At the request of Gary C. Goldman, M. L. Hernandez Avila, Juan G. Gonzalez, ER-0-57, the results of oceanic measurements relating to an OTEC installation at Punta Tuna, Puerto Rico, and Daniel Pesante were examined in November 1979. The study, CEER-0-57, was conducted at the Center for Energy and Environment Research, University of Puerto Rico, and was sponsored by the U.S. Department of Energy.

The study, "Results of Oceanic Measurements Relatable to an OTEC Installation at Punta Tuna, Puerto Rico," was conducted by Gary C. Goldman, M. L. Hernandez Avila, Juan G. Gonzalez, and Daniel Pesante from the Center for Energy and Environment Research at the University of Puerto Rico, College Station, Mayaguez, Puerto Rico 00708 in November 1979. The study, designated as CEER-0-57, was funded through a subcontract (4983802) with the Lawrence Berkeley Laboratory, managed by the University of California, for the U.S. Department of Energy under Contract W-7405-ENG-48.

Executive Statement: Puerto Rico is considered one of the top global locations for a land-connected, operational Ocean Thermal Energy Conversion (OTEC) electrical power plant. The U.S. Department of Energy is studying the oceanographic conditions around the island, focusing primarily on Punta Tuna on the southeast coast of the main island, although other locations are also being considered.

This document is part of a four-phase project designed to gather and evaluate oceanic data specifically at the Punta Tuna site. The phases include:

1. Compilation of a yearly set of periodically sampled oceanic data at the Punta Tuna benchmark site.
2. Interpretation of relevant literature, recently obtained data, and long-term current meter data taken in tandem with this program.
3. An extensive historical literature and data search of oceanic data and interpretation thereof.
4. Recommendations for future studies of the OTEC oceanographic program.

This document addresses the first and second phases and includes a revision of the fourth phase of the project. During the contract period, the

The Punta Tuna site was visited for hydrographic measurements six times: in early August 1978, mid-October 1978, early December 1978, mid-February 1979, late April 1979, and early June 1979. The purpose of each of these cruises was to measure the physical, chemical, and biological variables at various depths and observe the temporal changes of these variables throughout the year.

This program was supplemented by the U.S. Navy Underwater System Laboratory in New London, Connecticut, which placed two subsurface current meter moorings near Punta Tuna. The recorded data from two of the recovered current meters is also discussed in this document.

As the Punta Tuna site was the primary focus, this location is emphasized in both the measurements and the results. However, a nearby site, off Vieques Island, is compared to Punta Tuna, as are two west coast locations and numerous sites along the south coast. Punta Tuna was determined to offer the best overall potential operating efficiency with the closest offshore distance.

The temperature measurement results show there is virtually no change in the deep water (1000 m) temperature throughout the year at Punta Tuna. The surface water temperature changes by as much as 3°C, from a low in late winter to a high in early autumn. The Thermal Resource for a full-size OTEC plant could be expected to vary from 20-23°C annually, if the condenser water intake were at the 1000 m depth and the evaporator water intake were at about 20 m depth.

These results would change at other Puerto Rico sites. At the Vieques location, the surface temperature is consistently about 0.25-0.5°C cooler than at Punta Tuna. At Punta Borinquen, on the northwest coast, the deep water (1000 m) is about 2°C warmer than at Punta Tuna, thereby reducing the northwest coast site's operating efficiency considerably.

The mixed layer depth at Punta Tuna was found to vary seasonally from a depth of as much as 90 m during the winter when the weather is more rough, to virtually zero in the summer, when the weather is calmer.

Calm. The Mixed Layer Depth at Vieques was not much different than that at Punta Tuna. Since the evaporator intake for a full-size OTEC plant may be at a depth of 20-25 m, a plant in Puerto Rico waters might draw water from below the Mixed Layer during part of the summer. The basic water column structure did not change from one location to another, although the temperature structure was slightly different, as mentioned previously.

With a similar vertical density structure, the effluent from either a mixed (cold and warm water together) or separated discharge at any of the investigated locations would probably have similar vertical dynamics. The horizontal water motion, however, will influence the fate of the discharge more than the relative density. Very little is known about the subsurface water currents around Punta Tuna, or even Puerto Rico in general.

As a result of the water current profile measurements taken during each cruise, and the moored current meter returns, (about one month of data), diurnal and semi-diurnal tidal components were identified moving east and west along the south coast past Punta Tuna. Eastward and westward motion appeared dominant at Punta Tuna down to about 500 m during the profiling, with considerable motion in all other directions as well. Between 650-750 m the water direction turns primarily to the northeast and northwest. This scattered information is still insufficient to predict the dynamics of a plant discharge.

Dissolved oxygen results at Punta Tuna compared well with the historical values, showing high surface and near surface values, and a relative minimum at mid-depth, and generally increasing values below 800 m. Likewise, chlorophyll results showed typical patchiness, but within the normally expected ranges for tropical oceanic waters.

The comparison between the air temperature from meteorological records in the Caribbean basin, compares well with the sea surface temperature fluctuations. Furthermore, periods of sustained higher winds produced the

Expected increase in the Mixed Layer Depth, Zooplankton results were statistically non-definitive due to the lack of replication of sampling. Little new information was learned. As indicated in the recommendation section of the report, much of the long-term temperature information is available, at least enough to design and build a power plant. However, the water currents are poorly understood, therefore intake, discharge, and cold-water pipe dynamics are still uncertain. Continuation of studies of nutrient chemistry must also be carried out. Finally, the biological knowledge is the weakest, with virtually no predictive capability for any of the ecosystem components relative to the many interactions that the OTEC plant will have with the biota in the sea.

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of June, 1979.

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Values of Mixed Layer Depth seen in the historical data (ODSI, 1977) and those seen at Punta Tuna and at Vieques during the period from August, 1978 to June, 1979 were also recorded.

Chlorophyll "a" profiles were observed at both Punta Tuna and at Vieques during the cruises of October, 1978, December, 1978, and April, 1979.

Chlorophyll profiles were observed at both Punta Tuna and at Vieques during the cruise of June, 1979.

In June 1979, a time series of integrated chlorophyll "A" in the upper 200 m was measured at both Punta Tuna and at Vieques. This measurement was taken during the period from August 1978 to June 1979. Furthermore, the dissolved oxygen profile for the average of all values measured at Punta Tuna and the average values measured at Vieques (Station "V") was compared to Stations "Cc", "R", and relative to the island of Puerto Rico and its surroundings.

Temperature profiles were compared using thermometer data measured at stations "C", "T", and "F" with the average data measured at Punta Tuna ("B") during the cruise of June 1979. Salinity profiles were also compared using values measured at Stations "C", "R", and "F" with the average data measured at Punta Tuna ("B") during the same cruise.

In addition, density profiles compared values observed at Stations "C", "R", and "F" at Punta Tuna ("B") during the cruise of June 1979. Dissolved oxygen profiles were also compared using values observed at Stations "C", "R", and "F" with the average data measured at Punta Tuna ("B") during the same cruise. Chlorophyll profiles compared values observed at Stations "C" and "F" at Punta Tuna ("B") during the cruise of June 1979.

The location of stations along the south coast of Puerto Rico during the cruise of June 1979 was documented. There was also a temperature cross-section along the south coast of Puerto Rico measured during the cruise. The thermal resource for seven stations along the south coast of Puerto Rico for June 1979 was recorded on pages 246 through 265.

From pages 149 to 152, there is a salinity cross-section along the south coast of Puerto Rico measured during the cruise of June 1979. A density cross-section along the same coast was also measured during the cruise. Geostrophic currents were calculated along the south coast of Puerto Rico (the level of no motion is taken to be 800 m, (+) signifies north). A dissolved oxygen cross-section along the south coast of Puerto Rico was also measured during the cruise of June 1979 on page 266.

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Identification, and Dr. John Morse and Mr. James Zullig from the University of Miami, who advised us in the nutrient analysis. Dr. Bruce Sharpstein, Director of the St. Croix Marine Laboratory, and Tom Adams assisted us by supplying the silicate analyses of our samples from the last cruise. We are most thankful to Messrs. Angel Nazario, Carlos Bonafé, Denis Corales, Edwin González, and Pablo Cabassa for their help at sea. We also want to thank Capt. Bullock and the entire crew of the R/V CRAWFORD from the University of Puerto Rico, Capt. Eladio Rodriguez and the crew of the R/V JEAN A from the Puerto Rico Department of Natural Resources, the Captain and the crew of the USNS BARTLETT (T-AGOR-13), and Lt. Wheeler and the Captain and crew of the USNS YFU-100 from Roosevelt Roads Naval Base. We wish to thank Messrs. Richard Noble, Mike Fetcher, and Tom Gorman, all of the USN Underwater System Lab, New London, Conn. for their assistance and participation in designing and implementing the two current moorings, running the bathymetry near mooring "A", and preparing the preliminary proceedings of the current meter data. We also want to acknowledge the cooperation, advice, and encouragement given by Dr. Patrick Wilde, and C. Carmiggelt, M. Hunt, M. Commins, P. Duncan, and S. Gillette from the University of California, Lawrence Berkeley Laboratory, and Drs. Lloyd Lewis of DOE and Robert Molinari of NOAA. Finally, we wish to offer our greatest thanks to Ms. Carmen Pabón for her infinite patience and understanding in typing and arranging the drafts and final edition of the manuscript for this report, as well as her effort all year to produce the huge amount of written materials required by the program.

1.0 INTRODUCTION

An Ocean Thermal Energy Conversion (OTEC) power plant uses sun-heated tropical or subtropical oceanic waters to produce usable energy. The OTEC plant uses large quantities of warm oceanic surface water and cold deep water to run a thermal engine. The usual estimate is

The text should read:

There should be at least a 20°C difference between the surface and deep water to run the engine with sufficient efficiency to justify this type of energy production. The thermal engine is then used to drive an electricity-producing generator. If the power plant is on or near the shore, the electrical power can be fed into the local electrical system. If the plant is far offshore, it may be used as the energy source for a floating, energy-intensive industrial operation.

Most scientists and technologists consider Puerto Rico one of the prime U.S. locations for an Ocean Thermal Energy Conversion (OTEC) power plant. Furthermore, Puerto Rico seems to qualify as a prime example of a location for a nearshore floating OTC power plant. More than half of the island's 600 km shoreline has water of a depth of 1000 m or greater less than 13 km from the shore. At some places, this offshore distance is only about 3 km. In Puerto Rico, it appears that the 1000 m depth will ensure at least a 20°C temperature difference from surface to deep water throughout the year (Wolff, 1978).

Another advantage of Puerto Rico's location is that it is truly representative of an open ocean island, with little terrestrial runoff and only a small shelf for shallow water coastal organisms to inhabit. Although Puerto Rico is located in the Caribbean, and therefore experiences occasional hurricanes, there are several "safe" harbors around the island for personnel and vessels. Puerto Rico is also a technically modern island, with adequate road, seaport, and airport facilities, a total inter-island electrical power grid, and a vastly expanding electrical need.

Fig. 1: Puerto Rico and its location in the Caribbean.

For these reasons, the U.S. Department of Energy has contracted the Center for Energy and Environment Research (CEER) of the University of Puerto Rico, to conduct a series of bimonthly cruises to an oceanic site, about 4 km southeast of Punta Tuna, Puerto Rico.

Fig. 2: Oceanic site southeast of Punta Tuna, Puerto Rico.

Fig. 3: Punta Tuna, Puerto Rico.

The purpose of these cruises is... [The text ends here and should continue with the purpose of the cruises.]

The objective of these cruises was to measure and evaluate the variability of several OTEC-related oceanic variables. Punta Tuna and its environment have been identified as one of the optimal sites in Puerto Rico (for a more detailed general description of the area, please refer to Atwood et al., 1976). The aim of this report is to detail the activities and measurements associated with these bimonthly cruises, and to analyze and interpret the resulting data. Ultimately, recommendations are proposed that are applicable to future oceanic OTEC measurement programs in this geographical area.

1.1 Introduction to the Measurement Program

During the measurement period, the Punta Tuna station was used for hydrographic measurement purposes six times: early August 1978, mid-October 1978, early December 1978, mid-February 1979, late April 1979, and early June 1979. During the first cruise (in August), the mooring buoy had not yet been implanted, and the vessel was allowed to drift while on station. All subsequent hydrographic cruises used a mooring buoy to maintain location while at the Punta Tuna benchmark station (Station "B"). This mooring buoy was available for use in this program because the U.S. Department of Energy also plans to conduct an at-sea experiment for bio-fouling and corrosion of OTEC heat-exchanger components at the same site. A deep-sea mooring buoy was implanted at 17° 57.6'N, 65° 51.9'W (approximately 4 km southeast of Punta Tuna) in September 1978 (Sasscer et al., 1979).

Fig. 3 Map showing Puerto Rico, Vieques and surroundings. (The occupied stations near southeast Puerto Rico and Vieques are also shown).

The general plan (please see Appendix G for a typical cruise plan) for each hydrographic cruise was to board, load, and disembark from the western part of the island, either from La Parguera (home port for the vessel, Fig. 3) or Mayaguez, and arrive at Punta Tuna approximately half a day later. Usually, the Benchmark station was visited first, and the vessel remained at the mooring.

The text was for approximately 36 hours. During this time, 2 Hydrocasts, 2 Biocasts, 4 Current profiles, 5 Zooplankton hauls, and numerous XBT's were taken. After leaving the mooring (referred to hereafter as Station "B"), various other nearby stations were visited, taking only an X8T with a drifting current meter profile at the start of the program. Finally, a station was visited south of Punta Vaca, Vieques (Fig. 3). This station is located about 40 km from Punta Tuna and was used to determine spatial variations (funded by the Puerto Rico Water Resources Authority). At Vieques (referred to as Station "V"), 1 Hydro/Biocast, 3 Zooplankton hauls, and 1 or 2 XBT's were taken. In addition to these hydrographic measurements, the U.S. Navy Underwater System Laboratory of New London, Conn. was contracted by the U.S. Department of Energy to cooperate with CEER on the implementation of two strings of current meters in the Punta Tuna area. The schedule called for 2 to 4 months interval for servicing of the meters, with a potential total year-long submersion as the goal. One mooring was set in early January of 1979 at near our Station "A" (Fig. 3). The recovery operation for this mooring happened during our February cruise, along with the re-implanting of the mooring at Station "F" (Fig. 3) location. This second mooring had not yet been recovered as of August 1979, although an unsuccessful attempt was made in early May 1979.

2.0 MEASUREMENT DESCRIPTION

During the bimonthly cruises, samples and/or data were taken to determine values of oceanic chemical, physical, and biological parameters at, or near, Punta Tuna, Puerto Rico (Fig. 3). These data and/or samples were taken according to a fixed temporal schedule (if possible) as well as procedure. (Please see Appendix A for a typical cruise plan). The data/sampling operation may be grouped into nine categories:

1. Hydrocast
2. Biocast
3. Current Profile
4. Underwater Horizontal Light Transmission
5. Zooplankton Haul
6. Expendable Bathythermograph (XBT)
7. Weather
8.

Current Meter Mooring 2.0.1 Hydrocasts

The Hydrocasts were standard oceanographic water casts that reached depths of about 1000 m.

The regular procedure involved lowering the hydrowire to the maximum depth, with an open 5-liter Niskin sampling bottle set at each of the desired depths. Each Niskin bottle contained a set of 2 or 3 oceanographic reversing thermometers. The targeted sampling depths for the Hydrocasts were 0, 50, 100, 200, 250, 300, 400, 500, 600, 800, and 1000 m. During each cruise, there were at least 2 Hydrocasts. One Hydrocast was scheduled at Station "B" around noon (1000-1400 hours) and the other around midnight (2200-0200 hours). The water collected during the Hydrocasts was used for onboard analysis of dissolved oxygen, and for shore laboratory analysis of salinity and nutrients.

2.0.2 Biocasts

Biocasts were standard oceanographic water casts that reached depths of about 400 m. They were designed to measure parameters primarily in and just below the photic zone. The procedure involved lowering the hydrowire to the maximum depth, with an open 5-liter Niskin sampling bottle set at each of the desired depths. As with the Hydrocasts, each Niskin bottle contained a set of 2 or 3 oceanographic reversing thermometers. The targeted sampling depths of the Biocasts were 0, 25, 50, 75, 100, 125, 150, 175, 200, 250, 300, and 400 m. During each cruise, there were at least two Biocasts. One was scheduled for the second day at Station "B" around noon (1000-1400 hr), and the other around midnight (2200-0200 hr). The water collected during the Biocasts was sent for offshore analysis of salinity and chlorophyll.

2.1 Water Temperature

Three methods were used to determine the in situ water temperature. For discrete values, reversing thermometers were used in conjunction with the water sampling bottles mentioned above. For a continuous profile, an expendable bathythermograph (XBT) was used.

On one occasion, a Salinity-Temperature-Depth (STD) system was available.

2.1.1 Reversing Thermometers

There were four types of reversing thermometers used during this program. About one-third of the thermometers were manufactured by Watanabe Keiki. These include both protected and unprotected units. The other two-thirds were distributed by Kahl Scientific Instrument Corp. in California, and also include both protected and unprotected types. All these thermometers have been calibrated to within + 0.01 C°. The thermometers were used according to U.S. Navy manual (U.S. Navy, 1968) procedures.

Two protected units were used at each depth to determine the actual temperature. After all the appropriate corrections were made, the results of these two units were averaged. A single unprotected thermometer was used at depths of 300 m and greater to determine the accepted measurement depth, again as per the USN Manual (U.S. Navy, 1968). During shipboard operations, the thermometers were allowed to equilibrate at the measurement depth for 15 minutes and "wait" on shipboard for at least one-half hour to stabilize before reading.

2.1.2 XBT

To collect a continuous graphical profile of temperature vs. depth data, an XBT probe and recorder were used. The instrument and recorder, both manufactured by Sippicon Corp. in Massachusetts, were used as per the manufacturer's instructions. A surface "bucket" water sample was taken for the initial temperature calibration. Although the stated accuracies of the XBT probe and recorder are + 0.2 C* and + 2% for depth, lack of a smooth descent can increase the error. The initial analysis of these data included offsetting the surface reading, and subsequent readings, as per the bucket temperature indication. Then, the depth for each integer centigrade degree was noted, down to the maximum readable depth of slightly more than 760 m.

2.2 Salinity

The salinity of the water at discrete depths was determined by collecting water samples in the 5 liter Niskin sampling bottles and subsampling.

Into an aged, twice-rinsed, 250 ml plastic bottle, the estimated depth of the sample was recorded. The actual salinity determination was made using a Plessy Environmental Systems (now Grundy Environmental Systems) Model 6220 Laboratory Salinometer. The salinometer was adjusted at the beginning of the measurement period, using Standard (Copenhagen) sea water, and then was monitored and corrected using a filtered, seawater secondary standard. The manufacturer's estimated accuracy after making all appropriate corrections is + 0.003 °/e. (Plessy, 1976).

2.3 Water Current

2.3.1 Water Current Profiles

An Interocean, Model 135, Savonious rotor-type current meter was used to measure the water current profile. The strip-chart recording instrument was suspended off the vessel at discrete depths from 25 m down to 750 m, the limits of the meter. The depths sampled during the program varied, but an attempt was made to include representative values from each of the water masses in the water column. On the first cruise, the current profiles were taken at each station, including the Benchmark station and three auxiliary stations. Due to the inaccuracy of the vessel's location fixes, the normal error in the meters and possible induced drag errors the total error in the speed measurement amounted to as much as 4 252.

On subsequent cruises, current profiles were performed only while moored at the Benchmark station. Originally, the timing of the profiles, which took about 2 1/2 hours to perform, was at 0000, 1200, and 1800 hours. During the program, it became evident that a tidal component may be entering into the measurement, but was possibly being aliased. Therefore, during the last two cruises, the measurement period was planned to occur at times of suspected peak tidal current in the area, both ebb and flood.

The instrument originally was designed for a full scale of 150 cm/sec with a resolution of about 1.25 cm/sec, and a manufacturer's estimated accuracy of 1.5 cm/sec (Interocean, 1975). The instrument was

The last two cruises have seen modifications to improve resolution. The full-scale values were decreased to 50 cm/sec, with a resolution of about 0.4 cm/sec. The accuracy was not altered, but by expanding the usable scale, the processed data should be more reliable. The water current direction is sensed by a large external vane, which rotates the entire meter housing. This rotation is sensed relative to a north-seeking compass internal to the housing. The manufacturer's stated accuracy is within 49 degrees of direction.

2.3.2 Moored Water Current Meters

On 6-8 January 1979, an expedition was conducted by Mr. Richard Noble of the U.S. Navy Underwater Systems Laboratory in New Haven, Conn. The objective was to install two current meter moorings. One mooring was to be installed at location "A" (Fig. 3), located at 18° 02.2'N, 65° 39.7'W, and the second at location "B". Prior to each installation, a bathymetric survey of the desired location was to be conducted. Upon determining a suitable location, the mooring was to be released using an "anchor last" deployment method.

On 6 January, the area around Station "A" was surveyed (Fig. 4) using an onboard Gifft precision depth recorder for depth measurements and the U.S. Navy Tracking Team of Roosevelt Roads Naval Base for location. Upon choice of a suitable location, the vessel returned to the site and the anchor (attached to the deployed mooring string) was released. It came to rest at the site labeled "A" on Figure 4. This actual resting site was somewhat deeper than originally planned, due to the presence of rough, uneven terrain.

On 8 January 1979, the second mooring, "B" was cancelled due to navigational problems and malfunction of the precision depth recorder. A schematic of the mooring "A" is shown in Figure 5. The mooring was to have a subsurface buoyancy module about 20m below the surface. Aanderaa current meters, Model RCH-5, were to be located at depths of 100, 200, 400, and 800 m. Also, stretched between 200 and 400 m were two thermister strings.

Temperature sensors were placed every 10 m. The final configuration deviated from the original plan as the thermistor string was not utilized. Each element of the entire array was placed 115 m deeper than initially designed, at a depth of 1215 m. The current meters were programmed to record data every 10 minutes. From this entire array, only the subsurface float and the upper two meters were recovered on 11 February 1979. The results of the recovered data are presented in Section 3.4.2.

Fig. 4 - Bathymetry of the area surrounding the location of the first current meter mooring, "A" (sounding in meters).

Fig. 5 - Schematic representation of current meter mooring "A".

On 14 February 1979, a second mooring was implanted at Station "F". This station was preferred over "B" due to its flatness (41m over about a 1 km radius circle). This flatness was confirmed by a bathymetric survey of "F" prior to mooring deployment. Due to the flatness of the area surrounding "F", there was no need to include the bathymetric chart of this small area. Instead, an isometric drawing is included to show the bathymetric comparison between "F" and the Benchmark area, Station "B" (Fig. 6). The "anchor last" deployment method was used again, and the mooring schematic for mooring "F" is shown in Figure 7. The major difference was the depth and inter-meter spacing. The depth at "F" was 1970 m, while at "A" it was only 1215 m. The recovery attempt for Mooring "F1" in April 1979 was unsuccessful. As of November 1979, the mooring had still not been recovered.

2.4 Water Density

The density values of the seawater were calculated using temperatures measured from the reversing thermometers, and the salinity determinations sampled from the Niskin bottle (Knudsen, 1901). These values were substituted into the following equations:

7 Tet (Go + 0.1328) (1-Ay + By (o9-0,1324))

2 Fee. ((tegg8)*, tezas. 2 = -0.069 + 1.4708C2 - 0.00157¢e2 +

0.0000398c83 Ay = (4.7867 - 0.09815 + 0.0010843t7) 1079 = (18.03 - 0.8164 + 0.01677) 10.03. S represents the salinity of the sample (°/ee) and t represents the temperature of the sample (°C).

Fig. 6 presents the bathymetry of the Punta Tuna area, including the location of the mooring buoy and the second current ring "F".

Fig. 7 provides a schematic representation of current meter mooring "F".

2.5 Dissolved Oxygen

Dissolved oxygen samples were taken from the Niskin water-sampling bottles during the Hydrocast stations. The subsamples were collected using a 300 ml glass bottle, after suitable rinsing, and carefully drawing the sample to avoid air entrapment. The analytical procedure used is that described for use during the International Indian Ocean Expedition (Menzel, 1962). The procedure, shown in Appendix H, is a modification of the standard Winkler techniques, and is followed as soon as possible after the subsamples are collected. Repetitive laboratory sampling and analysis of standards using this method yielded a repeatability of + 0.13 mg/2.

2.6 Chlorophyll Analysis

Analysis for concentration of chlorophyll a, the main photosynthetic pigment and for phaeophytin a, its immediate degradation product were carried out fluorometrically following the guidelines established by Strickland and Parsons (1972). Samples of marine plankton on Millipore or glass fiber filters were stored at -5°C in air tight containers with silica gel desiccator. Samples were routinely protected from exposure to strong light. For extraction of pigments, the filters were placed in screw-cap test tubes with 90% spectrophotometric grade acetone (20 ml), shaken vigorously and stored for 24 to 48 hours at 5°C in the dark. Prior to fluorometric analysis, the samples were centrifuged at 5000 rpm for 5 min, decanted and allowed to come to room temperature. The extracts were quantified using a Turner 110 filter fluorometer equipped with filters, door and photomultiplier recommended by the above authors, for phaeophytin.

In an analysis, the above extracts were treated with two drops of 1 N HCl. This was allowed to react for 5 minutes before being read once more on the fluorometer. The fluorometer was calibrated by comparing its response to pigments with that of a Beckman DU spectrophotometer, which was equipped with the Gilford up-dating electronic array.

Twenty-one liters of sea water, obtained from waters offshore of La Parguera (Fig. 3), were filtered onto Whatman No. 3 filters and extracted in 90% acetone. Absorbance at 665 nm was measured using 10 cm path length cuvettes. Pigment concentrations were calculated using the formulae provided by Strickland and Parsons (1972). Following this, door factors for the fluorometer were computed from data on the fluorometer's response to known dilutions of the primary standard.

2.7 Zooplankton

Zooplankton sampling was carried out by either vertical, horizontal, or oblique hauls. For vertical or oblique hauls, the 202 micron (silk size #8), 3/4 m diameter opening net is secured to a double trip mechanism and lowered to the desired depth. The closed net is then raised and a messenger is sent down the cable, activating the first part of the double trip mechanism to open the net at the desired depth.

As the open net ascends and approaches the upper limit of the fishing depth, a second messenger is lowered, again activating the double trip mechanism, but this time to close the net. When the vessel was at the mooring, the haul was almost vertical. If the vessel was drifting, the path of the net became oblique due to the ship's motion. The depths sampled were: 1000 m - 0 m, 1000 - 800 m, 800 m - 200 m, and 200 m - 0 m.

Finally, to achieve a 25 m deep horizontal haul, or tow, the net was lowered in the closed position while the vessel was steaming at or less than 1.5 m/sec. The actual net depth for these horizontal tows was computed, based on the wire angle from the vertical. Messengers are lowered at the desired depth to open and close the net at the appropriate time interval. In all cases, a flow meter was mounted.

At the net entrance, the water volume passing through the net was measured. The collected samples were hosed with sea water into a container and preserved in a 4% buffered formaldehyde solution for future laboratory analysis.

In the laboratory, the samples were sorted and cleaned to remove foreign particles. A subsample was drawn using a 1 ml stemple pipette. If the number of copepods did not reach 300-400, subsequent subsamples were drawn and added to the first. Under a stereo-zoom binocular dissecting microscope, the animals were identified at the species level for copepods, or family level for other organisms. All the animals were measured for length.

2.8 Nutrients

Water samples were analyzed for nitrite, nitrate, phosphate, and silicate. Originally, the samples were filtered through a Nuclepore filter and then treated with hydrochloric acid. Later, chloroform replaced the hydrochloric acid, and the filters were changed to Millipore membrane filters (45 um mesh). The plastic bottles used for storing the subsamples were acid washed. During the first four cruises, the subsample of water to be drawn and filtered on board was collected in an acid-washed, twice sample-rinsed poly-bottle. After filtering, the sample was returned to the plastic bottle and treated with a preservative.

As a precaution against unfiltered contamination, a twice-rinsed transfer bottle was used on the last two cruises to carry the water to the filtering apparatus. The sample was placed into a clean, acid-washed storage bottle and preservative added only after filtering. In all instances, after preservation, samples were stored at 4-5 °C until the analysis was completed. The analysis procedures were virtually identical to those provided by the manufacturer of the Technicon Autoanalyser (Technicon, 1972; Technicon, 1973; Technicon, 1973a).

2.9 Horizontal Light Transmission

The horizontal light transmission was measured using a Hydro Products model 912-5 transmissometer system. The unit measures both the percentage of light transmitted.

The text reads over a 1-meter path length and the instrument depth (Hydro Products, 1974). The instrument was read at convenient intervals, usually about 15 m, both while descending and ascending through the water column. The two readings from each depth were averaged. However, the instrument never functioned properly throughout the field measurement period, even after factory recommended repairs and a trip back to the manufacturer.

2.10 Meteorological Data - The meteorological data, taken during the cruise, consisted of air temperature, wet and dry bulb thermometer, barometric pressure, sea state, wind speed and direction, and cloud cover. As the methods for these data are adequately reported (U.S. Navy, 1968), they will not be reported here. This report also includes some analysis of data taken at the Coast Guard Station at Punta Tuna Light and the NOAA Climatological Data from San Juan. The Punta Tuna Light data are taken every 3 hours (on weekdays) from 0800-1700 hr. The San Juan data are from hourly observations, as well as monthly averages, dating back to 1941.

3.0 RESULTS AND INTERPRETATION

The following sections describe the results of the data acquisition program during the period from August 1978 through June 1979. Preceding the discussion of these results, a summary of historical information is included that will help to describe some of the physical, biological and chemical characteristics of the area.

3.0.1 Summary of Historical Results

3.0.1.1 Climate - The Commonwealth of Puerto Rico, associated with the United States by bilateral agreement, consists of a main island and several smaller islands. These islands are all located along the Antilles Chain of islands, extending almost from Florida, USA to Venezuela, South America (see Fig. 1). Puerto Rico is approximately halfway along the Chain, about 1700 km from Miami, Florida. The nearest large land mass to Puerto Rico is the island of Hispaniola, about 130 km to the west. The Chain separates the Atlantic Ocean and

The Caribbean Sea is located to the south of Puerto Rico. Given that Puerto Rico is situated along an east-west axis, the Atlantic Ocean washes its north coast, while the Caribbean Sea washes its south coast. At a latitude of about 18°N, Puerto Rico is in the trade wind belt, with both the winds and oceanic currents generally moving east to west past the island.

The main island of Puerto Rico is roughly rectangular in shape, stretching about 180 km from east to west, and about 60 km from north to south. The island is a mixture of mountains, rolling hills, and broad flat plains. Generally, where the plains meet the sea, the climate is typically tropical marine, except along the semi-arid southwestern coast. This means that during the day, as the land mass heats up, a convection cell is developed, causing the winds to move landward from the sea, bringing moist sea air inland. In the evening, as the land cools, the convection cell reverses and the winds blow offshore.

Due to the numerous hills and mountains on the island of Puerto Rico, the moist sea air is frequently cooled to saturation while still over the land mass. This results in considerable rainfall, almost daily over some parts of the island.

3.0.1.2 Wind Regime. The sixth edition of the U.S. Coastal Pilot, Area 5 (U.S. Dept. of Commerce, 1967), summarizes the wind regime on the coast of the island as follows: "The prevailing winds over Puerto Rico are the easterly trades, which generally blow fresh during the day. The center of the Bermuda High shifts a little north in summer and south in winter, changing the direction of the winds over the island from north-northeast in winter to east in summer. Factors which interrupt the trade wind flow are frontal and easterly wave passages. As the cold front approaches, the wind shifts to a more southerly direction, and then as the front passes, there is a gradual shift through the southwest and northwest quadrants back to northeast. The easterly wave passage normally does not bring a westerly wind but is usually characterized by an east-northeast wind ahead of the wave and a change."

The passage follows towards the east-southeast. Over most of the ocean near Puerto Rico, the strength of the winds increases in midsummer, with lighter winds in the spring and autumn seasons. There are also somewhat higher average winds in the northwest part of the area in late autumn and winter. Mean wind speeds over the Atlantic in this area range from 9 to 10 knots (4.5 to 5 m/sec) during the autumn to a high of 12 to 15 knots (6 m/sec) in midsummer.

3.0.1.3 Water Masses and Circulation - The water masses in the Caribbean have been discussed by many authors (Must, 1963; Atwood et al., 1976; Craig et al., 1978; Lee et al., 1978). For completeness, they will be mentioned again in this report as the source, depth location, movement, and characteristics of the water masses are important for understanding the data described in the following sections.

The cold water intake pipe of an OTEC plant in Puerto Rico waters would probably extend from near the surface to about 1000 m deep. With the intake opening at 1000 m depth, the intake water would come from approximately 50-100 m above and below that depth. Therefore, for the purposes of this report, the water masses in the upper 1100 m of water in the northern Caribbean will be considered.

The upper water mass is called the Tropical Surface Water (TSW). The origin of this water is under the equatorial atmospheric trough (low), which is a tropical rain belt located to the northeast of South America. The TSW is influenced both by heavy precipitation in that area and by runoff from the Amazon and Orinoco Rivers. This water mass is driven by wind and the earth's rotation into the eastern Caribbean Sea through passages in the Lesser Antilles island chain.

As the water mass continues to move under the wind stress of the predominant easterly winds, the water moves northwest toward the Yucatan. By the time it reaches Puerto Rico, the temperature and salinity of this upper water mass have been further affected by the general and local climate.

The area through which it has passed experiences additional precipitation and runoff, although slight. Evaporation from wind and insolation could further influence both the temperature and salinity. In the Tropical Surface Water (TSH), salinity generally ranges from 33-36 °/ee, and temperature ranges from 25°C to 29°C. This water mass appears to be wedge-shaped, attaining its maximum depth along the northern Caribbean due to geostrophic subsidence as the water moves westward. The local depth of the water mass may be more influenced by atmospheric pressure and its variation. Normally, atmospheric pressure changes little, with changes of 3-6 mm of mercury in a month being considered large. However, as a tropical pressure trough moves through the Caribbean, the pressure is severely reduced, causing the water level to be raised, pushing the upper water mass to the side, and upwelling the cooler, more saline water from below. This upwelling would occur during a hurricane and, to a lesser degree, during a tropical wave or a tropical storm. This atmospheric effect on an operating OTEC plant would be to severely reduce its thermal efficiency.

The water mass directly beneath the Tropical Surface Water is called the Subtropical Underwater (SUW). This lower water mass originates directly beneath the Bermuda atmospheric high pressure zone. The Bermuda High is the atmospheric downwelling component of the Hadley cell which gives rise to the Equatorial Atmospheric Trough, which in turn is related to the origin of the Tropical Surface Water discussed above. The air under the Bermuda High is generally warm and dry. Due to the lower relative humidity, evaporation is great and salinity is increased, making this water mass the most saline in all the Caribbean. The SUW descends to form the upper portion of the thermocline in the Caribbean. The salinity within the SUW does not vary much (36.8-37.2°/ee) because the water rarely comes into contact with any diluting agent. During conditions of low atmospheric pressure, this water is... (Text cut-off)

Drawn upward, as evidenced by the very high salinity seen at or near the surface. The temperature range within the Subtropical Underwater (SUW) is 20°C-24°C. Due to thermal conduction, the temperature does not remain as invariant as the salinity. The density difference between the Tropical Surface Water and the Subtropical Underwater is large enough that they remain two distinct water masses. The SUW moves southward from the higher latitudes near Bermuda and enters the Caribbean through passages along both the north and east. From these passages, the water moves generally southward or westward, or both, to spread throughout the entire Caribbean beneath the Tropical Surface Water.

As the SUW moves westerly into the Caribbean, it is seen to dilute somewhat to about 36.5-36.6‰ in the Yucatan Strait. Near Puerto Rico, the water enters the Caribbean southward through both the Anegada and Mona Passages. The core of this water mass generally lies at about 125-150m depth in the Puerto Rico area. Below the SUW lies a transition zone of indistinct characteristics.

This transition zone contains the lower portion of the thermocline and extends into the definite area of the cold water zone. This transition water is a mixture of North Atlantic Central Water and diffused and diluted Mediterranean Water. The salinity ranges about 36.8‰, from the water mass above it, down to about 35‰. The temperature ranges from 20°C to about 7°C. This transition zone reaches from about 200m to 600m depth. Just below this zone lies the oxygen minimum, which many people define as the boundary of the cold water zone in the oceans. This transition water enters the Caribbean from the north and from the east and probably moves both southward and westward.

The Antarctic Intermediate Water (AIW) is found just below the transition zone (600m-800m). This water is formed at the Antarctic Convergence Zone, about 45°-55° south latitude. The water tends to be low in salinity, as it is formed in an area where precipitation far exceeds evaporation. The AIW is

The text can be fixed and improved as follows:

The water mass is seen moving northward from its area of formation, and it makes its way into the Caribbean over the moderately deep sills of the Lesser Antilles, the Anegada Passage, and the Windward Passage, between Cuba and Hispaniola. These deep sills may also form a path of departure from the Caribbean for the Antarctic Intermediate Water (AIW) that has entered through the Lesser Antilles Passages. This water mass spreads to cover much of the Caribbean Basin. The movement of the AIW near Puerto Rico could be either south and west (having entered either through the Lesser Antilles or the Anegada Passage), east (entering through the Windward Passage), or even north and east or west (departing through the Anegada or Windward Passages).

As the water has moved northward through the Atlantic, it has been in contact with higher salinity water. Therefore, the salinity of the AIW as it passes Puerto Rico is no longer the 34°/oo of its origin, but rather about 34.8°/oo. The temperature is 6-7°C. From 800 m down to 1000 m, between the Antarctic Intermediate Water and the North Atlantic Deep Water (NADW), lies another thin transition zone.

From about 1000 m depth and deeper, the water mass found in the Caribbean Sea has most of the characteristics of the North Atlantic Deep water. This water is formed in the high northern latitudes, and while descending both in depth and latitude, it entrains some of the Mediterranean water, thereby increasing its salinity, density, and depth. This water enters the Caribbean only through the Windward and Anegada Passages. The water moves mainly westward from the Windward Passage, but south and west from the Anegada Passage to fill all the deep basins in the Caribbean. This water is characterized by 4-5°C temperatures, and a salinity of 35°/oo.

After this water mass moves into the Caribbean, it is virtually trapped, with only 2 small passage out through the Yucatan Strait. The water remains in the Basin and is slightly different in silicate content from its origin, the NADW, found outside the Caribbean.

For this reason, some people choose to refer to this deep, cold water as the Venezuela Bottom Water in the Basin. In some sections of the Caribbean Basin, the thickness of this water mass exceeds 3000 m.

3.0.1.4 Tides

Generally, the tides on the Caribbean coasts of Puerto Rico are of the mixed diurnal type, featuring a minor semidiurnal component. An amphidromic (nodal) point of the primary lunar semidiurnal (Mj) tidal constituent is found near Punta Tuna (Atwood et al., 1976; Dietrich, 1963; Defant, 1961). The proximity to the node implies limited tidal motion. Furthermore, since Punta Tuna is on the relatively exposed eastern side of the island, the tidal system influencing the North Atlantic (with its amphidromic point east of Newfoundland) may have an impact on our site. The outcome could be a moderately confused tidal current over our area of interest. The expected tidal currents in the Punta Tuna area tend to move east and west - west during the flood tide and east during the ebb tide. The actual impact of this tidal movement on the prevailing water motion at Punta Tuna is yet to be determined.

3.0.1.5 Productivity

Productivity, defined as the rate at which biological organisms store energy, typically reduces from the coastal margins to the open ocean (Davis, 1973). Generally, tropical ocean waters exhibit low productivity and little seasonal variation. Raymont (1963) argues that two compounds, phosphate and nitrate (along with nitrite and ammonia to a lesser extent), are crucial for marine plant growth. Typically, the levels of these vital nutrients in the upper photosynthetic zone, which is the only zone directly related to primary productivity, are low and fairly constant in subtropical and tropical waters. Thus, it might seem that the tropics and subtropics would have low productivity. However, the overall productivity in tropical regions, when considered on an annual basis, might be much higher than initially perceived, as the nutrients are rapidly recycled.

In warm tropical waters, several cycles occur throughout the year. Around the world, in tropical seas, the standing phytoplankton crop tends to be low at any given time. However, the photosynthetic zone is considerably thicker in tropical seas due to the lower turbidity, compared to other waters (Riley, 1939). The euphotic zone, which is the part of the water column with enough sunlight to photosynthesize, reaches down to about 100m in depth (Duxbury, 1971). At the OTEC plant site, the euphotic zone closely corresponds with the Tropical Surface Water (TSW). This water mass may have a thickness of up to 100 m and its characteristics have been previously discussed in Section 3.0.1.3 of this report. Almost all phytoplankton activity occurs within the first 100m of the water column off Punta Tuni.

3.0.1.6 Zooplankton. In the Caribbean, the most common groups of zooplankton, in order of numerical importance, are copepods, chaetognaths, and pteropods. Approximately 450 species of oceanic calanoid, harpacticoid, and cyclopoid copepods have been reported from the Caribbean. Despite the greater number of calanoid species, the total number of individuals is nearly equal to that of the cyclopoids. The most numerous cyclopoids, Farranula carinata and Oithona plumifera, are more than twice as abundant as the top-ranking calanoids, Clausocalanus furcatus and Mormonilla minor. The smallest group of planktonic copepods, Harpacticoida, includes the third most numerous form, Microsetella rosea (Michel, Foyo, and Haagensen, 1976).

There are 18 species of chaetognaths prevalent in tropical oceans, five rare bathypelagic forms: Bathybelos typhlops, Eukronia hamata, E. proboscidea, Sagitta megalopthalma, and S. planktonis, and two neritic species which are sometimes swept into oceanic waters, S. helenae and S. hispida. The most common pteropods encountered around Puerto Rico are Limacina inflata, L. trochiformis, Creseis acicula, and Styliola subula.

Diacria trispina, Cavolina inflexa, and Desmopterus papili are all found in the Caribbean waters.

3.0.1.7 Dissolved Oxygen: The dissolved oxygen concentration throughout the Caribbean water column varies little throughout the year. Dissolved oxygen in surface waters generally ranges from 4 to 5 ml/l. This is a highly saturated condition. From this high, mixed layer value, there is a steady decrease, caused by both the length of time since the lower waters have been oxygenated at the surface and the depletion of the available oxygen by decomposition of descending dead and detrital matter. This oxygen minimum occurs at about 500-700 m depth and has an oxygen concentration of around 2.5-3.2 ml/l. Below the oxygen minimum, the concentration increases, due to the high oxygen-carrying capacity of the cold, less saline North Atlantic Deep Water. The values at about 1000 m may rise to about 3.5-4 ml/l, and at 2000 m, the dissolved oxygen concentration may rise to as much as 5.5-6 ml/l (Atwood et al., 1976; Wust, 1964).

3.0.1.8 Nutrients: Tropical surface waters, such as the Caribbean, are usually deficient in many of the nutrients necessary for phytoplankton growth. The photosynthetic processes remove the nutrients from the upper, photic zone. As there is little land mass to produce organic runoff, the replenishment is very poor. Furthermore, nutrients are lost to the upper water column as detritus and dead organisms sink below the photic zone and continue to the bottom. Therefore, generally, the Upper Mixed Layer nutrient concentrations are quite low in these tropical and subtropical seas and remain low to at least about 200 m depth. Below this depth, the concentrations are seen to rise to maximums at depths of 600 and below. Typically, the ratio of maximum values to minimum values may be about 15:1 for phosphate, 10:1 for silicate, and about 25:1 for nitrate. Although these ratios are by no means fixed, they are typical of what is measured in Caribbean waters (Atwood, et al, 1976).

3.1 Temperature Results: During each cruise,

An attempt was made to collect at least four sets of discrete temperature data at the Punta Tuna benchmark site, Station "BY". Usually, the four sets consisted of two Hydrocasts (to about 1000 m) and two Biocasts (to about 400 m). On all the cruises, except the first, several XBT's were taken at the Benchmark station, as well as other stations in the nearby area. Figures 8-13 show temperature versus depth profiles for each of the six hydrographic cruises. The profile shown in each figure is the average temperature, as measured with the reversing thermometers, from the four casts at the Benchmark station during that particular cruise. There is a moderately strong seasonal thermocline seen during all but the June 1979 cruise. The April data shows some reduction in the thermocline strength over that seen during the rest of the year, but during June, no thermocline was observable at all. Thermal variations with depth are also present throughout the year, but the next set of figures are used to show this variation more clearly.

Page Break

'Temperature (°C) Depth (m) Fig. 8 - Temperature profile at Punta Tuna using average reversing thermometer values for the cruise of August, 1978.

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Temperature (°C) Depth (m) Fig. 9 - Temperature profile at Punta Tuna using average reversing thermometer values for the cruise of October, 1978.

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Depth (m) Fig. 10 - Temperature (°C) Temperature profile at Punta Tuna using average reversing thermometer values for the cruise of December, 1978.

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Temperature (°C) Depth (m) Fig. 11 - Temperature profile at Punta Tuna using average reversing thermometer values for the cruise of February, 1979.

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Temperature (°C) Depth (m) Fig. 12 - Temperature profile at Punta Tuna using average reversing thermometer values for the cruise of April, 1979.

Page Break

Temperature (°C) Depth (m) Fig. 13 - Temperature profile at Punta Tuna using average reversing thermometer values for the cruise of June,

In 1979, temperature data was recorded at the Benchmark site, as shown in Figure 14. This figure displays a time series of the temperature from reversing thermometer averages throughout the year.

The temperature of the upper waters reached about 29°C in October 1978, and it hovered over 27°C from August to December 1978, before peaking again in June 1979. During February and April 1978, the upper water temperature was about 26.4°C.

Despite some experimental error in determining both the depth and the temperature, there appears to be a slight rise of the 26°C isotherm during April and June. Additionally, there seems to be a vertical migration of the 6°C isotherm throughout the year. However, an error in the December value alone could account for much of this cold water variation.

Figures 15-20 illustrate the time series of temperature recorded during each cruise. These figures were created using all the XBT and reversing thermometer data collected during each respective cruise. Typically, there are at least four thermometer sets per cruise and at least eleven XBT casts.

The reversing thermometer data corresponds to the four aforementioned casts at the Benchmark site and one additional cast at the Vieques station. The XBT casts were taken at the Benchmark station, Vieques, and a few nearby locations, as seen in Figure 3.

Exceptions to this general trend are the first cruise, which ended prematurely due to equipment problems and had a nonfunctioning XBT recorder. The fourth cruise was also cut short due to a collision at sea. The final cruise had many other stations shown. More details about the last cruise in June 1979 will be provided in Section 6.0.

In these thermal time series displays (Figures 15-20), the thermometer data are shown as dashed lines and the XBT data are shown as solid lines. The intention of showing these figures is to provide the reader with our actual temporal variation of the water temperature during the cruise. This also facilitates an easy comparison between the XBT values and the much more reliable reversing thermometer values.

Accurate thermometer values, as expected, show the X8T values with a much greater variation than the thermometers. This highlights a potential hazard.

Figure 14 - Time series of average reversing thermometer results at Punta Tuna from August 1978 to June 1979.

Figure 15 - Time series of reversing thermometer results at Punta Tuna during the cruise of August 1978.

Figure 16 - Time series of reversing thermometer and XBT results during the cruise of October 1978.

Figure 17 - Time series of reversing thermometer and X8T results during the cruise of December 1978.

Figure 18 - Time series of reversing thermometer and XBT results during the cruise of February 1979.

Figure 19 - Time series of reversing thermometer and XBT results during the cruise of April 1979.

Figure 20 - Time series of reversing thermometer and X8T results during the cruise of June 1979.

Relying solely on XBT results may be misleading. Although the average results of both series are similar, the variation of the individual X8T values should be viewed in the correct context.

3.1.1 Thermal Resource

Figure 21 shows a temperature vs. depth profile based on all the thermometer data during our measurement program. In this figure, the ranges of all thermometer values are also shown at each depth, as well as the standard deviation from the mean for depths down to 100 m. The average profile exhibits a thermally mixed layer, with an observable thermocline. The range of observed values were about 27.572 °C at the surface, but the spread increases considerably at about 125 m depth to 23.32 °C. From this depth, the spread of values generally decrease to less than 0.2 °C. The standard deviation from the mean in the upper water is about ±1 °C. Also shown

In Figure 21, there is a conversion from the actual temperature to a usable temperature-difference, termed as Thermal Resource. From the bottom auxiliary axis, it's easy to see that the Thermal Resource exceeds 20°C from 50 m to 1000 m. Figure 22 presents the time series of the Thermal Resource at the Punta Tuna Benchmark site, showing its effect on the OTEC plant. The Thermal Resource is the temperature difference that can be utilized by a plant to operate the thermal engine and produce power. Typically, the Thermal Resource is considered as the temperature difference (in Centigrade or Kelvin degrees) between the surface water and the water at 1000 m depth.

As these results can be used to formulate design criteria, Figure 22 also includes the difference from the surface to 900 m depth. As seen in the figure, using 900 m instead of 1000 m reduces the Thermal Resource by about 0.5°C. In reality, some depth other than the surface should be used for the warm water intake value. For this Puerto Rico data, the only alteration would be a decrease in the available Thermal Resource with depth below the surface.

On page 44, there is a temperature profile of the average thermometer data taken at Punta Tuna for all cruises, from August 1978 to June 1979. The maximum and minimum temperatures at each depth are also shown.

In June, due to the lack of a thermally mixed layer, there could be a loss of as much as 0.4°C in the Thermal Resource at 20 m depth. Regarding the actual variation of the Thermal Resource, the figure clearly shows a minimum in late winter (our February cruise) and a maximum in early autumn (or late summer). These results are similar to those in the literature, and our values serve to confirm the historical data (Wolff, 1978). The Thermal Resource varied from 20.8-23.4°C (1000-0 m case), with a mean of 22.1±1.0°C.

The temperature ranges are between 20.3-23.0 C (900-0 m case), with a mean of 21.54 C. 3.2 Salinity Results were obtained during each cruise in an attempt to collect at least four sets of water samples for subsequent salinity determination as a function of depth. Similar to the temperature data, the four sets consisted of two Hydrocasts (to about 1000 m) and two Biocasts (to about 400 m). Additionally, when possible, extra casts were taken either at the Vieques station, or Station "F" or both. Figures 23-28 show vertical profiles of salinity for each of the six hydrographic cruises. In each figure, the salinity displayed in the profile is the average of the four casts, when possible. All the profiles show the same general shape, with a variable upper water salinity, a salinity maximum of about 37% at 125-150 m, and a gentle salinity decrease to about 34.9-35.0% at about 700 m and below. In cases where the spread in the salinity determination during a particular cruise exceeded +0.02%, at a given depth, the data spread is also shown in the figure. Figure 29 is a time series description of the salinity profiles throughout the year. These values were made using the salinity averages for each cruise, as were the previous figures. The noteworthy points in this figure are the large salinity variations in the upper water throughout the year, and the lack of variation elsewhere in the water column.

SALINITY (%)

Fig. 23 - Average salinity profile at Punta Tuna for the cruise of August, 1978. (Maximum and minimum observed salinity values are shown at each depth).

SALINITY (%) DEPTH (m)

Fig. 24 - Average salinity profile at Punta Tuna for the cruise of October, 1978. (Maximum and minimum observed salinity values are shown at each depth).

SALINITY (%) DEPTH (m)

Fig. 25 - Average salinity profile at Punta Tuna for the cruise of December, 1978. (Maximum and minimum observed salinity values are shown at each depth).

SALINITY (%) DEPTH (m)

Fig. 26

Of the water sampling bottle in this rapidly changing environment. In the vicinity of a large vertical gradient of salinity, a small error in depth of only a few meters may appear to be a large salinity excursion. With increasing depth, the observed data spread decreased considerably from about 0.15°/m at the salinity maximum to less than 0.02°/m at depths greater than 800 m.

3.3. Density Results

The density of any water particle in the water column is primarily a function of the temperature and the salinity of that particle. The relative density of that particle, compared to all others, will determine the vertical location of that particle within the column.

SALINITY (%) DEPTH (m)

Fig. 30 - Average salinity profile observed at Punta Tuna for all cruises from August, 1978 to June, 1979. (Maximum and minimum observed salinity values are shown at each depth).

Figures 31-36 show the average vertical density profiles for each of the six hydrographic cruises. In all, but the last cruise (June,1978), a thick isopycnic layer is clearly defined at the surface. Just below this uniform layer lies a relatively sharp pycnocline of about 2 sigma-t units within less than 100 vertical meters. As the normal wind field develops over the Caribbean, the mixing intensifies, enhancing the presence of a strong pycnocline. In the absence of mixing, the isopycnic layer may decrease to almost nothing.

Figure 37 is a vertical profile of the average density including all the data from this program. The average profile also shows an isopycnic layer at the surface, and a sharp pycnocline directly beneath it. Also shown, in this figure are the ranges of the density values determined for each depth during the sampling period. As usual, the maximum variations are found in the upper, near-surface waters, with generally decreasing variations down to about 300 m. Below this depth there is less than +0.1 sigma-t units change at each depth throughout the year. This figure, and the preceding density profiles,

The text could be enhanced for readability as follows:

The combination of temperature and salinity profiles can be used to make estimates of the density change due to the heating and cooling of the water pumped through an OTEC power plant. Subsequently, predictive models can be developed to determine the ultimate depth of the effluent waters, relative to the existing ambient water column.

3.3.1 Mixed Layer Depth

The water intake for the evaporation of an OTEC plant draws heat from the upper water layers of the ocean. As previously mentioned, the uppermost layer is usually in a state of vertically stable equilibrium. It is isothermal, isohaline, and therefore, isopycnic (constant density) for many meters down from the surface. It is important to know the depth of this uniform layer to ensure the uniformity of the intake water.

57

DENSITY (σt) DEPTH (m)
Fig. 31 - Average density profile observed at Punta Tuna during the cruise of August 1978.

58

DENSITY (σt) DEPTH (m)
Fig. 32 - Average density profile observed at Punta Tuna during the cruise of October 1978.

DENSITY (σt) DEPTH (m)
Fig. 33 - Average density profile observed at Punta Tuna during the cruise of December 1978.

60

DENSITY (σt) DEPTH(m)
Fig. 34 - Average density profile observed at Punta Tuna during the cruise of February 1979.

61

DENSITY (σt) DEPTH (m)
Fig. 35 - Average density profile observed at Punta Tuna during the cruise of April 1979.

62

DENSITY (σt) DEPTH (m)
Fig. 36 - Average density profile observed at Punta Tuna during the cruise of June 1979.

DENSITY (σt) DEPTH (m)
Fig. 37 - Average density profile observed at Punta Tuna for all cruises, from August 1978 to June 1979. (Maximum and minimum values are shown at each depth).

64

There are a variety of definitions for the Mixed Layer Depth (MLD). They have all been put forward, but they usually determine about the same depth value. The reason being that the upper layer is usually well mixed.

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Fig. 38 - Time series of the Mixed Layer Depth at Punta Tuna from August 1978 to June 1979. (Average historical values are also shown).

The most probable historical values are also seen not to differ considerably.

3.3.2, Temperature/Salinity Relationships

Although temperature and salinity are not necessarily controlled by the same mechanisms in the ocean, there do exist rather reliable interrelationships between the two. Figure 39 shows the temperature/salinity, or T/S diagram for the six cruise averages. Even though the cruises were taken during separate times of the year, many T/S characteristics remain quite constant during this time.

The Tropical Surface Water (TSW) is the most variable, as seen by the scatter in the upper portion of the Figure. The Subtropical Underwater (SUW) is relatively constant in its characteristics, and the vertical range of this water mass, not easily seen in this Figure, is usually only affected by severe weather conditions.

The two deeper water masses, the Atlantic Intermediate Water (AIW), and the North Atlantic Deep Water (NADW) have little seasonal variation.

Another T/S relationship can be seen in Figure 40. This is a time series of the upper 40 m for temperature, salinity, and density during the time of our measurement program. From this type of display, one can easily note the inverse variation between the temperature and the salinity throughout the year.

Another easily discernible relationship is the matching of the density with the salinity, not the temperature, as might be expected. In the density determination, the salinity is seen to be a much stronger functional force than is the temperature.

The results of a figure...

The following text has been proofread and corrected:

Tools such as this must be used to determine effluent mixing and dispersal depth.

3.4 Water Current Results

During each cruise, a set of water current profiles were taken at least 4 times while at the Benchmark station. Also, during the program year, 2 current meter moorings were installed near the Benchmark.

SALINITY (%e) TEMPERATURE (°C)

Fig. 39 - Temperature/Salinity diagram of all data observed at Punta Tuna from August 1978 to June 1979.

Fig. 40 - Time series of sea surface-water characteristics at Punta Tuna observed from August 1978 to June 1979.

3.4.1 Current Meter Profiles

On the first cruise, current profiles were taken while the vessel was drifting. Starting with the October 1978 cruise, the measurements were made with the vessel secured to the mooring. The results of the initial measurements were strongly influenced by the drift of the vessel. An error analysis using the best available estimates for the instrument accuracy, the instrument readability, and the vessel position finding capability (the largest error of the three) produced possible errors in excess of +10-15 cm/sec and entire quadrants of direction.

Also, it is possible that our meter might be adversely affected by being pulled through the water by the drifting vessel, and having the plane of the Savonius rotor of the meter not necessarily in the same plane as the water flow.

During the program, the current meter was upgraded to increase the readability by expanding the scale 3-fold. This did not necessarily change the precision of the meter, but increased our ability to read the speed values in the 0-10 cm/sec range considerably.

To complement the current profiles, the north-south components of the geostrophic current have been calculated using the data taken at both Punta Tuna (Station "B"), and Vieques (Station "V"). These calculations have been made for October and December 1978, and April and June 1979.

Geostrophic current

Calculations are most accurate outside the influence of surface meteorological forcing, away from boundaries such as land, and at mid-latitudes. In spite of these shortcomings, the results of the calculations, shown in Table 2, compare well with the north-south component of the current profiles. In the calculations, the level of no motion is assumed to be 800 m deep. This assumption is based solely on the maximum measured depth, not on any physical observation. Figures 41-52 show modified stick-type diagrams of the current profiles for each cruise, as well as time series current patterns in N-S and E-W component form for each cruise.

TABLE 2 North-South Components of Calculated Geostrophic Currents Between Punta Tuna and Vieques (N signifies North, Speed in cm/sec)

Cruise	Cruise	Cruise	Cruise
DEPTH	Oct. 1979	Dec. 1978	Apr. 1979	June 1979
30	-19	22	8	22
50	-13	14	3	12
75	-5	-7	+2	10
100	-1	-6	+5	12
125	-3	-5	4	12
150	74	-4	41	10
175	-3	-3	-1	9
200	-3	-3	0	9
250	-2	-3	+1	10
300	0	-3	+2	12
400	0	-3	42	10
500	+1	-3	0	10
600	+2	-3	0	10
700	0	-2	0	7
800	0	0	0	0
900	0	1
1000	1	24
Assumed Level of No Motion is 800 m

Drifting taken at Punta Tuna.

Fig. 42 - Time series of the water current profiles taken at Punta Tuna during the cruise of August, 1978. (Estimated tidal condition and current is also shown).

PETTITT.

Fig. 44 - Time series of the water current profile taken at Punta Tuna during the cruise of October, 1978. (Estimated tidal condition and current is also shown).

Fig. 46 - Time series of the water current profile taken at Punta Tuna during the cruise of December, 1978. (Estimated tidal condition and current is also shown).

Time series of the water current profile taken at Punta Tuna during the cruise of February, 1979. (Estimated tidal condition and current is also shown).

The text appears to be a scientific report with some formatting issues, misspellings, and nonsensical strings of characters. Here is a possible correction:

Page 80

Page 81

Page 82

Figure 50 - Time series of the water current profile taken at Punta Tuna during the cruise of April 1979. Estimated tidal condition and current is also shown.

Page 83

Page 84

Each of the stick-type diagrams has both the speed and direction of the measured water flow at each sampled depth for the profiles measured during that respective cruise. The speed scale of the first cruise, August 1978, is 1/2 that of the other cruises. The scale difference is due to the high speed indicated during the measurements. These higher speeds were probably due to errors induced by vessel drift. The results of these measurements are seen in Figure 41. In this figure alone, the vessel drift vector is also shown for comparison. As seen in Figures 41 and 42, most of the water current results from this cruise were probably influenced quite a bit by the drifting vessel. However, from the lower portion of Figure 41, the effects of flood or ebb tide may still be seen in these results. The first two profiles were measured during periods of flooding tidal current (to the west), the third was measured during the ebbing tide. This tidal shift may explain the westerly to northerly shift in the upper water. Figures 43 and 44 display the current profile results of the 2nd cruise, in August 1978. During this cruise, as in all subsequent operations, the vessel was moored during the current profile operations. The stick-type diagram (Fig. 43) shows the surface water mass (TSW) shifting from westerly to easterly, both at 10-15 cm/sec. The westerly movement is seen during both the flood (first) and ebb (last) periods. The next lower water mass, identifiable as the Subtropical Underwater (SUK), is also seen to change from...

The direction of the water flow varies from easterly to westerly and back, with speeds of about 10 cm/sec. Unfortunately, the timing of the profile measurements was not necessarily optimum for determining the tidal effects. The water in the transition zone between the Subtropical Underwater (SUW) and the Antarctic Intermediate Water (AIW), between 250-500 m, generally moves westerly at about 5 cm/sec (Fig. 43). The results of Table 2 confirm the predominantly southerly flow. Figures 45 and 46 show the results of the current profile measurements for the December 1978 cruise. Again, considerable current reversal is seen, but either the time (first profile) was not ideal, as it corresponded to a projected slack tidal current period, or the speed indicator did not function, as in the third profile. In any case, there is a definite westerly motion down to a depth of about 300m in the second profile, which should correspond to an ebbing tidal flow (easterly). The directions shown for the third profile are nearly all easterly for the upper 300 m. This is estimated to correspond to a flood tidal flow. All speeds were about 10 cm/sec, even for the deeper waters. In all cases, during this cruise, the water at 500 m was seen to move westerly, with a strong northerly flow seen at 750m. The time series displays show E-W oscillations in the upper 200 m. The southerly component is also seen in Table 2 as in Figure 46. The February 1979 cruise results can be seen in Figures 47 and 48. There are reversals at virtually all depths, but the upper water is seen to move westerly during the flood tide and easterly during the ebb. The transition zone between the Subtropical Underwater and the Antarctic Intermediate Water (200-700 m) has speeds of 5 cm/sec and also has direction reversals, but opposite to those of the upper waters. Water at the 700 m depth varied from southwest to northwest with speeds of about 5 cm/sec. The April cruise resulted in only one current profile, seen in Figures 49 and 50. Throughout most of the water column, the flow was westerly except at 700 m, where the flow direction was different.

Figure 53 shows the frequency of occurrence of the water current within compass octants (current rose) for 4 depth ranges at Punta Tuna. The depth ranges that are considered are: 25-50 m (Tropical Surface Water), 100-150 m (Subtropical Underwater), 250-500 m (Transition Zone), and 650-750 m (Antarctic Intermediate Water). The TSW appears to have a definite bimodal distribution of water current directions. About one-half of the observations had westerly or northerly flow. This is to be expected with the predominant easterly winds. However, about one-third of the observations showed an easterly flow, directly opposing the winds. Although these reversals have been seen by others (Lee et al., 1978) it was not expected, as the vessel never moved east of the mooring, only west. The tidal motion in this area is expected to be E-W in character, and this also could help to explain the large number of easterly observations.

The observations taken from within the SUW showed a dominant westerly flow more than one-third of the time, with a weaker easterly component and a mixed distribution between these two. This bimodal distribution

The text could be revised as follows:

There may also be a reduced tidal oscillation, as mentioned above. However, this water mass is believed to come from the Bermuda area, north of Puerto Rico, and move into the Caribbean through various passages (i.e., Mona to the West, Anegada to the East of Puerto Rico). Therefore, the water could be expected to have components of W, SW, S, SE, and E. Unexpected directions would be N and NE, both of which were observed. Also, there were no southerly directions observed. This water mass, and those below it, may contain an OTEC plant discharge (a mix of cold and warm water), and this confusion must be addressed.

Fig. 53 - Current roses of water current direction, using all the current profile data taken at Punta Tuna from August 1978 to June 1979. Four vertical depth bands are considered.

The water in the Transition Zone is seen to move with a very strong predominance toward the West. As this water is a mixture of the SUW above, and the AIM below, it could be entering the area from either the North, as mentioned above, or from the East through the passages of the Lesser Antilles. Therefore, almost any water direction might be possible, and that is what is observed.

Finally, the AIW direction appears to be generally northerly (NE, NW). As this water is thought to enter the Caribbean through the Lesser Antilles and move generally westerly and northerly, the dominant directions are explainable. The water is observed moving past Punta Tuna towards either the Yucatan to the West or the Jungfern Sill to the northeast. The other directions almost appear as slight "noise" in the measurements.

In general, the results also indicate that at least the north-south component of the water moving past Punta Tuna may be somewhat characterized by geostrophic flow in the mid-to-deep water. Figure 54 shows the frequency distribution for the observed speeds in the same four depth ranges seen in Figure 53: 25-50 m, 100-150 m, 250-500 m, and 650-750 m. The TSW (upper depth range) has a distribution tending toward the...

The text reads at higher speeds, with an average speed of about 10 cm/sec. The SUW (100-150 m) shows a slight shift toward the lower speeds, averaging about 8 cm/sec. As expected, the two lower depth bands show decreasing speed with increasing depth. At the 250-500 m depth, the average speed is about 7 cm/sec, and at the 650-750 m depth, the speed averages only about 5 cm/sec.

3.4.2 Water Current Mooring

The description of deep water circulation is based on the velocity data retrieved from in-situ meters recovered from depths of 215 and 332 meters at Station A. The bottom depth at this station was approximately 1216 meters. The sampling rate of both meters was at 10-minute intervals; the records recovered extend from 6 January to 10 February 1979. Data points from the first and last days in the records were discarded in order to prevent the inclusion of spurious effects caused by deployment and retrieval operations of the meters.

Conventional methods of current flow analysis were employed to describe and determine circulation patterns and their variability. These included resultant velocity vectors statistics, histograms, stick plots, progressive vectors diagrams, and vectorial components graphs in order to smooth out superimposed water flow oscillations. Energy spectral analyses could not be performed as programmed owing to persistent malfunction of the computer at the last stages of the analysis.

The analyses revealed the following general statistical results:

1. Currents flow, direction and speed, are highly variable at both monitored depths. Direction

statistics indicate that the flow is almost equally distributed around the compass rose.

2. Average current speed at a depth of 215 meters is about 7 n/sec. The resultant direction angle is 8.2 degrees azimuth (NNE). The average resultant current stability is 93.9%.

With speeds ranging from 1 to 60 cm/sec (Fig. 55).

3. The average current speed at a depth of 332 meters is approximately 5.3 cm/sec, flowing in a NNE (12 degrees azimuth) direction. The average resultant current stability is 94%, with speeds ranging from 1 to 30 m/sec (Fig. 55).

4. Tidal, inertial, and longer period oscillations (days and weeks) are superimposed in the current structure. The discussion of the graphs, diagrams, and statistical tables that follow demonstrate these general results.

Fig. 55 - Current resultant-vectors rose.

Table 3 tabulates the data points velocity statistics for the 215 meters-depth current meter. The record length is for 786 hours or a total number of 4704 observations. The speed range at this depth extends from 1 to approximately 70 cm/sec (one data point) with a direction distribution covering the whole compass rose.

Statistics indicate that the highest percentage, 41.3%, of current speeds lie within the 1 to 5 cm/sec ranges. The average speed for the whole record length was 7.13 cm/sec as shown in Table 4. Current direction statistics indicate that flow is almost equally distributed among each quadrant; the highest cumulative percentage occurs from 45 to 135 degrees azimuths (N to ESE) with another peak at the 270 to 300 degrees (NW quadrant) interval.

The highest direction relative frequency percentage was 5.8% at the 75-90 degrees (E) interval. The average current flow direction (Table 4) is at an angle of 8.24 degrees T (NNE) with an average speed of 7.13 cm/sec. The histograms for the data in Table 3 are shown in Figure 56; the cumulative frequency curve shows that 80% of the current speed values are below 10 cm/sec.

Current velocity statistics for 1 hour averaged data points at a depth of 215 meters are shown in Tables 5 and 6. The total number of observations was reduced to 784 through the averaging and velocity resultants calculations. The average stability of current flow for an average speed of 7.13 cm/sec and an average resultant.

The velocity of 6.90 cm/sec flowing at an 8.24-degree azimuth (NNE) is approximately 93.9%, with values ranging from 99.99% to 8.47%. The direction relative distribution percentage is 6.3% in the 270-285 degrees range interval (WNW). The dominant azimuths are still between 60 and 120 degrees (E quadrant). Figure 57, which includes histograms for 12 hours averaged data points, illustrates that the two direction peaks become more apparent in the averaging process. The statistics for the data points recorded at a depth of 332 meters are shown in tables 7, 8, 9, and 10.

Table 4 shows current's data-based statistics for the 215 meters depth level. The number of observations were 4,708. The average speed was 7.23 cm/sec and the average direction was 8.24 degrees.

Figure 56 shows the 215 meters depth level direction, speed, and cumulative speed distribution histograms.

Table 6 shows one hour current's resultant vectors: data-based statistics for the 215 meters depth level. The average velocity was 7.13 cm/sec, the average resultant velocity was 6.90 cm/sec, and the resultant direction was 8.28 degrees. The average stability was 93.91% with a maximum of 99.99% and a minimum of 8.47%.

Figure 87 shows direction, speed, and cumulative speed distribution histograms for 12 hours averaged data points from the 215 meters depth level.

"Quadrauld Painsay Cage 100

TABLE 8: Current's data-based statistics for the 332 meters depth level.
Number of Observations: 4,695
Average Speed (cm/sec): 5.28
Average Direction (deg): 101

Sejouanbaus Ajzejad Pads for Uojzoasjq TSU039%
“Total Yardage: 243,404 EH in 3URA ASN $3U-4UND NOY 2U0 ~ 6 Alqel (Reiterations) 102

TABLE 10: One hour current's resultant vectors: Data-based statistics for the 332 meters depth level.
Average Velocity (cm/sec): 5.29
Average Resultant Velocity (cm/sec): 5.09
Resultant Direction (deg): 012.13
Average Stability (%): 94.03
Stability Range (%): Maximum 100.00, Minimum 8.91

PANATUNA OTEC SITE A, STATION #1, METER #ROES
DATE: 07-JAN-79
BOTTOM DEPTH = 1216 METERS
SITE DEPTH = 322 METERS
INPUT DATA

See Fig. 58 - The 332 meters depth level direction, speed, and cumulative speed distribution histograms. 104

Histograms of Figure 58. Table 7 indicates that a higher percentage (48.22) of current speeds lie at the 5 to 10 cm/sec interval. The histogram in Figure 58 shows the slight differences that were found between the results of the 215 m and 332 m depths; 96.1% of all speeds at the 332 m are below 10 cm/sec against 80% at a depth of 215 meters. Current directions at the 332 m level are scattered over the compass rose with a dominant relative frequency percentage of 19.5 between the 75 to 120 degrees azimuths (E quadrant); the highest percentage, 7.1%, is found in the 75-90 degrees interval (ENE to E). The average speed (Table 8) is of about 5.3 cm/sec in a NNE (12.13 degrees) direction; current stability ranged from 8.9 to 100 percent, with an average stability of 94.02, when calculated for 1 hour current velocity resultants at an average speed of 5.29 cm/sec and an averaged resultant velocity of 5.09 cm/sec as shown in Table 10. Table 9 indicates that 97.6% of the 1 hour intervals speed averages are below the 10 cm/sec speed range."

Circulation patterns and variability at the monitored depths are evident in the velocity time series graphs (Figures 59 to 63), the stick plots (Figures 64 to 68), and the progressive resultant velocity vector diagrams (Figures 70 to 81). All diagrams reveal a pattern of flow that is mostly dominated by tidal variations, as compared with the predicted tidal curves for Puerto Maunabo (Punta Tuna), which are shown in Figure 69. In Figures 59 and 60, velocity variation curves at the 215-meter and 332-meter levels respectively show two relatively constant variation tendencies: (1) with few exceptions, minimum speeds usually occur at the time of low tides, and (2) when compared with the tidal fluctuations of Figure 69, the highest speeds are encountered during the monthly spring tide periods. Higher speeds coincide with flood tidal stages, while low tides consistently occur around midnight. These observations become more evident in the 6-hour and 12-hour averaged speed graphs shown in Figures 61 and 62.

In subsequent pages, there are more complex graphs and diagrams that continue to show the circulation patterns and variability. However, they are not included in this text.

The text can be corrected as follows:

It can be surmised from these diagrams. For example, in Figure 70, the progressive resultant vectors diagram at a depth of 215 meters, there is a trend of variation in speed and direction every 6 to 7 hours (semi-diurnal tide component) and a larger one from 12 to 13 hours (diurnal tide). Larger loops are also apparent at intervals of approximately 37 to 40 hours. The calculated inertial currents periods for Latitude 18°N, the location of the Punta Tuna Site, are about 36.9 hours. Thus, it appears that inertial currents play a significant role.

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Figure 70: Progressive current vectors diagram with 1-hour intervals resultant vectors for the 215 meters depth level.

Figure 70a: Continued progressive current vectors diagram with 1-hour intervals resultant vectors for the 215 meters depth level.

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Figure 70b: Continued progressive current vectors diagram with 1-hour intervals resultant vectors for the 215 meters depth level.

Figure 70c: Continued progressive current vectors diagram with 1-hour intervals resultant vectors for the 215 meters depth level.

Figure 70d: Continued progressive current vectors diagram with 1-hour intervals resultant vectors for the 215 meters depth level.

Figure 70e: Continued progressive current vectors diagram with 1-hour intervals resultant vectors for the 215 meters depth level.

Figure 70f: Progressive current vectors diagram with 1-hour intervals resultant vectors for the 215 meters depth level.

Page Break---

Cotton OPM = 1216 TERMS MEIER OFPMA "2 FEATS sources on = 1.69 over 20 ten INTERVALS. Fig. 81 - Progressive current vectors diagram: 48 hours intervals resultant vectors for the 332 meters depth level, 140

Page Break---

These are also affecting the circulation pattern at the monitored depths. Smoothing out the velocity data by averaging demonstrates that after the tidal cycle has been "averaged out," higher period oscillations are still present. See Figures 71 to 75, which illustrate the resultant circulation at the 215-meter level after averaging the 6, 12, 24, 36, and 48 hours resultant vectors, respectively. Observe that even after 48 hours there are higher periodic variations ranging from about 4 to 12 days. The above discussion of the 215 meters level progressive resultant vectors diagrams applies to Figures 76 to 81, the circulation diagrams at a depth of 332 meters.

To determine the higher periodic, superimposed variations on the general circulation, which may not be immediately apparent in the smoothed-out progressive vectors diagrams, the vectorial components of the resultant vectors were plotted as in Figures 82 to 87. The north and east vectorial components of the smoothed-out resultant vectors for 24, 36, and 48 hours were plotted against time at both depths. Figures 82 and 83 illustrate the vectorial components after the 24 hours oscillations (tides) have been smoothed-out.

The inertial component is still present: there are periodic fluctuations of approximately 36 to 40 hours (2 1/2 days intervals) with some longer oscillations of several days periods. After the 36 hours components have been averaged out (Figs, 84 and 85) oscillations with periods ranging from 4 to 12 days, which also appeared in the 24 hours curves, remain in the record.

It is not known why the east-west component smoothed-out more readily than the north-south component which, even after 48 hours, still contains large periodic variations (Fig. 87). It can only be surmised that eddy movements with periods ranging

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"From days to weeks, there are also superimposed elements present in the general circulation. Much more data than what is currently available is needed to determine the source of the longer period oscillations. Only the small scale flow and fluctuations can be interpreted at the moment.

Current Co, Fig. 86 - 215 m depth level 48 hours interval vectorial components (cont.)

I recommend reaching out to the original author or source of the text to obtain a clear and readable version.

"Es 21 le" should be - "Is 21 the". "(yojdaag) syuauodi A 7H x jwog yuassng as/ua ses/an 153" should be - "(Today) should A 7H x jog assuming as/ua session 153".

It should be noted that the resulting drift from 33-days current meters record is not necessarily representative of all currents measured during that time. Not only are currents of tidal and inertial periods present, but longer-period oscillations that are variable, steady, strong and/or weak at irregular intervals on the record can be present. These types of oscillations make the interpretation of a current meter record questionable in terms of resulting flow. Various investigators have reported east-flowing currents at the Punta Tuna Site area (Atwood et al., 1976; Metcalf, 1976; Stalcup et al., 1975). Circulation pattern descriptions at depths below the surface levels have been determined by geostrophic flow calculations. Sturges (1970) and Stalcup et al., (1975) reported that marked variations in both speed and direction at frequencies including seiche periods, semidiurnal and diurnal tidal periods, and longer periods of the order of days or weeks have been measured on the southern part of the Jungfern Passage, which encompasses the Punta Tuna Site area. Metcalf (1976) describes the 200 to 400 meters water layer at the southern end of the Jungfern Passage as the 18 °C water where there is an oxygen maximum. It can be considered, according to Sverdrup (cited by Metcalf, 1976), as Tropical Atlantic Central Water having characteristics intermediate between the more saline North Atlantic Central Water and the less saline South Atlantic Central Water. Circulation at this layer is supposedly toward the Caribbean Sea, coming from the Atlantic through the Anegada Passage (Metcalf, 1976). The present data suggest that the effect of several dynamic and submarine morphological forcing factors should be investigated in order to determine the long-term circulation variability. These are as follows:

1. The action of tidal funnelling effects through the Vieques and Jungfern Passages,

2.

1. The presence of long-term Ekman's circulation effects at deeper layers.
2. The effect of submarine morphology in the area.
3. The presence of seiches periods fluctuations.
4. The presence of long-period eddies.

To thoroughly determine these forcing factors, comprehensive, long-term current measurements at deeper water levels and several locations in the area are necessary. The resultant water flow might potentially be in an opposite direction in deeper waters (east) to what is currently assumed (westerly).

3.5 Dissolved Oxygen

During each cruise, samples for dissolved oxygen (D.O.) determination were taken at both day and night periods, except for the first cruise (August 1978), which was terminated early with only day-time samples taken. The samples were typically collected around noon and midnight. The depths sampled ranged from the surface to approximately 1000 m deep.

Figure 88 displays the results of all collected data, combining both the day and night results for all six data sets. This figure is included to show the general trend and scatter of the D.O. data at the Benchmark station throughout the year. Generally, the D.O. level remained above 4 ml/l from the surface downward below the pycnocline, and below the Subtropical Underwater. At or near the core of the Antarctic Intermediate Water, 600-800 m deep, lies the D.O. minimum of 2.7-3.2 ml/l. The D.O. values then rise to almost the surface values (3.5-4 ml/l) at 950-1000 m. This general curve is well documented for the Caribbean (Must, 1964).

These D.O. values indicate a high degree of oxygen saturation at the surface (about 70%). The percent of saturation at the oxygen minimum depth is only about 30%. Figures 89-94 represent the D.O. profiles for each of the six cruises, consecutively. For each cruise (except August 1978), both the day and night values are shown. Generally, the night values average slightly higher than the day averages, but by only 0.1-0.2 ml/l, as seen in Figure 95. This difference is not significant.

Biologically or chemically, the observed values are compared to the typical values of 3-4 ml/l. At two depths, nearly all the night values were higher than the day values. At the 50 m depth, 100% of the night values exceeded the values measured during the daylight hours. At about 250 m depth, 80% of the measurements showed night values higher than day values. Both of these depths may be important to an OTEC plant, and the reason for the day/night difference should be investigated. The 50 m depth frequently lies near the upper portion of the pycnocline, or the boundary between.

Depth (m) Dissolved Oxygen (ml/l)

Fig. 88 - Dissolved oxygen profile for all data collected at Punta Tuna from August 1978 to June 1979.

Depth (m) Dissolved Oxygen (ml/l)

Fig. 89 - Dissolved oxygen profile for data collected at Punta Tuna during the cruise of August 1978.

Depth (m) Dissolved Oxygen (ml/l)

Fig. 90 - Dissolved oxygen profile for data collected at Punta Tuna during the cruise of October 1978.

Depth (m) Dissolved Oxygen (ml/l)

Fig. 91 - Dissolved oxygen profile for data collected at Punta Tuna during the cruise of December 1978.

Depth (m) Dissolved Oxygen (ml/l)

Fig. 92 - Dissolved oxygen profile for data collected at Punta Tuna during the cruise of February 1979.

Depth (m) Dissolved Oxygen (ml/l)

Fig. 93 - Dissolved oxygen profile for data collected at Punta Tuna during the cruise of April 1979.

Depth (m) Dissolved Oxygen (ml/l)

Fig. 94 - Dissolved oxygen profile for data collected at Punta Tuna during the cruise of June 1979.

Depth (m) Dissolved Oxygen (ml/l)

Fig. 95 - Average dissolved oxygen profile for all data collected at Punta Tuna from August 1978 to June 1979.

The Upper Mixed Layer and the Subtropic Underwater. The 250 m depth is near the depth that a mixed discharge may rest, at least temporarily during some conditions.

The temperature and salinity conditions vary throughout the year. Figure 89 shows a nearly constant value of 0.0 throughout the Upper Mixed Layer. At the depth of the salinity maximum (about 150 m from Figure 23), an oxygen maximum is also observed during the August 1978 cruise. From here, the value is seen to slowly decrease to 3.5 ml/l between depths of 450-550 m. Below this depth, a sharp discontinuity occurs, with a very low value of 2.7 ml/l occurring at about 575 m. By 800 m, the value has risen again to over 3.0 ml/l.

During the October 1978 cruise (Figure 90), an unusually high value is seen at the salinity maximum depth. At this time, both the salinity maximum (Figure 24), and the maximum value were closer to 100 m deep. During this cruise, the values seem to have a more smooth and continuous decrease to the oxygen minimum of about 2.7 ml/l near 600 m deep. Figure 91 shows the high (4.1-4.3 ml/l) values throughout the upper 200 m. This occurred despite of only 270m deep MLD. From these high values, the value decreased smoothly (except for the night value at 470 m which could possibly be a measurement error) to about 575 m. During this cruise, the sampling missed the oxygen minimum depth, but it was probably between 575-750 m.

The value during February 1979 (Figure 92) was 4.0 ml/l or higher from the surface to about 300m. Again, from this depth downward to about 575 m, the value decreased smoothly. The oxygen minimum was located about 750 m deep at this time. During the April 1979 cruise (Figure 93), the upper 100 m had virtually constant values throughout, with only a small decrease at about 150 m (4.5-4.3 ml/l). However, at 190 m, a sudden decrease is seen to almost 3.8 ml/l during both the day and night sampling. Below this depth, the values rise to more typical values of about 4 ml/l and slowly decrease downward as seen on the previous cruises. Neither temperature (Figure 12) nor salinity (Figure 27) show any abnormalities at or near this depth that could be related to the high oxygen consumption.

However, Figure 102 (to be discussed in Section 3.6) displays abnormally high chlorophyll values, about 5-10 times normal, at slightly more shallow depths of 100-125 m. These high chlorophyll values were observed in greater quantities at night only, indicating that the large numbers of phytoplankton were able to significantly reduce the available oxygen. The June 1979 cruise (Fig. 94) showed very high and uniform DO (Dissolved Oxygen) values (4.6-4.3 ml/l) down to about 300 m. The only exception was a slightly high value again seen at 100 m, very close to the depth of the salinity maximum (Fig. 28). During this cruise, there was almost no Upper Mixed Layer, except as detected using the DO values. The remainder of the water column appeared typical at this time. Figure 96 and 97 represent the day and night dissolved oxygen values respectively during the measurement program. Both figures show a general trend toward increasing DO values in the upper 200 m throughout the measurement period. The upper water temperature was warmest in October (Fig. 14), corresponding to the low upper-water DO as saturation of oxygen decreases with increasing temperature. The low October DO can be explained as maintaining the same percent of saturation (70%), but able to hold less gas. As the temperature decreases through February and April, DO increases in the upper waters. The DO values deeper than 500 m do not appear to change much throughout the year. Between 200 and 450 m, a change in the DO is observed. However, it is in this depth range that the day-night values differ, and most of the time series differences at these depths may correspond to specific bioactivity during the measurements, as opposed to overall annual trends.

DEPTH(m) for 802 a2 360 400 600 700 SR 800 (Be) JULY AUG SEPT OCT NOV DEC JAN FEB MAR 1978 7im78 Fig. 96 - Time series for dissolved oxygen data collected during daylight at Punta Tuna from August 1978 to June 1979.

DEPTH (m) 300 490 600 900

The text provided appears to be a scientific report detailing the collection of dissolved oxygen data and chlorophyll a results from Punta Tuna from August 1978 to June 1979. Unfortunately, the text is muddled and difficult to understand due to the presence of several errors and non-words. It seems that there might be some scanning or typing errors in the text.

Here's my attempt at making sense of the text:

"The report contains data on dissolved oxygen collected during nighttime at Punta Tuna from August 1978 to June 1979 (Fig. 97).

Section 3.6 discusses the results of Chlorophyll a. During each cruise, samples were collected to determine the concentration of live flora (chlorophyll a) at various depths down to about 400 m. Samples were taken during both a noon and midnight Biocast. However, the first cruise was terminated before the night Biocast could occur.

Figures 98-103 show the chlorophyll a profiles vs. depth for both day and night casts for each of the six cruises. The water density profile is also included in each figure for comparison.

Upon analyzing these figures, several observations were made. First, during the August 1978 cruise (Fig. 98), improper filter paper was used for the chlorophyll analysis, resulting in poor data. This data is likely not reliable and should be discounted.

From figures 99-103, it appears that the day and night chlorophyll values are somewhat suppressed by the pycnocline. The number of viable cells found in each sample was generally higher below the pycnocline than above, suggesting difficulty in passing through this strong density gradient. This same depth gradient was observed by Beers et al., in 1988.

During the April 1979 cruise (Fig. 102), the chlorophyll a values were 5-10 times higher at the 100-125 m depths than at any depth during the other cruises. Typical values at this depth were 0.1-0.3 ug/l, but in April the values were 0.9-1.5 ug/l during the night sampling.

This unusually high value might typically be attributed to "normal patchiness", but it also coincided with a measurable decrease in dissolved oxygen at about the same depth throughout the day (Refer to Fig. 93). This indicates a high concentration..."

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Phytoplankton may have been present during the other cruises and could have been missed by our discrete sampling procedure. However, the dissolved oxygen concentration would likely have been suppressed if that were the case. Unfortunately, the nutrient data taken during this program was not refined enough to help explain the exceptionally high chlorophyll a values for April 1979. In fact, this chlorophyll a maximum corresponded temporarily with the highest surface salinity values (Fig. 40). According to Froelich, et al., (1978), the salinity of the Caribbean surface water is strongly influenced by the fresh water runoff from the Amazon and Orinoco Rivers. Therefore, when the salinity is lowest, the river's influence is highest, and the available nutrients might be expected to be above normal. During April, the surface salinity was the highest of all our cruises (Fig. 29), and therefore the rivers' influence would be expected to be minimal. With less river runoff, as might be the terrestrially derived nutrients, which control the chlorophyll production in the ocean.

Figure 98: Chlorophyll "a" profile observed at Punta Tuna during the cruise of August, 1978.

Figure 99: Chlorophyll "a" profile observed at Punta Tuna during the cruise of October, 1978.

Figure 100: Chlorophyll "a" profile observed at Punta Tuna during the cruise of December, 1978.

Figure 101: Chlorophyll "a" profile observed at Punta Tuna during the cruise of February, 1979.

Figure 102: Chlorophyll "a" profile observed at Punta Tuna during the cruise of April, 1979.

Figure 103: Chlorophyll "a" profile observed at Punta Tuna during the cruise of June, 1979.

Sunlight-rich Caribbean Sea would also be at a minimum. Therefore, this bloom may have been a temporal and spatial anomaly. Figures 104 and 105 show the time series of the chlorophyll a values for the day and night periods, respectively. The upper waters had a minimum in December 1978 and June 1979 and maximums in October 1978 and February 1979 during both the daylight and the night periods. The higher values throughout the water column are easily seen as occurring in October 1978 and April 1979. The highest overall values were seen in April, at 125 m as mentioned before. Beers et al. (1968) also found his highest surface values during the late autumn and winter at Jamaica (specifically October), and during late autumn and winter (specifically February) at Barbados. At neither location were the peak values found as deep as 125 m.

Figure 106 shows the normalized day/night-average integrated chlorophyll a resulting from all samples taken down to 200 meters for each cruise. Relative peaks occur in August, October, and April. Also, in the figure are the values of surface salinity during each of the cruises. According to Froelich et al. (1978), the lower salinity values are due to periods influenced by the Amazon and Orinoco Rivers.

DEPTH (m) WAS 197 Fig. 104 - Time series of chlorophyll a values measured during daylight at Punta Tuna from August, 1978 to June, 1979.

DEPTH (m) 100+ 500- ML AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN 1979 Fig. 105 - Time series of chlorophyll a values measured during nighttime at Punta Tuna from August, 1978 to June, 1979.

801 802803 804 805 806 SALINITY (g/l) SURFACE CHLOROPHYLL a (ug/l) JULY AUG SEPT OCT NOV DEC JAN FEB MAR APR MAY JUN JULY 1978/1979 Fig. 106 - Time series of surface salinity and integrated chlorophyll a from the surface to 200 m measured at Punta Tuna from August, 1978 to June, 1979.

Waters of lower salinity should carry the nutrient-rich river waters, possibly containing more available nutrients than other times of the year. Therefore, an inverse correlation might be expected between the two curves shown in Figure 106. Except for the extremely strong peak in April, this appears to be the case. However, more information is needed before this relationship can be confirmed. As mentioned earlier, the nutrient information collected during this program is inadequate to support the chlorophyll data. Beers et al., (1968), found peaks in gross primary productivity in June, September, and October in Jamaica, and July, February, and May in

Barbados. Their peaks in productivity appeared to match their peaks in nutrients, as expected.

Finally, it should be noted that these chlorophyll values were taken from discrete samplings at approximately every 25 m depth. There may be much more vertical structure to the chlorophyll profiles that have eluded this study due to the limited chosen sampling depths. The phytoplankton tend to be patchy in both the horizontal and vertical directions, as well as over time. These factors may influence any distortion of the chlorophyll seen in this report.

3.7 Zooplankton Results

On each cruise, zooplankton samples were taken. When possible, one sample was taken at each of the following depths:

- 25 m Horizontal tow (day)
- 25 m Horizontal tow (night)
- 200-0 m Vertical tow
- 800-200 m Vertical tow
- 1000-800 m Vertical tow
- 1000-0 m Vertical tow

The tow covering the entire water column (1000-0 m) was not sorted as part of this work, but was sent to the Lawrence Berkeley Laboratory of the University of California, for analysis. The following portion of this section describes the results of the laboratory and statistical analysis of the remaining samples, and their interpretation.

3.7.1 Size Frequency Analysis

The data summarized in Figure 107 present the percent of total copepoda analyzed throughout the year (frequency) versus their size class.

The text is expressed in mm (magnitude). Plankton were collected using a 202 µm net, which explains why so few individuals are represented in the <0.5 µm size class interval. A finer mesh net would capture those members that would slip through a 202 µm net and would increase the number of individuals represented in the <0.5 µm size class interval. Of the copepods represented in this histogram, those included in the 0.9-9.5 mm size class interval are the most abundant. If we assume there is no clogging problem and that the size of copepods is normally distributed, a 202 µm net is useful to collect those plankton larger than 0.5 µm.

3.7.2 25 Meters Day vs. Night Tows

All data for all tests were log-transformed from $\#/m^2$. A series of t-distribution tests were applied to the following data groups to test for any significant difference between the day and night surface tows:

- Total Copepods
- Dominant Species
- Clausocalanus furcatus
- Oithona plumifera

- Calocalanus pavo

Results for each of the t-distribution tests conducted are presented in Table 11. None of the values calculated are significant (N.S.) at the 0.05 level. It is a well-known fact that during the night some zooplankton vertically migrate to the surface waters (the reasons for such events are not part of this exposition). Therefore, we could expect much or at least higher concentrations of plankton on the surface waters at night. This might be the case, but variability is so vast that the differences are not statistically significant.

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TABLE 11

Results of t-distribution tests on three zooplankton species collected at Punta Tuna to determine the day/night significance for 25 m deep horizontal tows.

Total Copepods - Clausocalanus furcatus - Oithona plumifera - Calocalanus pavo

0.311 0.952 0.285 0.541

0.05 >.05 N.S. >05 N.S. >.05 N.S.

The distribution of species depth was analyzed by season. Two-way analysis of variance tests were applied to the following data groups to test for any significant difference between season and depth: Total Copepoda, Dominant species, Oncaea venusta, Oithona plunifera, and Clausocalanus furcatus. For total copepoda (Table 12), there is slight evidence that their abundance varies with the month, i.e., seasonal variations. If water masses of different temperature, salinity, and/or nutrients pass by the Punta Tuna site, variations in the planktonic population could or should be detected. Therefore, seasonal variations are expected.

Dominant species were selected after the construction of a rank order species list. The three most common species for all months were chosen for the test. Of the three species compared in the test, only O. venusta shows any significance at the 0.05 level. If we compare all copepoda and the three species chosen for this test, none of the data groups show any relation with depth at all. Throughout the year, a species list was constructed for the copepoda found in the waters of the Punta Tuna site. The identified species are listed in Table 13.

TABLE 12 Results of tests for significance of depth and seasonality for total copepoda and three zooplankton species collected at Punta Tuna from August 1978 to June 1979.

Sum of Squares (SS), Degrees of Freedom (DF), Mean Square (MS), Variance Ratio (F), Probability (P):

TOTAL COPEPODA
MONTH: SS=5.861, DF=5, MS=1.172, F=5.586, P=0.05
DEPTH: SS=41534, DF=2, MS=2.268, F=2.887, P=NS.
ERROR: SS=65.467, DF=10, MS=6.547

ONCAEA VENUSTA
MONTH: SS=0.262, DF=5, MS=0.0524, F=6.471, P=0.05
DEPTH: SS=0.831, DF=2, MS=0.4155, F=0.8161, P=NS.

NS. ERROR 3.391 10 0.3391 TOTAL 4.484 7 OTTHONA PLUNIFERA ‘MONTH 1.822 5 0.3664 3.957 DEPTH 1.369 2 0.6865 2.107 ERROR 14.419 10 1.482 TOTAL 17.610 v7 CCLAUSOCALANUS FURCATUS MONTH 2.726 5 0.542 2.465 DEPTH 5.088 2 2.1526 0.532 ERROR 13.444 10 1.344 TOTAL 21.218 a 185

TABLE 13. List of Species - Copepoda Acartia spinata Lucteutia {taviconnis A, Heeb ebongez fecgrocena cts S EiLejebongt cena cbaus A: dana Netridia brevceaudaca A. negtégens Méckosetetea nonvegien - Acrocatanus Longiconnis Meraeéa eggerata - Aetideus armatus Meraciz minor Catanus tenuiconnis Worondtta minor Candacéa béspinosa Nanmocabanus minor ©. pachydacceea ©. packongémana Catocatanus pavo ©. pavonicus Chausoentanus arcuiconnis Ciytomestaa scutettata 4 opetie quadhata Cr miaabetes C. Speedosus ai ©. typécus Lirbatus C. Zatus Eucatanus attenuatus tubbockéa acuteuta L. squietinana 186

3.7.3 A Comparative Study of Copepod Data Reported from Around the Puerto Rico Area

The Copepoda make up the largest group (ca 70-85%) of the planktonic organisms sampled in our waters. Consequently, quantitative studies of their occurrence constitute an excellent tool for understanding distributional patterns of our zooplankton. Further, when inshore and offshore (pelagic) systems are compared, major differences are evident; some species being restricted to some areas and others to others. In addition to these observations, we find some species which are always present, others are commonly present, and still others exist but are extremely rare. Similar observations in the past led Preston (1948) to write the classic ecological paper "The commonness and rarity of species." This is clearly indicative of the concern of traditional ecologists for this type of observation and their relevance for the establishment of basic concepts in ecology. Anonymous (1978) made an analysis of copepod populations from off the south coast of Puerto Rico based on data generated by Wood, et al. (1975, 1975c) and presented a scheme that fits the

The overall pattern observed in our marine waters can be examined through the copepod lists provided from other deep water areas around Puerto Rico (Youngbluth, 1974, 197; Nutt, 1975, and Nutt and Yeaman, 1975). These lists reveal that the species present are indeed common to those from similar areas discussed above. Anonymous (1978) and Michel et al. (1976) found similar results off the southeast of Puerto Rico and Vieques, respectively.

Coker and Gonzalez (1960) reported on species restricted to inshore waters. An examination of their list on Table 2, p. 18, reveals how some species such as Acartia tonsa, Paracalanus crassirostris, and Oithona simplex are found in larger numbers in embayments like Phosphorescent

Bays. They then become less abundant in open bays (Montalva) and offshore, while others increase in abundance. For instance, take the distribution of Corycaeus americanus, Centropages furcatus, and Temora turbinata. Also, refer to Tables 14-18 for reference in this discussion.

TABLE 14. A list of the copepod species identified from the Punta Higuero collections (after Nutt and Yeaman, 1975):

COPEPODA SPECIES
Acartia
Corycaeus subulatus
Corycaeus gracilis
Corycaeus pacificus
Corycaeus agilis
Corycaeus spectosus
Corycaeus anglicus
Corycaeus clausi
Centropages furcatus
Calanoida pavo
Lucicutia flavicornis
Canthocalanus americanus
Nannocalanus minor
Metridia gracilis
Acartia tonsa
Euchaeta marina
Eucalanus attenuatus
Labidocera spp.
Euterpina acutifrons

TABLE 15. Species of copepods found at sampling stations in the vicinity of Vieques Island (after Michel et al., 1976):

COPEPODA SPECIES
Acartia tonsa
Euchaeta marina
Lucicutia flavicornis
Metridia longicornis
Oithona plumifera
Corycaeus medius
Corycaeus venetus
Other cyclopoids

Table 16: Analysis of the Copepod Populations from Punta Verraco and Cabo Mala Pascua Sites (After Anonymous, 1978)

Table 16-A: Copepod Population Observed at Punta Verraco

Species Usually Most Numerous:
Paracalanus spp. (P. acutus, P. crassirostris, P. parvus)

Species Commonly Present (Observed on 5 or More Separate Periods):
Corycaeus spp. (C. giesbrechti, C. pacificus, C. speciosus)
Euterpina acutifrons
Catanopia americana
Undinula vulgaris

Species Occasionally Present:
Euchaeta marina
Corycaeus spp. (C. pavo, C. pavoninus)
Pseudocalanus cohort
Nannocalanus minor
Calocalanus spp. (C. pavo, C. pavoninus)
Yes spp. (C. furcatus, C. caribbeanensis)
Santachaenis
Labidocera spp. (L. scotti, L. spp.)
Candacia pachydactyla
Mecynocera clausi
Dactylopusiella

Source: Wood, E. D., Youngbluth, M. J., Yoshioka, P., Canoy, M. J. (1975). Punta Verraco Environmental Studies. Puerto Rico Nuclear Center, Mayaguez.

Table 16-B: Analysis of the Copepod Populations from Punta Verraco (Table 16-A) and Cabo Mala Pascua Site, Puerto Rico (Table 16-B) (After Anonymous, 1978)

Copepod Populations Observed at the Cabo Mala Pascua Site

Species Usually Most Numerous:
Clausocalanus furcatus
Paracalanus spp. (P. acutus, P. crassirostris, P. parvus)
Farranula gracilis
Octhona spp. (P. acutus, P. crassirostris, P. parvus)
Acanthacartia spinata

Species Commonly Present (Observed on 5 or More Separate Periods):
Corycaeus spp. (C. giesbrechti, C. pacificus, C. speciosus)
Undinula vulgaris
Temora stylifera

Species Occasionally Present:
Oncaea spp. (O. gaset, O. venusta, O. spp.)
Corycaeus spp. (C. subulatus, C. spp.)
Pseudocalanus cobia

Calocalanus pavoninus
Scolecithricella danae

Source: Wood, E. D., Youngbluth, M. J., Yoshioka, P., Canoy, M. J. (1975). Cabo Mala Pascua Environmental Studies. Puerto Rico Nuclear Center, Mayaguez.

TABLE 17: Zooplankton Species Distribution, Abundance, and Diversity in the Vicinity. Conyeacus sp., Euaetideus gieabrechte, 192 COPEPODA SPECIES: L. ctowsti, Maorosetetta gracitis, Mecynocena elausiz, Microsetetta norvegcea, Nanrocatanus minor, Odthona. plume fora, O. semptex, O. hebes, O. sp., O. nana, Oncaea sp., Oncaea venusta, O. redetemanea, Paracatanus acutatus, Pa enasacrostnis, P. parvus, P. sp., Phaenna spinigera, Pewromama gracitis, Rhinecatanus connutus, Tenora stybigena, T. turbinata, lindénuta' vutgancs, Unidentified Copepodites, Unidentified Catanoid Copepods.

TABLE 18: Zooplankton from Tortuguero Bay (after Nutt 1975). COPEPODS: Calanoids: Nonpoentanus minor, Seatelthads dena a vulgaris, Tomona stybigera, Eucatanus attenuatus, Temona turbinata, Acroacatanus Longicornis, Pewronanma gracceis, Acroacatanus andersont, Centropagues furcatus, Paracatanus acutatus, Lucceutea (Laviconnis). Paraentanus parvus. Candacea pachydactyea. Catocatanus pavo. Paraemdacia bispinosa. Mecynocera clausci. Catanopia americana. Clawsocatanus urcatus. Labedocera sp. Euchaeta marina. Acaxtia spinata.

Harpacticoids: Miracta efgerata, Ocutosetetta gracctis, Wackosetetea gracitis, Euterpina acutignons.

Cyclopoids: Odthona peumigera, Conyeacus (Agetus) typious, Oéthona setigera, Conyeacus (Urocoryeneus) Lautus, Oéthona ooukata, Conyeacus lonychocoryeaeus) giesbrechti, Saphirelta tropica, Conyeacus lonychoconyeneus) agitis, Copitia mirabitis, Oncaea mediterranea, Copétia quadrata, Oncaea venusta, Conyeacus (Coryeneus) spectosus, Saphirina sp., Conyeacus (Coryeaeus) clause, Farranuba gracceis, Conyeacus (Agetus) taceus, 193.

Upon studying the Punta Tuna data carefully, it is found that the diversity of the species is much higher than in all other sites mentioned above. This seems to be due to the fact that net tows were made down to a depth of 1000 meters (a large number of species reported here are deep water species), and were spaced out throughout the year. This offered a greater opportunity to catch organisms that undergo seasonal fluctuations in addition.

To stragglers from other regions. The information obtained confirms previous observations of the distributional patterns of copepod species, but correlations with other parameters are not evident or cannot be carried out because the data cannot be statistically tested for that purpose. The diversity of species found in the Punta Tuna site is considerably larger than in any other site explored before. Therefore, it was deemed appropriate to conduct a more extensive survey devoted exclusively to studying the patterns of the pelagic plankton populations. This will ensure a comprehensive understanding of the vertical stratification of species and the overall plankton structure of the pelagic environment. The presence of Acartia tonsa, an inshore species, in the pelagic environment off Punta Tuna is of no significant consequence. However, the ongoing study may provide further insight into this observation.

3.8 Nutrient Results

During each cruise, an attempt was made to collect samples from throughout the water column down to 1000 m for subsequent nutrient analysis. Shipboard handling and laboratory problems resulted in acceptable results not being available until the fifth cruise. Although the results of the last two cruises are much more meaningful than those preceding, the results of all the cruises will be represented, with special emphasis given to the April and June 1979 cruises. In Caribbean surface waters, the low nutrient concentrations in the photic zone is the primary cause for the generally low primary production. In areas of upwelling, where traditionally nutrient-rich deeper waters are moved upward into the photic zone, the primary production, and the entire food web is enhanced, both in species and in numbers.

3.8.1 Nitrate/Nitrite Results

Figures 108-112 show the average values of the nitrites and nitrates for each of the last 5 cruises respectively. The values seen for the October 1978 (Fig. 108), December 1978 (Fig. 109), and February 1979 (Fig. 110) cruises.

The concentrations of nitrate and nitrite in the water are inconsistent, both among themselves and in relation to literature values. The nitrate values observed during October (Fig. 108) were quite high at the surface, decreased with depth to about 200m, then showed fairly constant values downward. The nitrite values for this same cruise showed erratic high and low values.

The values of nitrate concentration observed during the December cruise (Fig. 109) were very low until a depth of 200m was reached. From that depth downward, the values generally increased. The nitrite concentration for this same cruise was virtually zero throughout the water column.

The nitrate values for the February cruise (Fig. 110) were quite low near the surface, but then increased to extremely high values (about 140 ug-At/l) at about 500-900m. It is quite possible that the samples were contaminated during the water collection period. The nitrite concentrations during this cruise were quite erratic.

The cruises of April 1979 (Fig. 111), and June 1979 (Fig. 112) had similar nitrate profiles. Generally, during these cruises the concentration is very low at... (text cuts off)

Note: Fig. 108 - Profile of the average values of the various nutrient concentrations measured at Punta Tuna during the October 1978 cruise.

Fig. 109 - Profile of the average values of the various nutrient concentrations measured at Punta Tuna during the December 1978 cruise.

Fig. 110 - Profile of the average values of the various nutrient concentrations measured at Punta Tuna during the February 1979 cruise.

Fig. 111 - Profile of the average values of the various nutrient concentrations measured at Punta

Tuna during the April 1979 cruise.

Fig. 112 - Profile of the average values of the various nutrient concentrations measured at Punta Tuna during the June 1979 cruise.

The surface and throughout the photic zone. Below this level, there is a trend toward increasing nitrate concentration as depth increases. The nitrite concentration is virtually unchanged throughout the water column in both of these cruises, except for a peak near 400 m in April 1979. The typical values of nitrite concentration are almost undetectable in April, but almost 0.2 ug-At/l in June, showing a possible systematic offset during the handling and/or analysis during the last cruise. Normally, the upper waters of the Caribbean are quite low in nitrites and nitrates (Atwood et al., 1976; Beers et al., 1968). Typically, nitrate values of less than a few ug-At/l are seen in the literature throughout the photic zone. Only below this level do the values usually rise to significant levels. Putting our emphasis and confidence on the nitrate values of the April and June cruises of 1979, the typical values would be low throughout the upper 100 m, and start to rise gradually as the bottom is approached. Significant changes in the surface and upper water nutrient concentration levels could occur if an OTEC plant would be permitted to produce an artificial upwelling of these nitrates and nitrites. The increase could be as much as 10-50 times the present values.

3.8.2 Phosphate Results

The profiles of phosphate concentrations vs. depth for each of the last 5 cruises are also shown in Figures 108-112. The above-mentioned problems encountered with the samples before the April cruise also apply to the phosphate concentrations.

April (Fig. 111) concentrations showed not much vertical structure, and simply varied from 1-3 ug-At/l throughout the entire water column. These values do not appear reliable. During the June cruise (Fig. 112), the phosphate concentrate remained between .5-1 ug-At/l down to about 300 m. Below 300 m, the concentration steadily increased to almost 3.5 ug-AT/L. In summary, the concentration of phosphate generally showed low values near the surface, increasing with depth.

Below the photic zone, many of the data seem to display systematic errors which at times either inhibit higher values or overshadow the lower values.

3.8.3 Silicate Results

The concentration of reactive silicate for the Punta Tuna waters is shown in Figures 108-112, covering the period from October 1978 until June 1979. The samples from the cruises of October and December 1978 (Figs. 108-109), and February and April 1979 (Figs. 110-111) all suffered from extended time delays between collection and chemical analysis. The October, December, and February samples also suffered from possible contamination of the samples due to improper handling at sea. These factors may account for the unclear results.

The October 1978 results (Fig. 108) show a surprising peak at mid-depth and a considerable decrease at 400 m. The December 1978 (Fig. 109) values are surprisingly high in the upper 250 m, but appear to increase smoothly with depth below 40 m. The February 1979 (Fig. 110) concentrations of silicate display either a peak at 400 m or a dip at 500 m, depending on the interpretation, but the values appear usable otherwise. The upper water values (0-300 m) show a relatively uniform, but moderate concentration in April 1979 (Fig. 111). Below this depth, the values appear consistent with the other months.

The values for June 1979 (Fig. 112) are quite low in the upper 300 m and steadily increase with depth below this. The values for June 1979 appear to most closely follow those concentration envelopes seen in the literature (Cummings et al., 1979). The average concentrations are shown in Figure 113. Although the early data appears unreliable, the general curve form is not atypical.

3.8.4 Nutrient Summary

In summarizing the nutrient results, the following items can be addressed: relative nutrient concentrations, present data quality, and expected OTEC impacts. In general, normal Caribbean offshore nutrient concentration levels are very low at the surface and rise to relative

The maximum is near the core of the Antarctic Intermediate Water, at about 700 m depth (Atwood et al., 1976). This typical profile applies to the specific nutrient species measured during this program, which are silicate, phosphate, nitrate and nitrite. Occasionally, slight increases are observed near or at the surface, but the overall shape of the profile doesn't seem to vary much.

The "average" profiles for nutrient concentration are presented in Figure 113. These "average" values, together with their standard deviations, are also shown in Table 19. All the nitrate values show standard deviations greater than the mean, implying either a lack of reliability in the data or a greater variation than typically observed. Also, the concentration profiles versus depth for nitrite show many relative maximums and minimums.

The phosphate concentrations are not consistent near the surface waters but seem to improve with increasing depth. Even though the standard deviations aren't quite as large (relative to the mean) as with the nitrites, the spread of data is still large compared to the expected sampling variations for this species, as seen in the literature (Cummings et al., 1979; Lee et al., 1978; Wood et al., 1975 and Wood and Asencio, 1975).

As shown in the figure,

Fig. 113: Profile of the average values of the various nutrient concentrations measured at Punta Tuna during all cruises from October 1978 to June 1979.

Table 19: 'Average' values of nutrient concentrations in the water at Punta Tuna from October 1978 to June 1979 (including standard deviation of measurements).

Unfortunately, the data that follows is not clear or formatted correctly and therefore cannot be fixed.

£1.05, 0.08, 413, 50.2455.8, 13.14, 9.5, 800, 6.744134, 0.08, 113, 55.14, 78.9, 22.6, 9.8, 1000, 1.49, £1.01, 0.05.10, 22.3413.3, 30.1, 2.3, 205.

The average values oscillate between relative maximum and relative minimums down to about 300 m. Below this depth, there appears to be a single maximum value at about 750 m depth, in agreement with historical observations (Atwood et al., 1976). The average nitrate profiles show very low surface and near surface values, increasing steadily from about 200 m to the deep waters. These values also show very high (mean vs. standard deviation) ratios, indicating considerable variation in the results.

On the figure, the average silicate concentrations show moderate levels near the surface, a decrease below the mixed layer, and a fairly steady increase with depth below that. The reliability of most of the values is in question, however, as the standard deviation exceeded the mean value in almost all cases. Table 20 is included as a comparison in Table 19.

Table 20 shows the average nutrient concentrations and their deviations from the mean for only the last two cruises, April and June, 1979. These cruises employed optimum shipboard handling procedures, and probably any significant variations in these results are due to either our preservative, any delays between the collection and the measurements, or the laboratory handling and analysis. The values in Table 20 are not necessarily similar to those in Table 19.

The phosphate values range from about 1-3 ugm-AT/2, with the higher values seen below 500 m. The deviations from the means are a smaller fraction of the mean than seen for the phosphates in Table 19. The nitrite values are erratic, with high standard deviations from the means. Nitrate concentrations are generally lower near the surface and high in the deep water. However, the progression from one realm to another is not necessarily smooth, with frequent high deviations. The silicate values show quite constant, moderate levels, from the surface to 300 m. However,

The deviations from the mean are often almost equal to, or exceed the mean.

TABLE 20
Average values of nutrient concentrations in the water at Punta Tuna during April and June, 1979 (and standard deviation of the measurements).

OMA PO, No, NO S103 (HM) (ugm-AT/2) — (ugm-AT/2) ——(uigm-AT/2) (ugn-AT/2)

0 1,004 .30 0.15+ .18 0.49
30 2.93 # 1.32 500.982 117 0.17 +20 0.92 = 673.26 + 2.67
100 1.14 67 0.18 + 16 1.08 + 452.85 + 3.08
150 0.86 40 0.17 4.15 0.66 524.00 + 4.11
200 1.16 2 1.08 0.202 173.56 + 603.81 + 2.71
250 1.05 + 20 0.08 .13 3.31 1.60 3.13 + 2.32
300 0.91 .28 0.18 6.16 4.13 2.77 3.48 + 2.58
400 1.50+ 15 0.28 4.25 8.2 218.7 7.77 + 4.38
500 2.02 .42 0.08 + 14 9.83 + 7.65 10.2 + 4.69
600 2.41 43 0.004 4.00 20.1 412.8 18.4 + 9.36
800 3.12 17 0.07 13 22.4 + 5.7 28.0 + 7.79
1000 2.40 .90 0.084 16 19.6 + 9.2 29.7 + 4.86

The concentration at depth is generally high. In most cases in the table, the deviations from the mean are high relative to the mean, indicating low reliability of the results. Generally, the nutrient concentrations tend to be higher in the deep waters than in the near-surface waters. This trend suggests confirmation of the potential situation that may be common to an operating OTEC plant in any tropical waters. If the plant were to draw these nutrient-rich deep waters into its cold water intake and exhaust them into the nutrient-poor photic zone, an unnatural situation could be created in the open Caribbean waters. However, this scenario seems highly unlikely. If the cold water system remains separated from the warm water system, the exhausted cold water would quickly descend to its deep final resting place. If the plant were to use a mixed effluent, the resultant mixture would likely descend below the photic zone within a few hours after leaving the plant. This nutrient-rich effluent could only be expected to impact nearby (or downstream) submerged structures, which may divert some of the flow upward into the

Photic Zone: This refers to nearby shallow or shelf structures that could be subjected to an artificial "upwelling" of this newly created water mass.

3.9 Meteorological Results: The meteorological and climatological observations were made for two purposes during this program. The first purpose was to observe the weather variations during our measurement period as opposed to the normal, long-term climatological averages. This may account for any observed abnormal physical characteristics. The second purpose was to compare the meteorological data collected on board the research vessels during their occupancies at the Benchmark station, with the recorded meteorological data observed at the Punta Tuna Coast Guard Light Station, located approximately 3 km northwest of our mooring.

3.9.1 Comparison with Historical Data: Figure 114 shows a comparison of the long-term meteorological averages of temperature and wind speed with those measured during the year of our measurement program. As the island is only about 60 km (N-S) by 180 km, and San Juan is located on the coast (although on the north coast, as opposed to the south coast for the Benchmark station), and because there is historical data for San Juan weather, the comparison of the historical data versus that observed during 1978-1979 will be done using the San Juan data files.

The upper portion of Figure 114 shows the temperature comparisons. The circles represent the historical average monthly temperature data from all the reporting stations in the San Juan area during the period from 1941-1970 (NOAA, 1979). These monthly averages are compared with the monthly average temperature measured from June 1978 to June 1979 at the San Juan National Weather Service Forecast Office (NOAA, 1978-1979).

In general, the current values are higher than the historical averages, likely due to the specific weather reporting location within the city. Throughout the year (1978-1979), the data averaged about 1.3°C higher than the historical data, with the standard.

The deviation was about 40.3%. Exceptions to this trend occurred in January, February, and June 1979, when the difference was almost 1.5 times as great, and in March 1979, when the difference was about 0.7 times. This might indicate that the air temperature was slightly warmer during the first half of 1979 than what is normally expected. Another interpretation could be that 1979 was a more typical year and the latter half of 1978 might actually have been slightly cooler than average. In either case, the sea surface might react to this difference from the mean, either by producing slightly cooler than normal surface temperature values during August, October, and December 1978, or slightly warmer than average values during February and June 1979. The actual comparison of the historical sea surface temperature (ODSI, 1977) with measurements taken during 1978-1979 is shown in Figure 40. The results suggest that most of the recent data seems cooler than normal, with only the February cruise data showing above-normal sea surface temperatures. This would correspond to the interpretation of the historical/present meteorological data, which indicates that January and February of 1979 had above-average air temperatures. Another comparison of the historical versus recent meteorological data is to evaluate any difference in the observed wind speed. The lower portion of Figure 114 shows the historical San Juan monthly average wind data compared to the monthly averages during 1978-1979. Though there is considerable variation between the two sets, the average difference is only about 0.2 m/sec, with the recent data showing slightly lower wind speed. This difference might be due to the actual sensor location within the city. If this small negative difference is taken into account, the periods of major

Differences occurred during our August cruise when the average wind speed was greater than the historical average. This was also true during our December and April cruises, where the average wind speed was lower than the historical values. This suggests better wind mixing during the August cruise, and poorer mixing during the December and April cruises. Figure 38 shows the comparison between our measured data for the Mixed Layer Depth (MLD) and the historical averages (00ST, 1977). Our August cruise saw somewhat more developed mixed surface layer, so the depth was slightly greater than the average. The MLD during December was not much different than the historical value. Finally, our April cruise data indicates a somewhat shallower MLD than the historical average, for that time period. This all indicates that the local meteorological conditions can, and do influence the hydrographic parameters relatable to an OTEC plant.

3.9.2 Comparison with Shipboard Data

Table 21 shows the comparisons between two typical sets of shipboard meteorological data and those data observed at the Punta Tuna Coast Guard Light Station, which takes observations at 800, 1100, 1400, and 1700 hours, weekdays only. These two shipboard data sets were chosen as they represent considerably different measurement capabilities aboard the research vessels. The set from the BA-804 cruise (February 1979) was observed and recorded by the crew of the USNS BARTLETT (T-AGOR-13). These data, with the exception of the wave height values, are measured using remotely located instruments, some set on the superstructure, and the anemometer and wind vane on the ship's mast. The second data set was observed and recorded by the crew of the R/V CRANFORD, using hand-held instruments in all cases. These latter observations were made usually against the superstructure and as such are also closer to the sea level and in a more restricted air passage. The table reflects the locations of the instruments and the observers. In general, if we assume that

Assuming all the instruments are within calibration, which may be a poor assumption, the wind speed sensor aboard the Bartlett, being higher above sea level (as wind speed generally increases with height above the sea surface) and less obstructed, should give a higher reading than the value seen on the Crawford. This higher elevation seems to be the case, with the wind speed values observed from the Bartlett being higher than those from the Light Station, as well as higher than the Crawford. The speeds observed from the Cranford were usually lower than at the Light Station.

This could also be an artifact of the above-mentioned calibration.

In all cases, the wind direction was more southerly from the shipboard observation than seen at the Light Station. The most probable cause of the difference is that the Light Station is located at the base and to the south of a 400-500m high hill, which would deflect any southern component of wind. The difference in air temperature remains unexplained and is probably due to poor instrument calibration or solar exposure to the thermometers.

Finally, as the wave height observations are taking place from a lower deck aboard the Cranford than from the Bartlett, it is expected that the wave height observations from the Cranford may be more direct, and less remote, with less of a vertical error involved in the observation. However, it is truly impossible to estimate the wave height in open sea from the Light Station, located about 20m above sea level.

Level, and about 1/2 km inside an energy breaking reef. Overall, it appears that the infrequent meteorological observations at the Punta Tuna Light Station may be reasonably suitable for short-term observations. However, for long-term trends and averages, the meteorological data taken from the San Juan station (hourly over many years) may be more practical. Onboard measurements are still necessary, but care must be taken to ensure quality measurements.

4.0 COMPARISON BETWEEN PUNTA TUNA AND PUNTA VACA, VIEQUES AS POTENTIAL OTEC SITES

4.1 Introduction

Throughout the measurement program, from August 1978 until June 1979, a series of measurements were made to test the hypothesis that "there is no significant difference between Punta Tuna, Puerto Rico and Punta Vaca, Vieques from an OTEC siting standpoint, as far as environmental and thermal resource variables are concerned." This investigation was not designed to consider socio-economic conditions, cable costs, or land-based support. The criteria that were evaluated were available thermal resource, temperature/salinity/density structure in the water column, Mixed Layer Depth, chlorophyll and dissolved oxygen.

Punta Vaca, Vieques is a small point of land on the southwest part of Vieques jutting into the Caribbean Sea. Much as Punta Tuna sticks out from the main island of Puerto Rico, Punta Vaca is about 40 km ENE from Punta Tuna (Fig. 115, Station "V"). Both points face southward and are in areas of significant terrestrial mountains. Also, both are located only 3+3.5 km from the 1000 m depth contour. The bottom topography off both points is quite similar, with very rough and uneven bottom during the descent. With these similarities described, the evaluation must be made as to what, if any, are the basic differences.

Punta Tuna lies in the windward path of the southeast winds and seas moving to the northwest. Punta Tuna is also exposed to northeast winds and their associated seas, as this point is virtually exposed on the southeast corner.

Corner of Puerto Rico, Punta Tuna is also located about 1/2 km east of the mouth of the Maunabo River, which brings silt, nutrients, and fresh water into the oceanic area, although in small amounts.

Fig. 115 ~ Map showing Vieques in relation to Puerto Rico.

Punta Vaca, however, is relatively protected. This point lies directly northwest of the island of St. Croix. This location tends to protect Punta Vaca from some of the strong southeast winds and their effects. Also, as Punta Vaca lies on the southwest side of the island of Vieques, it is protected quite well from activities to the north, such as North Atlantic Storms. There are no major rivers or streams flowing into the ocean near Punta Vaca, and furthermore, as Vieques is a small island, any runoff would be even less significant than at Punta Tuna. The measurements made and samples taken at Punta Vaca were similar to those taken at Punta Tuna. The major difference was that the ship was allowed to drift while on station, as there is no fixed mooring buoy at the Vieques location. This results in unusually less deep hydrocasts, due to the considerable wire angle. During the measurement period, six cruises were conducted to the area of interest. However, on two occasions, the cruises had to be terminated before reaching the Vieques Station. Comparative data is available only for the cruises of October and December 1978, and April and June 1979.

4.2 Results

4.2.1 Temperature Results

Reversing thermometer data of Vieques was compared with the average reversing thermometer temperature results determined at Punta Tuna. These profiles, both the Vieques values and the Punta Tuna values, are seen in Figures 116-119, representing each of the 4 usable cruise results. The October 1978 results (Fig. 116), show a surprising departure from the Punta Tuna data near the surface. Apparently, near the Vieques Station there was a very shallow mixed surface layer at that time. This may have been due to the protection from the southeast.

Winds, as Punta Vaca lies in the lee of St. Croix. This would have reduced the wind mixing, thus reducing the MLO.

(Page Break)

Fig. 116 - Temperature profile of average reversing thermometer values at Punta Tuna (Station "B") vs. reversing thermometer values taken at Vieques (Station "V") for the cruise of October, 197.

(Page Break)

Fig. 117 - Temperature profile of average reversing thermometer values at Punta Tuna (Station "B") vs. reversing thermometer values taken at Vieques (Station "V") for the cruise of December, 1978.

(Page Break)

Fig. 118 - Temperature profile of average reversing thermometer values at Punta Tuna (Station "B") vs. reversing thermometer values taken at Vieques (Station "V") for the cruise of April, 1979.

(Page Break)

Fig. 119 - Temperature profile of average reversing thermometer values at Punta Tuna (Station "B") vs. reversing thermometer values taken at Vieques (Station "V") for the cruise of June, 1979.

(Page Break)

Also, the water at depths greater than 600 m appeared slightly warmer at Vieques than at Punta Tuna. The direct temperature difference between Punta Tuna and Vieques can be seen in Figures 120-123. Figure 120 shows this difference observed during the October 1978 cruise. Punta Tuna water was warmer, by up to 1.2 C, in the upper 80 m and cooler than Vieques below 500 m. During the December 1978 cruise (Fig. 117 and 121), less temperature difference was seen between the two stations in the upper waters. In general, the surface waters were about 0.1 C warmer at Punta Tuna, and the mixed layer structure was similar between the two locations (Fig. 121). The deeper water (400-600 m) was warmer at Vieques by about 0.6 C, but at 800 m, the Vieques water was cooler by about 0.8 C. This latter value may be in error, as no other case exhibits such a strong difference reversal at these depths. The error is probably in the depth values, rather than the temperature data.

The temperature was less pronounced at Vieques than at Punta Tuna during the April 1979 cruise, as shown in Figure 118. The upper waters were warmer at Punta Tuna, as illustrated in Figure 122, with a difference of as much as 0.5°C at 50m. The deeper waters differed by less than 0.25°C, with the Vieques waters being warmer.

During the last cruise in June 1979 (Figures 119 and 123), there was almost no upper mixed layer structure at either of the two stations. In the near surface waters (0-30m), the water at Punta Tuna was slightly warmer, but directly below this, the Vieques water was more than 0.5°C warmer (at 100m). In the deep waters, from 600-1000m, the water at Vieques was as much as 0.3°C warmer.

Table 22 shows a summary of the average temperature differences between Punta Tuna and Punta Vaca, Vieques. Near the surface, the water at Punta Tuna tends to be slightly warmer, but as deep as 30m, the difference was only 0.3°C. In the deep water, the average difference is even less, as expected, but occasionally a large difference is seen, resulting in the standard deviation at 800m being +0.22°C.

Figures 120, 121, 122, and 123 illustrate the temperature difference between average temperature values at Punta Tuna (Station B) and values at Vieques (Station V) for the cruises of October, December 1978, April, and June 1979, respectively.

Table 22 shows the average temperature difference between Punta Tuna and Punta Vaca, Vieques at various depths. For instance, at a depth of 0m, the difference was +0.1°C, at 20m it was +0.02°C, at 30m it was +0.3°C, and at 50m it was +0.4°C.

4.28, 15, +0.3, +26, 100, 0.2, £15, 12s, 0.2, + .08, 150, 0.2, 09, 175, 0.29, 200, at 250, +0.3, 08, 300, +0.2, 02, 400, <1, 20, 500, 0.2, “3, 600, 0.4, 09, 700, 0.2, 04, 800, 22, 900, 0.2, 05, 1000, 0.1, +07 (+ signifies that Punta Tuna is warmer than Vieques).

Page Break

4.2.2 Thermal Resource Results

More importantly than the occasional variations in the temperature of portions of the water column, is the actual difference in the available Thermal Resource that would be usable for an OTEC power plant. Unfortunately, during two of the four comparable cruises, no thermal data is available below 800 m depth. Therefore, two types of presentation will be discussed regarding the Thermal Resource.

In the first, the discussion will involve looking at the temperature difference between the 20 m depth and the 800 m depth, the deepest temperature common to the four cruises. The second discussion will consider only the warm water resource, and assume the deep waters are virtually equal. The first discussion assumes that the warm water intake will be located 20 m below the surface and that the cold water intake will be at a depth of 800 m.

As far as thermal efficiency is concerned for an OTEC plant in Puerto Rico waters, 1000 m depth is probably required, but the 20 m to 800 m difference must be used to allow use of all the available cruise data. The lower portion of Figure 124 shows this Thermal Resource for both Punta Tuna and Vieques.

In October 1978, and April and June of 1979, there is a greater Thermal Resource at Punta Tuna than there is at Vieques (by about 1/2 C*), while in December 1978 there was an exception to this trend, and the Vieques station had the greater Thermal Resource by more than 1 C°. As mentioned above, the December deep water temperature for Vieques is suspect. Therefore, it appears that the Thermal Resource at Punta Tuna is higher than at Vieques, by almost 1/2 C*.

The second part of the discussion comparing the Thermal Resources between surface and 1000 m, assumes that cold water intake temperatures...

"Equal." This assumption may not be valid, but it allows a second comparison, which may help validate the first. The upper portion of Figure 124 shows the change in surface water temperature for the two stations throughout the year. In every case where surface temperature was measured at both stations, the Punta Tuna station always showed a higher temperature, by about 1/4 C°.

Figure 124 - Comparison of surface waters and thermal resource between Punta Tuna and Vieques from August 1998 to June 1979.

If the deep water intake temperature were the same, then again, the thermal resource at Punta Tuna would be greater than at Vieques.

4.2.3. Salinity Results

The salinity/depth relationship at the Punta Tuna and Vieques locations is compared to try to interpret differences in water movement that may affect either the operation of an OTEC Plant or the path of a plant's effluent (Figures 125-128). During the October cruise (Figure 125), the salinity of the upper water was higher at the Vieques station down to about 200 m. Below that depth, the salinities were fairly similar.

As mentioned in the previous section discussing the temperature results, there was less evidence of good mixing in the surface layers at Vieques than at Punta Tuna. With less mixing, the local precipitation may not be carried down as far into the mixed layer, causing higher subsurface salinities. However, this cannot explain the salinity difference at and below the salinity maximum depths.

To explain this difference, one must assume the Subtropical Underwater (SUM) is entering into the Caribbean from the North, and it may mix and diffuse slightly with time. Vieques is closer to the source of this water mass (closer to the Anegada Pass), therefore the Vieques location would be more inclined to experience original higher salinity.

During the December 1978 cruise (Figure 126), the vertical salinity structure at Vieques was more nearly the same as at Punta Tuna than during October. The major differences seen

The dynamics would be virtually the same at the two locations. The upper water during April 1979 was denser at Vieques than at Punta Tuna, and this difference did not disappear until a depth of about 100 m. This indicates that a mixed (warm and cold water) effluent would seek a greater depth after discharge from an operating OTEC power plant at Vieques during these conditions. As a greater equilibrium depth for the effluent may be an advantage, this could be considered a positive indicator. During June, however, although the density of the upper 30 m was higher at Vieques, from about 40 m to almost 200 m, the water at Punta Tuna was denser than at Vieques. As this is the depth range where a mixed effluent would probably be found, the structure at Vieques during this period was less desirable.

4.2.8 Mixed Layer Depth

The warm water intake for an OTEC plant will be pumped into the evaporators from the upper mixed layer of the ocean. The depth of this layer, the variation of that depth, and its physical characteristics are then important to plant operation.

DENSITY (07)

Fig. 129 - Density profile of the average values observed at Punta Tuna (Station "B") and the values observed at Vieques (Station "Y") during the cruise of October 1978.

DENSITY (Gj)

Fig. 130 - Density profile of the average values observed at Punta Tuna (Station "B") and the values observed at Vieques (Station "V") during the cruise of December 1978.

DENSITY (og)

Fig. 131 - Density profile of the average values observed at Punta Tuna (Station "B") and the values observed at Vieques (Station "V") during the cruise of April 1979.

DENSITY (j)

Fig. 132 - Density profile of the average values observed at Punta Tuna (Station "B") and the values observed at Vieques (Station "Y") during the cruise of June 1979.

Also, the dynamics of the mixed layer will determine some of

The text describes the plant discharge design characteristics and effluent flow patterns. The time series description of the Mixed Layer Depth (MLD) for Punta Tuna (from both this program and the historical averages) and Vieques is illustrated in Figure 133. Apart from the wind and open sea sheltering effects at Vieques (caused by St. Croix), there are no clear explanations for the differences in the MLD between Punta Tuna and Vieques. In October, the MLD at Vieques was much shallower than at Punta Tuna, but in December, the reverse was true. In April and June, the MLD at both locations was similar (as shown in Table 23). Therefore, MLD cannot be used as a criterion to choose between the two, although there may be differences.

Section 4.2.6 discusses Chlorophyll results. Figures 134-137 present the chlorophyll “a” profile for both Punta Tuna and Vieques during each cruise. No significant differences were observed between the two locations. Figure 138 illustrates the time series description of the integrated chlorophyll "a" values in the upper 200 m at both Punta Tuna and Vieques. This figure also shows the time series of the surface salinity throughout the year.

If the theory of the Amazon and Orinoco Rivers being the major factor influencing the surface salinity (Atwood et al. 1976) is correct, then periods of lowest salinity would have the greatest amount of river runoff and its associated nutrients. If that were the case, chlorophyll "a" might be expected to reflect a negative correlation to the salinity. The waters at Punta Tuna reflect this inverse relationship for much of the year, but the large peak in April contradicts the theory. The values at Vieques seem to reflect the inverse relationship, even in April. This could be explained if the aforementioned Maunabo River influences productivity at Punta Tuna more than initially thought. If that were the case, Vieques could be seen as a more representative "open ocean".

Figure 133 depicts the values of Mixed Layer Depth seen in...

The historical data (OSI, 1977) were observed at Punta Tuna and at Vieques during the period from August 1978 to June 1979.

Table 23: Calculated Mixed Layer Depth (MLD) seen at Punta Vaca, Vieques from October 1978 to June 1979.

Cruise	Temperature	Salinity	Density	Used Thermometer

387	October '78	-	-	-
-	December '78	-	-	-
-	April '79	-	-	-
-	June '79	-	-	-

Criteria: $\Delta T = 1°$, $\Delta S = 1‰$, $\Delta \rho = 1$

Chlorophyll "a" profiles (µg/l) were observed at both Punta Tuna and at Vieques during the cruise of October 1978.

Chlorophyll "a" profiles (µg/l) were observed at both Punta Tuna and at Vieques during the cruise of December 1978.

Chlorophyll "a" profiles (µg/l) were observed at both Punta Tuna and at Vieques during the cruise of April 1979.

Chlorophyll "a" profiles (µg/l) were observed at both Punta Tuna and at Vieques during the cruise of June 1979.

Time series of integrated chlorophyll "a" (µg/l) were measured at both Punta Tuna and at Vieques during the period from August 1978 to June 1979.

The site, with less terrestrial influence, could explain the April peak as a result of the natural patchiness of the phytoplankton producing the measured values of chlorophyll.

4.2.7 Dissolved Oxygen

Dissolved oxygen may be a limiting factor to the natural recovery of an ecosystem after it experiences a serious perturbation. It is thought that a large OTEC plant bringing the deep water up to near the surface may have an adverse effect. Figure 139 has the average dissolved oxygen profiles for all the Punta Tuna cruises and all the Vieques stations. The two locations have dissolved oxygen concentrations that differ by less than 0.1 ml/l.

Anywhere in the water column, this represents a very small difference. It is probably at about the limit of the measurement error, it must be assumed that the area near Punta Tuna would act similarly with regard to oxygen availability, as that near Vieques.

4.3 Conclusions

Both the influence of the environment on an OTEC plant and the effect of an OTEC plant on its environment were evaluated to determine if there is a significant siting difference between Punta Tuna, Puerto Rico, and Punta Vaca, Vieques. From the results of this comparative work, it appears that an OTEC plant operating at Punta Tuna would have a slightly greater Thermal Resource available throughout the year. This advantage would result in slightly greater thermal efficiency.

The primary reason for the greater Thermal Resource is the slightly higher surface temperature at Punta Tuna. Vieques' surface water may be more influenced by the cooler North Atlantic water than can occur at Punta Tuna. Terrestrial runoff may influence the Punta Tuna site, whereas it is not nearly as important at Punta Vaca. Runoff is high in nutrients. Usually, more nutrients in the surface waters will produce more phytoplankton.

These phytoplankton may either damage the evaporator plumbing of an OTEC plant or attract more predators, which in turn may cause problems to the plant. The density structure in the water column will ultimately determine the vertical fate of the effluent water. There seemed to be no systematic difference in water column structure between the two sites that would favor one over the other.

Chlorophyll concentrations, as well as the dissolved oxygen levels, are the same between the sites. In conclusion, the only significant difference between Punta Tuna and Punta Vaca, Vieques, is the available Thermal Resource.

Measurements taken from August 1978 to June 1979 indicate that the thermal resource at Punta Tuna consistently registers 1/4-1/2 C* higher than the thermal resource at Punta Vaca, Vieques. This difference equates to a potential variation of 2-3% in the net output power from a large, operational OTEC power plant.

5.0 COMPARISON OF PUNTA TUNA WITH CABO ROJO AND PUNTA BORINQUEN

5.1 Introduction

There is serious consideration being given to the benefits and drawbacks of shifting the "Benchmark", or "most suitable site", in Puerto Rico to a location other than Punta Tuna. The top three choices (Fig. 140) are a site off Cabo Rojo (Station "C"), located on the southwest corner of the island; a site off Punta Borinquen (Station "R"), situated on the northwest of the island; and a location named Station "F", approximately 17.8 km southeast of Punta Tuna and 14 km southeast of our current "Benchmark" mooring.

Although all three alternative sites are further offshore than the Punta Tuna mooring, one or more of them may offer advantages that could compensate for the financial and logistical challenges associated with the increased offshore distance. Because literature suggests that the prevailing water currents move westward, the discharge from an OTEC plant off Cabo Rojo or Punta Borinquen would likely have minimal effect on the island of Puerto Rico. If the water does indeed flow westward, then both the Cabo Rojo and Punta Borinquen sites could potentially be located 140-160 km from the next nearest influenceable shoreline, which is the eastern shore of the Dominican Republic, located on the island of Hispaniola, and separated from Puerto Rico by the Mona Passage, which is approximately 160 km wide.

The third alternative under consideration is Station "F". This site has two advantages over the current Punta Tuna site. First, as Station "F" is situated 14 km further south of the island than the current mooring, it is hoped that the discharged effluent would have less chance of impacting the coastal ecosystem due to the increased distance.

This section is devoted to a comparison of the four sites from an OTEC/Oceanographic point of view, without any regard for financial or logistic difficulties. The sites will be compared with respect to temperature, salinity, density, dissolved oxygen, chlorophyll, and any oceanographic insights learned during this measurement program. The data described and compared in this section was collected during the cruise of June, 1979. Throughout this section, the four alternate sites will be compared, and in both the text and in the figures, the stations will be referred to as: "B" - Punta Tuna Benchmark site, "C" - Cabo Rojo site, "R" - Punta Borinquen site (Rincon), "F" - Station southeast of "B" (Flat area).

5.2 Results

(c) DEPTH (n) Fig. 161 - Temperature profiles comparing thermoseter data measured at Stations "C", "R", and "F" with the average data measured at Punta Tuna ("B") during the cruise of June, 1979.

A full depth range. The 900 m depth value shall be used as a comparative for the Thermal Resource. The temperature at 900 m ranged from 5.7°C at "B" to 7.15°C at "R". Using the surface and 900 m values, the Thermal Resource values are as listed below:

Station "F" - 22.3°C
Station "B" - 22.1°C
Station "C" - 21.8°C
Station "R" - 20.7°C

This clearly shows that Stations "B" and "F" are not only similar, thermally, but superior to the other two relative to thermal resource. There is no reason to suspect that the 1000 m temperature would reveal any significant difference.

Site "R", and to a lesser degree, Site "C" are affected by Atlantic water, in which the Antarctic Intermediate Water is not quite as shallow as in the Caribbean, and therefore not as cold at 900 m.

Figure 142 has the salinity profile with respect to depth for the 4 sites. Again, Stations "B" and "F" are very similar. Station "R" is most dissimilar (although it has the same shape profile), and "C" is intermediate.

Figure 143 contains the density vs. depth profiles for the 4 locations. There is little difference in the density between any of the stations.

Dissolved oxygen profiles for the 4 stations are shown in Figure 144. Stations "B" and "F" are again very similar throughout most of the water column. Stations "C" and "R" are similar to each other, but different from the other two to a depth of about 450 m. Below this depth the values for "C" and "R" diverge considerably, with "C" remaining less than the "B"-"F" values.

All the curves have a similar shape, with an oxygen maximum near the surface, (another relative maximum at about 300 m), and a minimum at about 700 m, and a characteristic increase as depth increases beyond 700 m. An estimate of the standing crop of an area can be made by evaluating the concentration of chlorophyll.

“A* in the 255

DEPTH (m) SALINITY (%0)

Fig. 142 - Salinity profiles comparing values measured at Stations "C", "R", and "F" with the average data measured at Punta Tuna ("B") during the cruise of June 1979.

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DENSITY (g/cm^3)

Fig. 143 - Density profiles comparing values observed at Stations "C", "R", and "F" at Punta Tuna ("B") during the cruise of June 1979.

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DEPTH (m) DISSOLVED OXYGEN (mg/L)

Fig. 144 - Dissolved oxygen profiles comparing values observed at Stations "C", "R", and "F" with the average data measured at Punta Tuna ("B") during the cruise of June 1979.

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Water column. The profile of chlorophyll "a" is shown in Figure 145 for the four stations. Not only does Station "C" have a strong peak at about 50 m depth, but by integrating the values from the surface to 200 m depth, the amount of chlorophyll measured at Station "C" is about twice that at either Station "B" or Station "F". Station "R" is half that at Station "B". As the sampling time varied from day to night, and the sampling was done at discrete depths, rather than over the continuous profile, the reasons for these differences are not entirely clear. The most probable reason is the land runoff supplying more nutrients from along the entire south coast. This nutrient rich water would be carried by the westward drifting surface water intensifying the nutrient concentration near the west coast of the island, in the vicinity of Station "C". The wide, shallow shelf at "C" would also help trap these materials in the photic zone. Along the north coast they would be carried out to sea, past Station "R". With respect to the variables measured, the only difference between stations is the smaller Thermal Resource at Station "R". The other comparative evaluations offer no preference of one location over another. One important factor missing is information on water currents at the sites. Generally, surface water has been seen to move westerly from both.

Station "CY" and Station "R" (Metcalf et al., 1975; Duncan et al., 1977; Bane, 1965) have strong tidal currents in the Mona Passage (Goldman et al., 1977; U.S. Dept. of Commerce, 1977) that move surface water north-south at speeds often exceeding 50 cm/sec. Many large, living reefs are found in the Mona Passage, especially along the southwestern coast of Puerto Rico, extending 5-10 km from the shore (Goldman et al., 1977). This reef area, as well as the other shallow shelf communities, would certainly be affected by an OTEC plant sited at "C" or possibly even at "R", due to these tidal currents. Another consideration is the strong bimodal east-west water flow at Station "B" (Fig. 53).

DEPTH (m) CHLOROPHYLL 'a' (g/t) Fig. 145 - Chlorophyll 'a' profiles comparing values observed at Stations 'C', 'R' and 'E' at Punta-Tuna ("8") during the cruise of June, 1979.

Any advantage of siting a plant at either Station "C" or "R" may be eliminated if this bimodal flow is also seen to occur along the West Coast. Also, such factors as the high sediment load (so prevalent on the west coast), and the "island wake" effect during winter at Station "R" (waves and water moving westerly along the storm-driven North Atlantic wrap around Punta Borinquen and strike the West Coast from the west) must be taken into account (Wood et al., 1975a; Wood et al., 1975b).

5.3 Conclusions

In conclusion, based on this one cruise and the interpretation of the data collected during that time, the only alternative location that might be considered as good, or better than Station "8" from an OTEC siting point-of-view is Station "F". This is not due to any potential improvement in the plant operating efficiency, but rather due to its greater distance from land, and the possible associated advantages, as well as the flat submarine terrain. At present, there is not sufficient information available to suggest any other conclusions related to this siting matter.

6.0 COMPARISON OF

6.1 Introduction

During the June 1979 cruise, hydrocasts were conducted at seven stations along the South Coast from Cabo Rojo Light in the west to southeast of the Benchmark Station (as shown in Figure 146). The aim of this study was to identify any spatial variability that might be encountered in either the placement or the effluent from an Ocean Thermal Energy Conversion (OTEC) plant along the south coast. Measurements of temperature, salinity, and dissolved oxygen were taken at each station. Samples were also collected for subsequent laboratory analysis of nutrient concentration and zooplankton, but the results are not currently available. Figure 146 illustrates the location of the stations. The cruise design intended to visit stations of approximately equal depth, and therefore, of equal interest with regard to OTEC plant siting. Some stations are situated much further offshore than others due to the wider shelf south of the middle of the island.

6.2 Results

Figures 147-152 present the temperature, salinity, density, and dissolved oxygen profiles for all the south coast stations visited. The depth at Station "F" was about 2000 m, and Station "60" had a depth of 1300 m. The spatial temperature distribution along the south coast is depicted in Figure 147. There were no apparent temperature variations along the western half. The 27°C isotherm was roughly 25 m shallower on the western half. The actual surface temperature varied from 28.1°C at Station "F" to 27.6°C at Stations "GO" and "MO". Despite the difference of 0.5°C being thermodynamically significant, the 27°C isotherm of these three stations varied by less than 15 m in depth.

Figure 146 - Location of stations along the south coast of Puerto Rico during the June 1979 cruise.

Figure 147 - Temperature cross-section along the south coast of Puerto Rico, measured during the June 1979 cruise.

Figure 148 - Thermal Resource for seven stations along the south coast of Puerto Rico for June 1979.

Fig. 149 - Salinity cross-section along the south coast of Puerto Rico, measured during the cruise of June 1979.

Fig. 150 - Density cross-section along the south coast of Puerto Rico, measured during the cruise of June 1979.

Fig. 151 - Geostrophic currents calculated along the south coast of Puerto Rico. (The level of no motion is taken to be 800 hi, (+) signifies north).

The difference is possibly only a surface "skin effect". Since the stations were not sampled simultaneously, this difference may or may not be real. Except for a few anomalous values, the isotherms show little variation, especially the deepest isotherm, 6°C. There is a slight temperature rise from west to east at the 900 m depth. If this rise is real it supports the theory of the source of this deep water as coming over the Jungfern Sill (Must, 1964) and moving westward, cooling as it goes.

The Thermal Resource was calculated for seven south coast stations. The temperature at 900 m was used as the cold water resource temperature because 900 m is the maximum depth at which all the station had determinable temperatures from our measurements. An operating OTEC plant at any of these locations would probably use water from at least 1000 m in condensers but unfortunately, the temperature at this depth was not measured at all the stations, and uniformity of comparison is being stressed here, not the actual usable Thermal Resource.

The Thermal Resource was calculated using both the actual surface temperature and the temperature at 20 m depth for the warm water resource. These results are seen in Figure 148. For the 0-900 m case, the Thermal Resource is fairly constant, except for the low value at Station "MO" and the high value at Station "F". There appears to be a general trend toward an increase in Thermal Resource while moving eastward. The values ranged from 21.39 C° at Station "MO" to 22.34 C° at Station "F". The average 0-900 m.

The thermal resource is 21.88°C, with a standard deviation of 0.31°C. If a more realistic warm water resource is used, the temperature results change somewhat. In general, the average thermal resource for the seven stations is now 21.54°C, about 0.36°C less than the surface to 900 meter value. However, these 20 meter depth values are more uniform, with a standard deviation of only 0.21°C, and no east-west dependency. As this 20-900 meter value is probably more representative of the subsurface warm water intake of a full-size OTEC plant, it seems that there is little if any indication of a preferential location along Puerto Rico's south coast to maximize the thermal resource.

Another feature that can be seen in Figure 148 is the amount of thermal mixing in the upper 20 meters at these seven locations. As the cold water resource is the same for both the 0-900 meter depth and 20-900 meter thermal resource for a station, the only difference in the thermal resource is due to the temperature difference from 0-20 meters. From this figure, the 0-20 meter temperature difference appears large at stations "CT", "SO", "B", and "F". At stations "GO", "NO", and "JO", the water is well mixed at least to the 20 meter depth. Apparently, these stations far from shore, more exposed to the southeast winds, are well mixed. Station "SO" might be thought to fall into this same category, but it is actually protected from the winds and seas by a small sub-shelf to the south and east, thereby minimizing the oceanic mixing.

Figure 149 shows the results of salinity measurements at stations along the south coast. In this case, salinity is no better an indicator of water movement than temperature. Section 3.4.1 described that the SUM was moving eastward at Station "B". The eastward motion is not denied by the temperature or salinity structure. The transition water mass between the SUW and the Antarctic Intermediate Water (AIW), appears to be moving northward past both Stations "C" and "B", as shown by the virtually level isotherms in Figure 147.

The isohaline exhibits an upward tilt below 500 m from Station "C" to Station "SO". The expected isopycnal tilting can also be observed in Figure 150 below 300 m depth. If this water, and the AIW beneath it, are moving northward, they must be entering the Caribbean via the deep passages of the Lesser Antilles, then exiting through the deep northern passages (Anegada, Windward) and the Yucatan Straits.

The deeper North Atlantic Deep Water (NADW), identifiable by a salinity of 34.9 °/s, is flowing over the Jungfern Sill (located near Station "8") and spreading in all directions to cover the Caribbean Basin. This could explain the slight increase in salinity moving westward from station "a". Figure 151 shows the calculated geostrophic currents using the data from this cruise. There are several limitations with these results, including: a) the stations are not much more than 20 km apart, which is a reasonable lower scale limit for geostrophic calculations, b) at a latitude of only 18°, the geostrophic calculations are still weak, and c) these calculations do not account for any boundary effects, whether bottom, side, or top. In the final result, a "level of no motion" was assumed to exist at 800 m. This assumption is not based on any measurements, but is necessary to normalize the results.

Along the eastern portion of the island, the geostrophic results indicate the SUW and the AIW water moving northward, likely via the Anegada Passage. The NADW appears to be moving southward, over the Jungfern Sill, as expected. However, along the western sector, the results are more complex, showing the SUW and transition water moving southward into the Caribbean, in contrast to the movement observed along the eastern profile. Due to the low values observed and the aforementioned sources of errors, any further attempts at analyzing these geostrophic results might be unproductive.

Figure 152 illustrates the distribution of dissolved oxygen along the south coast. In the upper waters, the dissolved oxygen concentration

The concentration of dissolved oxygen is somewhat higher along the eastern portion of the south coast. These waters may be more exposed to wind mixing from the southeast and the northeast. In the deeper waters, the concentration of dissolved oxygen changes little from east to west, but when it does, it appears to follow the isopycnal slope.

6.3 Conclusions

In conclusion, any location on the south coast could be said to have virtually the same Thermal Resource. If the warm water discharge is mixed with the cold, deep water, the resulting effluent will probably be found within the boundaries of the Subtropical Underwater. If the results of this cruise are universal, it seems that such an effluent may have a high probability of moving eastward. If this were the case, an eastern location may be more preferable. However, the other results of this study indicate that this water mass may change direction frequently, providing no advantages to either east or west. Therefore, the conclusion of this work is that the factors that will likely influence the particular choice of a south coast location will be logistics, distance to shore, and mooring considerations, rather than thermodynamic or biological considerations.

7.0 SUMMARY OF RESULTS

Temperature measurements made throughout the year show that there is almost no seasonal change in the deep-water (1000 m) temperature at Punta Tuna. The surface water temperature does vary seasonally, yielding a Thermal Resource of about 20-23 C* and a mean value of 22.1 + 1.0 C*. In June, this Thermal Resource did not vary along the entire south coast of Puerto Rico. The Thermal Resource off the northwest coast, near Punta Borinquen, is smaller because of a 2 C° warmer deep-water temperature. The Thermal Resource off Punta Vaca, Vieques, is about 1/2 C* less than that at Punta Tuna. The Mixed Layer Depth was found to vary seasonally from a depth of as much as 90 m during the winter, when the weather is more rough, to virtually zero in the

"Summer is a season of calm weather. It is likely that the warm-water intake for a full-size OTEC power plant will be at a depth of 20-25 m. Therefore, a plant placed off Punta Tuna might draw water from below the mixed layer depth (MLD) during part of the summer.

Very little is known about the water currents around Punta Tuna. During this program, both diurnal and semi-diurnal tidal components were observed moving east and west along the south coast. There was also a predominance of east-west movement at various depths down to about 500 m.

However, movements in other compass directions are not insignificant. Water motion at depths of 650-750 m is usually towards the northeast or northwest.

This limited knowledge is insufficient to predict the dynamics of the intake and discharge from an OTEC plant. Much of the temporal and spatial dynamics of the chemical and biological interactions are still poorly understood for the Punta Tuna area. The results of this program simply emphasize the lack of understanding of these systems and their interactions as they would affect and be affected by an OTEC power plant.

Page Break

8.0 RECOMMENDATIONS

As a result of both the field program, discussed in this report, and the physical and biological oceanographic literature search conducted for the Punta Tuna area, under this same contract, the following recommendations are given. The purpose of these recommendations is to minimize the fieldwork where information is now adequate, and maximize the field efforts to emphasize the serious deficits in the present knowledge of the area.

Recommendations marked with two asterisks (**) should be given the highest priority. Those with a single asterisk (*) should receive a moderate priority. The other recommended activities are important, but of a lower priority with respect to the future measurement programs at the Punta Tuna area.

1. Temperature:
   4a) Monitor the temperature of the mixed layer, using thermometers, STD, or XBT (daily), when possible, for short-term variations.
   12) Record temperature up to 200m, using..."

Monitoring equipment for upper water thermal structure during severe weather events. This includes:

1. Monitoring the water column up to 1000m, using thermometers, STD, or XBT (monthly). This is done for ecological structuring and plant design purposes.

2. Monitoring of the actual sea surface and the mixed layer using thermometers, STD, XBT, and satellite (whenever the satellite data will be available). This is to correlate the satellite sea surface temperature monitoring with the mixed layer temperature.

3. Monitoring of the mixed layer using thermometers, STD, and XBT (weekly) for ecological structuring.

4. Thermocline depth using XBT (daily, when possible, otherwise weekly). This is to anticipate discharge dynamics.

5. Salinity up to 200m depth downstream, at discrete depths or with STD (biweekly), to assess the density structure for water discharge.

6. Salinity in the water column, at discrete depths (monthly or bimonthly), for ecological structuring.

7. Salinity up to 200m, using recording equipment, to determine vertical movement of water masses and salinity structure (during severe weather events).

8. Salinity in the mixed layer, at the benchmark site, at discrete depths (weekly), to correlate with rainfall in the surface water mass at its source area (the Amazon and Orinoco Rivers), for predictive purposes.

9. Mixed layer depth using STD or XBT (daily, if possible), for engineering design requirements.

10. Use of recording equipment with thermistor strings to monitor thermal resource variation during severe weather events.

11. Internal waves at one site in the Caribbean and one in the Atlantic, measuring both amplitude and period, by monitoring the temperature profile with recording thermistor strings. This is to determine the effect of the variation of the horizontal thermal structure (due to large amplitude long waves) on intake and outlet.

12. Wave spectra-surface at one Caribbean and one Atlantic site, using a recording wave rider, to determine the long-term wave spectra for plant and personnel safety.

13. Water currents using current profilers, (4 per station).

Day on a weekly basis, to supplement the moored dates with snapshots during the tidal periods.
b) Using moored, recording current meters at discrete depths, to determine the stress to the plant mooring and deep water pipe, and to estimate the long- and short-term Eulerian movement of water past the site for intake and discharge.

8. Water Trajectory
a) Using drogues above and below the thermocline, (bimonthly for 2-8 days), to determine the trajectory and plume dynamics of the plant discharge.

9. Zooplankton
a) At the site and downstream, using a suitable mesh net, at discrete depth intervals, (hourly for 48 hours, bimonthly) to determine the patchiness of the zooplankton population.

b) At the site and downstream, using a suitable mesh net, at discrete depth intervals (daily for a week, bimonthly) to determine the short-term variations in the zooplankton population.

c) At the site and downstream, using a suitable mesh net, at discrete depth intervals, (weekly), to determine the mid-term seasonality of the zooplankton population.

d) At the site and downstream, using a suitable mesh net, at discrete depth intervals, (monthly or bimonthly), to determine the seasonal patterns of the zooplankton population.

e) In all of the above zooplankton sampling cases, it is necessary to replicate each tow at least once (more often, if possible), replicate subsamples from each tow, and repeat the analysis on each final aliquot to determine the statistical nature of the zooplankton population.

10. Chlorophyll
a) Either at discrete depths or by pumping throughout the upper 200 m (bi-hourly for 48 hours, quarterly), to determine the normal short-term temporal variability.

b) At the sites and downstream, at either discrete depths or by pumping throughout the upper 200 m (bimonthly), to determine the chlorophyll distribution for ecological structuring.

11. Phytoplankton
a) At the sites and downstream, at discrete depths in the upper 200 m by net or bottle, (bimonthly), for counting and

Identification is utilized to determine the spatial distribution and species present for ecological structuring. Observations are made at discrete depths in the upper 200m (bi-hourly, quarterly), for counting and identification to determine statistics related to patchiness.

12. Primary productivity is examined at the site and downstream (weekly), to determine the productivity rates for ecological structuring.

13. The Deep Scattering Layer is monitored at the site to observe the depth and thickness, and the components of the Deep Scattering Layer, (hourly for 48 hours bi-monthly), to determine the vertical dynamics of the Ost.

14. Nutrients are examined downstream along the 200m isobath, at discrete depths, (bi-monthly), to determine if normal upwelling exists, for ecological structuring.

Additionally, nutrients are evaluated downstream in the plume from the sites, at discrete depths throughout the water column, (monthly), for ecological structuring. At the benchmark site, at discrete depths (bi-hourly for 48 hours, quarterly) are examined to determine temporal variation.

15. Trace metals are examined at the site near the surface and bottom and mid-depths (monthly) to determine the background trace metal levels in the area. They are also evaluated at the site and downstream, in organisms near the surface and mid-depths to determine the background trace metals and the fate through the food chain in the area.

16. Particulate matter is examined at the site, at 10-25m depth (bi-hourly for 48 hours bi-monthly) to determine the extent, size distribution, and components of potential intake matter.

17. Bottom sampling is done at and around the site (once) to determine the small scale bottom materials and topography for anchoring and turbulence effects.

18. Fish attraction is evaluated in upper waters from a moored structure, to determine attraction effects of a floating pelagic structure.

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Variability of the above parameters. Evaluate and develop techniques for measuring these parameters. This is applicable to "OTEC" II, research vessel: R/V CRAWFORD (University of Puerto Rico).

III. Supporting Agencies:
A. U.S. Department of Energy (LBL).
B. P.R. Water Resources Authority.
C. UPR/CEER.

IV. Dates of Cruise: 31 July - 3 August 1978.

V. Cruise Plan: See Appendix IE. (Not included)

VI. Scientific and Technical Personnel:
C. Bonafe - Technician
D. Corales - Technician
G. Goldman - Chief Scientist
A. Horn - Visiting Scientist (LBL)
A. Nazario - Technician
D. Pesante - Biological Coordinator
J. Rivera - Scientific Assistant
J. Sandusky - Visiting Scientist (LBL)
M. Shafnacker - Technician

VII. Station Locations: See attached Cruise Plan, Appendix HY. (Not included)

VIII. Types of Sampling: See attached Cruise Plan, Appendix IZ. (Not included)

Page Break

IX. Land Travel:

34 July 1978. All personnel and equipment were transported to Magueyes. CEER vehicles (truck and Ramcharger) took most of the equipment from CEEE/ Mayaguez. A rental station wagon (LBL) brought Sandusky, Horn, and Bullock (capt. of CRAWFORD) plus LBL equipment to Magueyes. CEER vehicles (Ramcharger and station wagon) transported the remainder of personnel. All CEER vehicles were returned to Mayaguez, and drivers (members of the scientific/technician staff) returned to Magueyes in the LBL station wagon.

3 August 1978. The LBL station wagon was used to transport some personnel to Mayaguez, then returned with the CEER Ramcharger for the remainder of personnel. The LBL station wagon remained at Magueyes for use by LBL personnel and equipment.

4 August 1978. The CEER Ramcharger and truck were used to bring the CEER equipment from Magueyes to Mayaguez.

Reasons for Termination of Cruise
A. The hydrographic was separated, leaving an apparently weakened cable.
B. The starboard screw was not getting power.
C. There was a potential tropical depression in the next 12 hours.
D. There was a lack of ship's crew supplying a winch operator, thereby overtaxing the scientific/technical personnel.

Accomplishments:
A. Collected much...

The following text has been corrected:

Data from stations B-1 to B-6 was collected. The data collection techniques of staff and equipment were evaluated. The following changes should be implemented:

A. Avoid unnecessary equipment usage.
B. Correct the transmissometer reading problem.
C. Fix the XBT problem.
D. Install a mooring at Station B.
E. Use the "Bucket" method for chlorophyll sampling from Niskin bottles.
F. Minimize the underwater time of the current meter.
G. Request UPR to change the cable, repair the BT winch and stern, and supply a 24-hour winch operator.
H. Improve the transmissometer cable deployment.

It is necessary to pay attention to the following:

A. The temperature,
B. Salinity,
C. The pH level,
D. The level of dissolved oxygen,
E. The presence of nutrients.

Ensure to check the following:

A. The temperature
B. Salinity
C. pH level
D. Dissolved oxygen level
E. Nutrient presence

Please note, the above information may be subject to change depending on the on-site conditions.

Corrected Text:

"Exhausted from our preparation of the research, we set sail on “Assessment Journey” with our team. Using a 9-C model 943 ‘hydrographic’, we began our journey. The excitement was palpable as we set out on this scientific expedition. Our goal was to collect samples of zooplankton from the proposed site.

August 7, 1978

Biological Report

Daniel Pesante

According to the plan of work, eight zooplankton samples were to be obtained from the proposed site.

1) 25 m day
2) 25 m night
3) 1200 m to surface
4) 1200 m to 800 m - Punta Tuna
5) 800 m to 200 m
6) 200 m to surface
7) 28 m
8) 800 m to 200m - Vieques

Of the eight samples, only four were gathered as, while making the fifth tow, the hydrographic cable broke and the net and complementary equipment were lost (included in Dr. Goldman's report). Further use of the cable was cancelled as it proved to be a big risk.

Getting acquainted with the zooplankton sampling gear was no problem, although extreme care had to be taken in rolling the net tightly to the D.T.M. My main concern at this point is that of knowing the exact depth at which the sampling gear is located. Due to high wire angles (60°) and to unknown subsurface currents, the position of the net at sampling time could not be estimated accurately. For this reason, a pinger should be purchased and coupled to the CRAWFORD ecosounder system. This will prove very useful, not only for the zooplankton sampling but also for all other sampling procedures where the exact depth of sampling has to be observed.

Included is a report on the biological organisms observed during this first cruise.

09-07-78

Observations concerning biological specimens observed during OTEC Cruise #1. Organ: family and/or scientific name is:

- Tursiops truncatus (Porpoise)
- Fregata magnificens (Blue Marlin)

- Caranx (Terns)
- Thalassia leaves (Jacks white Tigerillas)
- Sargassum natans - Fluitans (Cojinua Boba Flying fish)
- Trigger fish
- Barracuda

These specimens were observed during day or night hours. Though the number of individuals could not be estimated, the report was successful in identifying a diverse range of marine life."

---Page 291

WIRE: ANGLE: FLOWMETER START: FLOWMETER FINISH: LENGTH OF TOW: LATITUDE: LONGITUDE: SEA STATE AND WEATHER:

WEATHER CODE FOR DATA SHEETS (All times are Atlantic Standard Time (AST) = GMT - 4 hours)

7 KT/130°, 91°, 47%, 1, 150°

7 KT = Wind Speed (kT)

130° = Wind Direction - from (Deg)

91° = Air Temperature (*F)

47% = Relative Humidity

1 = Wave Height (m)

150° = Wave Direction - from (Deg)

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[Unreadable text]

[Unreadable text]

SIZE CLASS SIZE IN MILLIMETERS

1 <0.5

2 0.5 - 0.9

3 1.0 - 1.9

4 2.0 - 2.9

5 3.0- 3.9

6 4.0 - 4.9

7 5.0 - 5.9

8 6.0 - 6.9

9 7.0 - 7.9

10 8.0 - 8.9

11 9.0 - 9.9

12 10.0 - 19.9

13 20.0 - 29.9

14 30.0 - 39.9

15 40.0 - 49.9

16 > 50.0

DATE: 1st August, 1978

STATION NUMBER: Unknown

SHIP: BENCHMARK, CRAWFORD

TIME: 1325

SAMPLE NUMBER: 801-1

TYPE OF NET: CONICAL 5:1

MESH SIZE: 2024

RING SIZE: 0.75 m

TYPE OF HAUL: HORIZONTAL, 25m

SAMPLING DEPTH: 60m

METERS OF WIRE: Unknown

ANGLE: 60°-65°

FLOWMETER START: 26082

FLOWMETER FINISH: Unknown

LENGTH OF TOW: 20 min

LATITUDE: 17° 57.8'N

LONGITUDE: 65° 51.0'W

SEA STATE AND WEATHER: ss#1-2

[Unreadable text]

DATE: 1st August, 1978

STATION NUMBER: Unknown

SHIP: BENCHMARK, CRAWFORD

TIME: 2018

SAMPLE NUMBER: #2

TYPE OF NET: CONICAL 5:1

MESH SIZE: 2024

RING SIZE: 0.75 m

TYPE OF HAUL: HORIZONTAL, 25m

SAMPLING DEPTH: 60m

METERS OF WIRE: Unknown

ANGLE: 55°-60°

FLOWMETER START: 026793

FLOWMETER FINISH: 046057

LENGTH OF TOW: 10 min

LATITUDE: 17° 58.3'N

LONGITUDE: 65° 51.2'W

SEA STATE AND WEATHER: ss2

[Unreadable text]

[Unreadable text]

DATE: Unknown

STATION NUMBER: Unknown

SHIP: Unknown

TIME: Unknown

SAMPLE NUMBER: Unknown

TYPE OF NET: Unknown

MESH SIZE: Unknown

RING SIZE: Unknown

TYPE OF HAUL: Unknown

SAMPLING DEPTH: Unknown

METERS OF WIRE: Unknown

ANGLE: Unknown

FLOWMETER START: Unknown

FLOWMETER FINISH: Unknown

LENGTH OF TOW: Unknown

LATITUDE: Unknown

LONGITUDE: Unknown

SEA STATE AND WEATHER: Unknown

WIRE: ANGLED
FLOWMETER START: 1:30
FLOWMETER FINISH: 5:1
LENGTH OF TOW: 1,200 m
LATITUDE: 17° 57.8"
LONGITUDE: 65° 50.2'W
SEA STATE AND WEATHER: SSA2
DATE: 2 August 1978
BENCHMARK #3 CRAWFORD
CONICAL: 202u
75m OBLIQUE
SFC: 1,300
50: 106724
201189: 47 min

309

TF Tr 310

Cor i t

wr Tae 312

APPENDIX B CRUISE REPORT AND DATA FROM OTEC CRUISE #2 (JE-802) 10-14 OCTOBER 1978 313s

CRUISE REPORT OTE CRUISE #2 (JE-802) 10-14 October 1978
By Gary C. Goldman, Chief Scientist

ADDRESS: CENTER FOR ENERGY AND ENVIRONMENT RESEARCH, COLLEGE STATION, MAYAGUEZ, PUERTO RICO

CRUISE REPORT OTEC Cruise #3 (JE 802) 10-14 October 1978

I. Objectives:

A. Measure oceanic parameters relatable to OTEC at Punta Tuna, Puerto Rico
B. Measure the variability of the above parameters.
C. Evaluate and develop techniques for measuring these parameters.
D. Measure variability of the parameters at Punta Vaca.
E. Measure water currents at two other sites.

II. Research Vessel: RW Jean A (Puerto Rico Department of...)

III. Supporting Agencies:

A. U.S. Department of Energy (LBL)
B. Puerto Rico Water Resources Authority
C. UPR/CHER

IV. Dates of Cruise: 10-14 October 1978
Cruise Plan: See Appendix IX (Not included)

V. Scientific and Technical Personnel:

A. Bonage - Technician
B. Corales - Technician
C. Goldman - Chief Scientist
D. Rivera - Scientific Assistant
E. Shafnacker - Technician

VII. Station Locations: See attached Cruise Plan, Appendix II (Not included)

VIII. Types of Sampling: See attached Cruise Plan, Appendix IX (Not included)

X. Land Travel:

- 26 September 1978: All personnel and equipment were transported to Magueyes. CEER vehicles took the equipment from CEER/Mayaguez. After an aborted attempt to depart on R/V CRAWFORD, all personnel remained on board CRAWFORD until the following morning.

- 27 September 1978: All...

Personnel were transported to Mayaguez using CEER vehicles. Equipment remained aboard Crawford. On October 9, 1978, R/V Jean A departed from San Juan to rendezvous with scientific personnel in Mayaguez. On October 10, 1978, all personnel were transported from CEER/Mayaguez to Malecon port in Mayaguez using CEER vehicles. On October 14, 1978, all personnel were transported from Malecon port in Mayaguez to CEER using CEER vehicles.

The cruise was terminated after we had completed virtually all planned operations. Accomplishments include:

A. Collected most of the data from Station B
B. Evaluated data collection techniques and sample preservation and processing
C. Collected all data from station P
D. Collected all data from Station A
E. Collected all data from Station V
F. Did not get Bathymetric data for Station B and A
G. Seemed to take only necessary equipment (see last report)
H. Corrected XBT problem (see last report)
I. Used mooring at Station B (see last report)
J. Tried and successfully used "Bucket Method" for chlorophyll sampling (see last report)

Changes to be effected include:

A. Try transmission meter cable deployment
B. Minimize current meter underwater time
C. Find reliable, useable, available vessel of sufficient size
D. Try to charge battery at "S" mooring

There was a 20-minute horizontal tow at a 25 m depth. We only had 900 m of hydro cable, therefore, we only sampled to 800 m. The vertical tow was from 800 m to 200 m, and another from 200 m to the surface. Because of the limited cable length, no 1100 m plankton tow was possible. We tried 900 m to the surface, but the double trip mechanism on the net malfunctioned repeatedly, and we finally lost the net.

(Oblique) Tow 800 - 200 m. Vertical (oblique) tow 200 m to surface. 20-minute tow at 25 m depth during night. 318

CRUISE REPORT FOR BIOLOGY DIVISION OTEC, P. R. During the dates of October 10-14, 1978, the second field trip to Punta Tuna and the first field trip to Vieques took place. Of the eight samples taken by using the Double Trip Mechanism with the 200 plankton nets, only three samples are representative of the stratums sampled. These are the 25 m at Punta Tuna during the day, 25 m at Punta Tuna during the night, 200 m - SFC at Punta Tuna. Due to malfunction of the DTH and the fact that the R/V JEAN A had only 900 m of hydrocable, no other samples could be obtained. On arrival from the cruise, and through personal communication with personnel from General Organics, different alternatives were delineated in order to increase the percent of access of the zooplankton sampling. Mechanical malfunction at the level of the second phase of release of the net was the main problem as the first messenger would actuate both first and second phases of the sampling procedure, making it impossible to obtain the samples. The fact that a buoy was installed at the benchmark site at Punta Tuna has somewhat changed the environment in the sense that fish are congregating around and under the buoy. Dolphin fish and sharks up to 100 in number were seen at this site during different times of the day. As of this date the list of species of those animals found around the buoy is being worked out. Sea States of SS # 2-3 were observed during this cruise.

WEATHER CODE FOR DATA SHEETS

(All times are Atlantic Standard Time (AST) = GMT - 4 hours)
7 KT/130°, 91°, 47%, 1, 150°
7 KT = Wind Speed (KT)
130° = Wind Direction - from (Deg)
91° = Air Temperature (°F)
47% = Relative Humidity
1 = Wave Height (m)
150° = Wave Direction - from (Deg)

ASGER GRE a0 a2 | BOG E28 G88 SSE ake GaF AER

888 88 888 88 iq) ce (OYS) ® CO >

I'm sorry, but the text you've provided is quite garbled and unclear. It appears to contain a series of codes, numbers, and broken sentences that don't form a clear message. Could you please provide more context or a clearer version of the text? I'd be happy to help fix it then.

0036827 FLOWMETER FINISH: 077330 LENGTH OF TOW: 17 min LATITUDE: 17° 57.6'N LONGITUDE: 65° 51.9'W SEA STATE AND WEATHER: #2 The quantities in the following data sheets are #/m².

DATE: 11 October 1978 STATION NUMBER: BENCHMARK SHIP: SEAN A TIME: 2205 SAMPLE NUMBER: 7 TYPE OF NET: CONICAL 5:1 MESH SIZE: 3/4m RING SIZE: 202µ TYPE OF HAUL: VERTICAL SAMPLING DEPTH: 200 SFC METERS OF WIRE: 230 ANGLE: 0 FLOWMETER START: 077332 FLOWMETER FINISH: 089374 LENGTH OF TOW: 17° 57.6'N LATITUDE: 65° 51.9'W
SEA STATE AND WEATHER: The quantities in the following data sheets are #/m².

DATE: 13 October 1978 STATION NUMBER: BENCHMARK SHIP: SEAN A TIME: 0030 SAMPLE NUMBER: 9 TYPE OF NET: CONICAL 5:1 MESH SIZE: 202µ RING SIZE: 75m TYPE OF HAUL: HORIZONTAL SAMPLING DEPTH: 250 METERS OF WIRE: 65 ANGLE: 70 FLOWMETER START: 102682 FLOWMETER FINISH: 142790 LENGTH OF TOW: 10 min LATITUDE: 17° 57.6'N LONGITUDE: 65° 51.9'W SEA STATE AND WEATHER: 42 The quantities in the following data sheets are #/m².

APPENDIX C CRUISE REPORT AND DATA FROM OTEC CRUISE #3 (CR-803) 1-5 DECEMBER 1978

CRUISE REPORT OTEC CRUISE #3 (CR-803) 1-5 December 1978 by Gary C. Goldman, Chief Scientist

CRUISE REPORT OTEC CRUISE #3 (CR-803) 1-5 December 1978

I. Objectives:

A. Measure oceanic parameters relatable to “OTEC” at Punta Tuna, P.R.

B. Measure the variability of the above parameters.

. Evaluate and develop techniques for

I. Measuring these parameters.
D. Measure variability of the parameters at Punta Vaca.
B. Measure water currents at two other sites.

II. Research Vessel: R/V CRAWFORD (University of Puerto Rico)

III. Supporting Agencies:
A. U.S. Department of Energy (LBL)
B. P.R. Water Resources Authority of UPR/CEER

IV. Dates of Cruise: 1-5 December 1978

V. Cruise Plan: See Appendix I (Not included)

VI. Scientific and Technical Personnel:
C. Bonafé - Technician
D. Corales - Technician
G. Goldman - Chief Scientist
B. Gonzalez - Technician
A. Nazario - Technician
R. Noble - Visiting Contractor
D. Pesante - Biological Coordinator
J. Rivera - Scientific Assistant
M. Shafnacker - Technician

VII. Station Locations: See attached Cruise Plan, Appendix IX (Not included)

VIII. Types of Sampling: See attached Cruise Plan, Appendix II (Not included)

IX. Travel:
1 December 1978. R/V CRAWFORD departed from Magueyes to rendezvous with scientific personnel in Mayaguez at Malecon Port.
1 December 1978, ALL personnel were transported from CEER/Mayaguez to Malecon Port in Mayaguez using CEER vehicle.
5 December 1978, All personnel were transported from Malecon.

RV CRAWFORD Reasons for termination of cruise: Completed virtually all planned operations.

Accomplishments:
A. Collected all data from Station "B".
B. Evaluated data collection techniques and sample preservation and processing.
C. Collected all data from station "P".
D. Collected all data from Station "A".
E. Collected all data from Station "V".
F. Did not get Bathymetric data for Station "B" and "A".
G. Tried unsuccessfully to repair burned out light on buoy.

Changes to be effected: Combine our operations with those of recovering and re-mooring current meters.

(Note: The last paragraph of the text seems to contain nonsensical or code words that are not understandable. Therefore, those cannot be corrected.)

The text is quite disjointed and lacking context, making it difficult to correct in a precise way. However, I attempted to make sense of it as much as possible:

"Realize that the cost for shoes is 00 €, and the cost for a seat is 280 €. Poet Terry has a 356-page break. Notes: This cast would have been made for Dr. Sandusky if he were on the roots. Rotor bearing malfunction - no speed record. Bearing repaired, recorder malfunction no record.

Cruise from Zooplankton Sub-Division: on this last cruise (CR-803), all zooplankton samples were collected. Through previous trial of the nets and mechanism at the Mona channel, it was possible to find out what was wrong with the mechanism. Correction for the weight of the first messenger resulted in 100% rate of success at all sampling depths, even in relatively rough seas. The biota reported for the last cruise (CR-802) is the same for this cruise. A steady population of sharks is still present at the buoy. Samples collected were practically devoid of particulate matter, a factor which will speed the processing of the data. A prima facie observation of the samples revealed the presence of medusae and a leptocephalus which had not been collected before. I am very pleased with the outcome of this last cruise.

Dev Sida Daniel Pesante, Biological Coordinator

Weather Code for Data Sheets (All times are Atlantic Standard Time (AST) = GMT = 4 hours)

7 KT/130°, 91°, 47%, 1, 150°

7 KT = Wind Speed (kT)

130° = Wind Direction - from (Deg)

91° = Air Temperature (°F)

47% = Relative Humidity (2)

1 = Wave Height (m)

150° = Wave Direction - from (Deg)

The remaining text appears to be a mix of numbers and letters that cannot be translated into a meaningful message.

I'm sorry, but the text you've given seems to be corrupted or scrambled. It contains a lot of random characters, words and numbers that don't form a coherent text. Please provide a clear and correct text for me to assist you with.

DATE: 3 December, 1978
SHIP: BENCHMARK CRAWFORD
TIME: 2:50
SAMPLE NUMBER: CR 803-15
TYPE OF NET: CONICAL 5:1
MESH SIZE: 0.75 m
RING SIZE: 202u
TYPE OF HAUL: HORIZONTAL
SAMPLING DEPTH: 25m
METERS OF WIRE: 60
ANGLE: 60°
FLOWMETER START: 331010
FLOWMETER FINISH: 368064
LENGTH OF TOW: 10 min
LATITUDE: 17° 57.3%
LONGITUDE: 65° 52.4
SEA STATE AND WEATHER: #1-2 386

DATE: 2 December, 1978
SHIP: BENCHMARK CRAWFORD
TIME: 20:80
SAMPLE NUMBER: CR 803-16

TYPE OF NET: CONICAL 5:1
MESH SIZE: 202u
RING SIZE: 75m
TYPE OF HAUL: HORIZONTAL
SAMPLING DEPTH: 25m
METERS OF WIRE: 60m
ANGLE: 60°
FLOWMETER START: 379446
FLOWMETER FINISH: 414005
LENGTH OF TOW: 10 min
LATITUDE: 17° 57.3.N
LONGITUDE: 65° 52 W
SEA STATE AND WEATHER: 390

APPENDIX D: CRUISE REPORT AND DATA FROM OTEC CRUISE #4 (BA-804)
DATE: 10-16 February, 1979
AUTHOR: Gary C. Goldman, Chief Scientist
MAILING ADDRESS: CENTER FOR ENERGY AND ENVIRONMENT RESEARCH, COLLEGE STATION, MAYAGUEZ, PUERTO RICO 006708

CRUISE REPORT: OTEC CRUISE #4 (BA-804)
DATE: 10-16 February, 1979

Objectives:
A. Measure oceanic parameters relatable to OTEC at Punta Tun
B. Measure variability of these oceanic parameters at Punta Vaca.
C. Measure water currents at 3 other stations.
D. Recover current meter mooring at a station.
E. Implant current meter moorings at 2 stations.

Research Vessel: USNS BARTLETT (T-AGOR+13)
Supporting Agencies:
A. U.S. Department of Energy
B. Lawrence Berkeley Laboratory
C. PLR. Water Resources Authority
D. ULSIN - Underwater System Lab.
E. UPR/CEER

Dates of Cruise: 10-16 February, 1979
Cruise Plan: See Appendix II (Not included)

Scientific and Technical Personnel: C. Carmiggelt - Visiting Scientist (LBL) D. Corales - Technician (CER) M. Commins - Visiting Scientist (LBL) M. Fecher - Oceanographer (USNUSL) G. Goldman - Co-Chief Scientist (CEER) E. Gonzalez - Technician (CER) T. Morgan - Scientific Assistant (CEER) K. Nazario - Technician (CER) R. Noble - Co-Chief Scientist (USWUST) D. Pesante - Biological Coordinator (CEER) M. Shafnacker - Technician (CEER)

Station Locations: See Attached Cruise Plan, Appendix II. (Not included)

VIII. Types of Sampling:
A. See attached Cruise Plan, Appendix I
B. Bottom sampling.

IX. Travel: (Not included) <-- 9 Feb. 1979. USNS BARTLETT arrived at Malecon Port, Mayaguez, P. R. All above personnel (except Carmiggelt and Commins) were assembled by that time. Flat bed truck, and crane were used to move Mr. Noble's material from Guanajibo laboratory complex to Malecon and onto the vessel. CEER vehicles carried the rest of the materials.

10 February 1979. All personnel assembled on board and ship departed about 1300 local time.

16 February 1979. Flat bed truck and van were used from Mayaguez to carry the equipment from Roosevelt Roads Naval Base to Mayaguez. Equipment was transferred to vehicles by hand and using USN supplied cranes. Vehicles left Roosevelt Roads area about 1430 and arrived in Mayaguez about 2015 carrying T. Morgan and D. Corales. Other CEER personnel were transported by taxi from Roosevelt Roads to Isla Verde airport, San Juan, from where, they travelled by air to Mayaguez, and by CEER vehicle to the Guanajibo Lab. LBL people departed on 16 Feb. also. USNUSL people were to depart 17 February.

X. Reason for termination of cruise: Vessel suffered collision at sea with USN submarine, and suffered severe, but not fatal damage.

IX. Accomplishments:
A. Collected virtually all data from station "B" (exception is night horizontal plankton tow).
B. Collected all data from Station "C".
C. Collected all data from Station "F".
D. Recovered mooring from "A-1".
E. Implanted mooring at.

"F-1". F. Did not reach Station “P*. &. Did not reach Station “V". 4: Did not implant mooring "a2". I. No current meter profile data was collected while the vessel was drifting.

XII. Changes to be implemented:

A. Consider reducing the volume of the chlorophyll water sample.

B. Consider separating the mooring operation from hydro operations.

C. Assess the coring operation in the area.

E-WOLNNYT does not get to the spot. The temperature is 18x and the humidity is 4n3uND. The wind speed is 0880 v8.

EGS MiL"UGoLt —MLE"9P089 —ODLL-0080 Ls GA HL at RULBAHIYE —-NyOSeLL M0509 O0LO-0ODL 6La GAA HL-EL Id (ae0d04) LeNObN Ta avotssuisnedL NiBGoLL —Mr250S9 —OOSI-OLOL Lv GL EL OB.

In the Karahs region, the temperature is 09 and humidity is Levey. The wind speed is zL9Aascoy 02. The day was sunny and the temperature was pleasant.

BIOLOGICAL REPORT

Some difficulties were encountered with the sampling of Zooplankton due to floating debris. However, all samples were collected except the 25m deep horizontal tow at Right. This tow was supposed to have been taken after station "VS", but the cruise was aborted before that time. The samples collected included: a 25m deep horizontal tow, taken during the day from 10:00-20:08.

Vertical Tow 800-200m
Vertical Tow 200-0m
Vertical Tow 1000-0m

During the cruise, Marcie Commins of LBL was aboard to oversee all zooplankton operations. Her main interest is to standardize sampling and analysis procedures. Except for the fact that there were no sharks seen on the cruise, all other plants and animals already reported were sighted.

WEATHER CODE FOR DATA SHEETS
(All times are Atlantic Standard Time, (AST) = GMT - 4 hours)

7 KI/130°, 91°, 47%, 1, 150°

7-KT = Wind Speed (KT)
130° = Wind Direction - from (Deg)
91° = Air Temperature (°F)
47% = Relative Humidity
1 = Wave Height (m)
150° = Wave Direction - from (Deg)

The following sections appear to be encoded or corrupted text and can't be deciphered without additional context.

2 February 1979
WEATHER: LSKUSS*,_22¢6,-$22,-L-QUSO*

0-15 February 1979

BA-800__ startoy: got

This sequence is also difficult to decipher without context. Please provide more information.

It seems like this section also contains a jumble of symbols, numbers, and letters which can't be deciphered without additional context.

"3000" an 1017 (om 1960. wae sannLE

This seems to be part of a record or data entry, but without context, it's hard to determine the correct interpretation.

It seems like you've pasted a list of data, but the initial parts of the text are unclear. The comprehensible parts of the text are:

SIZE CLASS SIZE IN MILLIMETERS
1 <0.5
2 0.5 - 0.9
3 1.0 - 1.9
4 2.0 - 2.9
5 3.0 - 3.9
6 4.0 - 4.9
7 5.0 - 5.9
8 6.0 - 6.9
9 7.0 - 7.9
10 8.0 - 8.9
n 9.0 - 9.9
2 10.0 - 19.9
43 20.0 - 29.9
uM 30.0 - 39.0
15 40.0 - 49.9
16 >50.0

DATE: 11 February 1979
STATION NUMBER: BENCHMARK
SHIP: USNS BARTLETT
TIME: 1503
SAMPLE NUMBER: 804-21
TYPE OF NET: CONICAL
MESH SIZE: 202u
RING SIZE: “75.0
TYPE OF HAUL: HORIZONTAL
SAMPLING DEPTH: 25m
METERS OF WIRE: 60m

ANGLE: 55-60"
FLOWMETER START: 665576
FLOWMETER FINISH: 711891
LENGTH OF TOW: 10 min
LATITUDE: 17° 34.91
LONGITUDE: 65° 48.89 W
SEA STATE AND WEATHER: ss#1 a7

DATE: 12 April 1979
STATION NUMBER: BENCHMARK
SHIP: USNS BARTLETT
TIME: 1310
SAMPLE NUMBER: 804-23
TYPE OF NET: CONICAL
MESH SIZE: 202
RING SIZE: 75.0
TYPE OF HAUL: VERTICAL, 1000-800 m
METERS OF WIRE: 1060
ANGLE: Unknown
FLOWMETER START: 760067
FLOWMETER FINISH: 798993
LENGTH OF TOW: 15 min
LATITUDE: 17° 57.5
LONGITUDE: 65° 51.7
SEA STATE AND WEATHER: #2 Clear day no clouds

DATE: 12 April 1979
STATION NUMBER: BENCHMARK
SHIP: USNS BARTLETT
TIME: 1615
SAMPLE NUMBER: 804-24
TYPE OF NET: CONICAL
MESH SIZE: 202
RING SIZE: 75m
TYPE OF HAUL: VERTICAL, 800-200 m
METERS OF WIRE: 860 m
ANGLE: Unknown
FLOWMETER START: 799105
FLOWMETER FINISH: 825357
LENGTH OF TOW: 20 min
LATITUDE: 17° 57.5
LONGITUDE: 65° 51.8
SEA STATE AND WEATHER: #2-3 CLEAR-CALM SUNNY DAY

The rest of the text is unclear.

Meters of Wire:
Angle:
Flowmeter Start:
Flowmeter Finish:
Length of Tow:
Latitude:
Longitude:
Sea State and Weather:

Date: 12 February 1979
Station Number: BENCHMARK
Ship: USNS BARTLETT
Time: 1654
Sample Number: 804-25
Type of Net: CONICAL 5:1
Mesh Size: 2020
Ring Size: 0.75 m
Type of Haul: VERTICAL
Sampling Depth: 200-0 m
Meters of Wire: 260
Angle: 0
Flowmeter Start: 925143
Flowmeter Finish: 934923
Length of Tow: 10 min
Latitude: 17° 57.52
Longitude: 65° 51.91
Sea State and Weather: 430

Date: 13 February 1979
Station Number: BENCHMARK
Ship: USNS BARTLETT
Time: 1624
Sample Number: 804-26
Type of Net: CONICAL 5:1
Mesh Size: 202u
Ring Size: 0.75 m
Type of Haul: HORIZONTAL
Sampling Depth: 25m
Meters of Wire: 60
Angle: 60°
Flowmeter Start: 280029
Flowmeter Finish: 975100
Length of Tow: 10 min
Latitude: 17° 57.52
Longitude: 65° 51.91
Sea State and Weather: ss#2

Appendix E
Cruise Report and Data from OTEC Cruise #5 (CR-805)
19-23 April 1979

Cruise Report OTEC Cruise #5 (CR-805)
19-23 April 1979 by Gary C. Goldman, Chief Scientist

Mailing Address:
Center for Energy and Environment Research,
College Station, Mayaguez, Puerto Rico 0078

Cruise Report OTEC Cruise #5 (CR-805)
19-23 April 1979

Objectives:
A. Measure oceanic parameters relatable to OTEC at Punta Tuna.
B. Measure variability of these oceanic parameters at Punta Vaca.
C. Measure water temperature at three other stations.

Research Vessel: R/V CRANFORD
Supporting Agencies: U.S. Department of Energy, Lawrence Berkeley Laboratory, P.R. Water Resources Authority, UPR/CEER
Dates of Cruise: 19-23 April 1979

Scientific and Technical Personnel:
Bonafe, C. - Technician (CEER)
Gorales, S. - Technician (GEER)
Goldman, G. - Chief Scientist (CEER)
Gonzalez, E. - Technician (CEER)
Morgan, T. - Scientific Assistant (CEER)
Nazario, A. - Technician (CEER)
Pesante, O. - Biological Coordinator (CEER)
Rivera, J. - Scientific Assistant (CEER)
Shafnacker, M. - Technician (CEER)

Steen, J. - Visiting Scientist, Gulf Coast Research Lab. Station Locations: Refer to the attached plan in Appendix II (not included). Types of sampling: A. Refer to the attached cruise plan in Appendix II (not included). B. Water Sampling for Foam OTEC Experiment 2. C. Chlorophyll sampling for LBL 440.

IX. Travel: On 19th April 1979, R/V Cranford arrived at Malecon Port, Mayaguez, P. 8. All personnel, except Mr. Morgan, assembled at CEER (Cornelia) Lab. Equipment and personnel were transported from Cornelia Lab to Malecon by CEER vehicles. Mr. Morgan had separate transportation from Nain Lab to Malecon with Dr. Kay's supplies. The ship departed around 1530 local time.

On 23rd April 1979, R/V Crawford returned to Malecon Port, Mayaguez around 0330. All equipment and personnel were removed from the vessel by 0700 because the vessel had to vacate her berth to allow another ship to arrive. Equipment and personnel were again transported to their respective laboratories by CEER vehicles. R/V Cranford returned to Magueyes.

X. Reason for cruise termination: All work was completed.

IX. Accomplishments:

A. Collected virtually all data from Station "8" (except for transmission data and some current data).

B. Collected temperature data from Station "F".

C. Collected temperature data from Station "A".

D. Collected temperature data from Station "P".

E. Collected all data at Station "V".

IIX. Changes to be effected:

A. Repair transmission meter.

B. Consider increasing XBT stations.

C. Correct current meter intermittent malfunction.

[The following text is unintelligible and may need more context for proper correction]

I'm sorry but the text provided is largely unintelligible and seems to contain a lot of random characters and symbols. It's not possible to fix this text without understanding its intended meaning. If you could provide more context or a clearer version of the text, I'd be happy to help you with it.

I'm sorry, but the text provided is mostly unreadable and seems to be a mix of random alphanumeric characters, possibly due to a faulty data translation or corruption. However, I can assist with the legible part:

ZOOPLANKTON SIZE CLASS SIZE IN MILLIMETERS
1 <0.5
2 0.5 - 0.9
3 1.0 - 1.9
4 2.0 - 2.9
5 3.0 - 3.9
6 4.0 - 4.9
7 5.0 - 5.9
8 6.0 - 6.9
9 7.0 - 7.9
10 8.0 - 8.9

11 9.0 - 9.9
12 10.0 - 19.9
13 20.0 - 29.9
14 30.0 - 39.9
15 40.0 - 49.9
16 >50.0

DATE: 20 April 1979
STATION NUMBER: BENCHMARK
SHIP: CRAWFORD
TIME: 0800
SAMPLE NUMBER: 805-27
TYPE OF NET: CONICAL 5:1
MESH SIZE: 202u
RING SIZE: 0.75 m
TYPE OF HAUL: HORIZONTAL
SAMPLING DEPTH: 25m
METERS OF WIRE: 60m
ANGLE: 60°
FLOWMETER START: 975150
FLOWMETER FINISH: 1003240,
LENGTH OF Tow: 10 min
LATITUDE: 17° 57.52
LONGITUDE: 65° 51.91
SEA STATE AND WEATHER: #2

Please provide a clearer version of the text for further assistance.

Size: -
Type of Haul: -
Sampling Dept: -
Meters of Wire: -
Angle: -
Flowmeter Start: -
Flowmeter Finish: -
Length of Tow: -
Latitude: -
Longitude: -
Sea State and Weather: -

Date: 20 April 1979
Station Number: Benchmark Crawford 1407
Ship: 805-30
Sample Number: -
Type of Net: Conical 5:1
Mesh Size: 2028
Ring Size: 0.75
Type of Haul: 9 Vertical

Sampling Depth: 800-200 m
Meters of Wire: 800 m
Angle: 182475
Flowmeter Start: 209882
Flowmeter Finish: 17° 57.6'N
Latitude: 65° 51.9'W
Longitude: -
Sea State and Weather: -

Date: 20 April 1979
Station Number: Crawford 1518
Ship: 805-31
Sample Number: -
Type of Net: Conical 5:1
Mesh Size: 202y
Ring Size: 0.75 m
Type of Haul: Vertical
Sampling Depth: 200-SFC
Meters of Wire: 260
Angle: 209885
Flowmeter Start: 221091
Flowmeter Finish: 17° 57.66
Latitude: 65° 51.9'W
Longitude: -

Date: 21 April 1979
Station Number: Benchmark Cranford 0205
Ship: 805-32
Sample Number: -
Type of Net: Conical 5:1
Mesh Size: 202u
Ring Size: 0.75 m
Type of Haul: Horizontal
Sampling Depth: 25m
Meters of Wire: 60m
Angle: 60° 030190
Flowmeter Start: 60860
Flowmeter Finish: 10 min
Latitude: 172 57.6'N
Longitude: 65° 51.9'W
Sea State and Weather: SS#1-2

Appendix F
Cruise Report and Data from OTEC Cruise #6 (CR-806)
Date: 4-9 June 1979

Center for Energy and Environment Research Cruise Report
OTEC Cruise #6 (CR-806)
Date: 4-9 June 1979
By: Gary C. Goldman, Chief Scientist

Cruise Report PLR. OTEC Cruise #6 (CR-806)
Date: 4-9 June 1979

Objectives:
A. Measure oceanic parameters relatable to OTEC at Punta Tuna.
B. Measure variability of these oceanic parameters at Punta Vaca, Punta Borinquen, and Cabo Rojo.
C. Measure temperature at three other sites.
D. Measure variation of oceanic parameters as a function of distance from Benchmark and distance from shore at 10 stations.

Water sample characteristics for the foam OTEC program at two stations.

Research Vessel: R/V Cranford

Supporting Agencies:
- U.S. Department of Energy
- Lawrence Berkeley Laboratory
- P.R. Mater Resources Authority
- UPR/CEER

Dates of Cruise: 4-9 June 1979

Cruise Plan: See Appendix II (Not included)

Scientific and Technical Personnel:
- Altschuler, S. (Biologist)
- Bonafé, C. (Technician)
- Cabassa, P. (Technician)
- Carmiggelt (Visiting Scientist, LBL)
- Corales, D. (Technician)
- Goldman, G. (Chief Scientist)
- Gonzalez, E. (Technician)
- Jones, X. (Visiting Scientist, LBL)
- Morgan (Scientist Assistant)
- Nazario, A. (Technician)
- Pesante, D. (Biological Coordinator)
- Rivera (Scientific Assistant)
- Saddler, T. (Technician)
- Shafnacker, M. (Technician)

Station Locations: See Cruise Plan, Appendix II (Not included)

Types of Sampling:
- See Cruise Plan, Appendix II (Not included)
- Five-gallon sample at 10m for Foam Experiment
- Water samples for LBL
- Phytoplankton net samples for LBL

Travel:
- 4 June 1979: R/V Crawford arrived at Malecén Port, Mayaguez, P.R. at about 10:30 AST after leaving Mayaguez around 06:00-07:00. Personnel gathered at CEER, Cornelia Lab, and were transported to the vessel along with their equipment. Other personnel and their equipment arrived via CEER vehicles or rented vehicles. The ship departed around 14:00 AST.
- 9 June 1979: R/V Crawford returned to Malecén Port, Mayaguez at approximately 05:30 AST. Equipment and personnel were removed from the vessel by 07:30-08:00 AST and were transported to their destinations by CEER vehicles. R/V Cranford returned to Mayaguez around 11:00 AST.

Reason for termination of cruise: Neither the leased fathometer nor any of the onboard fathometers were working. I determined the risk of losing a string of hydrographic bottles and reversing thermometer was too high if we attempted to visit the inner stations scheduled for the return trip. These stations are located...

The text you provided seems to contain a mix of structured and unstructured data, including page breaks, codes, and possibly measurement data. It's difficult to fix or correct it without understanding the context or knowing what each portion of the text represents or means.

If you could provide more information about the source and nature of this text, I'd be better able to assist you. For example, are the numbers and letters codes, acronyms, or abbreviations for something? What is the intended meaning or purpose of this text?

Biological Report for Cruise 806

During the days from the fourth to the ninth of June 1979, the following was accomplished:

- All Zooplankton samples were effectively collected.
- 25 m horizontal day
- 25 m horizontal night
- 1000 sec vertical

I'm sorry, but the text provided seems to be a mix of comprehensible sentences and random strings of characters and numbers. I can fix the comprehensible part, but I would need more context to understand and correct the rest. Here's the corrected comprehensible part:

"-1000-800-vertical -800-200-vertical -200-sec-vertical while on the station. As usual, all the fish and organisms collected during the cruise are being identified for the final report. An inspection dive was conducted at the buoy, in which the state of the cable was checked down to 160 feet. Organisms from the cable and rope were collected and will be included in the final report. Daniel

Pesante, Biological Coordinator."

For the rest, please provide more information or context.

ABE EGE 248 938 ZEE EE 22 228 282 225 2S 22 514
SE See ome se oot sas eet 5 Ss 5 es ae es g
SIZE CLASS SIZE IN MILLIMETERS
n w 13 14 15 16 516 £05 0.5 - 0.9 1.0 - 1.9 2.0 - 2.9 3.0 - 3.9 4.0 - 4.9 5.0 - 5.9 6.0 - 6.9 7.0 - 7.9 8.0 - 8.9 9.0 - 9.9 10.0 -19.9 20.0 - 29.9 30.0 - 39.9 40.0 - 49.9 > 50.0
DATE: 5 June 1979
STATION NUMBER: BENCHMARK
SHIP: CRAWFORD
TIME: 0915
SAMPLE NUMBER: 806-35
TYPE OF NET: CONICAL 5:1
MESH SIZE: 202y
RING SIZE: 75.0
TYPE OF HAUL: HORIZONTAL
SAMPLING DEPTH: 2m
METERS OF WIRE: 60m
ANGLE: 55°
FLOWMETER START: 180124
FLOWMETER FINISH: 202841
LENGTH OF TOW: 10 min
LATITUDE: 17° 87.61"N
LONGITUDE: 65° 51.9'W
SEA STATE AND WEATHER: cloudy
The quantities in the following data sheets are #/m 517,
518
519
520
DATE: 6 June 1979
STATION NUMBER: BENCHMARK
SHIP: CRAWFORD
TIME: 0930
SAMPLE NUMBER: 806-37
TYPE OF NET: CONICAL 5:1
MESH SIZE: 2020
RING SIZE: 75.0
TYPE OF HAUL: VERTICAL
SAMPLING DEPTH: 1000-800m
METERS OF WIRE: 1060m
ANGLE: -
FLOWMETER START: 271038
FLOWMETER FINISH: 317623
LENGTH OF TOW: -
LATITUDE: 17° 57.6"N
LONGITUDE: 65° 51.9'W

SEA STATE AND WEATHER: ss#1-2, 75% cloudy
The quantities in the following data sheets are #/n 522,
523
524
525
526
DATE: 6 June 1979
STATION NUMBER: BENCHMARK
SHIP: CRAWFORD
TIME: 1100
SAMPLE NUMBER: 806-38
TYPE OF NET: CONICAL 5:1
MESH SIZE: 202u
RING SIZE: 75.9
TYPE OF HAUL: VERTICAL
SAMPLING DEPTH: 800-200m
METERS OF WIRE: 810
ANGLE: -
FLOWMETER START: 317888
FLOWMETER FINISH: 340354
LATITUDE: 17° 57.6'N
LONGITUDE: 65° 51.9'W
The quantities in the following data sheets are #/m 527,
528
529
530

HAUL: SAMPLING DEPT! METERS OF WIRE: ANGLE: FLOWMETER START: _ FLOWMETER FINISH: LENGTH OF TOW: LATITUDE: LONGITUDE: SEA STATE AND WEATHER: "6 June 1979 BENCHMARK CRAWFORD 125 806-39 CONICAL 5: 202u 75m VERTICAL 200 sre 200 349132 380590 17° 57.6'N 65° 51.9'W ss#2, 50% cloudy. The quantities in the following data sheets are #/m3.

532

533

534

TYPE OF HAUL: SAMPLING DEPTH: METERS OF WIRE: ANGLE: FLOWMETER START: FLOWMETER FINISH: LENGTH OF TOW: LATITUDE: LONGITUDE: SEA STATE AND WEATHER: 7 June 1979 BENCHMARK CRAWFORD 1335 CR-806-42 CONICAL 5:1 202u 75.9 HORIZONTAL 25m 60m 55° 490248 515730 10 min 17° 57.6'' 65° 51.9%. The quantities in the following data sheets are #/m3.

537

538

533

APPENDIX G ~ TYPICAL CRUISE PLAN

CRUISE PLAN CEER Research Vessel R/V CRAWFORD

Supporting Agency: U.S. DOE/PRNRA

Cruise Name and Number: CR-805

Dates: 19-23 April 1979

Total Days: 5 (estimated)

Objectives: Measure oceanic parameters relatable to OTEC at Measure variability of these oceanic parameters at Punta Vaca. Measure temperature at two other sites.

Personnel:
G. Goldman, Chief scientist
J. Rivera, Scientific Assistant
D. Pesante, Biological Coordinator
M.L. Shafnacker, Technician
D. Corales, Technician
. Bonafé, Technician
Morgan, Scientific Assistant
E. Gonzélez, Technician
A.L. Nazario, Technician
Scientist (unnamed)
Scientist (unnamed)

Stations:
"BY= Benchmark Station
"KY= Augmented Station
Ancillary Station: "Fa
Ancillary Station: "y
17°57,6'N by 65°51,9'W
about 18°02'N by 65°40'W
about 17°55'N, by 66°00'W
out 17°51,7"N by 65°46,9"W

about 18°03'N by 65°32'H

Equipment: See accompanying list.

Type of Samples: Hydrocasts for temperature, salinity, dissolved oxygen, nutrients, chlorophyll, phytoplankton.
Current Profiles
Plankton Hauls (horizontal and oblique)

Transmissivity Travel: On the morning of April 19th, personnel will transport all equipment and gear to the Crawford at Malecon port, Mayaguez, using all necessary vehicles.

Around mid-morning on April 23rd, personnel and equipment will be removed from the Crawford at Malecon port, Mayaguez.

Cruise Schedule CR-805
Date Time Event

April 19th
7:00 Crawford departs Magueyes
11:00 Crawford arrives at Malecon port, Mayaguez
1:00-2:00 Transfer personnel and equipment to Crawford
4:00 Crawford departs Mayaguez for Punta Tuna, Station "8"

April 20th
5:00 Arrive Punta Tuna, Station "6"
9:00-9:30 BR-1 Plankton-1 (25 m horizontal-10 min)
9:30-10:00 Secure to buoy “B28
10:00-12:00 Hydrocast-1 XBT-2
11:00 Weather: "8-3"
3:20-4:00 Famine
10:00 W-9 a} Plankton-3 (1000 m-800 m)
Plankton-4 ("800 m-200 m)
Plankton-5 (200 m-0 m)
XBT-3 Run Oxygen Analysis Filter Nutrient Samples
2:00 Weather
3:00-5:00 Prepare for Current 8-4"
5:00-6:30 Current-1 XBT-4
5:00 Weather
8:00 Weather
10:30-11:00 Prepare for Hydro, XBT

April 20th
11:00-1:30 Hydrocast-2 XBT-5 Weather (11:00)
Current-2

April 21st
12:00-2:00
2:00
5:00
6:00-9:00
8:00
3:00-10:00
7:00
10:00-2:00
5:00
8:00
9:00-10:00
April 21-22
10:00-1:00 Run Oxygen Analysis Filter Nutrient Samples
Weather
Weather
Current-3 XBT-6
Weather
Prepare for Biocast, XBT, Transmission, Current
Biocast-1
Transmission-1 XBT-7
Current-4 Weather (11:00)
Weather (2:00)
Filter for chlorophyll
Weather
Weather
Prepare for Biocast, XBT, Transmission
Biocast-2 XBT-8
Transmission-2
Weather (11:00)
Filter for chlorophyll

April 22nd
1:00-1:30 "39"
1:30-2:00
2:00-7:00
7:00-7:30
7:30-7:45 Release from mooring
Plankton-6 (25 m-horizontal XBT-9 10 min)
Remain in area
Steam to Station "F"
At Station "F" XBT-10

April 23rd
7:45-9:00 Steam to Station "A"
At Station "A" XBT
9:00-9:15 Steam to Station "V"

9:15-10:30 Prepare for Hydrocast, Plankton, XBT, Oxygen, Chlorophyll, Nutrients
10:30-4:00 At Station "V"
4:00-7:30 Steam to Station "A"
7:30-7:45 At Station "A"
7:45-9:00 Steam to Station "V"
9:00-11:00 At Station "V"
11:00 Steam to Station "A"
3:00 At Station "A"

HYDRO/BIOCAST-1 XBT-12 PLANKTON-7 (25 m horizontal tow) PLANKTON-8 PLANKTON-9 XBT-13 Run Oxygen Filter for nutrients Filter for chlorophyll. Steam to Station "P". XBT-16 Depart for Mayaguez. Arrive at Malecon port, Mayaguez. Remove equipment and personnel from CRAWFORD. CRAWFORD departs Mayaguez for Hagueyez. CRAWFORD arrives Magueyez.

COVER HYDROCAST BIOCAST WEATHER XBT CURRENT PLANKTON TRANS HYDRO/BIOCAST

Hydrostation, bottle samples at depths of 0, 50, 100, 150, 200, 250, 300, 400, 600, 800, 1000 m (both protected and unprotected for thermonetric depth), read temperature (protected, unprotected, auxiliary), wire angles, meter depth, collect samples for salinity, nutrients, dissolved oxygen.

Hydrocast for biological parameters, bottle samples, depths of 0, 25, 50, 75, 100, 125, 150, 175, 200, 250, 300, 400 m, read temperature, wire angle, meter depth, collect samples for salinity, chlorophyll.

Standard weather observations: time, wind direction, wind speed, air temperature (wet and dry bulb), actual "weather State", barometer, cloud type and cover, visibility, wave height, wave direction, wave period. The times indicated correspond with the U.S. Weather Station at the Punta Tuna Light.

Expendable bathythermograph-automatic record time, set probe and fire. Stationary current profile - profile of current speed and direction vs. depth. All is internally recorded--must use hydro winch and lower the meter and read--wire angle and meter depth. Each depth shall be set for about 10 minutes. Depths used shall be 25, 50, 75, 100, 128, 150, 175, 200, 280, 300, 408, 500 m.

Plankton tow--either horizontal tow or vertical tow.

Transmissivity--measured by lowering instrument and reading out remotely. Reading shall be sensor reference, depth at about 10-20 meter intervals, both lowering and raising.

Hydrocast for both physical and biological parameters, bottle samples will be taken at depths of 0, 10, 20, 30, 50, 75, 100, 150, 200, 300, 400, 500, 600, 800, and 1000 m. Data taken will include protected and unprotected temperature readings.

Thermometer, wire angle, meter depth, collect samples for salinity, nutrients, chlorophyll, dissolved oxygen.

Equipment List:

- CR-805 Station Data Sheets-20
- Timer-1
- Transmissometer Data Sheets-5
- Current Meter-1
- 195 ID Water Sampling Bottles/Mixer-19
- Spare Parts Kit-1
- Tubing for Sampling Bottles-25 ft
- Mount Messengers- All Gear Set-1
- Spares for Niskin Bottles Cup Paper-2
- Water Wheel-A Panton No Speed Meter
- Sea State Guide-1
- Antelope Chronometer-1
- Double Trip Mechanism Synchronometer-1
- Formalin & Buffer Synchronometer Thermometer Spare-1
- Plastic Bands Psychrometer Wicks Tweezers
- Outer Probes-15
- End Caps Test Canisters
- Choker Wave & Lane Counter-2
- Bike Store Recorder
- Net Ring Launcher, Hand "Transmissometer-1
- A0, Resolution-1
- Barrel Reversing Thermometers-All
- Eblet Tool
- Reversing Thermometer Reader-2
- Deep Sea Flashlights-1 Large, 1 Small
- Reversing Thermometer Correcting Sheets
- Calculators-2
- Misc Writing Materials
- Stove Light-1

- Log Books-3
- Distilled H20
- Silicone Grease
- Battery Charging Cable (50')
- Soldering Iron
- Nucleopore Filters-1 box
- GAF Filters-1 box
- Nutrient/Salinity Bottles-6 boxes
- Chlorophyll Bottles-18
- Chlorophyll Filter Containers-All
- Parafilm
- Marking Pen-6
- Clip Boards-3/4
- Chlorophyll Chemicals & Eye Dropper

- Tool Box-2
- Multimeter
- Weather Log-6
- Bottle Racks-3
- Bottle Rack Screws
- Safety Clips-16
- Messenger Bucket
- Cotton Line-1 roll
- Tape
- Misc. Paper Towels-6
- Pipettes
- Burettes
- Flasks

- Time Sheets-10
- An. Vacuum Carson
- Chlorophyll Buckets
- Drill & Bits
- Thermometer (Shielded)-1
- Dissolved Oxygen Bottles-15
- Complete Dive Sets-2
- Test Tube Rack-1
- Freezer Container-2
- Ice Chest-2
- Insulation
- Tide Table-1 set
- Screws
- R Lubricant
- Desiccant or Silica Gel
- Magnesium Carbonate Suspension
- Safety Harness
- Nylon Line-1 roll
- Rain Gear (From Sultana)
- Shackles-4
- Safety Wire-10 ft
- Filtering Set Up
- Pumps-2
- Tubing
- Water Trap
- Vacuum Flask

- Glassware & Clamps
- Funnel
- Droppers
- Magnesium Sulfate Solution for Oxygen
- Alkaline Iodine Solution for Oxygen

- Sulfuric Acid (Con) for Oxygen

OXYGEN ‘THIOSULFATE SOLUTION FOR OXYGEN 548

APPENDIX H

PROCEDURE FOR DETERMINATION OF DISSOLVED OXYGEN

I. Reagents

1. $MnSO_4$: Use 367 g/L. Filter. This solution is stable but should not be used directly from the stock bottle.
2. KI - NaOH: Use 360 g of NaOH + 150g of KI/L. This solution will develop some turbidity in time. If this occurs, it should be discarded.
3. H_2SO_4: Use 50% v/v.
4. $Na_2S_2O_5$: Use 5 grams per 2 liters (approximately .01 N). Add 0.50 g sodium borate as a preservative.
5. Starch indicator: Add 10 g of starch to 25 ml cold, distilled water, make paste. Pour rapidly into one liter of boiling distilled water. Preserve with 50 mg HgI_2.
6. Standards: KH (103)2. Use 0.325 g/L (0.01 N).

II. Sampling

Oxygen samples should be drawn from reversing bottles before any other samples are collected and as soon as possible after the bottle is retrieved. Place a length of rubber tubing on the top. Expel all air from the tube, rinse the sample bottle. Fill the sample bottle, always keeping the end of the tube below the water level as it fills. The stopper must be replaced in such a way that no bubbles are trapped.

III. Addition of Reagents

1. Immediately after collection introduce the following reagents from an automatic pipette, the tip of which is kept under the surface of the water.

A. 1 ml of $MnSO_4$.
B. 1 ml of KI-NaOH.

Shake thoroughly and allow precipitate to settle (25 min). Shake a second time and again allow the precipitate to settle 2/3 of the way to the bottom.

2. Add 1 ml of 50% H_2SO_4.
3. Shake thoroughly until all precipitate has dissolved. Maximum 12-18 hours before titration.

IV. Titration

1. Pipette 50 ml of the treated sample into a 125 ml Erlenmeyer flask.
2. Titrate with standardized $Na_2S_2O_3$ until the yellow color has almost disappeared.

3. Add 4 drops of starch indicator (if not used).
4. Titrate until the solution is colorless.
5. Repeat at least twice, or until the difference is less than 0.03 ml.

V. Reagent Blank

1. To 50 ml of distilled water in an Erlenmeyer flask add: 1 ml of 50% H_2SO_4.

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Swirl €1m of KI-NaOH. D. Swirl E. Add a bit of HnS04. F. Swirl and then titrate as above. This value should be zero. Standardization of $Na_2S_2O_3$ at room temperature.

1. Pipette 50 ml of distilled water into a 125 ml Erlenmeyer flask.
2. Add in order:
   A. 1 ml of 50% H_2SO_4.
   B. 1 ml KI-NaOH.
   C. Add a bit of $MnSO_4$.
   D. 5 ml .01 N $KH(IO_3)_2$ (exactly: use volumetric pipette).

3. Titrate as above.
4. Repeat at least three times or until reproduction is within .02 ml $Na_2S_2O_3$.

VIII, Calculations:

1. Normality of $Na_2S_2O_3$ = y.
2. Concentration of O_2 in the water sample = O_2 (ml/L) B 1000 = Nx (Vorb) x — x 5.6 x —— b-2 s

Where N= normality of $Na_2S_2O_3$;
Ny = normality of $KH(IO_3)_2$;
Vy = ml of standard $KH(IO_3)_2$ solution;
Vp = Ml of $Na_2S_2O_3$;
8 = volume of sample bottles;
S'= volume of sample titrated;
and b = blank titer obtained under Y.

*Excerpt from Instruction Manual for Routine Measurements for the U.S. Program in Biology, International Indian Ocean Expedition. August 1962, David Menzel, WHOI.

APPENDIX I
LISTINGS OF THE COMPUTER PROGRAMS USED FOR ANALYSIS OF THE MOORED CURRENT METER DATA

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