects, Station Dives and Beach Stations at Punta Verraco

Transect T1	Location:	perpendicular to shore off Punta Verraco
	Depth:	0 - 15 m
	Date	21 May 1973
	Investigator:	V. P. Vicente
Transect T2	Location:	parallel to shore off Punta Verraco
	Depth:	5 m
	Date:	22 April 1974
	Investigator:	P.M. Yoshioka
Transect T3	Location:	parallel to shore at Cerro Toro Canyon
	Depth:	24 - 17 m
	Date:	21 May 1973
	Investigator:	V.P. Vicente
Transect T4	Location:	perpendicular to shore off Punta Verraco
	Depth:	10 - 7 m
	Date:	22 April 1974
	Investigator:	P.M. Yoshioka
Transect T5	Location:	perpendicular to shore near Punta Verraco
	Depth:	8 - 5 m
	Date:	21 May 1973
	Investigator:	V.P. Vicente
Transect T6	Location:	perpendicular to shore off Punta Verraco
	Depth:	8 - 5 m
	Date:	21 May 1973
	Investigator:	V.P. Vicente
Station 1	Location:	reef outside of sand spit off Punta Verraco
	Depth:	3 m
	Date:	6 March 1973
	Investigator:	A. Szmant-Froelich
Station 2	Location:	between sand spit and Punta Verraco
	Depth:	6 m
	Date:	21 May 1973
	Investigator:	V.P. Vicente
Station 3	Location:	canyon off Cerro Toro
	Depth:	26 m
	Date:	6 March 1973
	Investigator:	V.P. Vicente

APPENDIX 4.2A (continued)

Station 4 Permanent station	Location: Depth: Dates: Investigator:	off Punta Ventana 9 m 12 Feb. 1974, 22 May 1974, 21 August 1974, 13 November 1974 P.M. Yoshioka
Station 5	Location: Depth: Date: Investigator:	off Punta Ventana - offshore of Station 4 12 m 21 August 1974 P.M. Yoshioka
Station 5A	Location: Depth: Date: Investigator:	off Punta Ventana - offshore of Stations 4 and 5 15 m 13 November 1974 P.M. Yoshioka
Station 6	Location: Depth: Date: Investigator:	off Punta Ventana 7 m 21 March 1973 P.M. Yoshioka
Station 7	Location: Depth: Date: Investigator:	off Punta Vaquero 10 m 6 March 1973 V.P. Vicente
B1	Location: Date: Investigator:	sand spit off Punta Verraco 6 March 1973 V.P. Vicente
B2	Location: Date: Investigator:	Cerro Toro beach 28 February 1973 V.P. Vicente
B3	Location: Date: Investigator:	Punta Vaquero 28 February 1973 V.P. Vicente

APPENDIX 4.2B. Species found at Punta Verraco shore stations

	B2 Cerro Toro 2/28/73	B3 Vaquero Shore 2/28/73	B1 Verraco Island Shore & sand spit 0' - 4' 3/6/73
Phylum Chlorophyta			
Caulerpa prolifera		X	
Penicillus capitatus		X	X
Udotea flabellum			X
Ulva lactuca	X	X	X
Phylum Phaeophyta			
Dictyopteris delicatula	X	X	
Padina haitiensis		X	
Padina sp.			X
Sargassum polyceratium	X	X	
Phylum Rhodophyta			
Acanthophora spicifera			X
Agardhiella tenera	X	X	
Bryocladia cuspidata		X	
Bryothamnion triquetrum		X	
Ceramium sp.		X	X
Chondria tenuissima		X	X
Cryptonemia crenulata		X	
Galaxaura cylindrica		X	
Galaxaura marginata		X	
Goniolithon strictum			X
Gracilaria foliifera		X	X
Gracilaria sp.			X
Grateloupia gibbesii		X	
Hypnea musciformis	X	X	X

APPENDIX 4.2B (continued)

	B2 Cerro Toro 2/28/73	B3 Vaquero Shore 2/28/73	B1 Verraco Island Shore & sand spit 0' - 4' 3/6/73
Phylum Rhodophyta			
Laurencia papillosa	X	X	X
Laurencia sp.			
Spyridia aculeata - v. hypneoides	X	X	
Phylum Spermatophyta			
Family Hydrocharitaceae			
Syringodium filiformis		X	X
Thalassia testudinum	X	X	X
Phylum Cnidaria			
Class Anthozoa			
Subclass Zoantharia			
Order Actiniaria		X	
Phylum Annelida			
Class Polychaeta			
Eunice rubra			X
Eurythoe complanata			X
Phylum Mollusca			
Class Amphineura			
Subclass Polyplacophora			
Acanthopleura granulata		X	
Ischnochiton purpurascens		X	
Ischnochiton sp.		X	
Class Gastropoda			
Acmaea cubensis		X	
Alaba incerta			X
Astraea tuber	X		
Bulla striata		X	X
Cerithium variabile		X	
Cittarium pica		X	

APPENDIX 4.2B (continued)

	B2 Cerro Toro 2/28/73	B3 Vaquero Shore 2/28/73	B1 Verraco Island Shore & sand spit 0' - 4' 3/6/73
Phylum Mollusca			
Class Gastropoda			
Cypraea zebra			X
Diodora cayenensis			X
Diodora dysoni		X	
Diodora listeri	X	X	
Fissurella angusta		X	
Fissurella barbadensis	X	X	
Fissurella nimbosa	X		
Fissurella rosea	X		
Hemitoma emarginata		X	
Hemitoma octoradiata		X	
Hipponix antiquatus		X	
Littorina meleagris		X	
Littorina ziczac	X	X	
Lucapina suffusa		X	
Nerita sp.		X	
Nerita tessellata		X	
Nitidella laevigata		X	
Nodilittorina tuberculata	X	X	
Polinices lacteus			X
Rissoina cancellata			X
Tonna maculosa			X
Turbo castanea		X	X
Class Pelecypoda			
Arca imbricata			X
Cyclinella tenuis			X
Donax denticulatus	X		
Pinna carnea			X
Trachycardium muricatum			X

APPENDIX 4.2B (continued)

	B2 Cerro Toro 2/28/73	B3 Vaquero Shore 2/28/73	B1 Verraco Island Shore & sand spit 0' - 4' 3/6/73
Phylum Arthropoda			
Class Crustacea			
Subclass Malacostraca			
Order Stomatopoda			
Gonadactylus oerstedii		X	X
Order Pericarida			
Suborder Isopoda			
Paracerceis caudata		X	X
Order Decapoda			
Suborder Reptantia			
Section Brachyura			
Epialtus bituberculatus		X	
Mithrax coryphe			X
Portunus anceps			X
Section Anomura			
Calcinus tibicen		X	
Clibanarius tricolor		X	
Dardanus venosus			X
Suborder Natantia			
Section Caridea			
Alpheus bouvieri			X
Phylum Echinodermata			
Subphylum Eleutherozoa			
Class Echinoidea			
Echinometra lucunter	X		
Class Ophiuroidea			
Ophiocoma echinata			X

APPENDIX 4.2C. Shoreline fishes of Punta Verraco

	3/22/72	4/18/72	5/10/72	12/11/72	2/14/73	3/30/72
MURAENIDAE						
Echidna catenata						26r*
Gymnothorax funebris				3r	1r	
Gymnothorax vicinus				1r		
CLUPEIDAE						
Opisthonema oglinum			1g**			
ENGRAULIDAE						
Anchoa lamprotaenia						4r
MYCTOPHIDAE						
*Myctophum affine*****						
GOBIESOCIDAE						
Tomicodon fasciatus			3g			3r
OPHIDIIDAE						
Ogilbia sp.				7r		
EXOCOETIDAE						
Hemiramphus brasiliensis					74	12r
BELONIDAE						
Strongylura marina		2s***				2r
ATHERINIDAE						
Atherinomorus stipes					6r	
HOLOCENTRIDAE						
Holocentrus ascensionis			2g			

APPENDIX 4.20 (continued)

	3/22/72	4/18/72	5/10/72	12/11/72	2/14/73	3/30/73
SERRANIDAE						
Epinephelus guttatus				1r		
CARANGIDAE						
Trachinotus falcatus						3r
Trachinotus goodei						21r
LUTJANIDAE						
Lutjanus analis				1r	1r	
Lutjanus apodus				1r		
Lutjanus griseus					2r	
Lutjanus jocu					1r	
Ocyurus chrysurus			6g			
GERREIDAE						
Diapterus rhombeus			11g			
Eucinostomus gula			1g	1r		
Eucinostomus jonesii						9r
POMADASYIDAE						
Anisotremus surinamensis						1r
Haemulon aurolineatum		2s				
Haemulon flavolineatum			1g			
Haemulon plumieri			6g		15r	
Haemulon sciurus			8g	2r	7r	
Haemulon sp.						
SPARIDAE						
Archosargus rhomboidalis	3s	3s	1g	1r	2r	3r
SCIAENIDAE						
Bairdiella conchus					25r	2r
Odontoscion dentex					7r	
Ophioscion						4r

APPENDIX 4.2C (continued)

	3/22/72	4/18/72	5/10/72	12/11/72	2/14/73	3/30/73
CHAETODONTIDAE						
Chaetodon capistratus				3r	4r	
POMACENTRIDAE						
Abudefduf saxatilis		2s				
Pomacentrus sp.				1r		
MUGILIDAE						
Mugil curema			1g			
SPHYRAENIDAE						
Sphyraena barracuda			1g			
POLYNEMIDAE						
Polydactylus sp.						4r
SCARIDAE						
Scarus coeruleus				10r	4r	
Scarus croicensis				2r	4r	
Sparisoma chrysopterum		3s		4r	6r	
Sparisoma radians				19r	15r	
Sparisoma rubripinne				2r		
Sparisoma viride					1r	
BLENNIIDAE						
Entomacrodus nigricans						5r
Hypleurochilus aequipinnis					1s	
CLINIDAE						
Labrisomus bucciferus		1s				
Labrisomus nuchipinnis					1s	
Malacoctenus delalandei						1r
Malacoctenus gilli				7r	2s	
Paraclinus nigripinnis	2s					1r

APPENDIX 4.2C (continued)

	3/22/72	4/18/72	5/10/72	12/11/72	2/14/73	3/30/73
GOBIIDAE						
Bathygobius curacao				1r		
Bathygobius soporator		2s			1r 29s	
Coryphopterus glaucofraenum		1s				
Erotelis smaragdus					1s	
ACANTHURIDAE						
Acanthurus bahianus				3r	1r	
Acanthurus				7r		
Acanthurus coeruleus	2s	1s				
OSTRACIIDAE						
Lactophrys trigonus				1r		
TETRAODONTIDAE						
Sphoeroides spengleri				1r		
DIODONTIDAE						
Diodon holocanthus					2r	

* collected with rotenone
** collected with gill net
*** collected with seine
**** jumped into a 17' boat on the night of 21/8/74 about two miles from shore

APPENDIX 4.2D. Macroinvertebrates and fish of Punta Verraco

	Permanent Station (S4)	Station S5	Station S5A
ANIMAL KINGDOM			
Phylum Porifera			
Agelas sp.			X
Callyspongia vaginalis			X
Chondrilla nucula			X
Cinachyra cavernosa			X
Gelliodes sp.			X
Haliclona rubens			X
Ircinia sp.			X
Mycale sp.			X
Verongia lacunosa			X
Verongia longissima			X
Xestospongia muta			X
Iothorhota sp.			X
Desmapsamma anchorata			X
Sphaeciospongia sp.			X
Phylum Cnidaria			
Subclass Zoantharia			
Acropora cervicornis			X
Agaricia sp.	X		
Colpophyllia sp.			X
Dichocoenia stokesii	X	X	X
Diploria labyrinthiformis		X	X
Diploria sp.	X	X	X

APPENDIX 4.2D (continued)

	Permanent Station (S4)	Station S5	Station S5A
Phylum Cnidaria (continued)			
Subclass Zoantharia			
Eusmilia fastigiata			X
Favia fragum	X		
Meandrina sp.		X	
Millepora sp.	X	X	X
Montastrea annularis	X	X	
Montastrea cavernosa	X	X	X
Mussa sp.			X
Palythoa sp.			
Porites astreoides	X	X	
Siderastrea radians	X	X	
Siderastrea siderea	X		X
Stephanocoenia sp.	X		

	Permanent Station 12/2/74	Permanent Station 21/8/74	Station S5	Station S5A
Phylum Chordata				
Subphylum Vertebrata				
Class Pisces				
Family Holocentridae				
Holocentrus sp.	X		X	X
Myripristis jacobus				X
Family Aulostomidae				
Aulostomus maculatus				X
Family Serranidae				
Cephalopholis fulva			X	X
Epinephelus striatus	X		X	X

APPENDIX D (continued)

	Permanent Station 12/2/74	Permanent Station 21/8/74	S5	S5A
Phylum Chordata (continued)				
Family Carangidae				
Caranx ruber				X
Family Lutjanidae				
Ocyurus chrysurus				X
Family Pomadasyidae				
Haemulon flavolineatum				X
Haemulon sp.				X
Family Chaetodontidae				
Chaetodon capistratus			X	X
Pomacanthus paru				X
Holacanthus tricolor				X
Family Pomacentridae				
Pomacentrus partitus		X	X	X
Family Labridae				
Bodianus rufus				X
Thalassoma bifasciatum	X	X		X
Halichoeres poeyi		X		
Unid. labrid				X
Family Acanthuridae				
Acanthurus sp.	X			X
Family Balistidae				
Balistes sp.				X

*Sponges were not identified at Stations S4 and S5.

APPENDIX 4.2E

Species occurring in 1/4 m quadrat substrate samples at Punta Verraco, Stations S1, S6, and S4 (Replicates A and B).

	S4 (Permanent Station)			
	Repl. A	Repl. B	S1	S6
PLANT KINGDOM				
Phylum Phaeophyta				
Dictyopteris delicatula	o	o	o	+
Sargassum polyceratium	o	o	+	o
Phylum Chlorophyta				
Ulva lactuca	o	o	+	o
Phylum Rhodophyta				
Amphiroa fragilissima	o	o	o	+
Coelarthrum albertisii	o	o	o	+
Galaxaura cylindrica	o	o	o	+
Galaxaura marginata	o	o	o	+
Grateloupia filicina	o	o	o	+
Hypnea musciformis	o	o	+	o
ANIMAL KINGDOM				
Phylum Porifera				
Adocia sp.	o	o	o	+
Geodia papyracea	o	o	o	+
Ircinia fasciculata	o	o	o	+
Tethya sp.	o	o	o	+
Unid. sponge	o	o	+	+
Phylum Coelenterata				
Astrangia solitaria	o	o	3	o
Phylum Nemertea				
Unid. nemertean	0	0	1	0

APPENDIX 4.2E (continued)

	S4 (Permanent Station) Repl. A	Repl. B	S1	S6
Phylum Annelida				
Class Polychaeta				
Arabella opalina	0	0	6	0
Eunice fucata	1	6	0	2
Eunice rubra	0	0	2	0
Eunice unifrons	0	0	1	0
Eunice sp.	1	3	8	3
Eurythoe complanata	1	0	0	0
Glycera tesselata	0	0	0	1
Glycera sp.	0	0	2	0
Lepidonotus branchiatus	0	0	3	0
Lumbrinereis bilabiata	0	0	0	3
Lepidonotus variabilis	0	0	2	0
Lysidice sulcata	0	9	6	2
Marphysa sp.	0	0	3	0
Nereis antillensis	0	0	2	0
Nereis mirabilis	0	0	1	0
Nicidion kinbergii	0	0	0	2
Nicidion sp.	0	0	1	0
Onuphis sp.	0	0	2	0
Paramarphysa sp.	0	3	0	0
Paraxiothea torquata	0	0	1	0
Phyllodice sp.	0	0	1	0
Phyllodoce papillosa	0	0	4	0
Pontogenia sericoma	0	6	0	0
Sabella sp.	0	0	14	0
Sthenelais sp.	0	1	0	0
Stylaroides glabra	0	0	5	0
Syllis prolifera	0	0	10	0
Terebella sp.	0	0	12	2
Unid. flabelligeridae	1	2	0	0
Unid. lysidicean	1	0	0	0
Unid. serpulidae	0	0	0	1
Unid. syllidae	0	0	0	4
Phylum Sipunculoidea				
Sipunculid sp. 1	0	14	0	0
Sipunculid sp. 6	0	2	0	0
Sipunculid sp.	0	0	26	1
Phylum Arthopoda				
Class Crustacea				
Order Pericarida				
Suborder Isopoda				
Accalathura crenulata	0	0	1	0
Cirolana parva	0	0	1	2

APPENDIX 4.2E (continued)

	S4 (Permanent Station) Repl. A	Repl. B	S1	S6
Class Pelecypoda				
Arcopsis adamsi	0	0	1	0
Arca imbricata	0	0	1	1
Arca zebra	0	0	0	1
Barbatia domingensis	0	3	23	3
Brachiodontes exustus	0	1	0	0
Chama congregata	0	0	5	0
Chama sp.	0	0	0	1
Chione cancellata	1	0	0	0
Diplodonta nucleiformis	0	0	2	0
Drillia sp.	0	0	0	1
Gastrochaena hians	2	0	6	0
Gregariella coralliophaga	0	0	1	0
Isognomon radiatus	0	0	5	3
Lima lima	0	0	1	0
Lithophaga bisulcata	0	0	7	0
Lithophaga nigra	0	0	9	0
Lithophaga sp.	1	0	0	0
Macoma orientalis	0	0	0	1
Ostrea equestris	0	0	3	0
Petricola lapicida	0	5	6	0
Spengleria rostrata	0	0	4	0
Phylum Echinodermata				
Class Ophiuroidea				
Amphiura stimpsonii	0	0	1	0
Ophiacantha bidentata	0	0	2	0
Ophiacantha oligocantha	0	0	1	0
Ophiactis savignyi	0	0	2	0
Ophiocoma echinata	1	0	2	0
Ophiocoma pumila	0	0	3	0
Ophiocoma riisei	0	0	0	1
Ophionereis squamulosa	0	3	0	0
Ophiophragmus sp.	0	2	0	1
Ophiopsila riisei	0	0	0	1
Ophiothrix angulata	0	2	2	1
Ophiothrix brachyactis	0	0	1	0
Ophiozona impressa	0	0	1	0
Unid. amphiurid	0	0	3	0
Class Echinoidea				
Echinometra lucunter	0	0	1	0
Unid. echinoids	0	0	2	0
Phylum Chordata				
Class Ascidacea				
Microcosmus helleri	0	0	0	2

APPENDIX 4.2E (continued)

	S4 (Permanent Station) Repl. A	S4 (Permanent Station) Repl. B	S1	S6
Phylum Arthopoda (cont.)				
Order Decapoda				
Suborder Natantia				
Section Caridea				
Alpheus amblyonyx	0	0	2	0
Alpheus cristulifrons	0	0	4	0
Alpheus paesei	0	0	3	0
Alpheus sp.	0	0	1	0
Synalpheus brooksi	0	0	1	0
Synalpheus mcclendoni	0	0	1	0
Thunor rathbunae	0	0	1	0
Suborder Reptantia				
Section Anomura				
Pagurus brevidactylus	0	0	2	0
Petrolisthes galathinus	0	0	1	0
Upogebia operculata	0	0	1	0
Section Brachyura				
Domecia hispida	0	0	1	0
Eurypanopeus sp.	0	0	1	0
Mithrax pleuracanthus	0	0	8	0
Parapinnixa bouvieri	0	1	0	1
Percnon gibbesi	0	0	1	0
Pinnotheres sp.	0	0	1	0
Pinnixa sp.	0	0	0	2
Phylum Mollusca				
Class Amphineura				
Acanthochitona pygmaea	0	1	1	0
Ischnochiton limaciformis	0	0	1	0
Class Scaphotoda				
Dentalium antillarum	0	0	0	1
Class Gastropoda				
Bulla striata	3	1	0	1
Coralliophila caribaea	0	5	1	1
Cymatium sp.	1	0	0	0
Hipponix antiquatus	0	0	1	0
Isognomon radiatus	0	1	0	0
Persicula pulcherrima	1	0	0	0

APPENDIX 4.2F

Gorgonians species and numbers of individuals collected from Stations S4 and S5.

	Station S4 #/replicate	Station S5 #/replicate
FAMILY PLEXAURIDAE		
Plexaura homomalla	2,1	2,5
Plexaura flexuosa	19,10	30,24
Pseudoplexaura porosa	9,4	-,-
Pseudoplexaura flagellosa	2,8	-,-
Pseudoplexaura wagenaari	1,4	-,-
Pseudoplexaura sp.	1,0	29,17
Eunicea fusca		2,8
Eunicea laxispica	6,4	48,48
Eunicea tournefort?	13,2	35,63
Eunicea calyculata	1,4	6,17
Eunicea clavigera	0,2	34,17
Eunicea laciniata	1,0	2,4
Eunicea succinea	10,7	5,5
Eunicea mammosa	1,1	0,0
Eunicea sp.	5,0	0,0
Muriceopsis sulphurea	1,1	0,0
Muriceopsis flavida	34,45	20,21
Plexaurella dichotoma	2,2	0,0
Plexaurella grisea	0,0	1,0
Muricea muricata	6,19	41,32
Muricea atlantica	4,2	12,11
Muricea laxa	0,0	1,0
FAMILY GORGONIIDAE		
Pseudopterogorgia citrina	0,1	0,0
Pseudopterogorgia acerosa	0,1	1,3
Pseudopterogorgia americana	7,12	6,11
Gorgonia ventalina	35,11	8,10
Gorgonia mariae	2,8	1,8
Pterogorgia guadalupensis	1,0	0,0

APPENDIX 4.3A

TERRESTRIAL SPECIES LIST

Species	Site Punta Verraco
Reptilia:	
Bufo marinus	X
Anolis crystatelis	X
Anolis sp.	X
Aves:	
Columbigallina passerina	X
Buteo jamacensis	X
Pelecanus occidentalis	X
Cathartes aura	X
Fregata magnificens	X
Bubulens ibis	X
Mammalia:	
Herpestes javanicus	X
Capra	