CEER - 51

A HISTORICAL REVIEW OF THE PHYSICAL AND BIOLOGICAL CHARACTERISTICS OF THE OCEAN NEAR PUERTO RICO, RELATIVE TO AN OTEC POWER PLANT

by

M. L. HERNANDEZ AVILA, J. A. SUAREZ CAABRO AND GARY C. GOLDMAN

REPORT FOR WORK SUPPORTED BY U.S. DEPARTMENT OF ENERGY THROUGH
LAWRENCE BERKELEY LABORATORY, PROJECT NUMBER 4983802

Gary C. Goldman, Principal Investigator
Center for Energy and Environment Research
University of Puerto Rico
College Station
Mayaguez, Puerto Rico 00708

August 1979

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CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
UNIVERSITY OF PUERTO RICO — U.S. DEPARTMENT OF ENERGY

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EXECUTIVE STATEMENT

As Puerto Rico is considered among the prime locations for operating OTEC plants, the U.S. Department of Energy is looking at the oceanographic conditions around the island. The OTEC criteria apply to more than one location around the island, and although this report covers the general characteristics of the waters around Puerto Rico, the primary emphasis is on the Punta Tuna area, on the southeast of the main island.

This document is in response to a portion of a 4-phase project designed to secure and evaluate oceanic physical and biological data at the Punta Tuna site. The phases provide for:

1. The compilation of a yearly set of periodically sampled oceanic data at the benchmark site of Punta Tuna.
2. An interpretation of the relevant literature, recently procured data, and long-term current meter data taken concomitant to this program.
3. A thorough historical literature and data search of oceanic data and an interpretation thereof.
4. Recommendations for future studies of the OTEC oceanographic program.

This document addressess the last two phases of the project.

One of these two phases consists of two major requirements: an historical literature search and a historical data search. The literature search has provided two full bibliographies. Each of these bibliographies appears as a separate appendix in this report, one dealing with the physical oceanography, and the other with biological citations. The data search has reaffirmed to us the fact that this area of the world's oceans has not been sufficiently studied to statistically say, with any certainty, what the year-to-year and month-to-month variations in most of the physical parameters might be, let alone the short-term variations. We can only begin to identify some trends in most cases (i.e., surface temperature, thermal resource, subsurface temperatures, and salinity). The historical record of deep water motion studies in the area is sparse indeed, as are biological descriptions of the area.

The other phase of the project consists of recommendations for future oceanographic studies. These recommendations are based on both the present understanding of the OTEC concept, and our understanding of the oceanic conditions in the area.

The other two appendices at the end of the report contain pertinent supplimental information. One of these appendices discusses the near shore currents along the south coast, and the other has temperature vs. depth profiles from the historical data sets of the area.

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ACKNOWLEDGEMENTS

The authors wish to acknowledge and thank the followin persons for helping us produce this report. Mrs. Mary Jane Vakili helped with much of the editing. Miss Carmen Pabón, Mrs. Veda Medina de Seda, and Mrs. Elba Cardona all helped us with the typing and transcribing of the various drafts a the final manuscript. Mrs. Evangeline Fradera de Hernández and Alexis Lugo Fernández helped to produce the physical oceanography section. To these people, and all the others not mentioned, we say thank you for the fine job.

1.0. INTRODUCTION

Puerto Rico is now considered by the U.S. Department of Energy as being among the prime locations for the placement of one of the first operating Ocean Thermal Energy Conversion (OTEC) power generating plants. The specific area of Puerto Rico that is being considered lies about two miles southeast of Punta Tuna, a point on the southeast of the main island. This site is close to deep, cold water, has year-round warm surface water, is reasonably available by air and surface transportation, and could be easily incorporated into the island-wide electrical power grid. These criteria also apply to many locations around the island. This report covers the general characteristics of the waters around Puerto Rico, but the primary emphasis in the report is placed on the Punta Tuna area.

The intent of this document is to gather and interpret the available information, both published and unpublished, that will enhance the knowledge of the physical and biological oceanography of the area. We have also developed two extensive bibliographies, one of the pertinent physical oceanography, and one of the pertinent biological oceanography. Finally, after a review of the historical results and the fiscal 1979 data collection program, recommendations are made for increasing the effectiveness of the future OTEC field data collection program.

2.0. PHYSICAL OCEANOGRAPHY

2.1. INTRODUCTION TO PHYSICAL OCEANOGRAPHY

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, U.S.A. to Venezuela, South America (see Fig. 1). Puerto Rico is approximately half way along the Chain, about 1700 km from Miami, Florida. The nearest large land mass to Puerto Rico is the island of Hispañola, about 130 km to the west. The Chain can be considered the separation between the Atlantic Ocean and the Caribbean Sea. As Puerto Rico is situated along an east-west axis, the Atlantic washes its north coast, and the Caribbean, its south coast. At the 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, about 180 km east to west, and about 60 km north to south. The island is a mixture of mountains, rolling hills, and broad flat plains. Where the plains meet the sea, the climate is typically tropical marine (except along the desert-like southwestern coast).

This literature review of the physical oceanographic conditions at the proposed Punta Tuna OTEC Site in Puerto Rico will be restricted to the following parameters:

1. Climate
2. Wind regime (including hurricanes)
3. Waves regime
4. Oceanic and island shelf currents
5. Salinity and temperature depth distribution

Two distinct seasons appear to emerge in the literature, as seen from the standpoint of the hydrographic conditions of the surface waters along the south coast of Puerto Rico. This assertion is based mainly on climatological processes, in particular the wind system, generate the water circulation patterns (currents) in the upper waters, which affect and modify the distribution of mass as determined by the distribution of temperature and salinity. The available climatic and sea-state observations along the continental shelf of the South Coast are sufficient to indicate a winter trend and a summer trend. The hydrographic data, although sparse and probably insufficient, also reveal

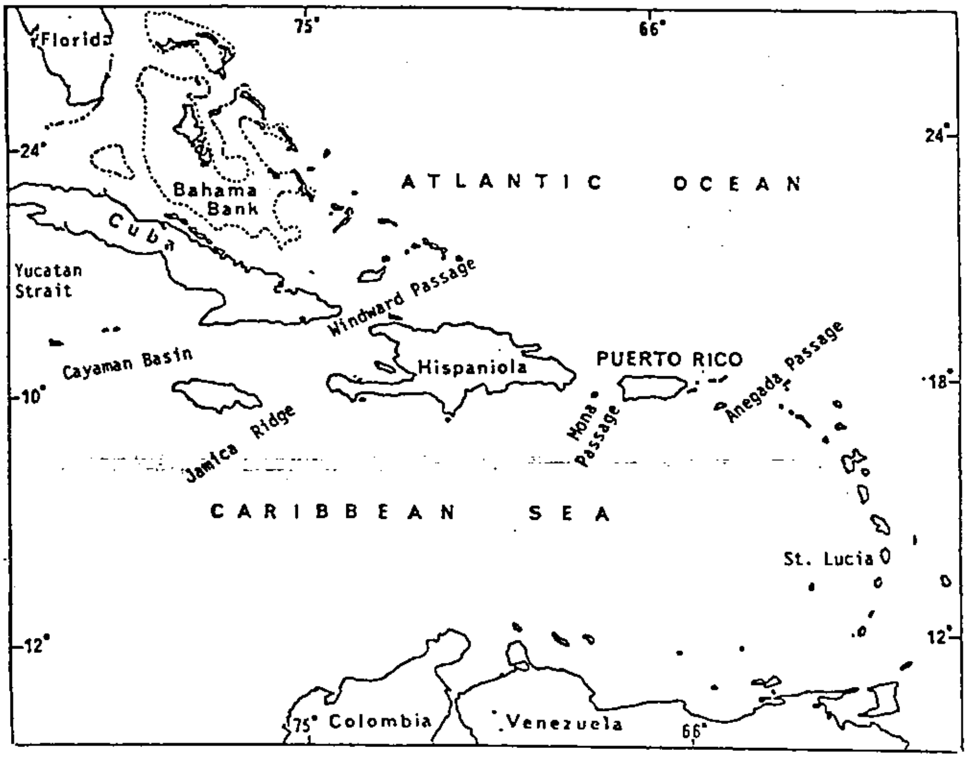


Figure 1. Map of the Caribbean

significant seasonal variations during the winter and summer months. These winter-summer variations are demonstrated by the existing reports and regional environmental data summaries to be discussed within this report.

Deep water circulation at the Punta Tuna OTEC site needs to be monitored for longer periods of time; the available data are insufficient to characterize the current variations in the area (Webster, 1969).

2.2. CLIMATE

In general, the climate of Puerto Rico is typically tropical marine. That is, during the day as the land mass heats up, a convection cell is developed, causing the winds to move landward from the sea, bringing the moist sea air with them. 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 causes considerable rainfall, almost daily over some parts of the island.

The Punta Tuna OTEC site, typical of much of the island, also has a tropical marine climate. Using data from the U.S. Weather Service Command (1974) and the U.S. Air Weather Service, general meteorological statistics can be developed.

In summary, the meteorological conditions are as follows:

For the north coast area (Fig. 2) there is no summer and winter, but simply a change from wet season to a somewhat drier season. Air temperatures vary within a mean daily range of 10 to 15 Fahrenheit degrees, fluctuating between the low 70's and the low 80's from December through April and between the mid 70's and the upper 80's from May through November. The lowest value recorded at San Juan Airport was 60.1°F.

Prolonged intervals of either sunny, cloudless weather or completely overcast weather are unusual. The common condition is partly cloudy, in which the cumuli occupy between 40 to 60 percent of the sky. Relative humidities are high during the entire year, usually ranging between 65 and 85 percent. Only rarely does the relative humidity drop below 50 percent. Dense fog is seldom seen. Squalls and thunderstorms are common from May through November.

Although the U.S. Coast Guard has maintained a light station at Punta Tuna for many years, no statistical compilation has ever been made of the weather data observed at that station. Statistics do exist for San Juan, about 40 km

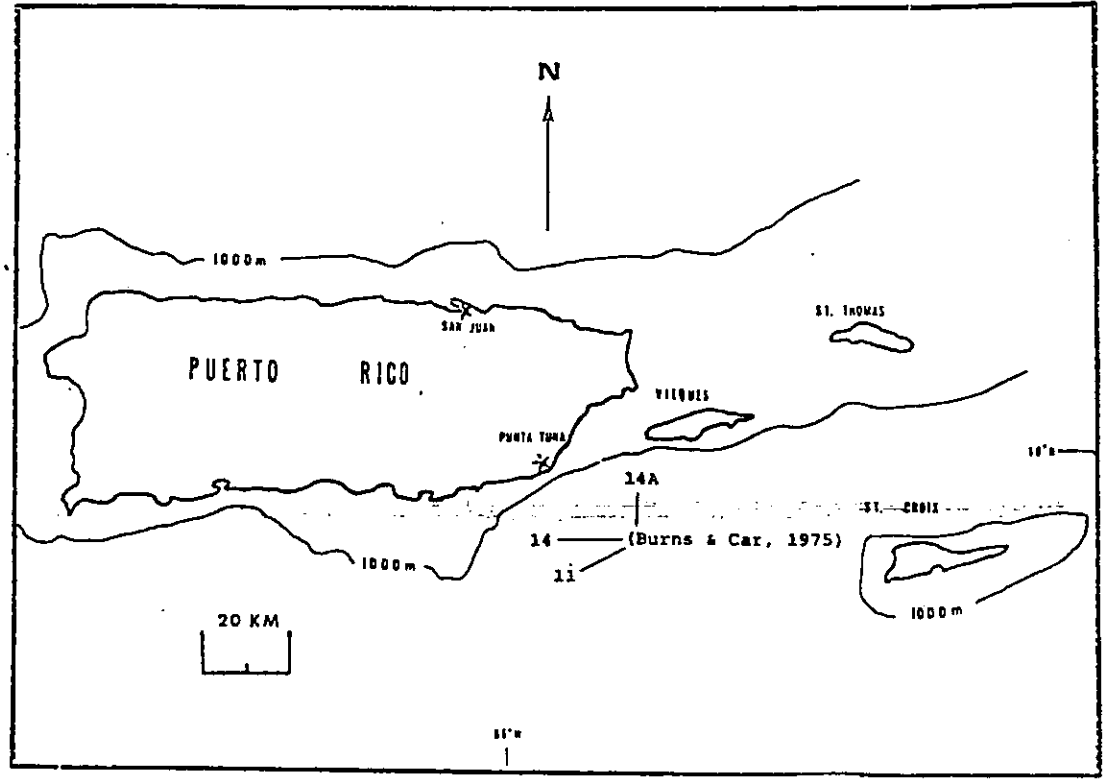


Figure 2. - Puerto Rico and Vicinity

northwest of Punta Tuna. Some of these values are shown in Table 1. The thirty-year (normal) values of temperature and rainfall, as well as the 23-year (normal) values of relative humidity, are seen in the table as a function of month. Values from Punta Tuna would probably be similar to these.

For tropical marine areas, atmospheric pressure changes are normally very small. Changes of 5 mm of mercury (0.2 inches) over a couple of months is rare. However, the proximity of severe tropical weather, such as tropical depressions, waves, storms, or hurricanes, could cause large drops in the atmospheric pressure. These pressure changes, in turn, are instrumental in controlling the local sea level. As the sea level is changed by such pressure disturbances, deep water is brought up toward, and in some cases, to, the surface. This could bring cooler, more dense water to the surface, which could seriously affect the operation of an OTEC plant. Table 2 shows the expected minimum pressures as a function of frequency in years to return again.

Figures 3 and 4 are reproduced from (Atwood, et al. 1976). Figure 3 shows graphically the monthly maximum, minimum, and mean air temperature for the oceanic area south of Puerto Rico. The data indicate that the maximum temperatures usually occur in late summer, and the cooler temperatures occur in late winter. The monthly mean temperature seems to vary only a couple of Fahrenheit degrees above or below 80°F. The maximum range of values ever expected would be only ±10 F° from the mean.

Figure 4 shows the frequency of occurrence of values of relative humidity for the same oceanic region south of Puerto Rico. About 85% of the time the relative humidity is above 70%.

Table 3 summarizes the meteorological and climatic factors for the Caribbean Sea, as taken from Publication H.O. 21, U.S. Dept. of Commerce (1958). The summary indicates there are very small pressure variations throughout the year, and relatively higher temperature and precipitation in the summer and autumn months.

2.3. TIDES

The tides on the Caribbean coasts of Puerto Rico are generally of the mixed diurnal type, with a small semi-diurnal component. An amphidromic (nodal) point of the principal lunar semidiurnal (M_2) tidal constituent lies near the site (Atwood et al., 1976; Dietrich, 1963; Defant, 1961). The nearness to the node implies minimal tidal motion. In addition, as Punta Tuna is on the somewhat exposed eastern side of the island, the tidal system affecting the North Atlantic

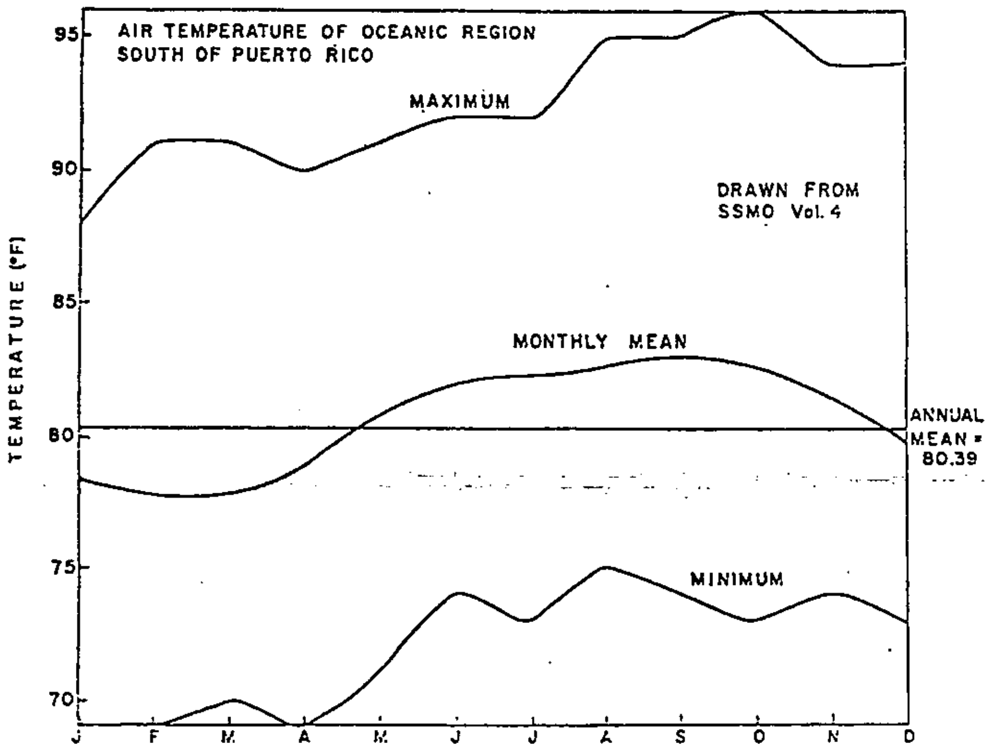
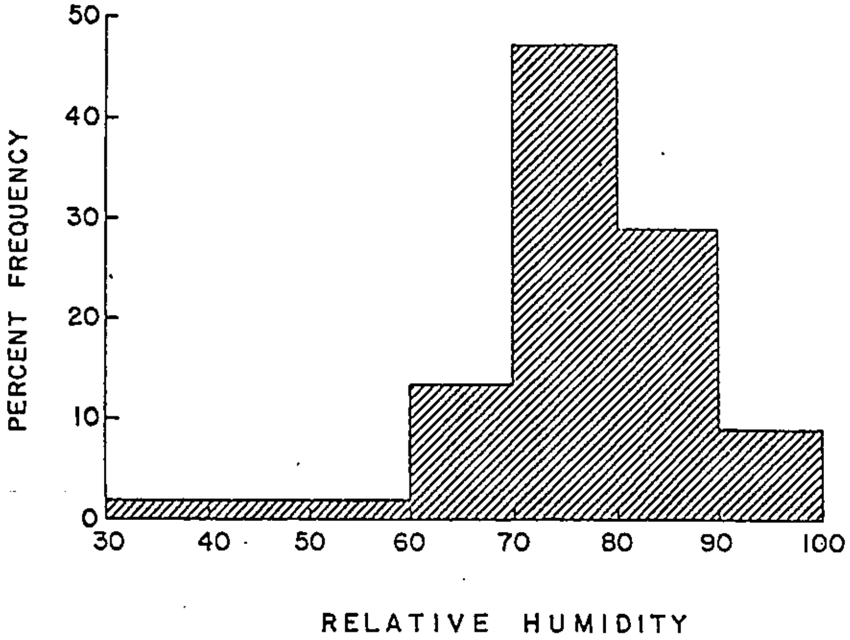


Fig. 3. (after Atwood, et. al. 1976).



DISTRIBUTION OF RELATIVE HUMIDITY—OCEANIC
REGION SOUTH OF PUERTO RICO.....Dwn. from SSMO,vol.4

Fig. 4. (from Atwood, et. al. 1976).

Table 1. Monthly Temperature (30 year normal), Rainfall (30 year normal), and Relative Humidity (23 year record) in San Juan, Puerto Rico.*

Month	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann
Temperature (°F)	74.5	74.3	75.4	76.6	78.9	79.9	80.4	80.8	80.6	80.1	78.3	76.3	78
Relative Humidity (%)	76	74	74	74	77	78	78	78	79	79	78	77	77
Rainfall (inches)	4.69	2.87	2.21	3.70	7.13	5.67	6.26	7.13	6.77	5.83	6.46	5.47	5.3

*Data Source: U.S. Weather Bureau

Table 2. Minimum atmospheric pressure due to tropical storm and hurricane as a function of return period in the general study area.*

Return period (years)	2	5	10	20	50	100
Pressure (mb)	998.12	968.18	976.14	965.50	948.43	934.55
Pressure (inc. Hg)	29.48	29.12	28.83	28.50	28.01	27.60

*Data Source: U.S. Air Weather Service

Table 3. Climatic Factor Statistics for the Caribbean Sea (from H.O. 21, U.S. Dept. of Comm. 1958).

Months		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Pressure Sea level pressure (Millibars)	¼ of obs. ≦ Median ¼ of obs. ≧	1011 1012 1014	1012 1013 1015	1012 1013 1015	1011 1012 1013	1011 1012 1013	1012 1012 1014	1012 1013 1014	1011 1012 1013	1010 1011 1012	1010 1011 1012	1010 1011 1012	1011 1012 1013
Temperature, air (° F.)	¼ of obs. ≦ Median ¼ of obs. ≧	77 78 80	76 77 78	77 78 79	78 79 80	79 81 82	80 81 82	80 81 82	81 82 83	81 82 83	81 82 83	80 81 82	78 80 81
Temperature, mean sea surface (° F.)		80	79	79	80	81	82	82	83	84	83	81	81
Precipitation: Percent of observations with precipitation		11	5	4	4	4	8	8	8	11	9	8	7
Cloudiness: Percent of observations with	≦ [illegible] cover ≦ [illegible] cover ≦ [illegible] cover	43 77 93	50 73 92	52 79 93	42 71 92	41 63 85	31 62 83	34 63 84	41 70 89	40 67 89	41 72 90	52 70 90	49 77 89
Visibility: Percent of observations	< 2 miles < 5 miles	1 2	1 2	1 2	1 2	1 2	1 2	1 2	1 2	1 2	0 1	0 1	1 2

Median—Half the observations fall below and half above this point.
≦ Equal to or less than.
≧ Equal to or more than.
< less than.

(with its amphidromic east of Newfoundland) may also affect our site. The result could be a moderately confused tidal current over our area of interest. Figure 5, reproduced from Atwood et al. (1976), shows the predicted tides as taken from the U.S. Department of Commerce Tide Tables (1973) for Puerto de Maunabo, Puerto Rico. This listed station is only about 0.5 km west of Punta Tuna. The figure illustrates the maximum (spring) typical tidal range (about 55 cm) which coincides with a new moon stage and summer solstice.

The tidal currents in the Punta Tuna area are expected to move generally east and west. The tidal current is expected to move westerly during the flood tide, and easterly during the ebb tide. The actual result of this tidal motion on the prevailing water motion at Punta Tuna is still unknown.

2.4 WIND REGIME

The periodicity and overall stability of the wind regime and atmospheric pressure variations along the north coast of Puerto Rico, being under the influence of the Trade Wind system, are documented for all to see. This is illustrated in Tables 4 and 5, taken from the U.S. Coastal Pilot, Area 5 (U.S. Dept. of Commerce, 1976), and from the U.S. Naval Weather Service Command (1974), respectively. Table 4 shows the summary of weather data observed at the San Juan airport. The results are similar to, but not the same as, the oceanic conditions along the south coast. Table 5 summarizes the wind observations at Vieques, the large island east of the main island (Fig. 2).

The U.S. Coastal Pilot, Area 5 (U.S. Dept. of Commerce, 1976), summarizes the wind regime on the coasts of the island as follows:

> "The previaling winds over Puerto Rico are the E trades, which generally blow fresh during the day. The center of the Bermuda High shifts a little N in summer and S in winter changing the direction of the winds over that island from NNE in winter to E in summer.
>
> Factors which interrupt the trade wind flow are frontal and E wave passages. As the cold front approaches, the wind shifts to a more S direction, and then as the front passes there is a gradual shift through the SW and NW quadrants back to NE. The E wave passage normally does not bring a W wind but is usually characterized by an ENE wind ahead of the wave and a change to ESE following the passage.

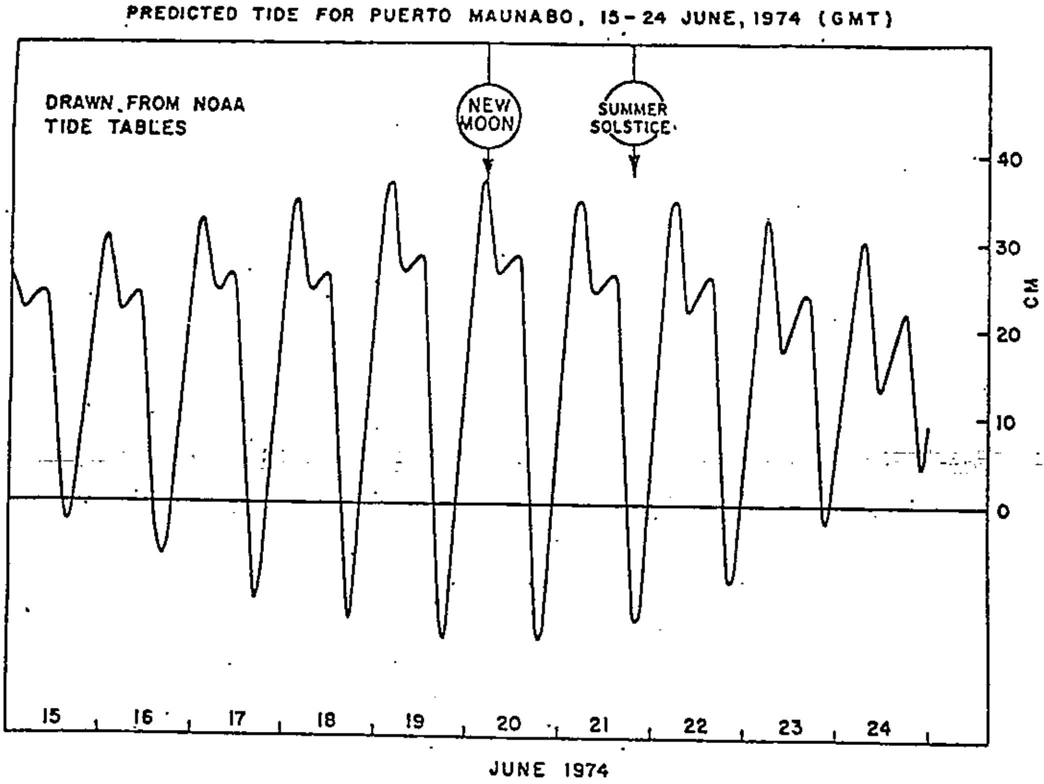


Figure 5. (from Atwood, et. al. 1976).

Table 4

WEATHER DATA FOR SAN JUAN, PUERTO RICO,
(from the U.S. Coastal Pilot, 9th ed., 1976, U.S. Dept. of Comm.).

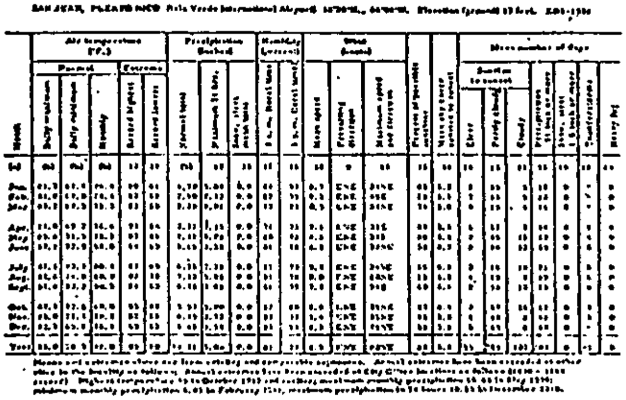


Table 5. Wind data at Vieques, Puerto Rico
(from the U.S. Naval Weather Service Command, 1974).

ANNUAL

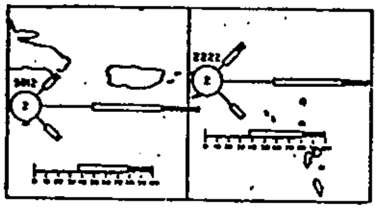
PERIOD: (PRIMARY) 1943-1973
(OVER-ALL) 1863-1973

AREA 0023 VIEQUES
18.2N 65.3W

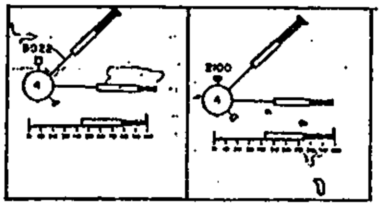
PERCENTAGE FREQUENCY OF WIND SPEED BY HOUR

WIND SPEED (KNOTS)

HOUR	CALM	1-3	4-10	11-21	22-33	34-47	48+	MEAN	PCT FREQ	TOTAL OBS
2000-2300	1.2	7.6	33.7	53.1	4.4	*	.0	11.8	100.0	4241
0200-0500	1.1	2.8	34.3	56.7	4.9	.1	.0	12.6	100.0	3719
0800-1100	.9	9.2	33.2	51.9	4.8	*	.0	11.7	100.0	5088
1400-1700	.7	2.3	30.1	62.5	4.3	.0	.0	13.0	100.0	4248
TOT								12.2		17296
PCT	.9	6.0	32.8	55.7	4.6	*	.0		100.0	



JUNE



DECEMBER

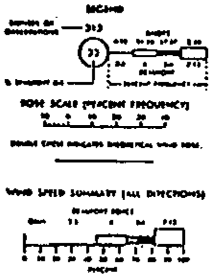
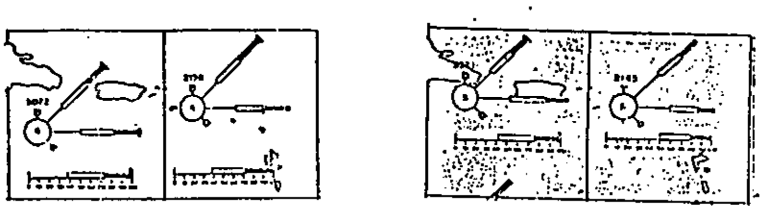


Fig. 6. Summary of winter-summer wind data (from U.S. Naval Oceanographic Atlas of the North Atlantic Ocean, Section IV, 1970).



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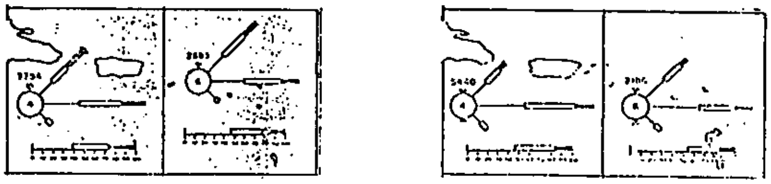

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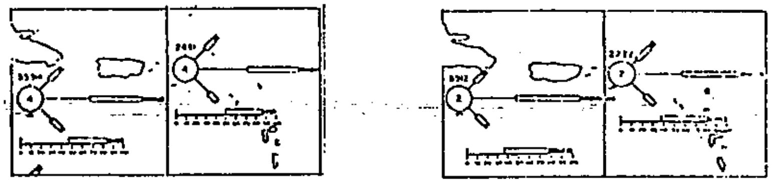

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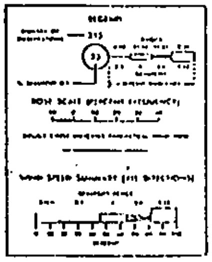
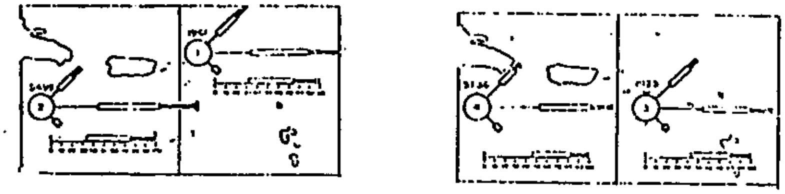
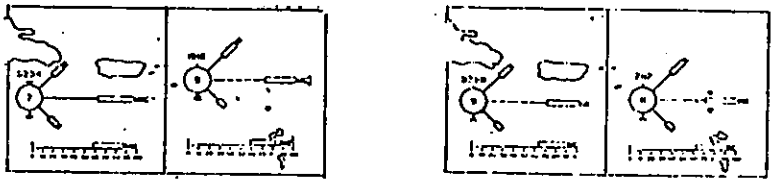


Fig. 7. Monthly wind roses for the Caribbean Sea (from USNOO, Sec IV, 1970, Pub. 700).



JULY

AUGUST



SEPTEMBER

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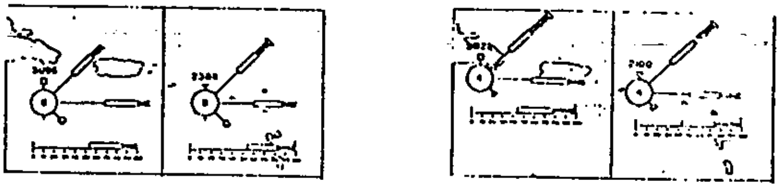

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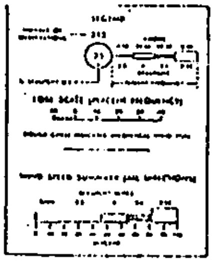


Fig. 7. (cont.) Monthly wind roses for the Carribean Sea (from USNOO, Sec. IV, 1970, Pub. 700).

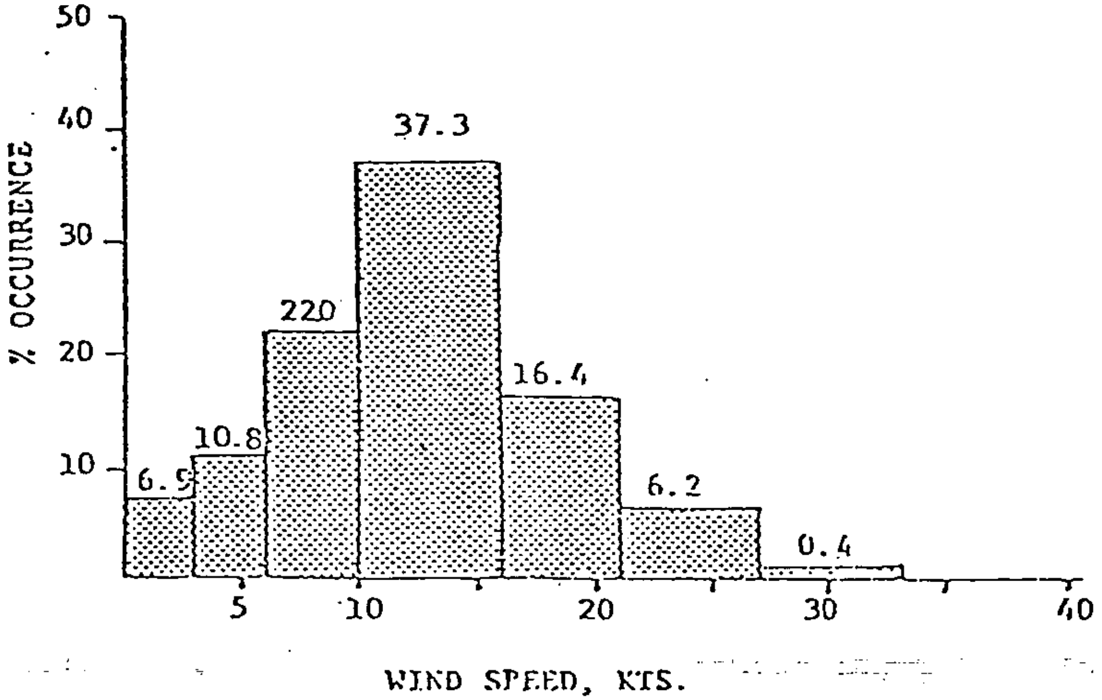


Figure 8. Annual frequency distribution of wind speeds in the area of Vieques.

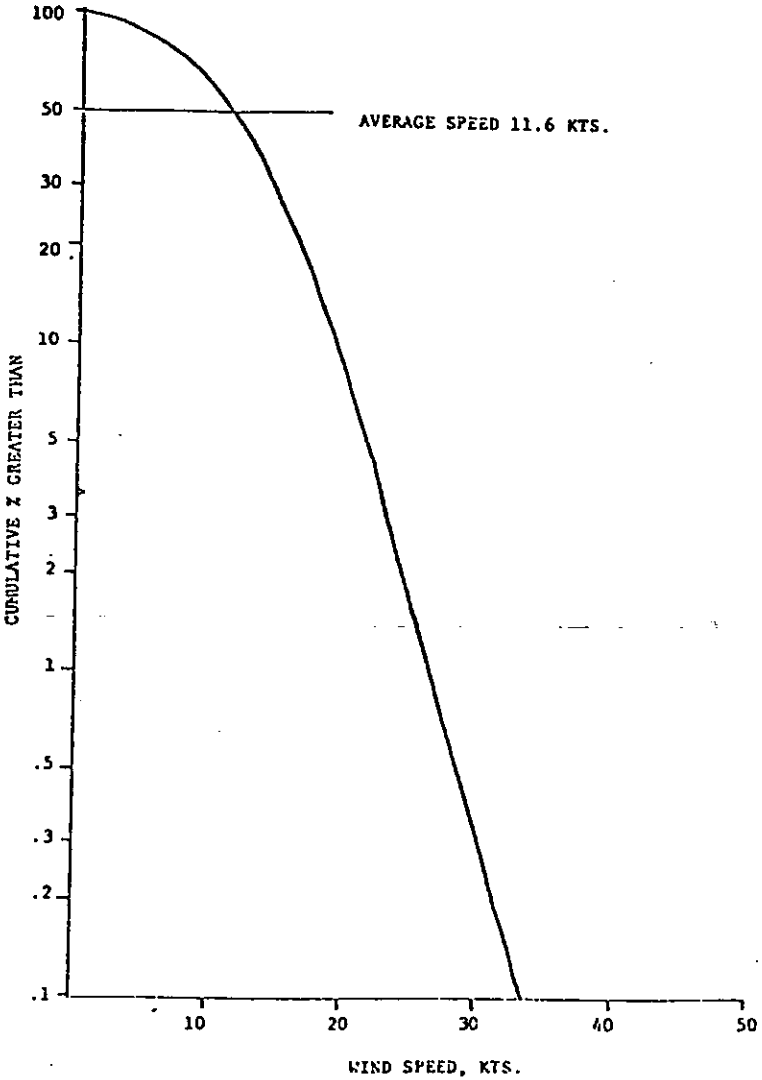


Figure 9. Annual cumulative percentage of winds exceeding given values.

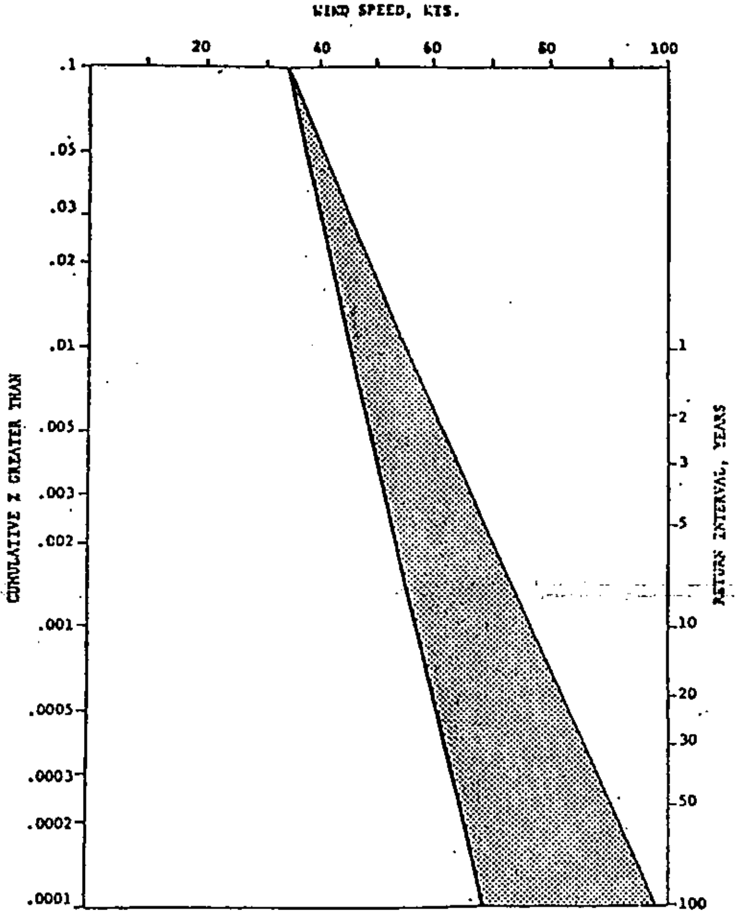


Figure 10. Cumulative percentage of hurricane winds exceeding given values.

Major disturbances to the normal trade wind circulation are caused by the passage of easterly waves, hurricanes, tropical storms, squalls, and thunderstorms. Hurricanes and tropical storms are the two most important influences. Durring the winter months, cyclones originate over the Gulf of Mexico and move northward along the east coast of the United States. These depressions move slowly out into the North Atlantic where they can generate southward-moving waves having large heights and long wave lengths. Swells produced in this manner commonly approach the study area.

The distribution of wind speed for the area near Vieques is given in Figure 8. The most frequently occurring wind speeds lie between 5 to 8 m/s, occurring 37.3% of the year. Wind speeds between 3 and 11 m/s occur 75.7% of the year and indicate the predominance of moderate wind speeds in the study area. High wind speeds in excess of 14 m/s occur only .4% of the year.

The percentage of the year that wind speeds at Vieques exceed a given value is shown in Figure 9. The average wind speed is 6 m/s. Winds exceed 18 m/s about .1% or approximately 9 hours a year.

Extreme wind speeds associated with hurricanes are given in Figure 10. The Figure gives the percentage of time the wind speed will exceed a given value for the duration of one hour and the return interval for extreme winds. The annual maximum wind speed for one hour is expected to be between 23 and 28 m/s. The maximum wind speed lasting one hour expected in ten years is between 29 and 39 m/s.

The distribution of winds over the principle compass directions is given in Figure 11. Winds from the east dominate the statistics, occurring 52.5% of the year. The next most likely wind direction is northeast, occurring 23.9% of the year. Winds with an easterly component (NE, E, SE) account for 89.5% of the observed winds.

Atwood, et al. (1976), summarized wind regime data for the area taken from Publication H.O. 21, U.S. Dept. of Commerce (1958), and from the USNOO, Environmental Acoustic Atlas of the Caribbean Sea and Gulf of Mexico (Vol. II, Mar. Envir., SP 189, 1972). The data show that windspeeds average from 4.5 to 5 m/s in autumn, to 6 to 8 m/s in summer, with strong northerly winds of greater than 14 m/s occurring from November to April when the passage of fronts and easterly waves interrupsts the normal trade wind pattern. The frequency of these northerly winds, according to the data in SP 189II, is about 2% of the year. Northerly winds are also common during the nighttime when diurnal variations in the Trades are accentuated by the landbreeze system generated by the island of Puerto Rico landmass. Figures 7 to 10 of the

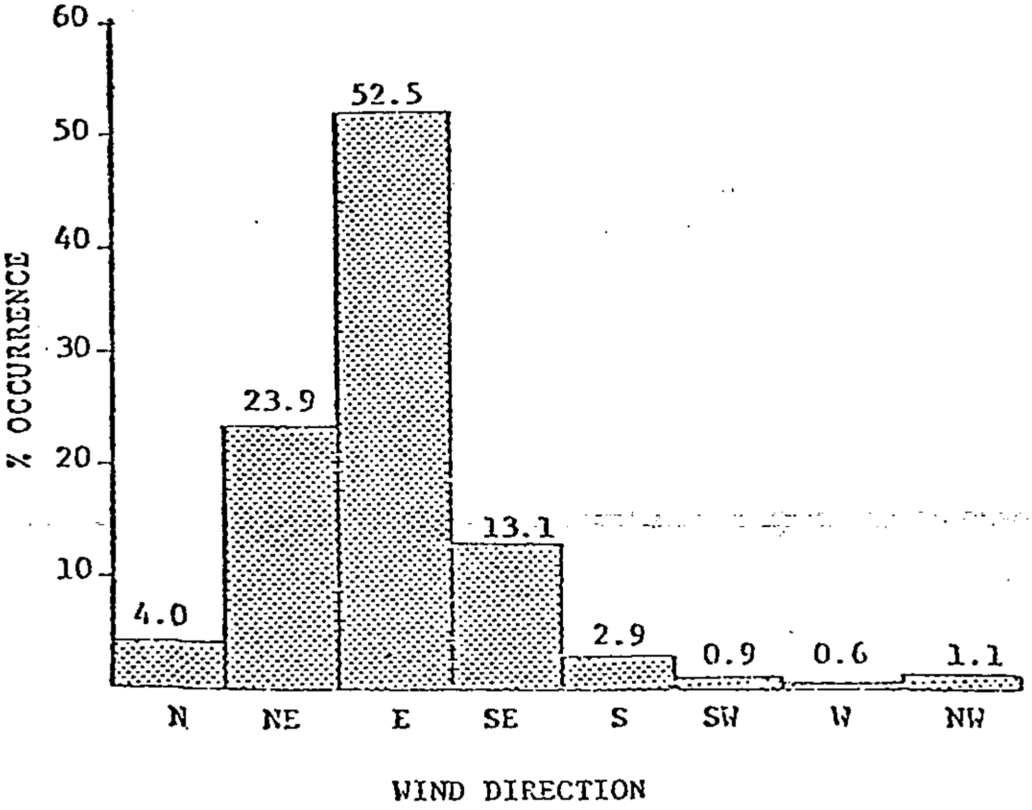


Figure 11. Annual frequency distribution of winds over the principal compass directions.

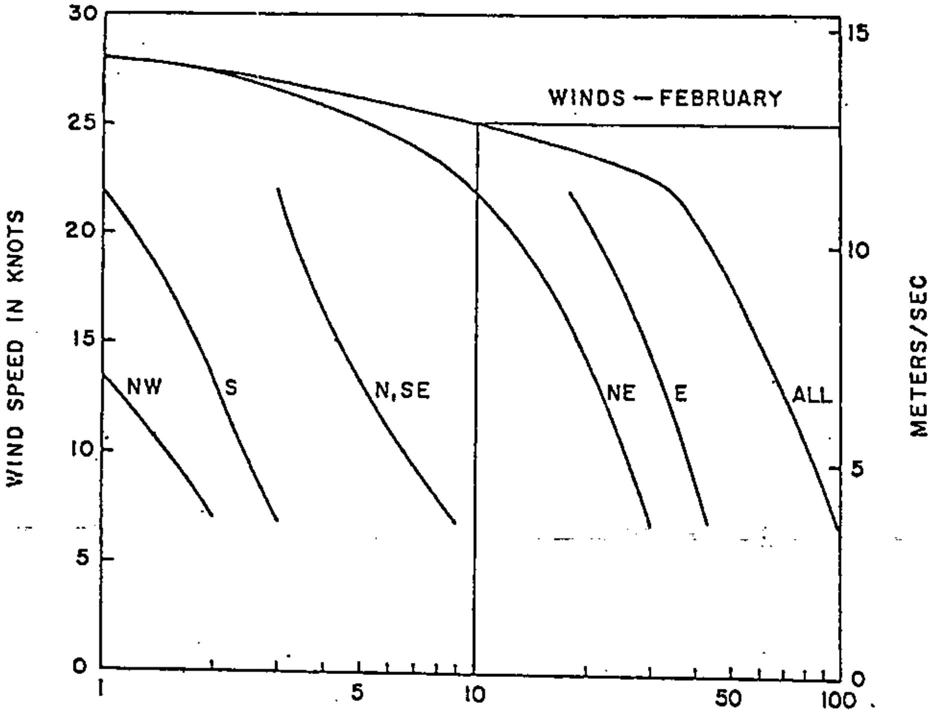
Atwood report (reproduced here as Figures 12 to 15) show a "crude summary of the oceanic wind conditions around the island of Puerto Rico," (Atwood, et al. 1976).

Lee, et al. (1978) summarized the wind regime of a nearby area in their assessment of an OTEC site off the island of St. Croix, U.S. Virgin Islands. They referred to the slight seasonal variation of the Trade Winds system which generates high winds from 7 to 13 m/s during mid-summer. The average monthly wind speeds range from 5 m/s in October to 8 m/s in July (Miller, 1977--cited by Lee, et al. 1978), with an annual mean of approximately 6 m/s, according to Burns, 1977, cited by Lee, et al. 1978. Citing the above investigators, the wind regime variations are summarized as follows:

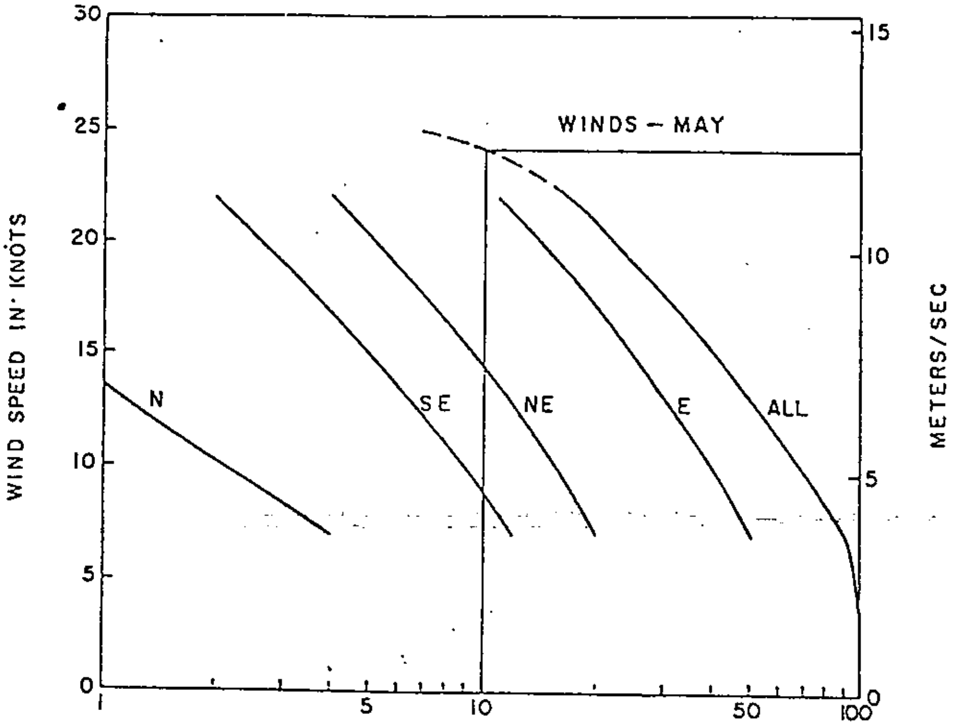
> "The wind direction is out of the eastern quadrant throughout the year. Winds are generally due east during the summer, when the doldrum belt is over Venezuela and the Bermuda High is most intense and extensive. At other times of the year, when the doldrum belt is south over the equator, the Bermuda High weakens and winds are more out of the northeast. Tropical storm force winds (17 m/s) have been observed in all months.
>
> Easterly waves occasionally affect the Virgin Islands area. During summer, 1977, two waves passed in the vicinity of St. Croix causing an increase in wind speeds (up to 15 m/s) and heavy rains. These tropical waves form to the north of the inter-tropical convergence zone in the deep easterly flow that flows clockwise around the southern portions of the Azores anti-cyclone (H.O. Pub. 22). During the passage of an easterly wave, winds are ENE ahead of the wave and ESE following (Burns, 1977)."

2.5. HURRICANES

The characteristics of hurricanes reaching the United States have been intensively studied; however, similar information is not available for hurricanes at lower latitudes. The study site does, in fact, lie somewhat along the hurricane track as the storms transit westward from the Atlantic to the Gulf of Mexico.

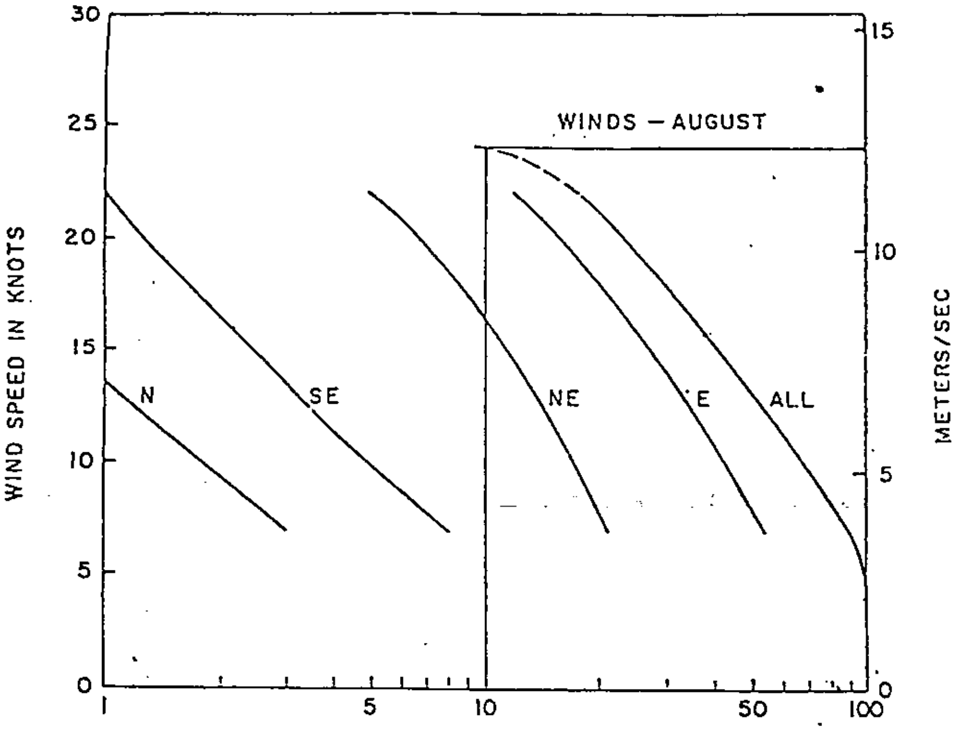


PERCENT AS GREAT OR GREATER THAN
(10% of all winds have speeds greater than 13 m/s)
Fig. 12. (from Atwood, et. al. 1976).



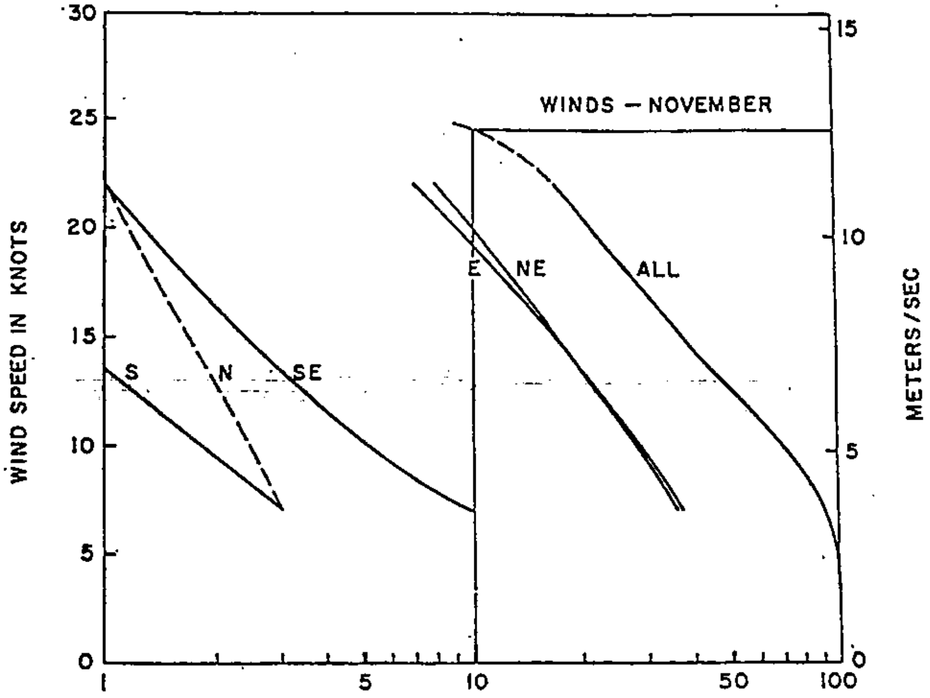
(10% of all winds have speeds greater than 12.5 m/s)

Fig. 13. (from Atwood, et. al. 1976).



PERCENT AS GREAT OR GREATER THAN
(10% of all winds have speeds greater than 12.3 m/s)

Fig. 14. (from Atwood, et. al. 1976).



(10% of all winds have speeds greater than 12.5 m/s)

Fig. 15. (from Atwood, et. al. 1976).

Some information about hurricanes affecting the study site can be determined from the U.S. Dept. of Commerce review of major hurricanes between the years 1873 and 1967. During these 94 years there were 94 hurricanes reported, an average of one hurricane per year. Many of these hurricanes passed to the north or south of the proposed site, and would have affected weather conditions around it. Figure 16 shows the track of two such hurricanes. There were 30 hurricanes during the 94-year period that passed within 100 km of Vieques. The intensity range of the storms, in increasing order, is: average, major, extreme, and great hurricanes, as given in Table 6. The mean recurrence interval for hurricanes strongly affecting Vieques is about 1 per 3 years. These storms, however, are not uniformily distributed over the years. As shown in Figure 17, the hurricanes affecting Vieques have occurred in groups. In some years (1933 and 1955) two hurricanes occurred in one year. During some other periods, no hurricanes occurred for many years.

Atwood, et al. (1976) and Lee, et al. (1978) showed the tracks of some devastating North Atlantic hurricanes in their reports. These hurricanes must have affected the proposed Puerto Rico OTEC site. The map of these hurricane tracks is reproduced here as Figure 18. Figure 19 shows the graph for the occurrence of tropical cyclones in the five degree square bounded by 150°-20°N, 65°-70°W, from Atwood, et al. (1976). Recurrence probability of tropical storms in the Puerto Rico area is about 70% annually; mean translation velocity movement of these storms is about 12 kts towards the west-north-west (U.S. Naval Weather Service Command, 1974). Clearly, August and September are the most affected months, with a significant number occurring in July and October as well.

2.6. WAVE STATISTICS

Wave statistics for the study area were taken from the Summary of Synoptic Meteorological Observations (SSMO), Area 23, which is near Vieques, P.R. Wave statistics for the SSMO data are based upon several years' visual observations. In addition, one year of measured data reported by Deane (1974) was also used.

The distribution of significant wave heights for the area of Vieques is given in Figure 21. The most frequently occurring wave height is in the interval of .3-.8 m occurring 41% of the year. The average significant wave height is 1 m. Wave heights in the range from .3 to 1.4 m occur 79.3% of the year. Large wave heights greater than 2.3 m occur rather infrequently, accounting for only 1.3%.

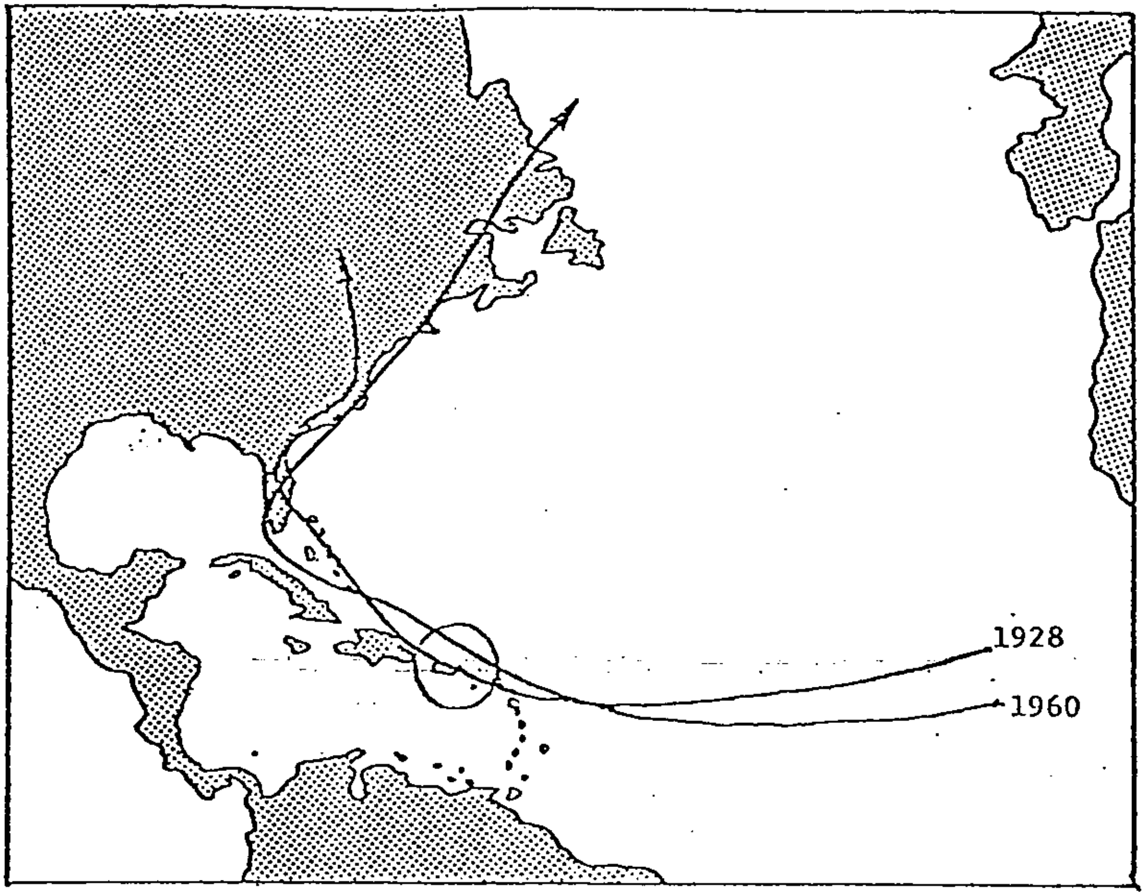


Figure 16. Track of hurricanes affecting the study site.

TABLE 6. HURRICANES COMING WITHIN 100 KM OF VIEQUES - 1873 to 1967

DATE	INTENSITY	DIRECTION TO HURRICANE AT NEAREST POINT
August 1873	Major	S
August 1879	Extreme	N
August 1880	Major	S
August 1881	Major	N
September 1882	Major	N
September 1883	Major	S
August 1885	Extreme	N
September 1894	Average	S
September 1896	Average	S
September 1898	Extreme	NE
August 1899	Extreme	S
August 1900	Great	S
August 1915	Great	S
September 1917	Average	S
September 1919	Great	W
September 1926	Great	N
September 1928	Great	S
August 1933	Great	N
August 1940	Major	N
September 1945	Extreme	N
September 1947	Great	N
August 1949	Extreme	N
September 1954	Extreme	NE
August 1955	Great	NE
September 1955	Great	NE
August 1960	Great	N
August 1964	Major	S
August 1965	Great	E
September 1966	Great	S
September 1967	Great	S

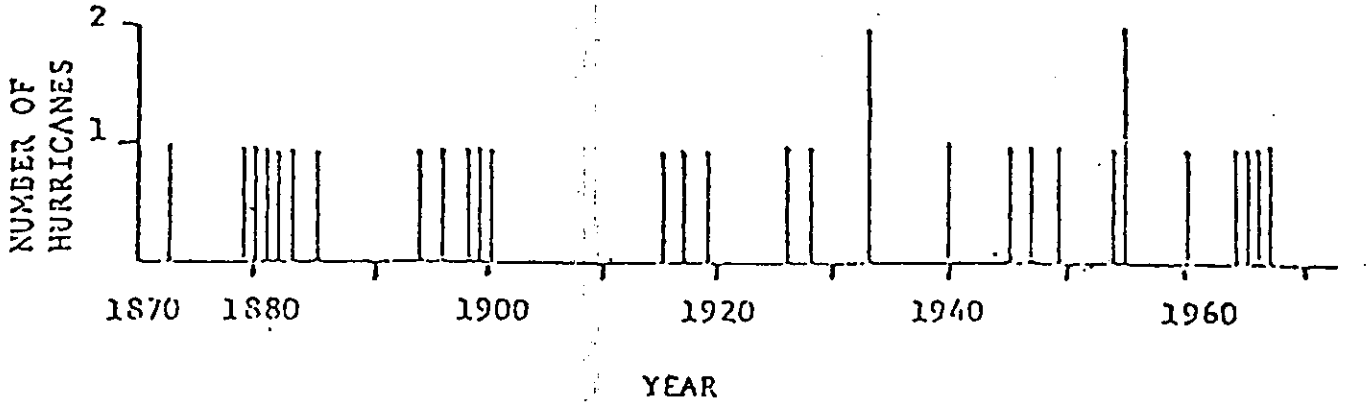


Figure 17. Year and number of hurricanes affecting Vieques during the period 1873-1967.

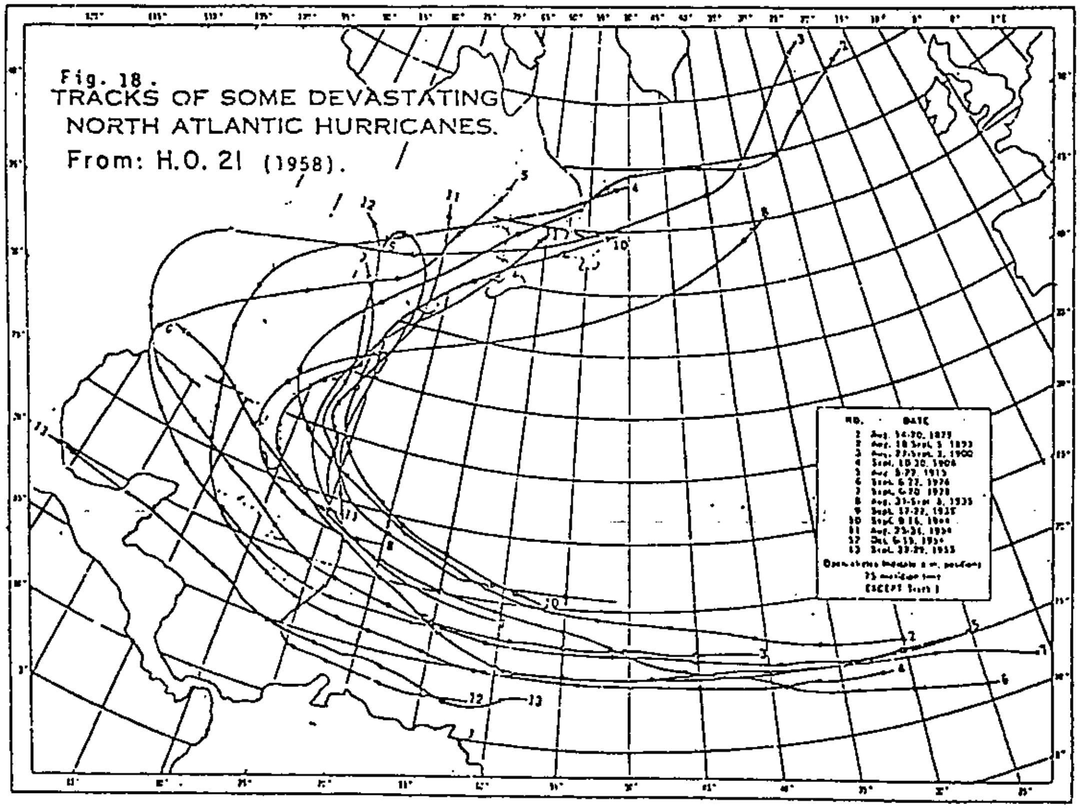


Fig. 18.
TRACKS OF SOME DEVASTATING NORTH ATLANTIC HURRICANES.
From: H.O. 21 (1958).

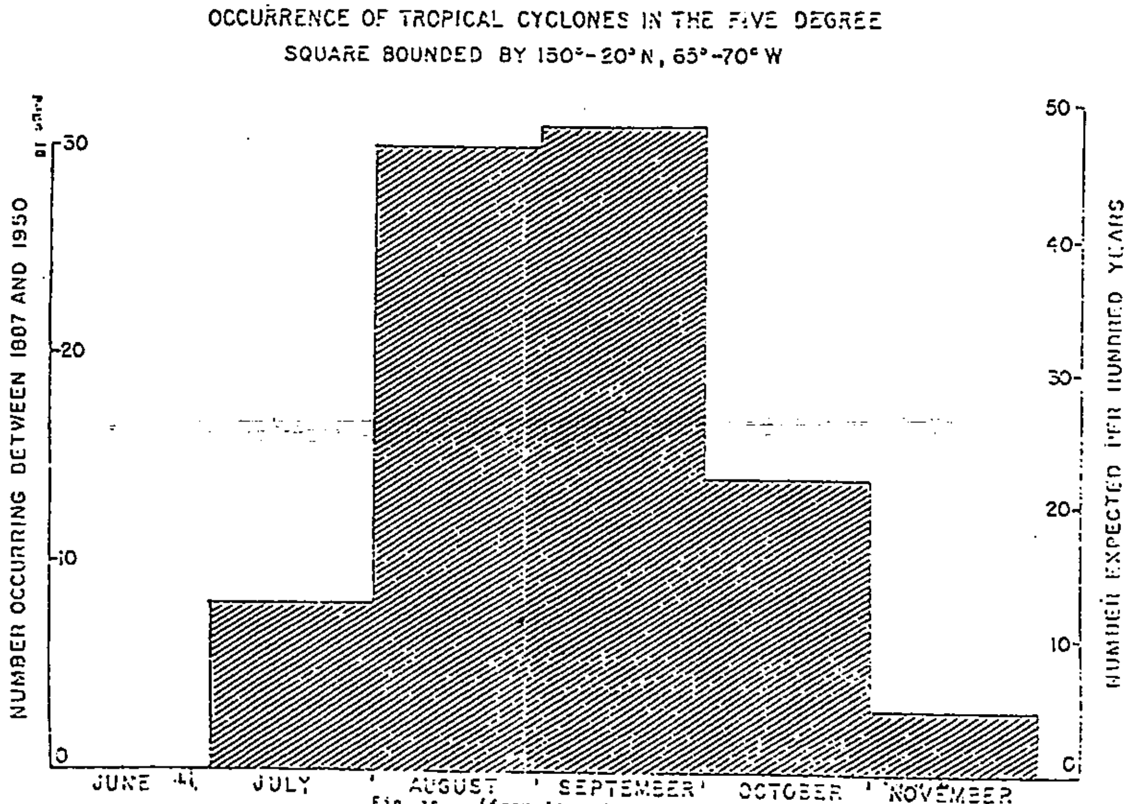

OCCURRENCE OF TROPICAL CYCLONES IN THE FIVE DEGREE SQUARE BOUNDED BY 150°-20°N, 65°-70°W

Fig. 19. (from Atwood, et. al. 1976).

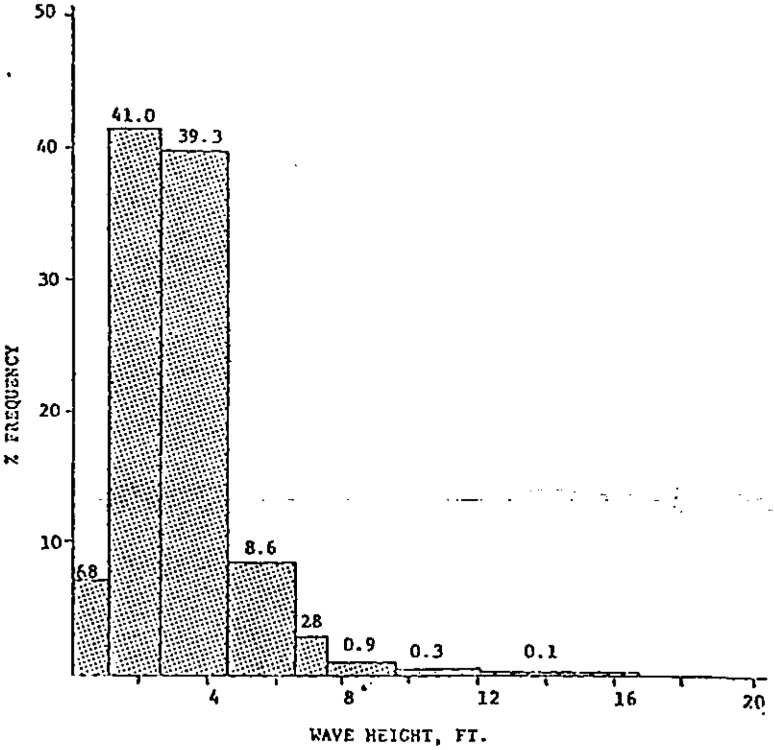


Figure 21. Annual frequency distribution of significant wave heights, for Area 23, Vieques, Puerto Rico.

The distribution of wave periods for Area 23 is given in Figure 22. The dominant wave period is less than 6 sec, accounting for 78.7% of the year. The average wave period is 5.9 sec. Wave periods indicative of swell (greater than 9.5 sec) occur only 1.8% of the year.

The percentage of wave heights that exceed a specific value is given in Figures 23 and 24. Figure 23 gives the cumulative percent of low to moderately large wave heights. Wave heights exceed 3 m only about 0.5% of the year, or about 2 days (43.8 hours) per year. The extreme wave height cumulative percentages and return intervals are given in Figure 24. Two lines are shown which give conservative (larger value) and liberal (smaller value) height values. Wave heights between 5.5 and 6 m would recur on an average of once every 3 years. Wave heights of above 8 m are expected very infrequently, recurring on the average of about once every 100 years.

Wave height versus wind speed for the study area is shown in Figure 25. Wave height increases slowly with wind speed until about 6 m/s, then there is a rapid increase in wave height. At a wind speed of 4 m/s, the significant wave height would be about .3-.5 m; for a 8 m/s wind, the significant wave height is 1 to 1.2 m, and for a 9 m/s wind, the significant height is about 2.7 m.

"Seas and swells" observations are reported daily to the U.S. Naval Oceanographic Data Center (NODC). This governmental agency compiles all the observations reported by ocean going ships, and statistically summarizes the characteristics and range of the waves. Tables 9 to 11 are reproductions of summaries published by the U.S. Naval Weather Service Command in the SSMO (1974). An analysis of these tables reveals a winter-summer wave regime difference. Table 9, the tabulated annual summary, points out the known dependent relationship between the wind system and generated swell variations. Wave periods, although very infrequently, may reach values greater than 10 seconds, the mean range being from 4 to 8 seconds for a mean wave height range of .6 to 2 m. A summary of the sea swell data in the tables indicates that the values fo direction and period for the swells in the winter are similar to those of autumn, and those occurring in the spring are similar to the summer values. In the winter, the swells of period less or equal to 5 seconds usually come from the east or northeast, about equally divided. In summer, the direction comes fromthe east almost all the time. For the 6-9 second period swells, the winter values are usually from the east, with a significant percent from the northwest to northeast. In the summer, the number from non-east directions is almost zero. Finally,

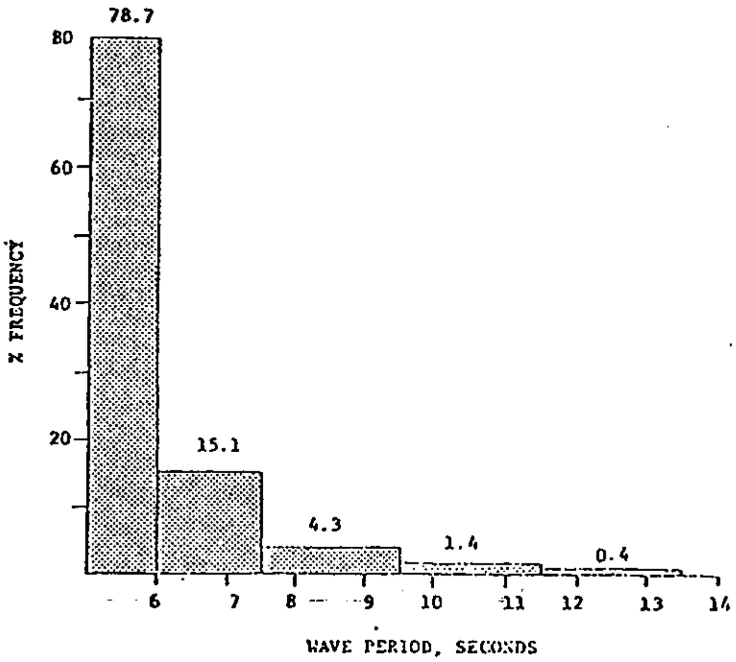


Figure 22 . Annual frequency distribution of wave periods, Area 23, Vieques, Puerto Rico.

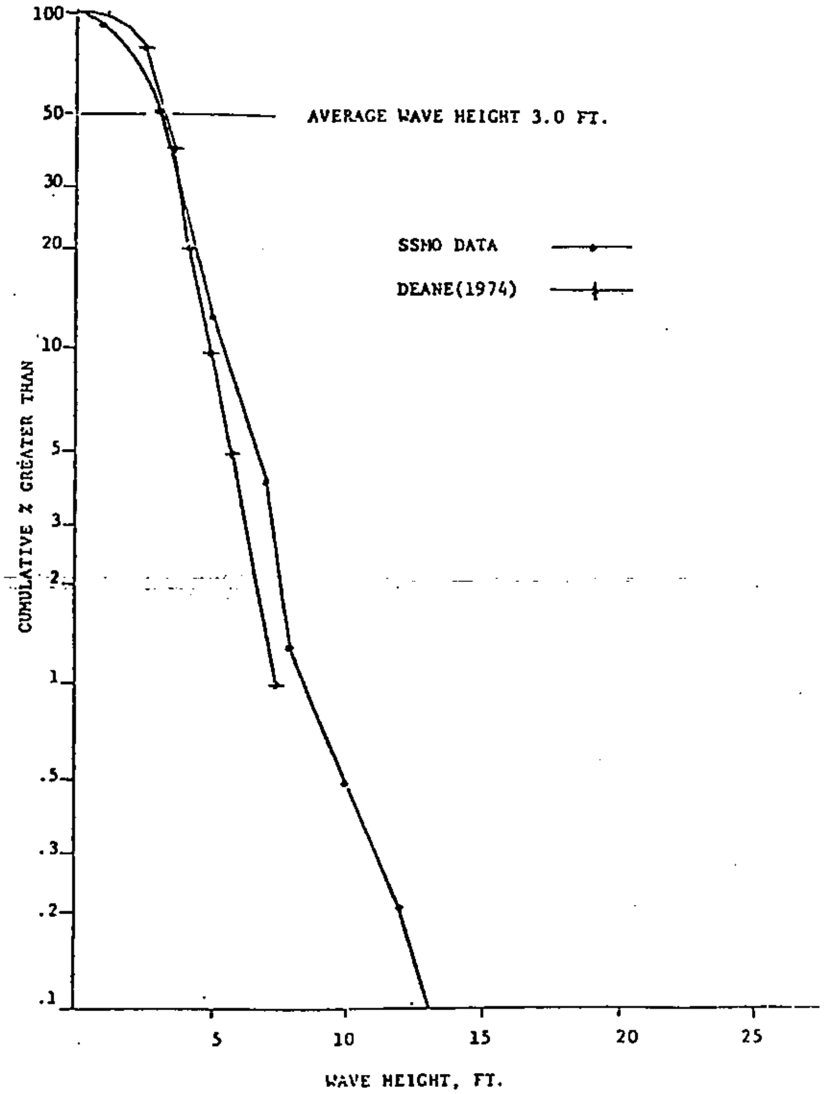


Figure 23. Annual cumulative percentage of wave heights exceeding given values, for Area 23, Vieques, Puerto Rico.

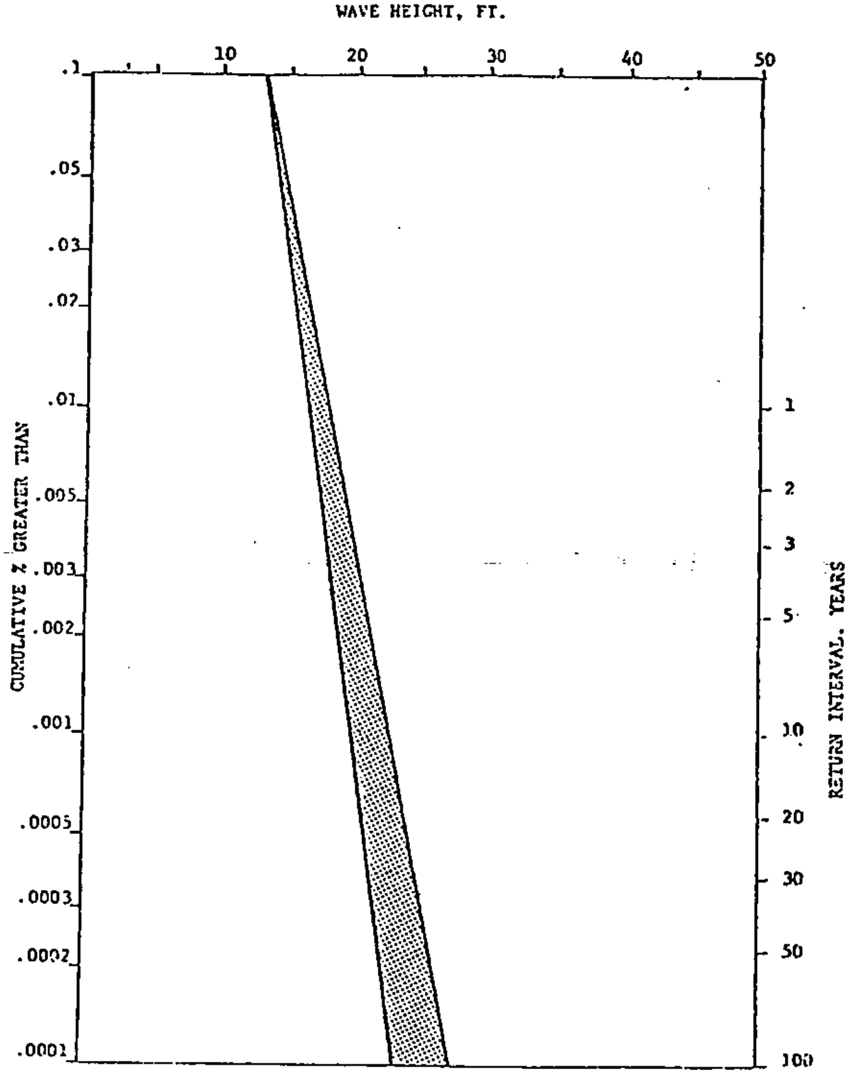


Figure 24. Cumulative percentage of hurricane wave heights exceeding given values, for Area 23, Vieques, Puerto Rico.

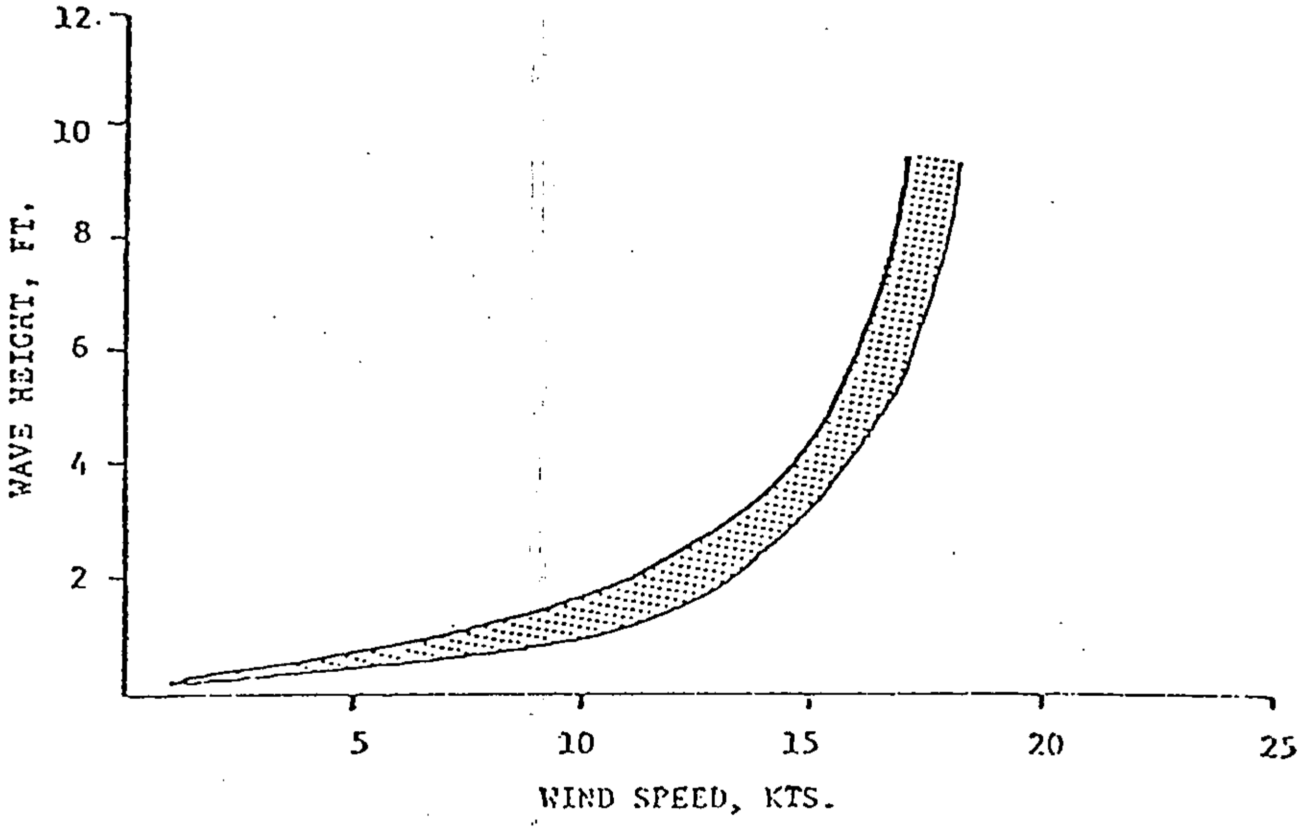


Figure 25. Wave height versus wind speed for the study area.

PERIOD: 1963-1973

Table 9

PCT FREQ OF WIND SPEED (KTS) AND DIRECTION VERSUS SEA HEIGHTS (FT),
(after U.S. Naval Weather Service Command, SSMO, 1974).

				N							NE			
HGT	1-3	4-10	11-21	22-23	34-47	48+	PCT	1-3	4-10	11-21	22-33	34-47	48+	PCT
<1	.2	.9	.1	.0	.0	.0	1.1	.4	1.6	.1	.0	.0	.0	2.1
1-2	.1	.9	1.2	.0	.0	.0	2.2	.1	4.1	7.4	.0	.0	.0	11.6
3-4	.0	.2	.8	.1	.0	.0	1.1	*	1.3	5.5	.7	.0	.0	7.5
5-6	.0	*	.2	.1	.0	.0	.2	.0	.1	1.1	.2	.0	.0	1.4
7	.0	*	*	*	.0	.0	.1	.0	*	.4	.1	.0	.0	.5
8-9	.0	.0	.0	.0	.0	.0	.0	*	.0	*	.1	.0	.0	.1
10-11	.0	.0	.0	.0	.0	.0	.0	.0	.0	*	*	.0	.0	*
12	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
13-16	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	*	.0	.0	*
17-19	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
>19	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
TOT PCT	.2	2.0	2.2	.2	.0	.0	4.6	.5	7.1	14.5	1.1	.0	.0	23.2

				E							SE			
HGT	1-3	4-10	11-21	22-23	34-47	48+	PCT	1-3	4-10	11-21	22-33	34-47	48+	PCT
<1	.4	2.0	.3	.0	.0	.0	2.7	.2	1.2	.1	.0	.0	.0	1.5
1-2	.3	8.6	16.1	.0	.0	.0	24.9	.2	3.7	3.7	.0	.0	.0	7.6
3-4	*	2.7	15.3	1.6	.0	.0	19.7	.1	1.0	2.6	.1	.0	.0	3.8
5-6	.0	.2	2.9	.3	.0	.0	3.4	.0	.1	.3	*	*	.0	.4
7	.0	*	.6	.2	.0	.0	.8	.0	*	.1	*	.0	.0	.2
8-9	.0	.0	.1	.1	.0	.0	.1	.0	.0	*	*	.0	.0	*
10-11	.0	.0	*	*	.0	.0	.1	.0	.0	.0	.0	.0	.0	.0
12	.0	.0	.0	*	.0	.0	*	.0	.0	.0	.0	.0	.0	.0
13-16	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
17-19	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
>19	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
TOT PCT	.7	13.5	35.3	2.2	.0	.0	51.8	.5	6.0	6.8	.2	*	.0	13.4

Table 10

WIND SPEED (KTS) VS SEA HEIGHT (FT),
(after U.S. Naval Weather Service Command, SSMO, 1974).

HGT	0-3	4-10	11-21	22-33	34-47	48+	PCT	TOT OBS
<1	2.5	7.1	.6	.0	.0	.0	10.2	
1-2	1.0	19.0	29.2	.0	.0	.0	49.2	
3-4	.2	5.5	24.8	2.6	.0	.0	33.0	
5-6	.0	.4	4.4	.7	*	.0	5.5	
7	.0	.1	1.2	.3	.0	.0	1.6	
8-9	*	.0	.1	.1	.0	.0	.3	
10-11	.0	.0	*	*	.0	.0	.1	
12	.0	.0	.0	*	.0	.0	*	
13-16	.0	.0	.0	*	.0	.0	*	
17-19	.0	.0	.0	.0	.0	.0	.0	
>19	.0	.0	.0	.0	.0	.0	.0	
								7453
TOT PCT	3.8	32.2	60.3	3.8	*	.0	100.0	

PERIOD: 1949-1972

Table 11

PERCENT FREQUENCY OF WAVE HEIGHT (FT) VS WAVE PERIOD (SECONDS), (after U.S. Naval Weather Service Command, SSMO, 1974).

PERIOD (SEC)	1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	2.2	34.5	30.4	4.5	.9	.2	.1	*	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	8402	3
6-7	*	3.4	6.5	2.8	1.0	.3	.1	*	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1639	4
8-9	*	.7	1.4	1.0	.5	.2	.1	*	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	530	4
10-11	.0	.5	.3	.1	.2	.1	.1	*	.0	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	158	4
12-13	.0	.0	.2	*	.1	.1	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	58	5
>13	.0	*	.0	*	*	*	*	.0	*	.0	*	.0	.0	.0	.0	.0	.0	.0	.0	19	7
INDET	4.6	1.9	.4	.1	*	.0	.0	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	793	1
TOTAL																				11599	3
PCT	6.8	41.0	39.3	8.6	2.8	.9	.3	.1	.1	*	*	.0	.0	.0	.0	.0	.0	.0	.0	100.0	

some swells of period greater than 9 seconds occur in the winter, going from north to east. During the remainder of the year almost none of these long waves can be expected.

Figures 26 to 32 are reproductions of Figures 15 to 19, and 21 to 22 in the Atwood, et al. (1976) report. These figures show a seas and swells analysis for different months of the year as taken from the data contained in SP 189II for the oceanic region surrounding Puerto Rico. The authors point out that these data "do not take into account the masking at Yabucoa by the islands of Puerto Rico and Vieques." According to these investigators the information in these figures is given for "its value as a guide to the conditions which may be expected while the plant is being towed to the site from its place of construction." The data in the mentioned report are summarized as follows:

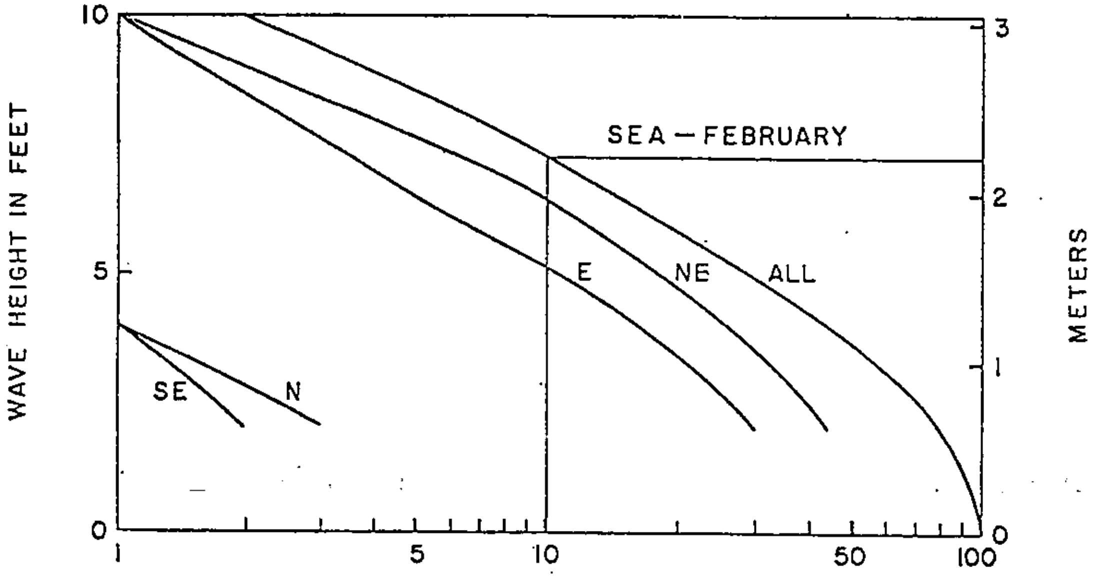
> "The percentage of "calm" swell is over 85% for winter and summer in coastal waters and less than 19% in the open ocean. Similarly, swell in the coastal area is never observed in the quadrant N to E (0°to 90°) but in the open ocean this quadrant accounts for over two-thirds of all observed swell, and nearly all observations greater than 12 feet high (3.6 meters)."

Bretschneider (1977) calculated by hindcasting methods a design wave for potential OTEC sites which included the Punta Tuna site in Puerto Rico. Table 12 shows the results of the analysis conducted by Bretschneider (1977) for hurricane wave and wave spectra parameters for the sites considered. From this table the most probable hurricane is predicted as having a wind of greater than 41 m/s, with waves averaging over 7 m, and peaking at about 20 m. The results of a frequency and spectral density analysis for various sea state and wind velocity spectrums are illustrated on pages 19 to 39 of Bretschneider's report, by means of spectral density curves and tables.

2.7. WATER MASSES

The water masses in the Caribbean have been discussed by many authors (Wust, 1963; Atwood et al. 1976; Craig et al. 1978, Lee et al. 1978), but for completeness they shall be mentioned again here in this report in order to consolidate the information.

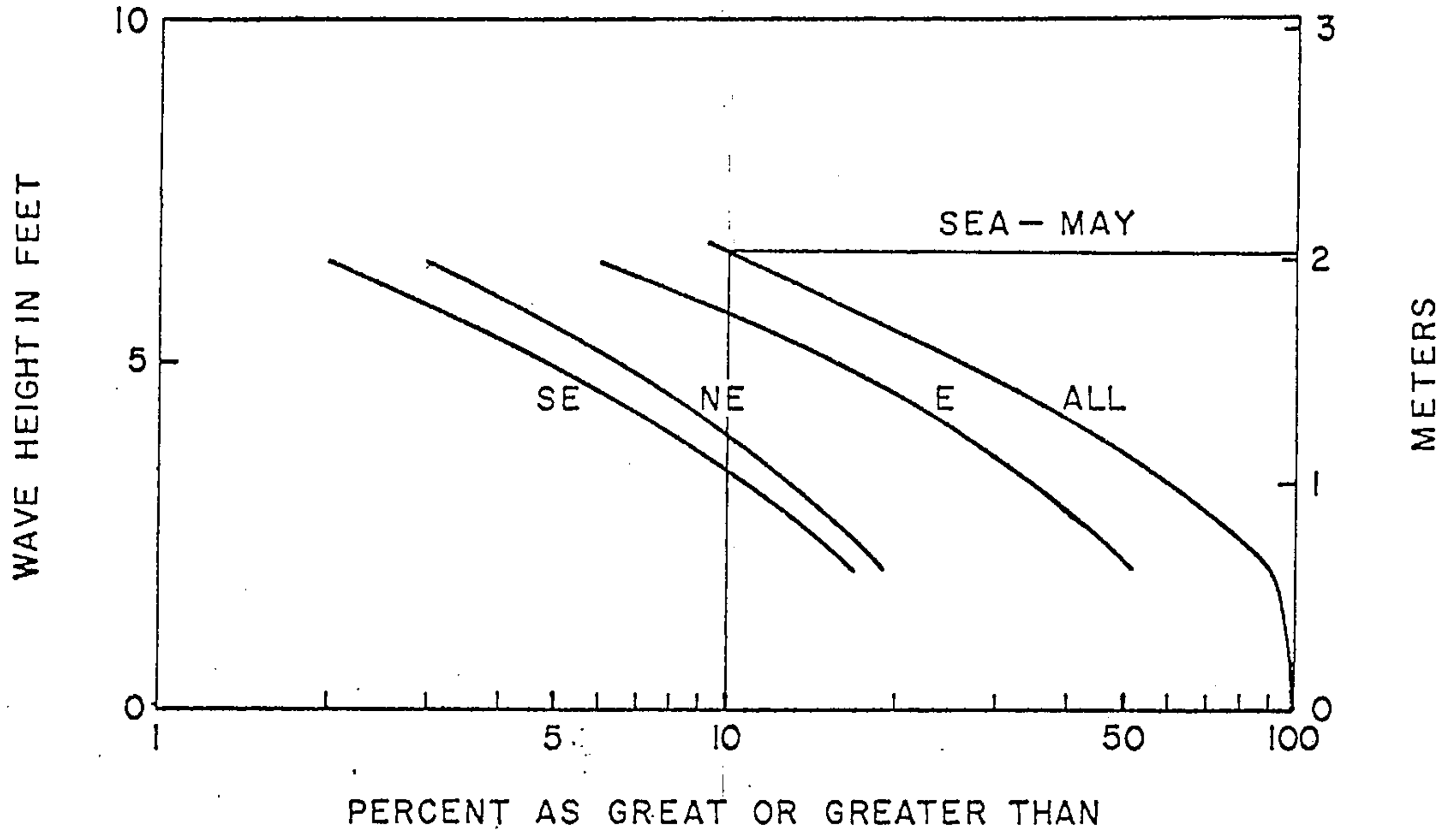
The cold water intake pipe of an OTEC plant would probably extend from the surface to about 1000 m deep. With the



PERCENT AS GREAT OR GREATER THAN

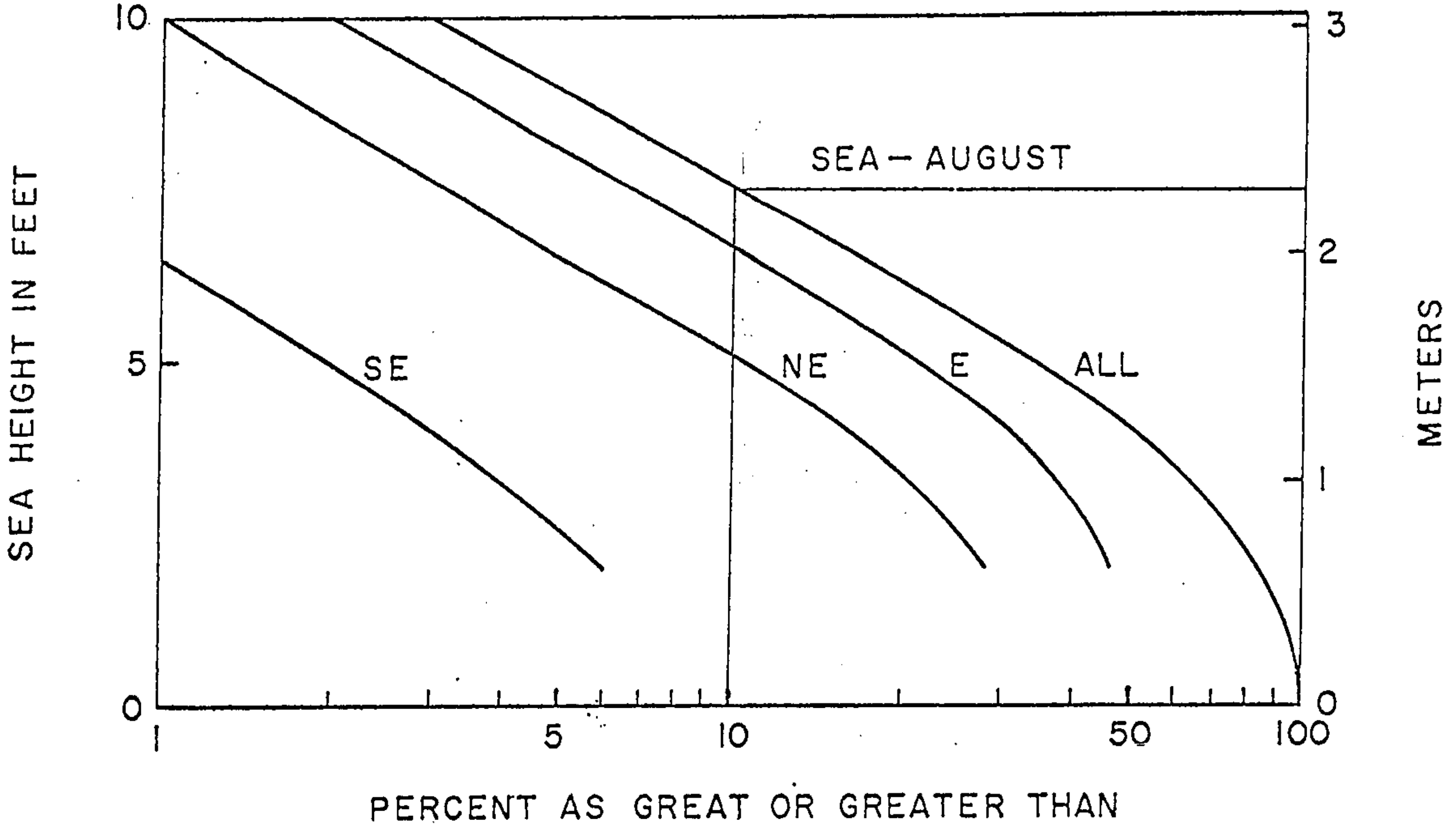
(10% of all seas are greater than 2.2 meters)

Fig. 26. (from Atwood et. al. 1976).



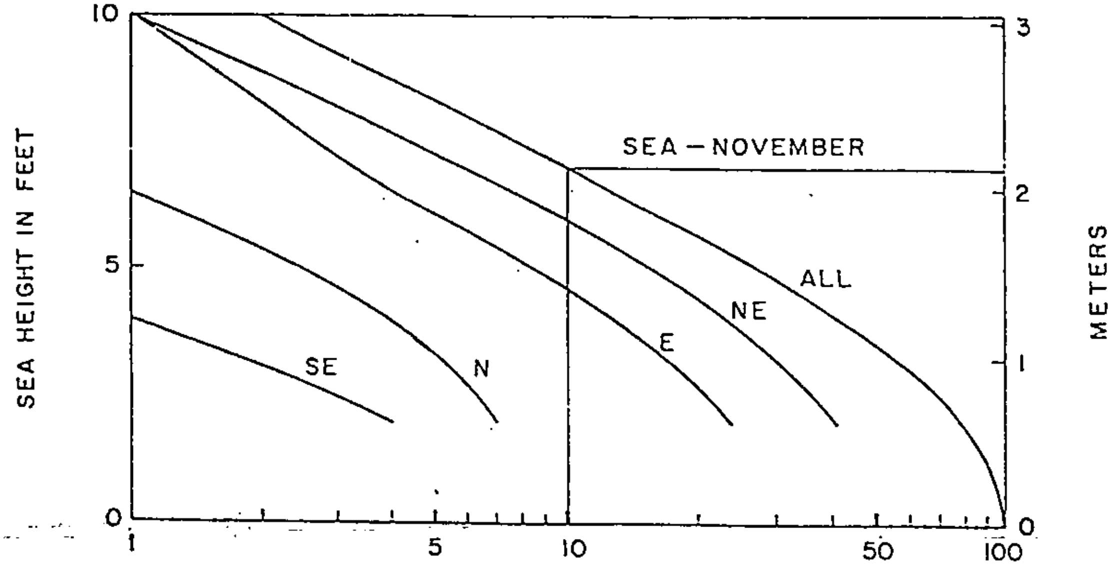
(10% of all seas are greater than 2.0 meters)

Fig.27. (from Atwood et. al. 1976).



(10% of all wave heights are greater than 2.3 meters)

Fig. 28. (from Atwood et. al. 1976).



PERCENT AS GREAT OR GREATER THAN
(10% of all wave heights are greater than 2.1 meters)
Fig. 29. (from Atwood et. al. 1976).

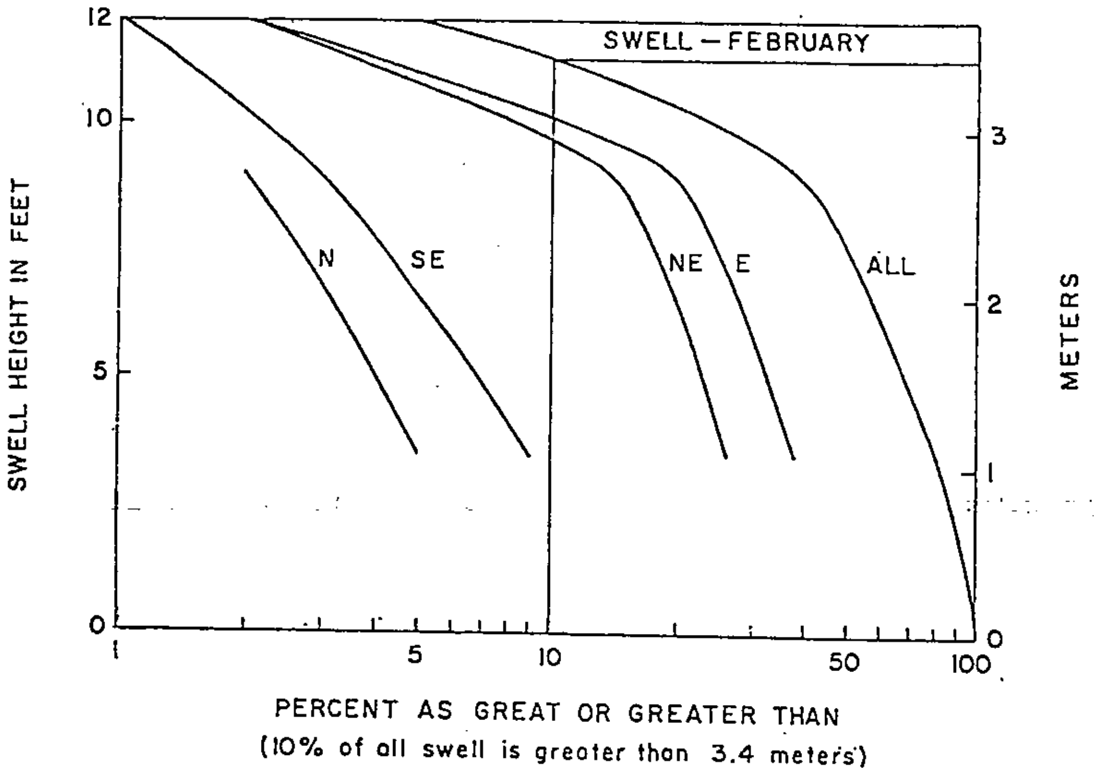
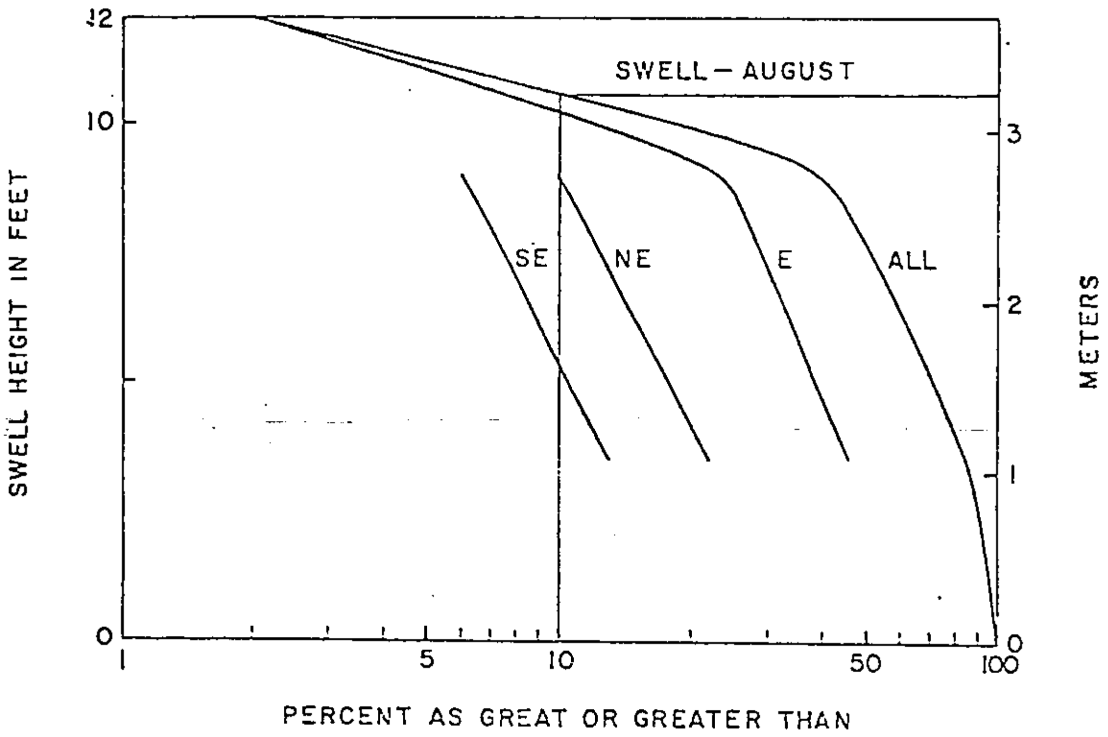
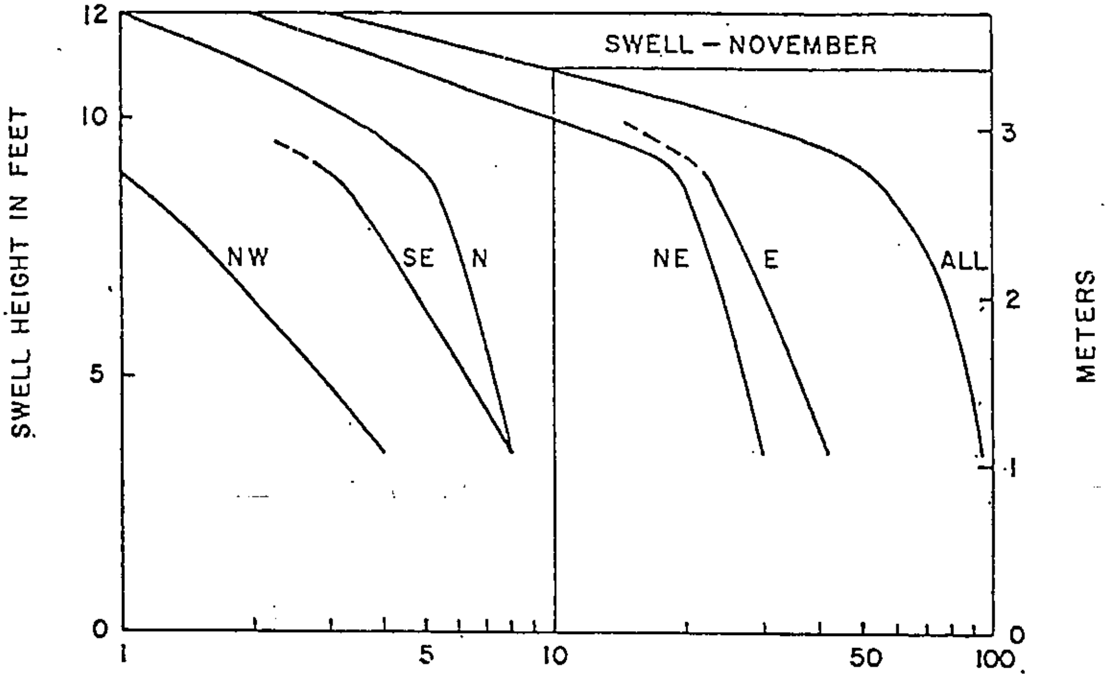


Fig. 30. (from Atwood et. al. 1976).



(10% of all swell is greater than 3.2 meters)

Fig. 31. (from Atwood et. al. 1976).



(10% of all swell is greater than 3.3 meters)

Fig. 32. (from Atwood et. al. 1976).

Table 12.

Hurricane Wave and Wave Spectra Parameters
for Punta Tuna OTEC site (after Bretschneider, 1977).

100-Year Hurricane Design Critera	Most Probable Hurricane	Exceptional Hurricane
Mean wind speed for significant wave, U_s (knots)	84.8	92.8
Mean gust speed for significant wave, G_s (knots)	122.5	134.6
Height for significant wave, H_s (feet)	36.9	44.2
Period of significant wave, T_s (seconds)	11.9	13.0
Frequency of maximum energy density, f_o^{-1} (seconds)	12.6	13.8
Wave spectra peak, $S(f_o)$, (ft^2second)	1536	2414
Average wave height, $\overline{H}$ (feet)	23.1	27.6
Average wave period, $\overline{T}$, (seconds)	10.8	11.8
Maximum wave height, H_{max}, (feet)	66.4	79.6

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 named the Tropical Surface Water. 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. As this water mass is influenced by the precipitation in that area, it is also influenced by the rain and runoff in the drainage basins of the Amazon and Orinoco Rivers in the northeastern part of South America. The water mass is then driven by the winds and the earth's rotation into the Caribbean Sea. By the time it reaches Puerto Rico, the temperature and salinity of this upper water mass has been further affected by the general and local climate of the area through which it is passing. Further precipitation, runoff, and evaporation from wind and insolation could further influence both the temperature and salinity. Typical ranges of these parameters seen in the Tropical Surface Water are salinities varying from 33-36 (with excursions both above and below these values), and temperatures from 25°C to 29°C. This water mass may attain its maximum depth and actually be wedge-shaped along the northern Caribbean, due to the geostrophic subsidence as the water moves westward. However, the actual depth of the water mass, may be influenced greatly by the atmospheric pressure and its variation. Normally, the pressure changes little, with changes of 3-6 cm of mercury in a month 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 lower water mass. These conditions would occur in the case of a hurricane, but also to a lesser degree during a tropical wave or a tropical storm. The effect on an operating OTEC plant could be at least to severely reduce its efficiency, in the case that the plant had not already been shut down.

The water mass directly below the Tropical Surface Water is called the Subtropical Underwater. This lower water mass originates directly beneath the Bermuda atmospheric high pressure zone. This high pressure zone 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 and climate under the Bermuda High is warm and dry. Also, due to the relative humidity, evaporation is great and salinity is increased, making this water the most saline in all the Caribbean. This water mass then descends to form the upper portion of the thermocline in the Caribbean. The salinity seen within the Subtropical Underwater ranges from 36.8°/₀₀ to 37.2°/₀₀. As the water rarely comes into contact with any diluting agent, the salinity remains quite high, and relatively invariant. Furthermore, as mentioned above, during conditions of low atmospheric pressure, this water can push upward, and the very high salinity seen in the surface water during these times is evidence of this water mass having been upwelled.

The temperature range within this water mass is greater (20°C-24°C) than the water mass above. As the heat may be conducted upward or downward, 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 to maintain the two water masses as quite distinct. The Subtropical Underwater moves generally south and westward into the Caribbean, under the faster moving, more turbulent surface water mass. As the lower water mass moves westerly into the Caribbean, it is seen to dilute to about 36.5°/oo-36.6°/oo in the Yucatan Strait. In the vicinity of Puerto Rico, the water moves southward through both the Anegada and Mona Passages, then south and westward through the Caribbean. The core of this water mass is frequently seen to lie at about 150 m depth in the Puerto Rico area.

Below this water mass lies a transition zone of indistinct characteristics. The 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°/oo, from the water mass above it, down to about 35°/oo. The temperature ranges from 20°C to about 7°C. This transition zone reaches from about 200 m to 600 m depth. Just below this zone lies the oxygen minimum, which many people define as the boundary of the cold water zone in the oceans.

The Antarctic Intermediate Water is found just below this transition zone. This water is formed at the Antarctic Convergence Zone, about 45°-55° latitude. The water tends to be low in salinity, as it is formed in an area where precipitation far exceeds evaporation. The water mass is seen moving northward from its area of formation, and 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 Hispañola. This water mass generally is seen spreading from these sills out to cover much of the Caribbean Basin. The movement near the southeast coast of Puerto Rico could be expected to be south and west. As the water moves northward through the Atlantic it is in contact with higher saline water, increasing the salinity from its origin of about 34°/oo to 34.8°/oo off Puerto Rico. The temperature is from 6°C-7°C.

From 800 m down to 1000 m, between the Antarctic Intermediate Water and the North Atlantic Deep Water, lies another 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 north latitudes, and while descending both in depth and latitude, 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 35.0°/₀₀. After this water mass moves into the Caribbean, it is virtually trapped, with only a small passage out through the Yucatan Strait. The water remains in the Basin and is slightly different in silicate content from its origin, the North Atlantic Deep Water, found outside the Caribbean Basin. For this reason, some people choose to call this deep, cold water the Venezuela Bottom Water. In some portions of the Caribbean Basin, this water mass is over 3000 m thick.

2.8. CURRENTS

The general circulation of the Caribbean Sea has been described by Wust (1963), Worthington (1971), Gordon (1967) and Perlroth (1971), among others. The Caribbean Current is a warm westward flow which is formed from the junction of the North Equatorial Current and the Guiana Current (Burns and Car, 1975), both generated by the Northeast Trade Winds. There are seasonal variations in the Caribbean Current. Surface velocities attain their maximum speed during the summer (June-August) and their minimum during October and November. Burns and Car (1975) reported maximum speeds along the north coast of Venezuela of about 43 cm/sec, with a peak of 135 cm/sec. Most of the water entering the Caribbean Sea comes through the straits north and south of St. Lucia (Fig. 1). The main flow crosses the Jamaica Ridge southwest of Jamaica, moves west through the Cayman Basin, and then keeps flowing north through the Yucatan Strait into the Gulf of Mexico, contributing to the formation of the Florida Current (Burns and Car, 1975).

Comprehensive summaries of the water masses and surface circulation of the Caribbean Sea have been given by many researchers. Most of these summaries quote the work of Wust (1963), reproducing this author's descriptive diagrams of the surface circulation. These diagrams are also reproduced here as Figures 33 to 36. These figures show the tabulated speeds and directions of the surface currents around Puerto Rico for the months of January, April, July, and October. Tables 14 and 15 are summaries of ship drift data taken from the Naval

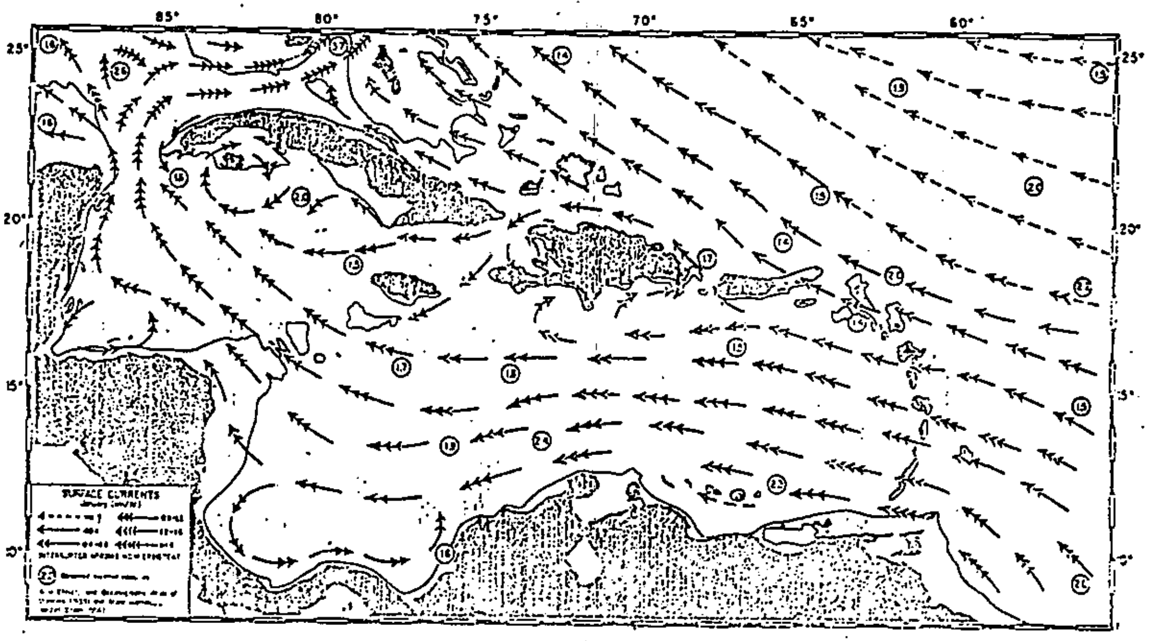


Fig. 33. Surface currents in the Caribb. Sea for the month of January (from Wust, 1963).

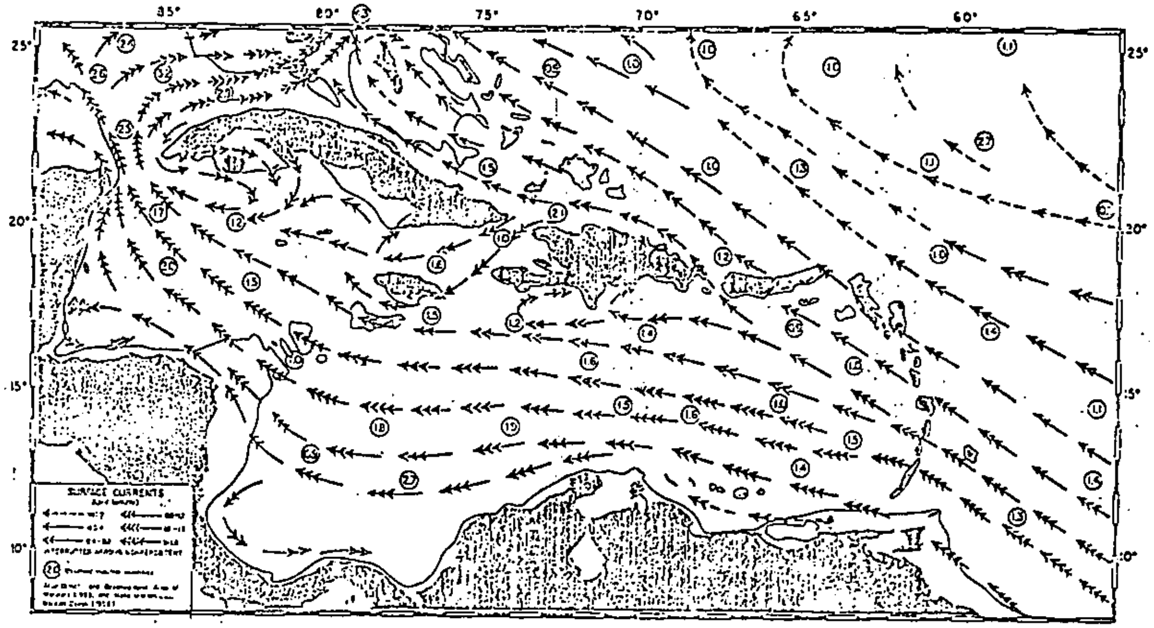


Fig. 34. Surface currents in the Caribbean Sea for the month of April (from Wust, 1963).

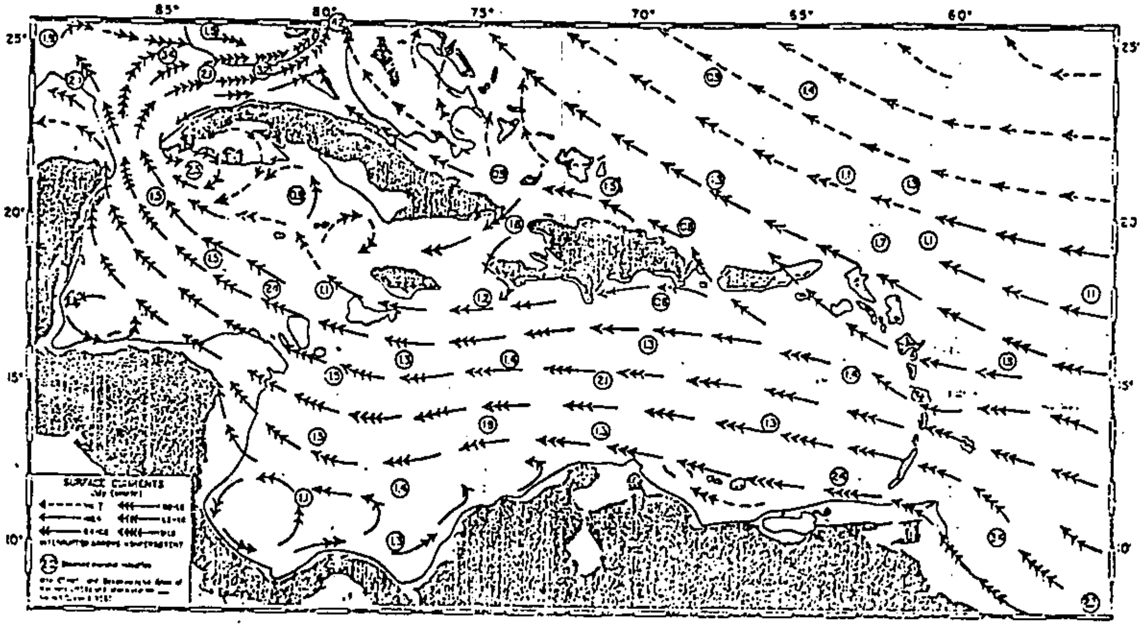


Fig. 35. Surface currents in the Caribbean Sea for the month of July (from Wust, 1963).

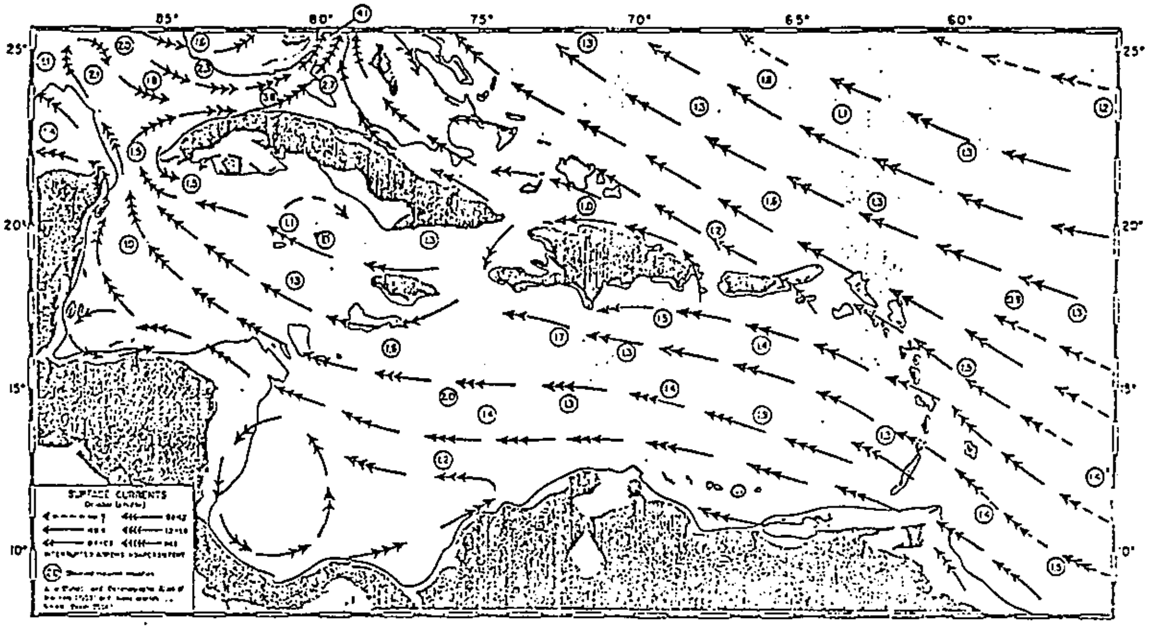


Fig. 36. Surface currents in the Caribbean Sea for the month of October (from Wust, 1963).

Table 14. Surface current data for Puerto Rico (SCUDS).

SITE: Puerto Rico
10 DEGREE SQUARE: 1008
1 DEGREE SQUARE: 75
1/4 DEGREE SQUARE: 1

Month	Total Observations	Number of Calms	North Comp.	East Comp.	Resultant Direction	Resultant Speed
1	17	1	-0.0	-0.4	267	0.4
2	7	0	-0.0	-0.3	266	0.3
3	7	1	0.2	-0.5	286	0.6
4	12	0	0.2	-0.4	293	0.5
5	11	1	0.0	-0.4	275	0.4
6	2	0	0.7	-0.1	351	0.7
7	3	0	0.6	-0.0	357	0.6
8	13	2	0.0	-0.2	273	0.2
9	4	0	0.3	-0.2	317	0.4
10	13	0	0.2	-0.6	284	0.6
11	18	1	0.1	-0.5	279	0.5
12	3	0	0.2	-0.3	305	0.3

SITE: Puerto Rico
10 DEGREE SQUARE: 1008
1 DEGREE SQUARE: 75
1/4 DEGREE SQUARE: 2

Month	Total Observations	Number of Calms	North Comp.	East Comp.	Resultant Direction	Resultant Speed
1	13	2	0.3	-0.3	317	0.4
2	16	0	0.1	-0.2	303	0.2
3	16	0	0.1	-0.1	298	0.1
4	10	1	0.1	-0.2	298	0.2
5	19	4	0.0	-0.3	272	0.3
6	7	2	0.0	-0.2	273	0.2
7	2	0	0.0	-0.0	315	0.0
8	11	0	0.1	-0.3	282	0.3
9	22	1	0.1	-0.2	302	0.3
10	17	0	0.1	-0.1	309	0.2
11	13	1	0.1	-0.5	283	0.5
12	4	0	0.1	-0.6	276	0.6

Table 15. Surface current data for Puerto Rico (SCUDS).

SITE: Puerto Rico
10 DEGREE SQUARE: 1008
1 DEGREE SQUARE: 75
1/4 DEGREE SQUARE: 3

Month	Total Observations	Number of Calms	North Comp.	East Comp.	Resultant Direction	Resultant Speed
1	11	0	0.0	0.0	85	0.0
2	13	1	0.1	-0.2	301	0.3
3	6	0	0.3	-0.5	300	0.6
4	5	1	0.0	0.0	52	0.0
5	11	0	0.0	-0.4	275	0.4
6	4	0	0.4	-0.4	309	0.6
7	3	0	-0.2	-0.5	240	0.6
8	8	0	0.5	-0.3	328	0.5
9	10	1	-0.1	-0.4	251	0.4
10	9	0	0.0	-0.3	275	0.3
11	9	2	0.0	-0.4	273	0.4

SITE: Puerto Rico
10 DEGREE SQUARE: 1008
1 DEGREE SQUARE: 75
1/4 DEGREE SQUARE: 4

Month	Total Observations	Number of Calms	North Comp.	East Comp.	Resultant Direction	Resultant Speed
1	11	0	0.0	-0.1	308	0.1
2	13	1	0.1	-0.2	306	0.2
3	9	0	-0.0	-0.1	269	0.1
4	13	2	0.0	-0.3	275	0.3
5	6	2	-0.1	-0.1	208	0.2
6	1	0	0.5	0.0	360	0.5
7	3	0	-0.0	-0.2	264	0.2
8	11	0	0.2	-0.1	310	0.2
9	15	2	0.2	-0.2	309	0.3
10	9	0	0.1	-0.2	303	0.2
11	15	2	0.1	-0.3	281	0.3
12	3	1	-0.1	0.0	180	0.1

Oceanographic Data Center (NODC). These tables are reproduced from Lee, et al. (1978). The data show the surface drift range as being from WSW to NW at 20 to 80 cm/sec with NW currents of about 40 cm/sec as average. Easterly flows have also been reported (Atwood, et al. 1976, and Lee, et al. 1978).

Very few water current measurements have been made near Punta Tuna. Burns and Car (1975) reported current measurements in the southeast part of Puerto Rico. Figure 2 indicates the location at which their arrays were moored. Tables 16 and 17 show the results reported by Burns and Car (1975) that apply to this study, as do Figures 37-40. Speed direction histograms are shown in the figures. Mean currents from 2 to 15.7 cm/sec were measured at depths ranging from 100 m to 1910 m over the three arrays. Direction of currents varied from 001 degrees (°T) to 349 degrees (NW) including all quadrants of the compass. In Array 11 (Lat. 17°50' 53"N, Long. 65°47' 37"W), south of Punta Tuna, P.R., a total of 2,722 observations were made at a depth of 220 m (water depth: 1975 m). The direction histogram indicates that about 20% of the direction measurements lie between 240 and 255 degrees in a WSW azimuth. Approximately 75% (cumulative) of the time, the current at this depth moves towards the western quadrants (SW, NW). Speeds ranged form 5-35 cm/sec; 34.7% of the time the current speed was about 15 cm/sec. For this array and depth, the authors found the mean current to be 15.7 cm/sec towards 252°. Progressive vectors and spectral energy diagrams are shown in the Burns and Car (1975) publication for all three arrays.

Current measurements in Array 14 (Lat. 17°52'53"N, Long. 65°54'38"W) were made at depths of 100, 105, 810, 1905, and 1910 m at ten minute intervals (Figures 38 and 39). Current direction fluctuates around the compass at all depths, the most frequent direction being towards the western quadrant (210°-300°). Speeds ranged from 0 to 30 cm/sec at the 100 and 105 m levels, and from 0-10 cm/sec at the 810 and 1905 m depths. The records show a definite current speed profile that changes with depth. For this array, the mean current at 100 m and 105 m was 4.4 cm/sec (250°) and 4.9 cm/sec (265°) respectively. The mean current at 810 m was 4.2 cm/sec toward 260°.

Current statistics in Array 14A (closer to Vieques than to Punta Tuna) show variations from Arrays 11 and 14. The location of Array 14A is at 17°58'24"N, 65°37'46"W; the station lies northeast of stations 14 and 11. Direction histograms (Figure 40) indicate that at 240 m depth, 70% of the measured water direction was toward the northwest quadrant. Speeds range between 0 and 25 cm/sec with a mean of about 10 cm/sec. At a depth of 605 m the direction is mostly to the northeast quadrant at speeds ranging from 0-20 cm/sec and a mean of about 5 cm/sec. The actual mean current at 240 m and 605 m

Table 16

DESCRIPTION OF CURRENT METER MOORING ARRAYS,
(after Burns and Car, 1975, Table 1).

ARRAY	FILM SERIAL	SAMPLE DEPTH (M)	WATER DEPTH (M)	LAT. N			LONG. W			INTERTIAL PERIOD (HOURS)	START TIME (Z) HOUR,DAY,MO,YR	USABLE RECORD (HOURS)	SAMPLING INTERVAL (MINS)
				0	1	11	0	1	11				
14	566	100	1915	17	52	53	65	54	38	39.08	1800,30,03,67	360	10
	569	105									1800,30,03,67	354	10
	571	810									1800,30,03,67	356	10
	567	1905									1800,30,03,67	354	5
	568	1910									1800,30,03,67	297	10
14A	544-	240	1430	17	58	24	65	37	46	38.89	1900,16,12,68	1249	20
	545	605									1900,16,12,68	286	20
	546	1335									1900,16,12,68	1245	20
	543	1420									1900,16,12,68	1242	20

NOTE: Mooring Type-Taut Line with Subsurface Buoy(s)-All Arrays

Table 17. (after Burns and Car, 1975, Table 2).

MEAN CURRENT SPEED AND DIRECTION AT CURRENT METER MOORINGS

ARRAY	DEPTH (M)	CM/SEC			DIRECTION (°T)
		E-W	N-S	SPEED	
14	100	-4.2	-1.5	4.4	250
	105	-4.9	-0.4	4.9	265
	810	-4.2	-0.7	4.2	260
	1905	-0.2	0.4	0.4	339
	1910	0.0	0.7	0.7	001
	240	-7.6	2.6	8.0	289
	605	4.7	2.6	5.4	061
	1335	-0.1	0.5	0.5	349
	1420	3.4	2.6	4.3	053

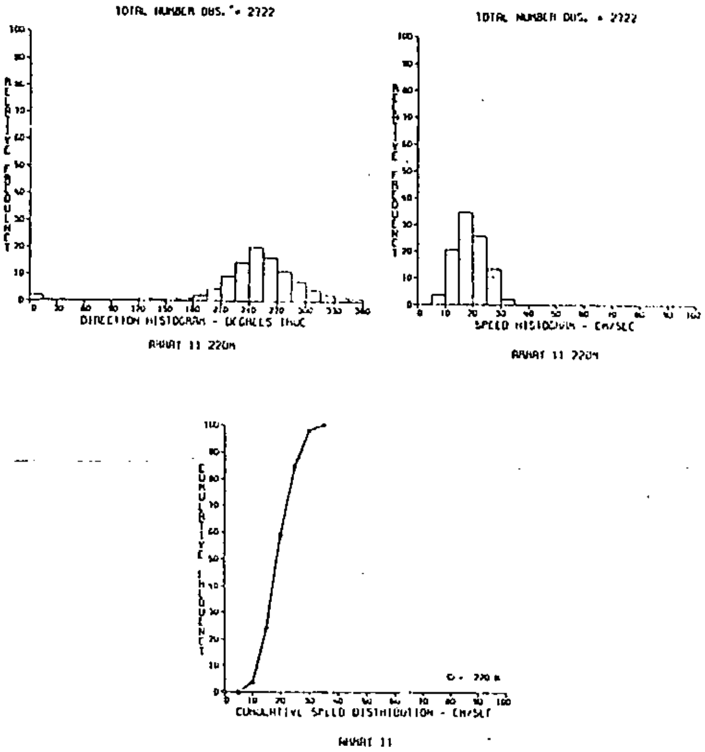


Figure 37. Relative frequency of occurrence of direction and speed values for 220 m deep current meter at Array 11 (after Burns and Car, 1975).

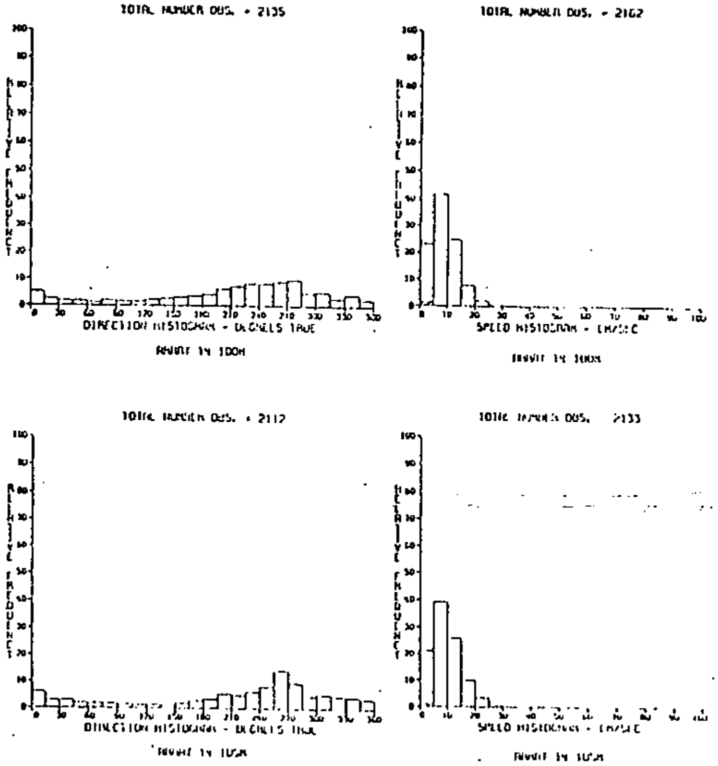


Figure 38. Relative frequency of occurrence of direction and speed values for 100 m and 105 m deep current meters at Array 14 (after Burns and Car, 1975).

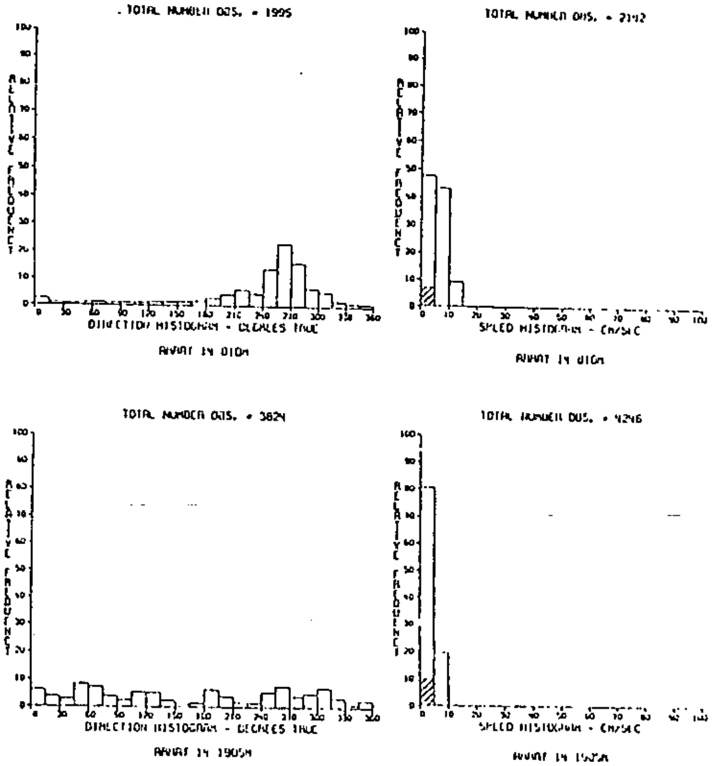


Figure 39. Relative frequency of occurrence of direction and speed values for 810 m and 1905 m deep current meters at Array 14 (after Burns and Car, 1975).

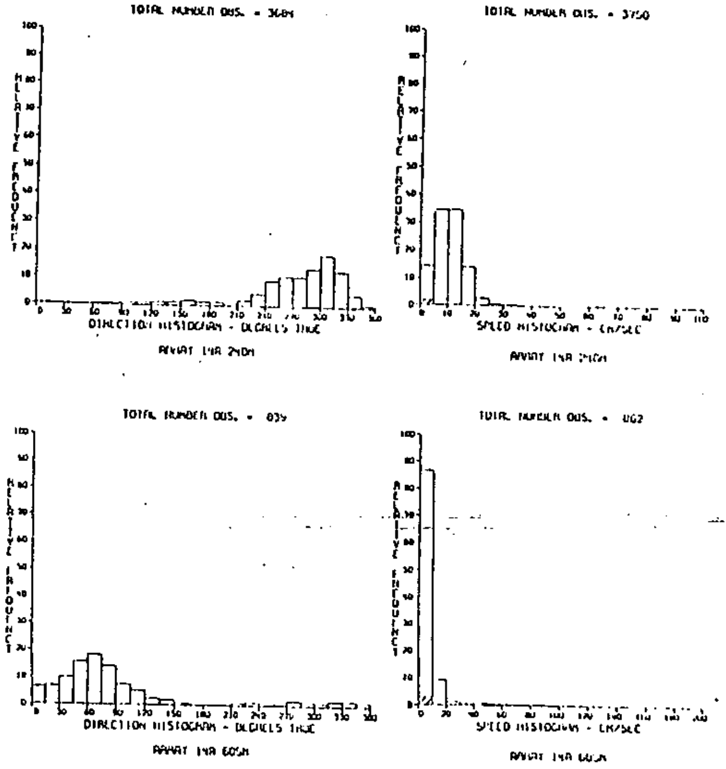


Figure 40. Relative frequency of occurrence of direction and speed values for 240 m and 605 m deep current meter at Array 14A (after Burns and Car, 1975).

was found to be 8.0 cm/sec (289°) and 5.4 cm/sec (061°) respectively. The direction was seen to be significantly variable at depths below 1335 m. The histograms show the number of observations in any direction about equal throughout the compass. Speeds at these depths are below 10 cm/sec 90% of the time.

Oser and Freeman (1969) report the installation of two deep-water current meter arrays in the area during December of 1968. The arrays were located between Vieques and Punta Tuna in about 1000 m and 1500 m deep water respectively. The generalized results of these arrays are that the upper meters (at about 300 m depth) recorded up to 25 cm/sec as a maximum speed, and the primary direction was westerly. A meter at about 600 m showed a maximum speed of about 50 cm/sec, with the primary direction indicated as northeast. The 1000 m deep meters show northwest and east as the two primary directions, with about 15 cm/sec as the maximum speed. No other information is given for these measurements.

Ostericher (1967) also reports both current meter and drogue measurements were made just south of Punta Tuna in 1967. The current meter data is not given in the report, but may be in the naval archival files. The drogue data indicate that a general west or southwest drift is seen in the surface waters during up to six hours of observations.

Predictions of reversals of deep water currents in the Punta Tuna sector and the northern Caribbean Sea have also been reported by Atwood, et al. (1976), based on the dynamic height method of calculation. Figure 31 in Atwood, et al. (1976) shows the subsurface current profiles extracted from the SP189 II publication. In station 41, their closest location to the Punta Tuna site, the current profile indicates water movement towards the northeast at a depth of about 600 m, while above 500 m and below 800 m the current direction is westward at speeds approaching 52 cm/sec (1 kt). Station 42, west of Punta Tuna, and station 40 to the north, show steady westward flow along the water column to depths of approximately 900 m. Geostrophic velocities, as calculated by Atwood, et al. (1976) along a transect extending from Puerto Rico to the coast of Venezuela (Figure 32 in the original publication), indicate an eastward flow in June 1972, between Lat. 17° and 16°N, at speeds reaching above 20 cm/sec in the near surface waters and 5 cm/sec at approximately 500 m depth. Further to the south, the current direction is westward. The October 1972 geostrophic velocity calculations show westward flow near the coasts of Puerto Rico and Venezuela and an eastward flow in the center of the Caribbean Sea.

Ekman currents analyses were made by Bretschneider (1977) for all the proposed OTEC sites; this is a comprehensive work in which calculations have been performed, taking into consideration wind speeds, design wave heights, significant periods, and depth intervals down to about 150 m. Bretschneider's calculations also indicate wind drift current flow reversals below 100 m depending on sea state. Velocities ranged from 78.98 cm/sec at the surface (for a 100-year exceptional hurricane) to .09 cm/sec at 100 m depths for sea state 4 (wind speeds of 17 knots, 5-ft wave heights and a wave period of 5.34 seconds). For the 100-year exceptional hurricane there are no current reversals (east) above 350 m.

Although the above reported measurements and calculations have been made in locations near the Punta Tuna OTEC site the resultant variability indicates that further and more precise monitoring of water circulation in this area should be undertaken. The characterization of the water circulation, as needed to evaluate the environmental conditons for an OTEC site, necessarily entails long term observations.

2.9. SALINITY AND TEMPERATURE DISTRIBUTION

The seasonal salinity and temperature distribution in the Caribbean Sea has been reported and reviewed by Dietrich (1939), Wust (1963), Sturges (1965), Fukuoka (1965), Worthington (1966), Gordon (1967), Perlroth (1971), Sands, et al. (1978), Hamnski (1975), Shanley and Duncan (1972), Munir, et al. (1978), and Craig, et al., (1978). Hydrographic stations data near the Punta Tuna OTEC site area have been reported by Shanley (1971), Atwood, et al. (1976), Lee, et al. (1978), Oser and Freeman (1969), Ostericher (1967), and Wood, et al. (1975).

2.9.1. Salinity

Salinity profiles measurements at the Punta Tuna OTEC site were performed by Atwood, et al. (1976). Figures 52 to 56 of their report show the salinity profiles at the OTEC site as monitored during four cruises undertaken in September, 1975 and in January, March and May of 1976. These figures are reproduced in this report as Figures 41 to 45. Surface salinities lower than 34.8°/₀₀ were not observed at the site according to these profiles. Also, from Atwood's figures of the individual cruises, as well as the composite curve (Fig. 45), it is apparent that below the salinity maximum (100-200 m), there is little change in salinity with time, certainly not enough change to affect an OTEC power plant. From this observation, it is clear that the salinity of the upper 200 m is more variable, and consequently of more concern to this study.

The measurements of salinity discussed by Wood, et al. (1975), show similarities with those of Atwood, et al. (1976). The stations visited were about 5 km west of Punta Tuna. For

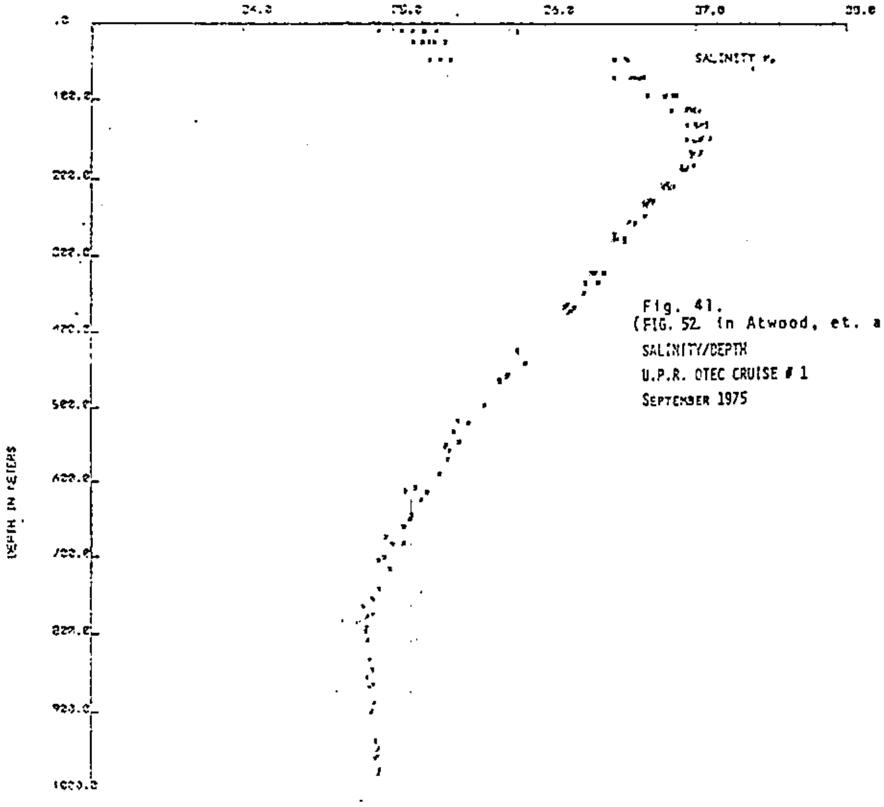


Fig. 41.
(FIG. 52 in Atwood, et. al. 1976).
SALINITY/DEPTH
U.P.R. OTEC CRUISE # 1
SEPTEMBER 1975

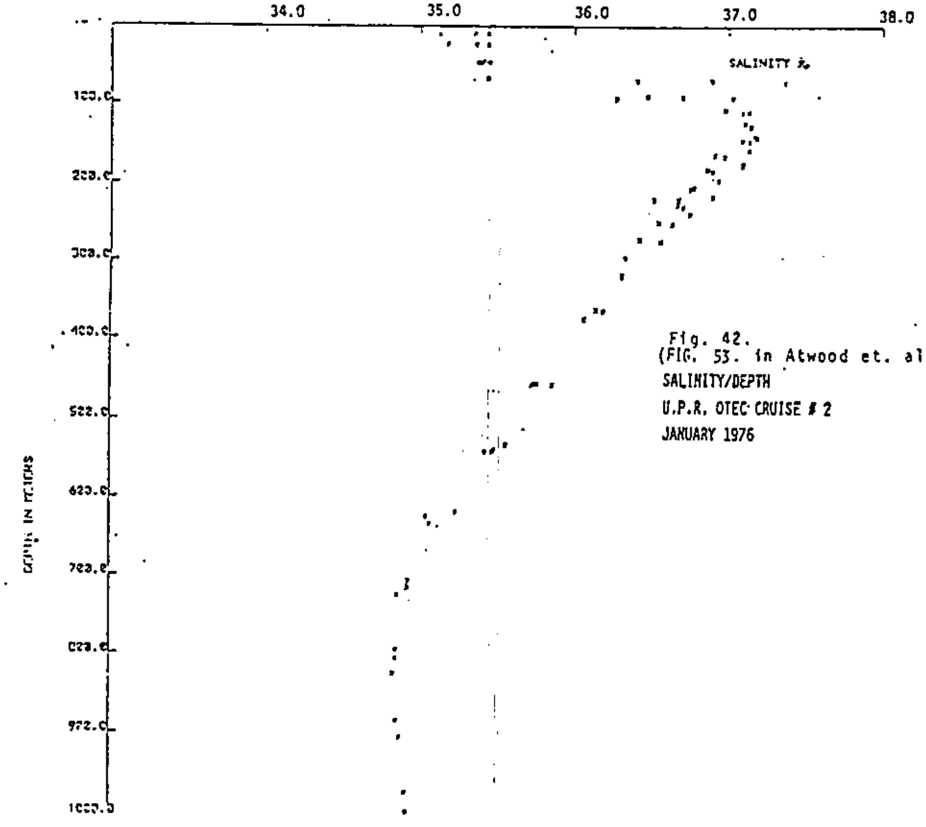


Fig. 42.
(FIG. 53. in Atwood et. al. 1976)
SALINITY/DEPTH
U.P.R. OTEC CRUISE # 2
JANUARY 1976

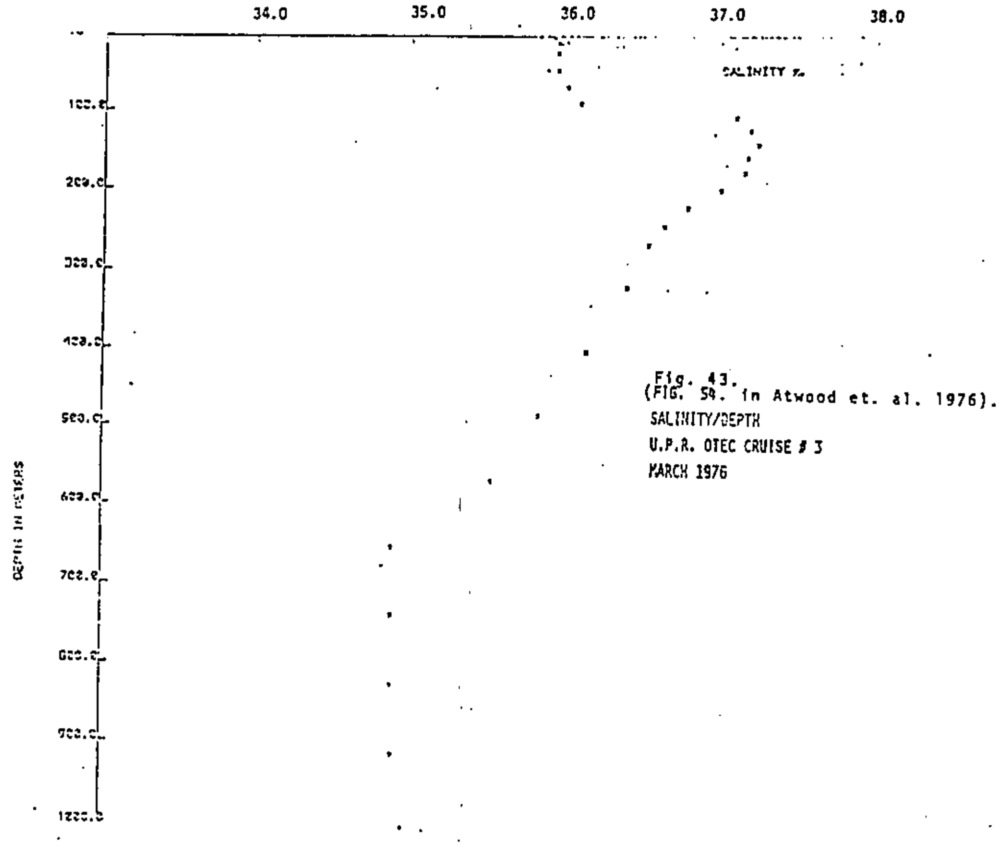


Fig. 43.
(FIG. 54. in Atwood et. al. 1976).
SALINITY/DEPTH
U.P.R. OTEC CRUISE # 3
MARCH 1976

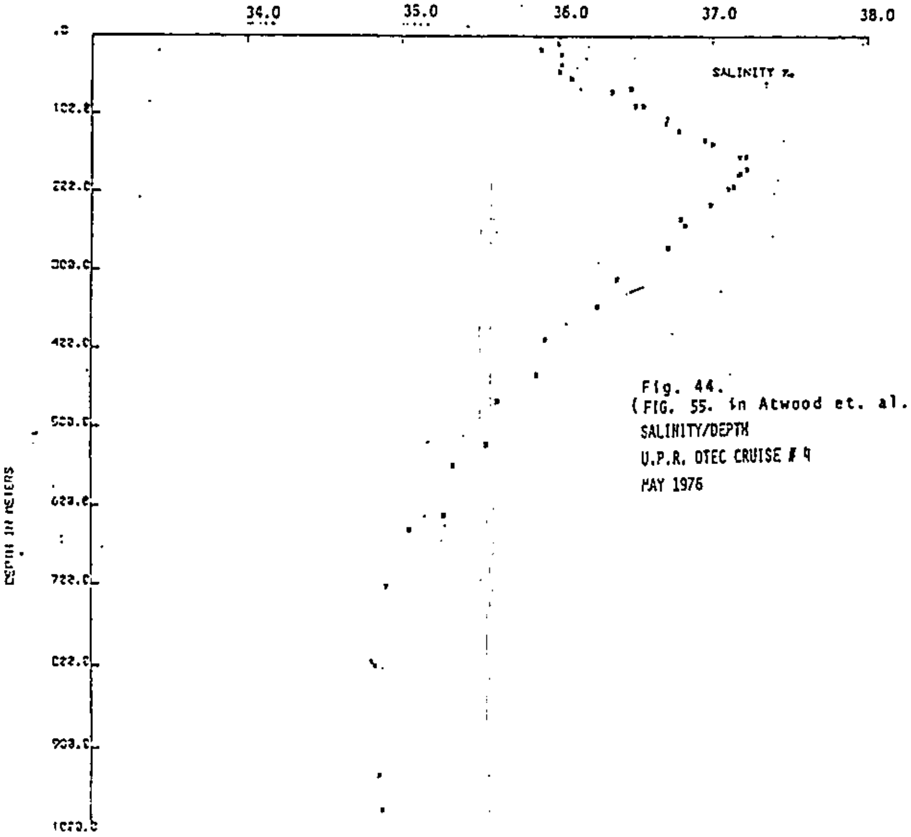


Fig. 44.
(FIG. 55. in Atwood et. al. 1976).
SALINITY/DEPTH
U.P.R. OTEC CRUISE # 4
MAY 1976

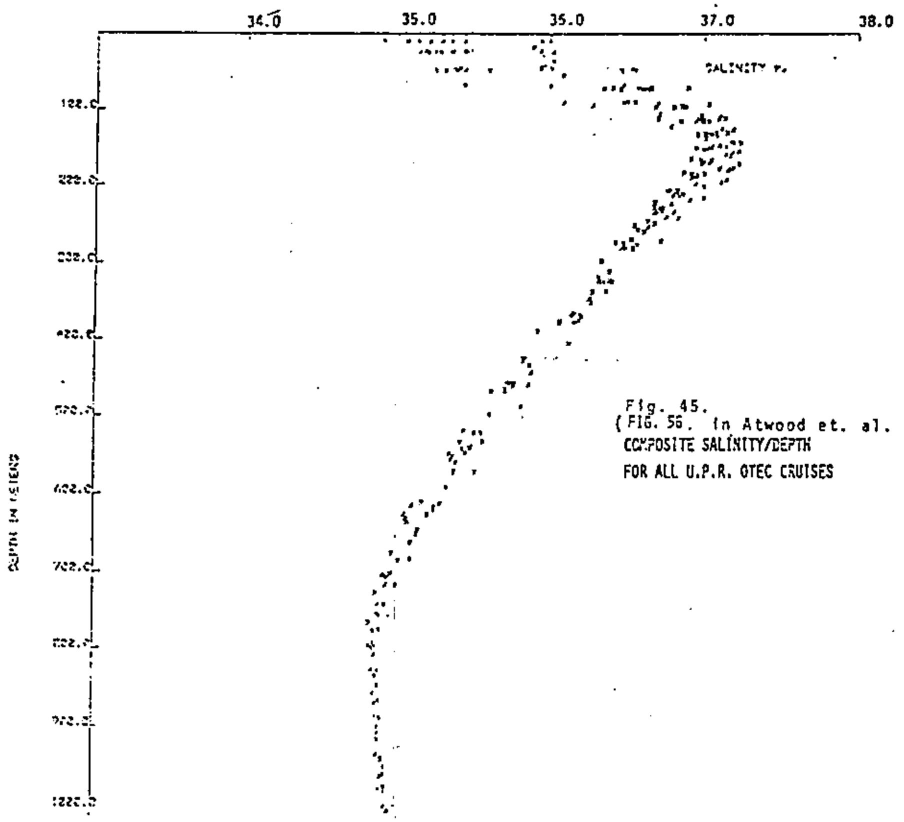


Fig. 45.
(FIG. 56. In Atwood et. al. 1976).
COMPOSITE SALINITY/DEPTH
FOR ALL U.P.R. OTEC CRUISES

the surface salinity, Wood, et al. (1975), found values of about 35.7°/₀₀, 35.7°/₀₀, 35.5°/₀₀, and 33.5°/₀₀ for winter, spring, summer, and fall, respectively during 1973-1974. These data do not differ greatly from those of Atwood, et al. (1976), except for the intrusion of fresh water, lowering the salinity in the fall, as seen by Wood et al. As this is the peak of the rainy season, the reduction is not unexpected.

Ostericher (1976) took 7 hydrocasts in the Punta Tuna area in April, 1967. During that time, he found the surface salinity to vary from 36.30°/₀₀ to 36.35°/₀₀. These values tend to be somewhat higher than those of Atwood or Wood.

Oser and Freeman (1969) discussed their measurements of salinity made in the Punta Tuna area in December, 1968. Their measurements showed a surface salinity range of 34.71°/₀₀ to 34.81°/₀₀. These lower values again occurred at the end of the rainy season, and are not unexpected. They lie between those appearing in the Atwood and Wood studies.

Table 18 shows the summary of surface salinity values seen by Shanley and Duncan (1972) during 1971. The overall values range from 34.18°/₀₀ in October to 36.00°/₀₀ in March. These values were measured at one of two stations south of Puerto Rico which were visited monthly. Table 19 shows the summary of NODC-collected data (Munier, et al., 1978) from 1953-1968. (Appendix II contains the original NODC data). Munier shows the surface salinity ranging from 33.51°/₀₀ in August of 1967 to 36.45°/₀₀ in April, 1953.

Figure 46 graphically shows a seasonal summary of both Shanley and Duncan (1972) and Haminski (1975). Although the high values that have been measured over the years do not vary much seasonally, the low values have been measured as low as 25°/₀₀, due to rainfall, runoff, and source-water dilution by the Amazon and Orinoco Rivers.

The value of the depth of the salinity maximum, which occurs within the core of the Subtropical Underwater, gives an indication of the water mass structure. This water mass, usually located close to the thermocline, has the highest salinity in all the Caribbean, regardless of depth. Again, Tables 18 and 19 give the values of this salinity maximum, with their observed depths. The total range seen for all these measurements is from 36.88°/₀₀ to 37.14°/₀₀. The salinity may not actually have changed to the extent indicated, as the inability to locate the absolute maximum is probably the cause for the variation. The depth range of the maximum is more apparent, with the listed values ranging from 100 m to 187 m. This variation may be another manifestation of the inability to locate the exact maximum, but the depth is also related to the atmospheric pressure above the water: lower pressure tends to draw the lower water closer

Table 18

Summary of Surface and Maximum Salinity Data Reported by Shanley and Duncan (1972)

Month	Surface Salinity Range	Average Sed Max. and Depth
Jan. 1971	35.13-35.33°/oo	37.05°/oo (144 m)
Feb. 1971	35.73°/oo	37.04°/oo (147 m)
Mar. 1971	35.84-36.00°/oo	37.02°/oo (145 m)
April 1971	35.80-35.99°/oo	36.96°/oo (144 m)
May 1971	35.96°/oo	36.91°/oo (149 m)
June 1971	35.17-35.90°/oo	36.95°/oo (148 m)
July 1971	35.72°/oo	36.93°/oo (150 m)
Aug. 1971	35.17°/oo	36.89°/oo (121 m)
Sept. 1971	34.93°/oo	36.88°/oo (164 m)
Oct. 1971	34.18-34.21°/oo	36.91°/oo (158 m)
Nov. 1971	34.41-34.86°/oo	---
Dec. 1971	34.54-34.89°/oo	36.93°/oo (148 m)

Table 19

Summary of NODC Nansen Cast Salinity Data for Puerto Rico*

Month	Station	Depth (m)	Salinity (‰)	OBS.
Feb. 1960	PR-1	SFC	35.72	
		150	36.94	MAX.
		4505	34.97	
Mar. 1955	PR-2	SFC	35.78	
		141	37.01	MAX.
		1818	34.99	
Apr. 1953	PR-3	SFC	36.45	
		133	37.01	MAX.
		2610	35.03	
May 1962	PR-4	SFC	35.96	
		100	36.93	MAX.
		1986	35.14	
Aug. 1967	PR-5	SFC	33.51	
		187	36.95	MAX.
		3876	34.98	
Sept. 1963	PR-6	SFC	34.46	
		150	36.90	MAX.
		3936	34.97	
Oct. 1964	PR-7	SFC	34.39	
		160	36.97	MAX.
		4651	34.97	
Nov. 1962	PR-8	SFC	34.42	
		114	37.14	MAX.
		1092	34.94	
Dec. 1968	PR-9	SFC	34.78	
		100	36.90	MAX.
		1984	34.97	

*After Munier, et. al. (1978).

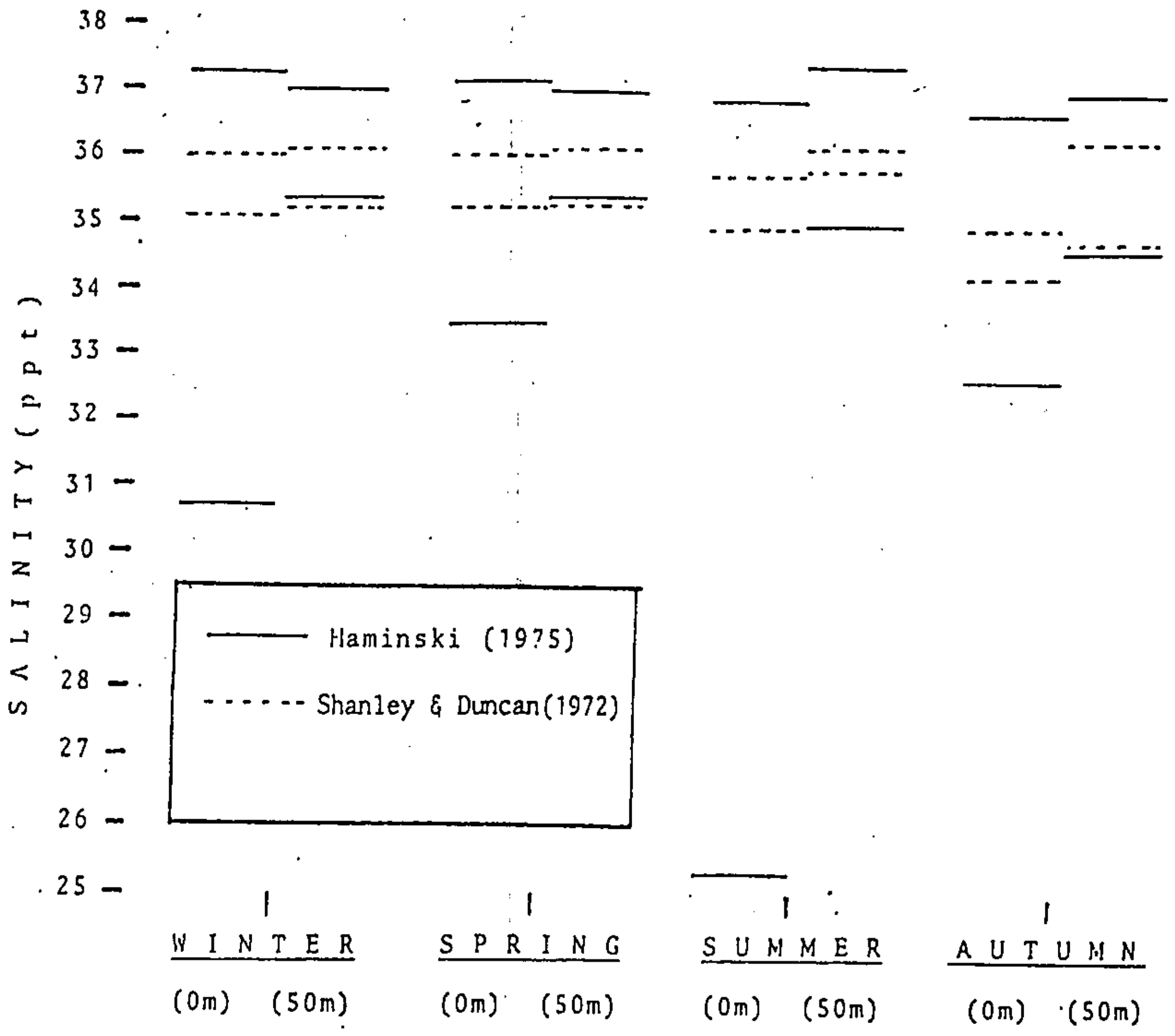


Figure 46. Seasonal summaries of salinity near Punta Tuna, after Shanley and Duncan (1972) and Haminski (1975).

to the surface, exposing more of the higher salinity water to surface conditions.

2.9.2. Temperature

Some upper water temperature measurements have been made in the northern Caribbean Sea near Puerto Rico, but not many. The temperature profiles for the oceanic area near the Punta Tuna OTEC site are shown in Appendix B. These profiles are constructed from NODC computer data-listings up to 1977. Figure 47 indicates the geographical sectors, divided into 5-minute squares, in which the area was partitioned to construct the composite temperature profiles in Appendix B.

An analysis of the surface temperature range from these profiles indicates the minimum recorded value was 24.7°C, seen in February, 1971 (Square 14), and the maximum recorded was 30.7°C, seen in September, 1971 (Square 10). In that year the surface temperature varied by 6.0°C.

Figure 48 shows the NODC data processed and averaged by ODSI (1977). The average surface temperature usually varies from slightly more than 26°C in October. This implies an average annual variation of only about 3°C.

Table 20, after Craig et al. (1978), tabulates an observed temperature for each month of the year. The data source extends from 1953 to 1968. Again, the low value is seen in February, but the highest value is seen in September. Another fact seen in this table is that the temperature maximum does not always occur at the surface, but may actually be seen up to 50 m below the surface. Table 21, showing typical temperatures reported by Shanley and Duncan (1972) has similar trends, with the highest temperature seen in September, and lowest in March. The maximum temperature frequently occurred at the surface, but during the cooler, winter months, the maximum was often as much as 50-70 m below the surface.

In the Caribbean Sea, near Punta Tuna, the top of the thermocline is usually found between 80-100 m. The bottom of the thermocline usually is located about 260 m below the surface. Atwood, et al. (1976) indicates that a wedge of warm water is always found in the northern Caribbean Sea. They conclude from the data that:

> "The 25°C isotherm lies at about 100 meters, with small durations. This ensures a thick warm surface layer which is accentuated in the summer months by an increase in temperature of the water above 100 meters to as much as 29°C."

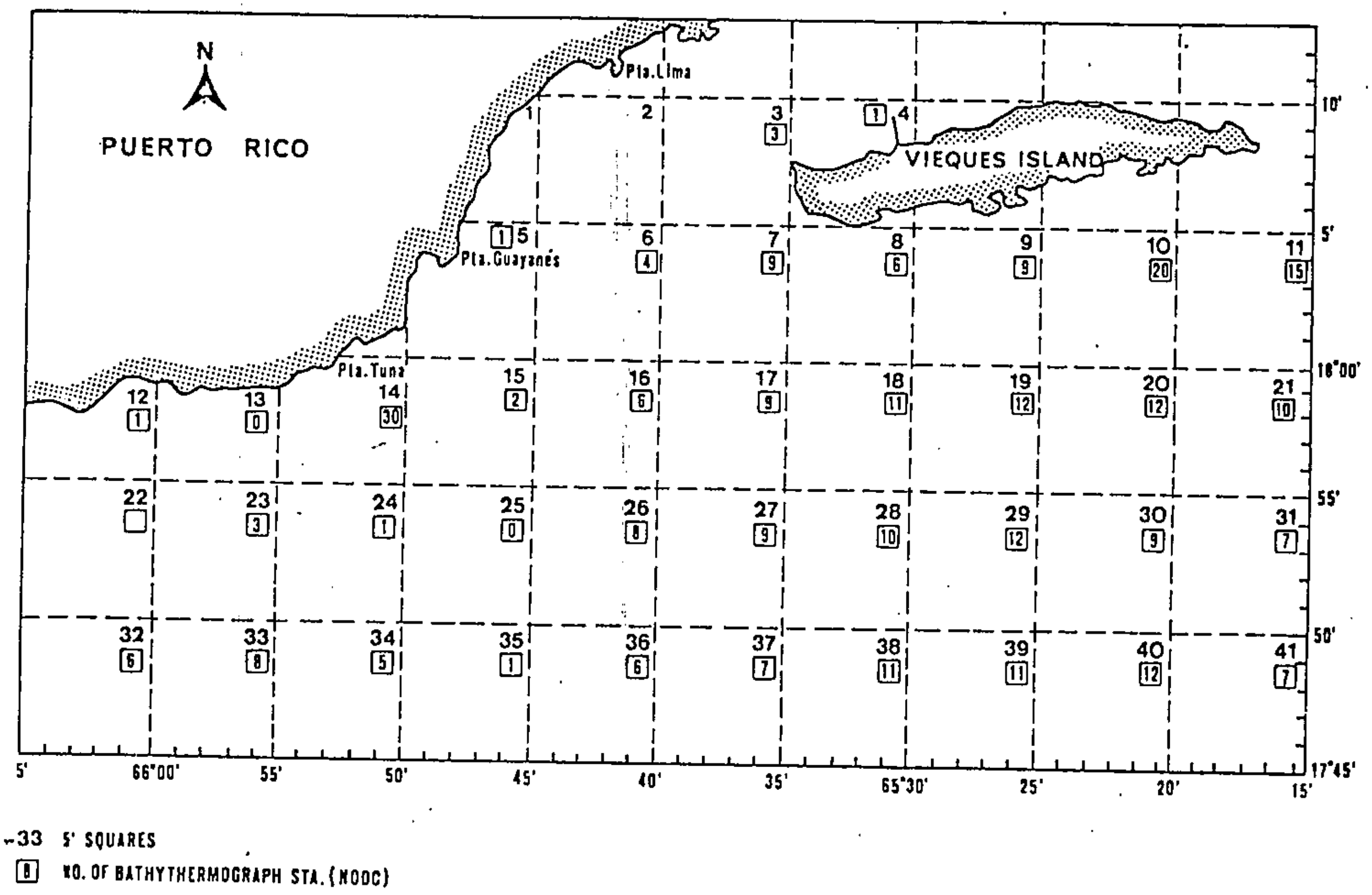


Figure 47. Location of 5' Squares to construct temperature profiles.

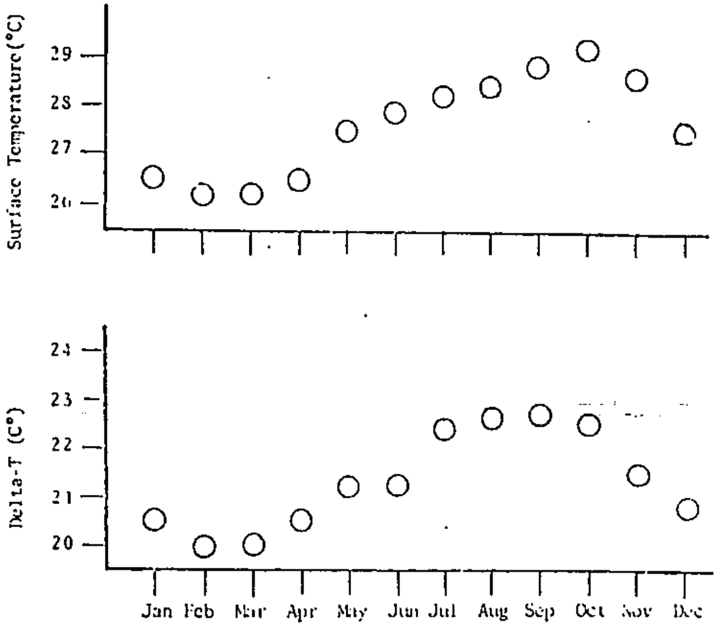


Figure 48. NODC temperature data as processed and averaged by ODSI (1977).

Table 20

Summary of NODC, Nansen Cast Temperature Data for Puerto Rico*

Month	Station	Depth (m)	Temp. (°C)	(T C°) (Surf.-1000 m)	OBS
Feb. 1960	PR-1	SFC	26.57		
		55	26.80		MAX.
		1000	5.28	21.29	
Mar. 1955	PR-2	SFC	25.00		
		20	25.02		MAX.
		1000	5.21	19.79	
Apr. 1953	PR-3	SFC	26.16		MAX.
		1000	5.53	20.63	
May 1962	PR-4	SFC	27.33		MAX.
		993	5.13	22.20	
Aug. 1967	PR-5	SFC	28.37		MAX.
		1000	5.21	23.16	
Sept. 1963	PR-6	SFC	28.67		
		24	28.80		MAX.
		1000	5.18	23.49	
Oct. 1964	PR-7	SFC	28.54		MAX.
		1000	5.20	23.34	
Nov. 1962	PR-8	SFC	28.59		
		45	28.67		MAX.
			5.56	23.03	
Dec. 1968	PR-9	SFC	27.78		
		10	27.81		MAX.
		1000	5.27	22.51	

*After Craig et al. (1978)

Table 21

Typical Temperatures of the Caribbean Sea, South of Puerto Rico after Shanley and Duncan (1972)

Month	Surface Temp. (°C)	Max. Temp. (°C)	1000 m Temp. (°C)	(T Surface-1000 m) (°C)
January	26.36	26.48 (74 m)	5.52	20.84
February	25.91	25.91 (0 m)	5.59	20.32
March	25.82	25.88 (73 m)	5.31	20.51
April	26.20	26.21 (10 m)	5.44	20.76
May	27.70	27.70 (0 m)	5.35	22.35
June	27.77	27.77 (0 m)	5.35	22.42
July	27.82	27.93 (9 m)	5.48	22.34
August	28.21	28.21 (0 m)	5.51	22.70
September	29.09	29.09 (0 m)	5.58	23.51
October	28.17	28.17 (0 m)	5.51	22.66
November	28.03	28.03 (0 m)	---	---
December	27.40	.84 (49 m)	5.53	21.87

2.9.3. Mixed Layer Depth

This parameter is important both to design engineers and to environmentalists. The designers must use great volumes of water to run the power plant. The plant intake openings will have some non-zero vertical dimensions. The designers must know to what depth they can reach to maintain the same surface water characteristics, with little or no chance of the intrusion of subsurface water to reduce the thermal efficiency or to change the water chemistry in other ways. The environmentalists are aware that the upper mixed layer is usually identified with the Tropical Surface Water, the upper water mass in the Caribbean Sea. This water has certain ranges of temperature, salinity, and light transmission. Also, many organisms spend much of their life in, or reacting to, this water mass. If this water mass is altered unnaturally, by the presence of one or many OTEC plants, this may affect the natural balance between predator and prey, or between flora and fauna, in ways we cannot even begin to understand.

The actual definition of Mixed Layer Depth (MLD) varies from person-to-person, group-to-group. Molinari and Chew (1979) define the MLD as "the depth to the center of the first depth interval in which the temperature changes by 0.3°C." This definition is very tight in terms of temperature, but leaves much room for ambiguity in the definition of the other words used. Sands, et al. (1978) on the other hand, uses a definition that is easier to understand and use, but not as thermally restrictive. Sands says that the MLD is the depth where the temperature drops 1C° from that of the surface value. Unfortunately, the latter definition could result in a great loss of thermal efficiency in an OTEC power plant. The MLD may also be defined in terms of salinity instead of temperature (Lee, et al., 1978).

Using the thermal criterion of Sands, a drop of 1C° from the surface value, we can whow how the depth of the MLD has ranged over the years, using the historical data of ODSI (1977). The criterion of a change of 1C° is not difficult to justify, since usually the temperature is invariant with depth to the lower limit of the MLD. At that point the temperature undergoes a great change within a small vertical distance overcoming both the 0.3C° and the 1C° criteria at about the same depth.

Figure 49 shows the results of the data compiled by ODSI (1977). Shown in the figure are the most probable values and the maximum and minimum values seen in the literature. The general trend is for the maximum depth of the MLD to be greater in the winter months, and then to rise in the spring and summer. The late summer and fall months are times of water mixing with severe storms occurring most frequently

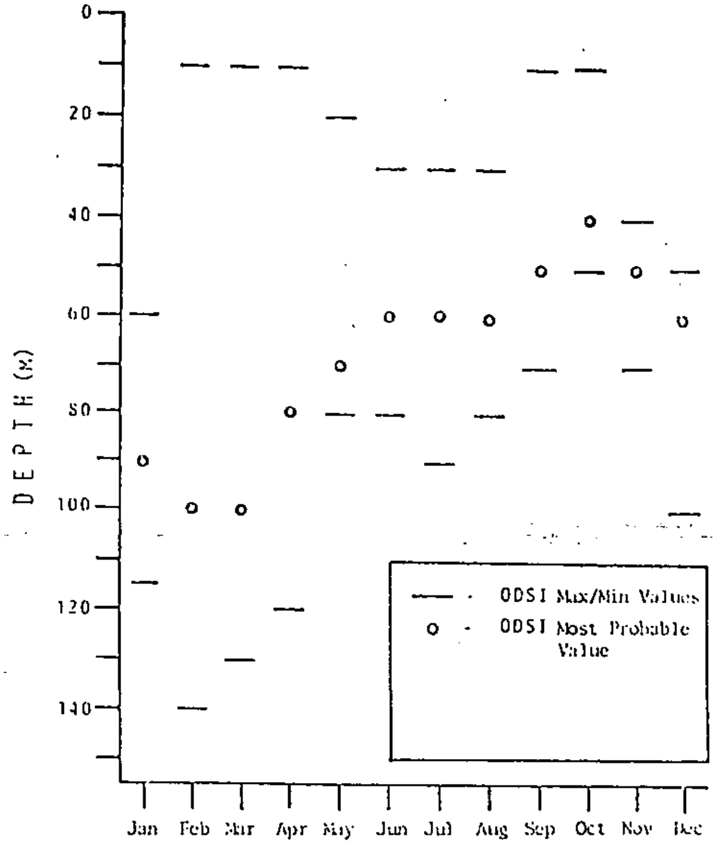


Figure 49. Most probable, maximum, and minimum values of Mixed Layer Depth (after ODSI, 1977).

during this time, but again, the MLD starts to show a decrease toward the winter values.

2.9.4. Thermal Resource

Although this parameter is discussed last, it is the single most important parameter in an OTEC power plant. The plant is designed to maximize efficiency depending on the value of the thermal resource, and how the thermal resource changes throughout the year.

The thermal resource is the heat energy available between the surface mixed layer and the deep, cold water. Usually, the practical definition of the thermal resource is the temperature difference (Delta-T), in Centigrade degrees, between the surface water and the water at 1000 m depth.

Many authors have discussed this parameter directly (Atwood, et al., 1976; Wolff, 1978; Sands, et al., 1978, and ODSI, 1977). As most of the authors tended to use the same sparse data, and ODSI compiled the results, Figure 48 shows the values discussed by ODSI. In the figure, the average values of the thermal resource (Delta-T from surface to 1000 m) are given for each month. The values for the Punta Tuna area range from about 20°C to about 23°C throughout the year.

Tables 20 and 21 show the observed 1000 m depth temperature both for the Craig, et al. (1978) computation, and for the Shanley and Duncan (1972) data. In the Craig data, the 1000 m temperature varied by less than 0.40°C over 15 years. The Shanley and Duncan data show a variation of less than 0.30°C. These small variations may be real, or merely measurement errors, but both confirm that the Thermal Resource will tend to vary with the surface temperature, with little apparent change in the cold water temperature. This is also shown in Figure 48, where the thermal resource seems to follow the surface temperature values. Therefore, the surface temperature itself may be a good indication of the available thermal resource.

2.10. REFERENCES

Aftring, R. P., et al. 1978. Biofouling and site characterization studies in the ocean thermal energy conversion (OTEC) experiment at St. Croix, U. S. Virgin Islands. U. M. Report to DOE, Battelle Pacific Northwest Labs. and Tracor Marine.

Atwood, D. P., P. Duncan, M. Stalcup & M. Barcelona. 1976. Ocean thermal energy conversions: Resource assessment and environmental impact for proposed Puerto Rico site. Final Report. NSF Grant #AER75-00145, U.P.R., Dept. of Marine Sciences, Mayaguez, P. R. 104 p.

Bane, G. W. Jr. 1965. Results of drift bottle studies near Puerto Rico. Caribb. J. Sci. 5(3/4): 173-174.

Bretschneider, C. L. 1977. Design wave and current criteria for potential OTEC sites. Draft, ERDA SOLAR-OTEC Contract (Preliminary copy).

Brucks, J. T. 1971. Currents of the Caribbean and adjacent regions as deduced from drift-bottle studies. Bull. Mar. Sci. Miami 21(2): 455-465.

Brucks, J. T. 1971. The current east of the Windward Islands, West Indies. Symp. Invest. and Res. of the Caribb. Sea and Adj. Reg. UNESCO 18-26 Nov. 1968 Curacao: 31-36

Burns, D. A. 1977. The oceanographic and meteorological environment west of St. Croix Physical Oceanography Div. Naval Oceanography Lab. NORDA Report #13, 81 pp.

Burns, D. A. and M. Car. 1975. Current meter data report for the eastern part of the Caribbean Sea. Naval Oceanographic Office, TN6110-6-75, Washington, D. C.

Colón, J. A. 1963. Seasonal variations in heat flux from the sea surface to the atmosphere over the Caribbean Sea. J. Geoph. Res. 68(5): 1421-30.

Coston, J. M. 1968. Direct current measurements in the Antilles Current. J. Geoph. Res. 73(10): 3341-44.

Craig, H. L., T. Lee, H. B. Michel, S. C. Hess, R. Munier, and M. Perlmutter. 1978. S source book of oceanographic parameters affecting biofouling and corrosion of OTEC plants at selected sites. Rosentiel School of Marine and Atmospheric Science, Univ. of Miami. TR 78-1.

Deane, C. 1974. Wave climate in the eastern Caribbean. Proc. of International Symposium on Ocean Wave Measurement and Analysis, Sept. 9-11, New Orleans, LA., p. 214-232.

Defant, A. 1961. Physical Oceanography, Vol. II. Pergamon Press, N.Y., 598 pp.

Dietrich, G. 1939. Das Amerikanische Mittelmeer. Gesellsch. f. Erdkunde zu Berlin. 3-4, p. 108-130.

Dietrich, G. 1963. General Oceanography, an Introduction. Wiley and Sons, N.Y. 588 pp.

Frassetto, R. & J. Northrop. 1957. Virgin Island bathymetric survey. Deep-Sea Res. 4:138-146.

Froelich, P., D. A. Atwood, J. Polifka. Seasonal variations in the salinity-silicate structure of the Upper Venezuela Basin, Caribbean Sea. Trans. Amer. Geophs. Union, 55(4): 309.

Froelich, P. N., and D. K. Atwood. 1974. New evidence for sporadic renewal of Venezuela basin water. Deep-Sea Res. 21(11): 969-975.

Fukuoka, J. A., A. Ballester & F. Cervigon. 1964. An analysis of hydrographical conditions in the Caribbean Sea III. Especially about upwelling and sinking. Studies on Oceanography, Kidaka Commemoration, 145-149. Univ. of Washington Press, Seattle.

Fukuoka, J. 1965. Hydrography of the adjacent sea (11). Some characteristics of oceanographical conditons in the Caribbean Sea, especially in the region adjacent to Venezuela. Instituto Oceanográfico Universidad de Oriente Cumaná, Venezuela.

Gordon, A. 1965. Quantitative study of the dynamics of the Caribbean Sea. Columbia University doctorate dissertation. New York. 237 pp.

Gordon, A. L. 1967. Circulation of the Caribbean Sea. J. Geoph. Res. 72(24): 6207.

Haminski, S. J. 1975. Temperature, salinity, oxygen and phosphate in waters of Eastern Central America and Northern South America. NODC, Washington D.C. 189 pp.

Hazelworth, J. B. 1968. Water temperature variations resulting from hurricanes. J. Geoph. Res. 73(16): 5105-5123.

Ichiye, Takashi. 1972. Experimental circulation modeling within the Gulf and Caribbean. Tex. A & M Univ. Dept. Oceanography Ref. No. 69-17T.

Kinard, W. F., D. Atwood & G. S. Giese. 1974. Dissolved oxygen as evidence for 18°C Sargasso Sea Water in the Eastern Caribbean Sea. Deep-Sea Res. 21:71-82.

Lee, T. N., R. S. C. Munier and S. Chiu. 1978. Water mass structure and variability north of St. Croix, U.S. Virgin Islands, as observed during the summer of 1977 for OTEC assessment. Technical Report, UM-RSMAS #78004, Univ. of Miami.

Leipper, D. F. 1967. Observed ocean conditions and Hurricane Hilda, 1964. J. Atmos. Sci. 24: 182-196.

Leming, T. D. 1971. Eddies west of the southern Lesser Antilles. Sump. Invest. and Res. of the Caribb. Sea and Adj. Reg. UNESCO 18-26 Nov. 1968. Curacao: 113-120.

Luedeman, E. F. 1967. Preliminary results of drift-bottle releases and recoveries in the western tropical Atlantic. Bolm Inst. Oceanogr. S. Paulo, 16(1):13-22.

Metcalf, W. G. 1959. Oceanographic data from the Caribbean Sea Crawford Cruise 17, Feb-Mar. 1958 for the International Geophysical Year of 1957-1958. Woods Hole Ocean Inst. Refi. 59-9: 1-91. M. S. Unpublished Manuscript.

Metcalf, W. G., and M. C. Stalcup. 1974. Drift bottle returns from the eastern Caribbean. Bull. Mar. Sci. 24(2): 392-395.

Millas, J. 1965. The hurricanes of the Caribbean Sea and adjacent regions during the eighteenth century. University of Miami Final Report to U.S. Weather Bureau, Contract No. Cwb-10938.

Miller, A. R. 1977. Ranges and extremes of the natural environment related to design criteria for ocean thermal energy conversion plants. WHOI Technical Report #WHOI-77-61, 36 pp.

Molinari, R. & F. Chew. 1979. Ocean thermal and current structure in the tropical South Atlantic relative to the placement of a grazing OTEC plant. NOAA. Tech Memo ERL-AOML-35. 57 pp.

Munier, R. S. C., and Craig, H. Lee. 1977. Oceran thermal energy conversion (OTEC) biofouling and corrosion experiment, St. Croix, U.S. Virgin Islands: report on the corrosion task. Submitted to Tracor Marine, Inc., for Battelle Pacific Northwest Laboratories and Department of Energy, 103 pp., UM-RSMAS #78007.

Munier, R. S. C., S. C. Hess, T. N. Lee and H. B. Michel. 1978. A supplement to a source book of oceanographic parameters affecting biofouling and corrosion of OTEC plants at selected sites (St. Croix). Rosenteil School of Marine and Atmospheric Science, Univ. of Miami. TR-78-2.

NOAA, Environmental Data Service. 1974. Environmental guide for the Mona Passage Area, National Climatic Center. Asheville, North Carolina.

Ocean Data Systems Inc. (ODSI). 1977. Ocean thermal resource report for Puerto Rico. ODSI, Monterez, California. 39 pp.

Oser, R. K. & L. J. Freeman. 1969. Oceanographic cruise summary, Vieques Island, Puerto Rico area, December 1968 to March 1969. Naval Oceanographic Office, Washington, D.C. Informal Report IR#69-66.

Ostericher, C. 1967. Oceanographic cruise summary Atlantic Fleet Tactical Underwater Range: Southeast Puerto Rico-1967. Naval Oceanographic Office, Washington D.C. Informal Report IR#67-76, 44 pp.

Parr, Albert E. 1937. A contribution to the hydrography of the Caribbean and Cayman Seas, based upon the observations made by the R.V. Atlantis, 1933-1934. Bull. Bingham Oceano. Coll. 5(4): 1-110.

Parr, A. E. 1938. Further observations on the hydrography of the eastern Caribbean and adjacent Atlantic waters. Bull. Bingham Oceano. Coll 6(4): 1-29.

Perlroth, I. 1971. Distribution of mass in the near surface waters of the Caribbean. SIRCSAR, UNESCO, Paris. pp. 147-152.

Puerto Rico Nuclear Center. 1975. Hydrographic data report for the south coasts of Puerto Rico. PRNC-185, ERDA-UPR, Mayaguez, P.R.

Richards, F. A. & R. F. Vaccaro. 1956. The Cariaco Trench, an anaerobic basin in the Caribbean Sea. Deep-Sea Res. 3: 214-228.

Ross, C. K. & C. R. Mann. 1971. Oceanographic observations in the Jungfern Passage and over the sill into the Venezuela Basin, February 1968. SIRCSAR, UNESCO, Paris. pp. 171-174.

Sands, M.D., M. Andrews, M. K. Howard, M. Smookler, and S. M. Sullivan. 1978. Draft environmental impact assessment-ocean thermal energy conversion (OTEC) pre-operational Ocean Test Platform. Interstate Electronics Corp., Anaheim, Ca. Under contract to U.S. Dept. of Energy #EG-77-C-06-1033. Volume I and II.

Shanley, G. 1972. Hydrographic data for Caribbean Sea and Pesca Serial Station at 17°38'N, 67°00'W for 1971. Dept. Mar. Sci., U.P.R., Mayaguez #72-1.

Shanley, G. E., Rev. by C. P. Duncan. 1972. Hydrographic data for Caribbean Sea and for Pesca Serial Station at 17°38'N, 67°00'W for 1971. Dept. of Marine Sci., UPR, Mayguez #72-1 (REV). 34 pp.

Stalcup, M. C. and W. C. Metcalf. 1972. Current measurements in the passages of the Lesser Antilles. J. Geoph. Res. 77(6): 1032-49.

Stone, R. G. 1942. Meteorology of the Virgin Islands. In: Scientific Survey of Puerto Rico and the Virgin Islands, Vol. XIX, New York Academy of Science, 138 pp.

Sturges, W. 1965. Water characteristics of the Caribbean Sea. J. Mar. Res. 23(2): 147-162.

Sturges, W. 1970. Observations of deep water renewal in the Caribbean Sea. J. Geoph. Res. 75: 7601-7602.

U.S. Department of Commerce. 1959. Climatological and Oceanographic Atlas for Mariners. Vol. 1. U.S. Government Printing Office, Wash., D.C.

U.S. Department of Commerce. Review of Major Hurricanes. U.S. Government Printing Office, Wash., D.C.

U.S. Department of Commerce. 1973. Tide tables 1974. East Coast of North and South America. National Ocean Survey.

U.S. Department of Commerce. 1976. U.S. Coastal Pilot 5 Atlantic Coast, Gulf of Mexico, Puerto Rico, and Virgin Islands. Ninth Edition: July 1976. NOAA/NOS, Chapter 13, p. 291-321.

U.S. Department of Commerce. 1958. U.S. Navy Hydrographic Office Sailing Directions (H.O. 21, 1958).

U.S. Naval Oceanographic Office, 1972. Environmental acoustic atlas of the Caribbean Sea and Gulf of Mexico. Vol. II, Marine Environment SP189.

U.S. Naval Oceanographic Office, 1970. Oceanographic Atlas of the North Atlantic Ocean, Section II, Physical Properties, and Section IV, Sea and Swell, Publ. 700. Wash., D.C.

U.S. Naval Weather Service Command. 1974. Summary of Synoptic Meteorological Observations: Area 21-Puerto Rico South, Area 23-Vieques Island. National Climatic Center, Asheville, North Carolina.

Webster, F. 1969. On the representativeness of direct deep-sea current measurements. Progress in Oceanography. 5: 3-15.

Wood, E., M. J. Youngbluth, P. Yoshioka, and M. Canoy. 1975. Cabo Mala Pascua environmental studies. Puerto Rico Nuclear Center. UPR, Mayaguez, PRNC-188. 95 pp.

Wood, et al. 1975. Punta Verraco environmental studies. Puerto Rico Nuclear Center. PRNC-188. University of Puerto Rico. Mayaguez.

Wood, E. D., 1975a. Winds for Puerto Rico with summaries. Vol. I: Ponce, 1971-1974. Puerto Rico Nuclear Center. University of Puerto Rico, Mayaguez.

Worthington, L. V. 1955. A new theory of Caribbean bottom-water formation. Deep-Sea Res. 3: 82-87.

Worthington, L. V. 1966. Recent oceanographic measurements in the Caribbean Sea. Deep-Sea Res. 13: 731-739.

Worthington, L. V. 1971. Water circulation in the Caribbean Sea and its relationship to North Atlantic circulation. In UNESCO-FAO. Symposium on Investigations and Resources of the Caribbean Sea and Adjacent Regions, Curacao, November, 1968. UNESCO, Paris. p. 181-191.

Wust, G. 1963. On the stratification and circulation in the cold water sphere of the Antillean-Caribbean basins. Deep-Sea Res. 10: 165-187.

3.0. MARINE BIOLOGY

3.1. INTRODUCTION TO MARINE BIOLOGY

The scope of this section is to relate the marine biota to the presence and/or operation of an OTEC power plant in the northeastern Caribbean based on the available historical information.

Margalef (1971) compares the Caribbean and the Gulf of Mexico (the American Mediterranean) with the European Mediterranean with regard to productivity. He mentions that even though with the few available data, it seems that the American Mediterranean is more productive than its old world counterpart, and that its resources are underexploited. However, as determined mostly by C-14 uptake tests, the primary production in the Punta Tuna area is only 80 mg/m^2 day, making it one of the lowest areas in the Caribbean.

There is not much biological information from the proposed site of the OTEC plant, near Punta Tuna, Puerto Rico, or the surrounding area. However, the most important biological characteristics of the area closest to Punta Tuna will be discussed. Also, as the oceanic conditions for the OTEC plant require being at least 3 km from shore in that area, and being over at least 1000 m deep water, we would expect predominantly open ocean water, however, there still should be some coastal species present, at least in the upper waters.

Cabo Mala Pascua, located about 3 km west of Punta Tuna, was the site of an environmental study undertaken by the staff of the Puerto Rico Center for Energy and Environmental Research (formerly the Puerto Rico Nuclear Center). The report from the Cabo Mala Pascua study discusses the biological information related to physical, chemical, and geological parameters, zooplankton, benthic invertebrates and fish studies, and plant associations (Wood et al., 1975). Although this study did not consider conditions in water much greater than 300 m deep, much of their relevant information will be discussed within this review.

There is no doubt that an OTEC plant would produce some kind of disturbance in the ecological pattern of any site area. However, some people believe that this type of activity would have little effect on the biota. It is difficult to predict what would happen or how serious any alteration of the biological system would be, were an OTEC plant to be located or operating in an area. There is very little information that is known about the biology of the prime Puerto Rico OTEC site. Nevertheless, this report shall attempt to summarize and evaluate the available information. Only after several years of research, both before and after the existance of the OTEC plant, will anyone actually know the effects of such a perturbation on the biological environment.

As an OTEC plant will be both in deep water and also relatively near shore, this biological section will deal with both the nearshore and open ocean environments. Furthermore, the various subsets of the oceanic biota shall be considered, where applicable, such as: primary production, phytoplankton, zooplankton, benthos, and fish.

3.2. BIOLOGICAL ENVIRONMENT

3.2.1. Nearshore Life

3.2.1.1. Productivity

Margalef (1971), in his paper related to the pelagic ecosystem of the Caribbean Sea, stated that cruises and surveys in this area have been insufficiently coordinated and have rarely been repeated frequently enough to give a fair idea of the yearly cycle, and much less of the interannual changes.

In the Gulf of Cariaco, northern Venezuela, in the Caribbean Sea, the extraction of fish approaches up to 5 g C/m^2/year with a primary production of the order of 800 g C/m^2/year (Margalef, 1971).

In regard to the euphotic layers, the circulation of the American Mediterranean can be described in an oversimplified form as an anticlonic gyre (Wust, 1964; Bogdanov, 1965). Figure 50 shows data on geopotential topography summarized and based on Duxbury (1962) and Gordon (1967). The areas of low topography (areas where dense water approaches the surface) have been striped, and the areas of high topography (where nutrient poor water of low density accumulates) are cross hatched. As we can see, Puerto Rico is located far from the nutrient rich water masses located in the southeast Caribbean.

It is known that areas of high fertility may also be associated with the discharge of rivers. A river as large as the Mississippi contributes high amounts of phosphate (2 to 16 mg P/m^3 on the surface); a great number of fresh water diatoms (over 1000 Melosira per ml), and huge amounts of detrital chlorophyll. The observed increase in plant biomass is in great part due to the augmented productivity

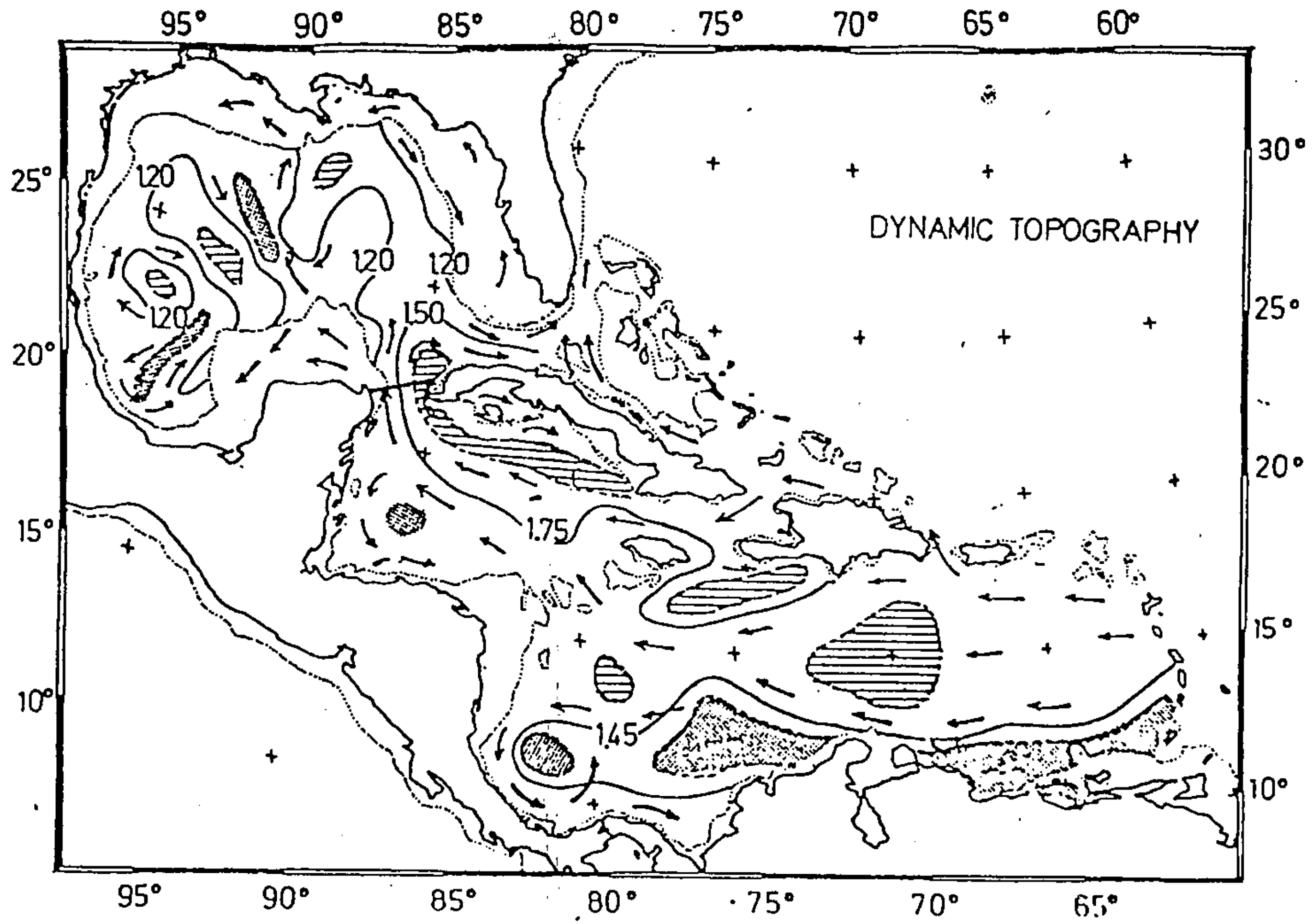


Fig.50 Average dynamic topography of the American Mediterranean, in dynamic metres. For the Gulf of Mexico (north of the double line), data of Duxbury (1962) and contours referred to the surface of 1000 decibars. For the Caribbean (south of the double line), data of Gordon (1967) and reference to the 1200 db level. The areas of presumed upwelling are shown stippled, and the areas of possible sinking are hatched. Arrows indicate the principal currents.

of local marine populations (Thomas and Simmons, 1960; Simmons and Thomas, 1962). It is important to mention that in Puerto Rico there are no large rivers. Although the effluent from the Amazon and Orinoco (both in South America) probably reaches the Puerto Rican shores, enough time has elapsed to consume all the excess surface nutrients.

Some values of the primary production in the Caribbean, as determined by 14-C uptake, are shown in Figure 51. This method gave figures between 25 and 50 g C/m^2/year. Cell counts fall mostly between 5 to 15 cells/mℓ (Hulburt, 1963, 1966, 1968), and pigment concentration between 0.05 and 0.3 mg chlorophyll a/m^3. Phytoplankton extend to relatively major depths; diatoms are represented primarily by only those species associated with ciliates, such as Chaetoceros coarctatus. There are also sizeable populations of coccolithophorids, dinoflagellates and blue-green Oscillatoria (Hart, 1959, Ivanov, 1966).

3.2.1.2. Phytoplankton

There is no published information on the phytoplankton of the coastal waters of Puerto Rico, particularly at the benchmark site. Nor are there any specific data on marine productivity. However, considering some available information from the Punta Tuna site, we can speculate on the actual conditions at this area and the possible changes that would occur if an OTEC plant were established in this region.

The only known studies related to the phytoplankton of Puerto Rico are on the tintinnids by Duran (1957) and various studies of Margalef (1957, 1960). The former mentions and illustrates 22 different species. In the coastal area of Punta Tuna, and towards the southeast, facing Cabo Mala Pascua, one could find the same as in the European Mediterranean, such as the tintinnids species of the Stenosemella genus and other similar genera should be found that present an outer sheath or heavy lorica. These genera develop together with the first stage of succession of the phytoplankton, coinciding with upwelling movements of the water. This succession may occur around the OTEC site due to the production of an abnormal upwelling that could bring the ocean bottom water, rich in nutrients, to the surface. According to Margalef (1967) the Eutintinnus and Favella genera are genuinely pelagic forms which have a very thin and light sheath or lorica, which are physical characteristics of the final stages of succession.

A great number of other genera and different species of phytoplankton should be found, among which are dinoflagellates like Noctiluca, which are carnivorous; Ceratium, which has a size varying from 200 to 500µ; and Peridinium,

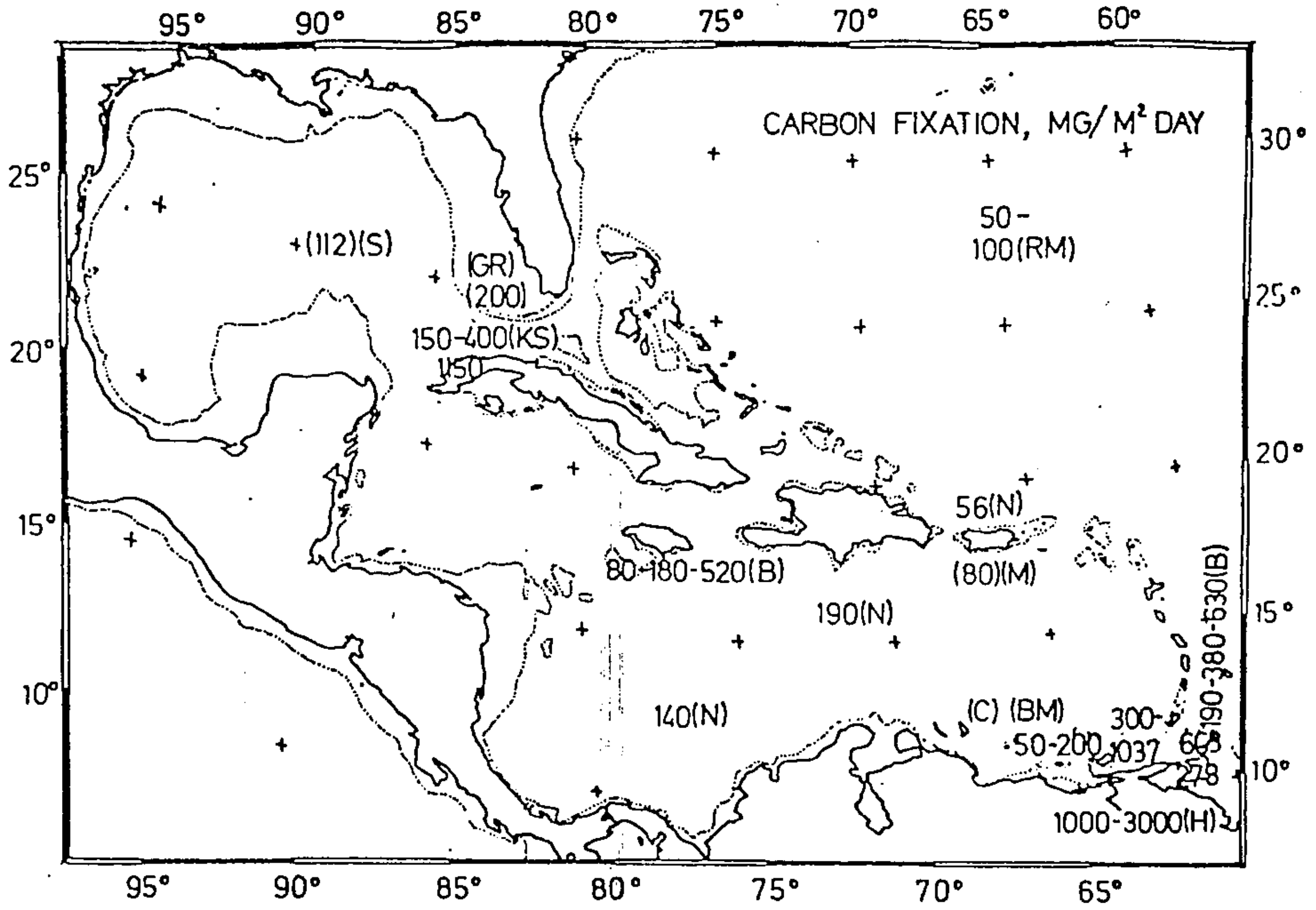


Fig.51 Some values of the primary production, as determined mostly by 14-C uptake, in the Caribbean and Gulf of Mexico. Key to authorities : B - Beers, Steven and Lewis ; BM - Ballester and Margalef ; C - Curl ; GR - Riley ; H - Hammer ; KS - Kondratieva and Sosa ; N - Stemann Nielsen and Jensen ; RM - Ryther and Menzel ; S - Steele.

size of 200 to 250μ. Furthermore, in this environment genera such as Pyrocystis are common, which together with the Noctiluca, are responsible for the luminescence in tropical waters. The other important group of phytoplankton is composed of the diatoms, with probably the most common being: Coscinodiscus, Rhizosolenia, Bacillaria, Hemidiscus, Gyrosigma, Biddulphia, Asterionella and Thalassiothrix. There is also the Trichodesmium, a blue-green algae of filamentous consistence, which appears in the form of small bundles on the plankton. The appearance of these and similar species in large quantities, caused by an upwelling rich in nutrients, might produce difficulties in the operation of an OTEC plant, located downstream from the effluent of a first plant.

Reference should also be made to some common planktonic organisms like the Foraminifera, Globigerina, Radiolaria like Acanthometra, about 200μ in diameter; coccolithophorids of the Coccolithus genus; and finally the silicoflagellates, which are very small like the Dictyocha that are frequently found in the copepod's intestines.

3.2.1.3. Zooplankton

The data available on zooplankton in the Punta Tuna nearshore region are more complete than the phytoplankton data. Estimates of the abundance and diversity of zooplankton in the surface waters along the eastern portions of the south coast of Puerto Rico (Fig. 52), including the Cabo Mala Pascua area (3 km SW of Punta Tuna), are reported in Wood, et al. (1975). About 39 species of copepods were identified. Also, the total number of copepods, chaetognaths, larvacean, veliger larvae, caridean larvae, brachyuran larvae, cirripede nauplii, number of fish eggs, holoplankton, and meroplankton were counted (number/m^3).

According to the above authors, seasonal changes in the abundance of the total zooplankton at any station (Fig. 52) or among all samples were within the same range (Table 22). The highest concentrations occurred in December. These large densities, however, probably represent the typical patchiness among tropical zooplankton communities in the coastal waters around Puerto Rico rather than a recurrent seasonal pulse, since the 95% confidence intervals from each station overlap (Table 23).

These fluctuations in density refer primarily to holoplanktonic organisms (permanent plankton) since they amounted to, in most cases, 60 to 90% of the total zooplankton. Meroplankton or temporary plankton formed 3 to 27% and were more numerous during April and August. The dominant meroplanktonic groups were prosobranch veligers and caridean larvae (Table 24).

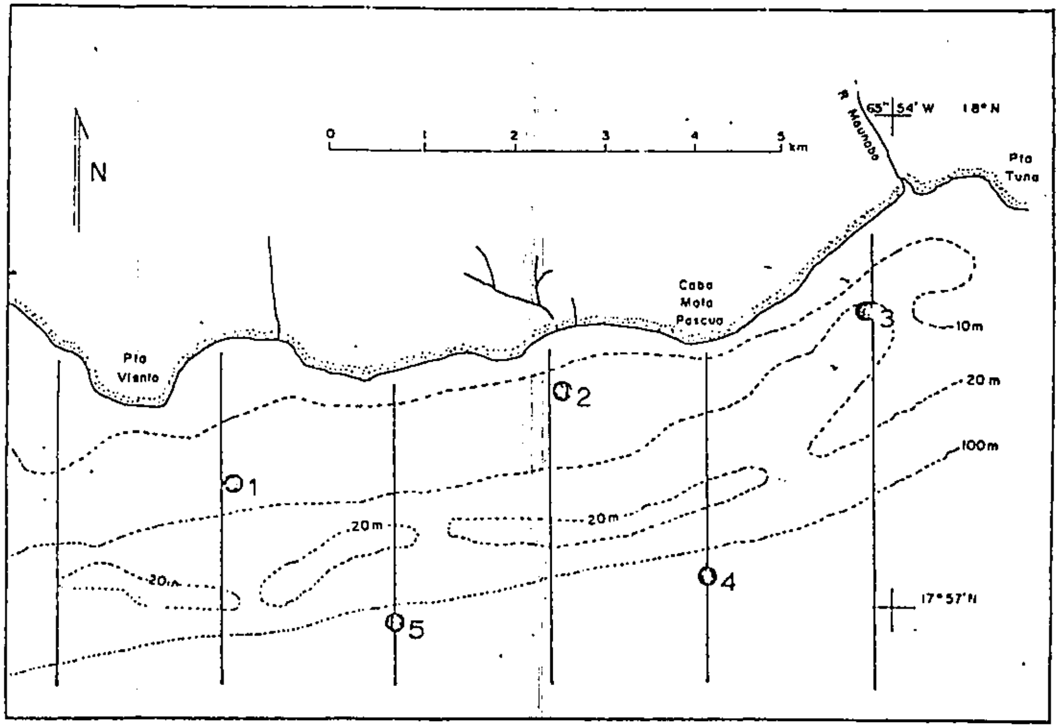


Figure 52 Zooplankton stations at the Cabo Mala Pascua site 2 miles S.W. of Punta Tuna. (from Wood et al. 1975).

Table 22

Total number of zooplankton (number/m^3)

	Nearshore Replicate Tows			Nearshore Tows			Offshore Tows	
	Stations			Stations			Stations	
Date	2a	2b	2c	1	2	3	5	4
220273	360	350	485	626	320	654	231	288
230573	830	807	881	530	840	718	564	663
130274*	617/203	710/223	611/230	646	646/219	566	557	586
230474	913	666	691	486	757	289	812	613
220874*	636/595	595/689	532/445	693	532/577	836	393	304
141174°	881	946	1079	-	969	-	-	-
121274	1420	1180	1388	-	1330	-	636	-

*Midnight/Midday; °Midnight

Table 23

Average density of all zooplankton collected.

Total Zooplankton/m^3

	1973		1974				
	22 Feb	23 May	13 Feb	23 Apr	22 Aug	14 Nov	12 Dec
Range	231-654	530-840	557-646	289-812	304-836	-	-
Median	320	663	586	613	532	-	-
Mean	424	663	600	591	552	-	-
95% C.L.	±497	±308	±107	±525	±538	-	-

Table 24

Total number of holoplankton (number/m^3)

	Nearshore Replicate Tows Stations			Nearshore Tows Stations			Offshore Tows Stations	
Date	2a	2b	2c	1	2	3	5	4
220273	98	303	400	559	267	544	182	237
230573	678	662	755	455	698	630	521	456
130274*	347/70	471/84	388/98	492	402/84	352	262	336
230474	761	543	530	314	611	197	586	473
220874*	278/452	483/536	455/371	532	405/453	710	320	209
141174°	743	738	896	-	792	-	-	-
121274	1330	1099	1315	-	1248	-	573	-

Total number of meroplankton (number/m^3)

	Nearshore Replicate Tows Stations			Nearshore Tows Stations			Offshore Tows Stations	
Date	2a	2b	2c	1	2	3	5	4
220273	6	17	22	22	15	21	9	7
230573	108	95	72	43	91	59	35	46
130274*	97/8	45/1	42/11	53	62/6	14	56	32
230474	95	55	93	131	81	72	87	80
220874*	56/110	101/122	87/48	148	81/93	144	37	62
141174°	108	155	138	-	134	-	-	-
121274	68	53	51	-	58	-	37	-

*Midnight/Midday; °Midnight

Fish eggs were abudant in this area, forming 2 to 40% of the total zooplankton (Table 25). The largest density $229/m^3$, was observed at Station "5" on February 13, 1974. Fish eggs were more numerous throughout the area on this date than any other, averaging $177/m^3$ and forming 31% of all zooplankton collected. Most of the eggs were round and 0.5 to 2 mm in diameter. Oblong eggs were also common. It is not reported which groups of fish are represented by most of the eggs.

Diurnal changes in zooplankton density were large in February and small in August. A detailed account of the magnitude of fluctuations among several groups was reported earlier (Youngbluth, 1974a and 1974b). Nearly all organisms were much more numerous at night during this period but only two groups, the larvaceans and the gastropod larvae, were observed in greater numbers at night during August (Table 26). Sea state and sky conditions were similar during each period, i.e., calm and moonless at night, lightly choppy and sunny during the day.

Copepods formed 60 to 85% of the zooplankton community, with 39 identified species. The report did not have a detailed examination of species abundance at all stations, however, one sample from their Station "2" for each period was selected for study. Table 27 shows the species most numerous, those commonly observed, and others occasionally observed.

Table 28 shows the total number of chaetognaths. This group was very numerous during February 1974, but not many different species were found. The variety and abundance of zooplankton observed at the Cabo Mala Pascua site, both nearshore and offshore, were similar throughout the year. Diurnal changes in densities varied. Large increases in nearly all groups were observed at night during February. In August no obvious differences were noticed except among larvaceans and prosobranch veligers.

Copepods always dominated both the zooplankton community and the holoplankton (Table 29). The larvae of gastropods and decapods (Table 26 and 30) were the major meroplanktonic organisms. The largest proportion of meroplankton occurred during April and August. Fish eggs were very numerous during February 1974 (Table 31).

Because the nearshore area where the above research was performed is located near the prime future OTEC plant site, we can presume similar conditions in the coastal waters of Punta Tuna. Any change in the food chain produced by the upwelling that would occur in that region would surely change the quantity and distribution patterns

Table 25

Summary of densities of fish eggs from all stations sampled at the Cabo Mala Pascua site.

	1	2	3	4	5
Range	12-96	19-151	4-197	32-229	23-204
Median	34	35	25	46	57
Mean	41	51	60	88	81

Table 26

Total number of larvaceans (number/10m^3)

	Nearshore Replicate Tows Stations			Nearshore Tows Stations			Offshore Tows Stations	
Date	2a	2b	2c	1	2	3	5	4
220273	26	91	250	234	122	333	244	278
230573	1024	1113	1389	437	1176	381	583	594
130274*	137/27	479/48	529/23	84	382/33	143	57	138
230474	511	189	242	245	314	105	294	324
220874*	355/116	718/112	486/22	103	520/83	129	70	125
141174°	266	115	151	-	178	-	-	-
121274	330	510	632	-	490	-	143	-

Total number of veliger larvae (number/10m^3)

	Nearshore Replicate Tows Stations			Nearshore Tows Stations			Offshore Tows Stations	
Date	2a	2b	2c	1	2	3	5	4
220273	20	22	110	140	50	136	26	66
230573	568	414	431	91	471	65	140	40
130274*	151/81	527/65	112/113	148	263/86	135	458	214
230474	496	378	669	978	547	365	578	534
220874*	287/289	488/393	554/192	427	442/291	775	132	207
141174°	284	185	231	-	233	-	-	-
121274	489	325	316	-	377	-	278	-

*Midnight/Midday; °Midnight

Table 27

Copepod populations observed at the Cabo Mala Pascua Site.

Species usually most numerous (5 individuals/m^3)

- *Clausocalanus furcatus*
- *Paracalanus* spp. (*P. aculeatus*, *P. crissirostris*, *P. parvus*)
- *Farranula gracilis*
- *Oithona* spp. (*O. plumifera*, *O. spp.*)
- *Acartia spinata*
- *Temora turbinata*
- *Calanopia americana*

Species commonly present (observed on 5 or more sampling periods)

- *Corycaeus* spp. (*C. giesbrechti*, *C. pacificus*, *C. speciosus*)
- *Undinula vulgaris*
- *Calocalanus pavo*
- *Euchaeta marina*
- *Nannocalanus minor*
- *Labidocera* spp.
- *Candacia pachydactyla*
- *Mecynocera clausi*
- *Acrocalanus longicornis*
- *Temora stylifera*

Species occasionally present

- *Oncaea* spp. (*O. mediterranea*, *O. venusta*, *O.* spp.)
- *Corycaeus* spp. (*C. subulatus*, *C.* spp.)
- *Pseudodiaptomus cokeri*
- *Calocalanus pavoninus*
- *Scolecithrix danae*
- *Centropages furcatus*
- *Eucalanus* spp.
- *Lucicutia flavicornis*
- *Miracia efferata*
- *Copilia* spp.
- *Sapphirina* spp.
- *Monstrilla* spp.
- *Macrosetella gracilis*
- *Phaenna spinifera*

Table 28

Total number of chaetognaths (number/$10m^3$)

	Nearshore Replicate Tows			Nearshore Tows			Offshore Tows	
	Stations			Stations			Stations	
Date	2a	2b	2c	1	2	3	5	4
220273	95	172	227	421	165	514	66	137
230573	212	259	204	100	225	33	37	462
130274*	108/6	150/10	79/18	45	113/11	56	101	97
230474	482	228	169	122	293	12	252	193
220874*	7/99	43/159	50/44	22	33/101	75	39	54
141174°	355	415	481	-	417	-	-	-
121274	367	441	340	-	383	-	150	-

*Midnight/Midday; °Midnight

Table 29

Total number of copepods (number/m^3)

	Nearshore Replicate Tows			Nearshore Tows			Offshore Tows	
	Stations			Stations			Stations	
Date	2a	2b	2c	1	2	3	5	4
220273	82	273	348	483	234	438	140	198
230573	530	510	593	390	544	571	355	405
130274*	303/58	349/70	308/80	471	320/69	327	226	278
230474	648	496	486	270	543	183	510	416
220874*	240/427	402/496	401/358	513	348/426	683	296	186
141174°	663	660	820	-	714	-	-	-
121274	1238	988	1198	-	1141	-	495	-

Table 30

Total number of caridean larvae (number/$10m^3$)

	Nearshore Replicate Tows			Nearshore Tows			Offshore Tows	
		Stations			Stations		Stations	
Date	2a	2b	2c	1	2	3	5	4
220273	6	59	44	31	37	45	19	15
230573	156	52	96	173	101	370	+	26
130274*	618/1	246/1	185/1	321	350/1	+	57	41
230474	99	47	73	69	73	192	42	114
220874*	137/421	316/+	134/148	912	196/190	301	109	198
141174°	213	277	320	-	270	-	-	-
121274	49	70	49	-	56	-	83	-

Total number of brachyuran larvae (number/$10m^3$)

	Nearshore Replicate Tows			Nearshore Tows			Offshore Tows	
		Stations			Stations		Stations	
Date	2a	2b	2c	1	2	3	5	4
220273	21	54	34	+	36	15	4	4
230573	122	155	120	109	133	33	+	13
130274*	237/1	48/1	119/2	26	135/1	+	31	7
230474	99	32	+	+	44	12	21	18
220874*	34/231	43/178	50/111	52	43/173	11	128	55
141174°	36	254	116	-	135	-	-	-
121274	24	46	+	-	24	-	23	-

*Midnight/Midday; °Midnight

Table 31

Total number of fish eggs (number/m^3)

	Nearshore Replicate Tows			Nearshore Tows			Offshore Tows	
	Stations			Stations			Stations	
Date	2a	2b	2c	1	2	3	5	4
220273	42	26	56	39	33	59	37	37
230573	30	38	38	23	35	25	54	82
130274*	164/129	181/134	165/126	96	170/30	197	229	204
230474	47	43	67	34	52	17	139	57
220874*	27/32	49/22	49/20	12	42/25	4	34	-
141174°	43	46	43	-	44	-	-	-
121274	18	16	23	-	19	-	32	-

*Midnight/Midday; °Midnight

of the previously mentioned zooplankton, as more phytoplankton would be available for grazing upon.

The total biomass of zooplankton (Table 32) expressed in mℓ/m^3 was calculated as wet volume (Ahlstrom and Thraikill, 1962). Wood et al., (1975) mentioned that this estimate is subject to considerable error and should be viewed only as a rough measure of standing stock. The measurements were reproducible but are undoubtedly biased toward higher than actual values by the variable proportion of interstitial water and detritus.

3.2.1.4. Benthos

The effect of an OTEC plant on the benthos of Punta Tuna is relative, and will depend on the type of power plant that is established. If the generating plant is shore-based, there is no doubt that it will influence the benthic organisms along the shore, both flora and fauna. However, if the power plant is afloat more than 3 km from Punta Tuna, the resulting environmental changes to the benthos will be minimal for the inhabitants in the zone between the shore and the 100 m isobath, except where a power line may pass.

Yoshioka, in Wood et al., (1975), reports the results of benthic and fish studies conducted at the Cabo Mala Pascua site. Most of the effort invlolved mapping and describing major benthic communities, in an area located between the shore and the 20 m isobath, off the coast from Punta Tuna to Punta Viento (Fig. 53). Macroinvertebrates, algae and fishes were observed at selected stations. Tables 33-36 list the species observed and collected during these studies. Of all these species, probably those most affected by a shore-based OTEC plant would be the following: the zoanthid Palythoa, an encrusting organism, as well as the gorgonians, coral sponge and fish species as observed at Station "S-12" (Fig. 53), which are mentioned in Table 34; Caulerpa, Udotea, Halophila and Halimeda, as observed at Stations "S-2" and "S-3"; and in the area between the 10 and 20 m isobath at Station "S-10", a decrease of organisms typically associated with hard substrates, which includes Montastrea cavernosa, a hard coral, and various species of sponges such as Callyspongia vaginalis, Haliclona rubens, Verongia longissima and Ircinia strobilina. Also, changes in distribution could be produced among the fishes of this region (Tables 33-34) but they would not be as marked as in the case of the sedintary invertebrates and the aforementioned plants.

Table 32

Total biomass of zooplankton (ml/m^3)

	Nearshore Replicate Tows			Nearshore Tows			Offshore Tows	
	Stations			Stations			Stations	
Date	2a	2b	2c	1	2	3	5	4
220273	.045	.048	.063	.070	.052	.098	.063	.085
230573	.078	.097	.108	.046	.094	.065	.108	.119
130274*	.086/.034	.082/.036	.079/.044	.071	.083/.038	.039	.079	.124
230474	.137	.087	.081	.061	.101	.087	.084	.101
220874*	.031/.094	.050/.094	.059/.067	.062	.047/.080	.081	-	.074
141174°	.103	.112	.133	-	.116	-	-	-
121274	.083	.113	.097	-	.104	-	.062	-

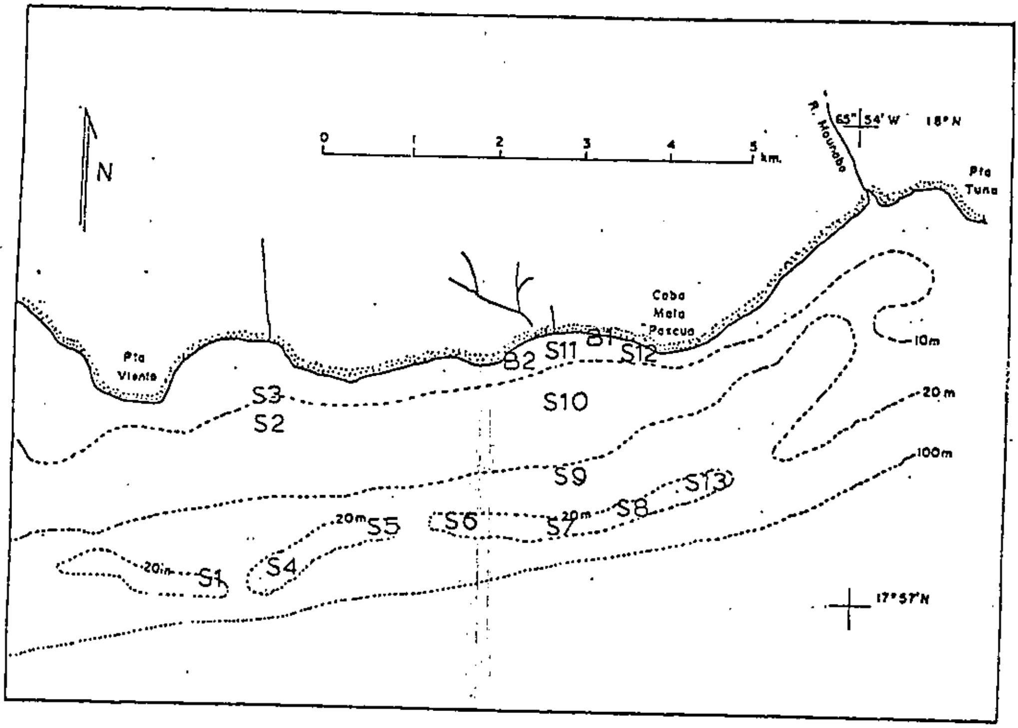


Figure 53 Benthic studies field stations at the Cabo Mala Pascua site (from Wood et al. 1975).

Table 33 (from Wood, et al. 1975).

Shoreline fishes of the Cabo Mala Pascua site

FAMILY	27 Feb 73 Seine	27 Feb 73 Rotenone
Muraenidae		
Echidna catenata		12
Ophichthidae		
Myrichthys acuminatus	1	1
Gobusocidae		
Arcos macrophthalmus		1
Arcos rubringenosus		35
Tomicodon fasciatus		1
Arcos artius		2
Scorpaenidae		
Scorpaena plumieri	1	
Gerreidae		
Eucinostomus melanopterus	1	
Pomacentridae		
Abudefduf taurus		6
Abudefduf saxatilis		19
Mugilidae		
Mugil liza	2	
Labridae		
Doratonotus megalepis	1	1
Halichoeres maculipinna		1
Scaridae		
Sparisoma rubripinne		2
Blenniidae		
Entomacrodus nigricans		10
Clinidae		
Emblemariopsis leptocirris		1
Labrisomus guppyi		7
Labrisomus haitiensis		1
Labrisomus nuchipinnis	1	

Table 33 (Cont.)

	27 Feb 73 Seine	27 Feb 73 Rotenone
Gobiidae		
Awaous tajasica	11	
Bathygobius soporator		8
Gingsburgellus novemlineatus		1
Gnatholipis thompsoni	7	
Gonionellus boleosoma	1	
Balistidae		
Aluterus schoepfi	1	

Table 34 (from Wood, et al. 1975).

Macroinvertebrates, algae and fish observed at selected stations at Cabo Mala Pascua

	S2 22 Aug 74	S12 22 Aug 74	S8 22 Aug 74
PLANT KINGDOM			
Phylum Rhodophyta			
Gracilaria sp.	X		
Phylum Chlorophyta			
Caulerpa mexicana	X		
Halimeda sp.	X		
Penicillus capitatus	X		
Udotea conglutina	X		
Udotea flabellum	X		
Udotea spinulosa	X		
Phylum Spermatophyta			
Halophila baillonis	X		
ANIMAL KINGDOM			
Phylum Porifera			
Agelas			X
Anthosigmella varians		X	X
Callyspongia vaginalis			X
Chondrilla nucula		X	X
Cinachyra cavernosa		X	
Gelliodes sp.		X	X
Haliclona rubens		X	X
Ircinia sp.		X	X
Iotrochota birotulata		X	
Mycale angulosa			X
Mycale sp.		X	
Neofibularia massa			X
Oligoceros hemorrhages			X
Verongia lacunosa		X	X
Verongia longissima			X
Verongia sp.		X	X
Xestospongia muta		X	X
Phylum Onidaria			
Class Anthozoa			
Subclass Octocorallia			
Briareum asbestinum			X
Erythoropodium sp.			X

Table 34 (Cont.)

Phylum Onidaria (cont.)	S2 22 Aug 74	S12 22 Aug 74	S8 22 Aug 74
Eunicea laxispica			X
Eunicea sp.		X	X
Gorgonia sp.		X	X
Muricea sp.			X
Muriceopsis sp.		X	
Plexaura flexuosa			X
Plexaura homomalla			X
Pseudoplexaura sp.			X
Pseudopterogorgia sp.			X
Pterogorgia sp.		X	X
Subclass Zoantharia			
Acropora cervicornis		X	X
Acropora palmata		X	
Agaricia sp.			X
Colpophyllia sp.			X
Dichocoenia stokesii			X
Diploria labyrinthiformis			X
Diploria sp.		X	X
Eusmilia fastigiata			X
Isophyllia maltiflora			X
Meandrina sp.			X
Millepora sp.		X	X
Montastrea cavernosa		X	X
Palythoa sp.		X	
Porites astreoides		X	X
Siderastrea radians		X	
Siderastrea siderea			X
Stephanocoenia			X
Phylum Chordata			
Subphylum Vertebrata			
Class Pisces			
Family Dasyatidae			
Unid. Dasyatid	X		
Family Muraenidae			
Gymnothorax moringa			X

Table 34 (Cont.)

	S2	S12		S8	
	8/22	8/22	2/13	8/22	12/12
Phylum Chordata (cont.)					
Family Holocentridae					
Holocentrus sp.			X	X	
Myripristis jacobus			X		X
Family Aulostomidae					
Aulostomus maculatus			X		
Family Sphyraenidae					
Sphyraena barracuda			X		
Family Serranidae					
Cephalopholis fulva				X	X
Unid. serranid			X		
Family Grammistidae					
Rypticus sp.			X		
Family Echeneidae					
Echeneis naucrates				X	
Family Carangidae					
Caranx crysos	X				
Decapterus sp.				X	
Family Lutjanidae					
Lutjanus sp.			X		
Family Pomadasyidae					
Haemulon flavolineatum			X		
Family Sciaenidae					
Equetus sp.			X		
Family Sparidae					
Calamus bajonado			X	X	
Family Mullidae					
Pseudupeneus maculatus				X	
Family Chaetodontidae					
Pomacanthus para			X	X	
Holocanthus tricolor			X	X	
Chaetodon capistratus					X
Prognathodes aculeatus					X

Table 34 (Cont.)

	S2	S12		S8	
	8/22	8/22	2/13	8/22	12/12
Phylum Chordata (cont.)					
Family Pomacentridae					
Chromis cyaneus			X	X	X
Chromis multilineatus				X	X
Pomacentrus partitus		X	X	X	X
Pomacentrus sp.		X	X		
Family Labridae					
Bodianus rufus			X		X
Thalassoma bifasciatum			X	X	X
Halichoeres sp.			X		X
Unid. labrid	X				
Family Scaridae					
Sparisoma sp.			X		
Unid. scarid		X		X	
Family Acanthuridae					
Acanthurus sp.				X	X
Family Balistidae					
Balistes sp.			X	X	
Balistes vetula					X

Table 35 (from Wood, et al. 1975)

Cabo Mala Pascua shore collections

	Station B1 22 March 1973	Station B2 22 March 1973
PLANT KINDOM		
Phylum Chlorophyta		
Caulerpa racemosa	X	
Chamaedoris peniculum	X	
Enteromorpha sp.	X	
Halimeda opuntia	X	
Penicillus capitatus		X
Penicillus dumetosus	X	
Udotea flabellum	X	
Ulva lactuca	X	
Phylum Phaeophyta		
Dictyota ciliolata	X	
Dictyota dentata	X	
Dictyota sp.	X	
Padina sp.	X	X
Sargassum hystrix	X	
Sargassum polyceratium	X	
Phylum Rhodophyta		
Bryothamnion triquetrum	X	
Ceramium sp.	X	
Galaxaura sp.	X	X
Jania adherens	X	
Jania capillacea	X	
Laurencia papillosa	X	
Polysiphonia sp.	X	
Phylum Spermatophyta		
Syringodium filiforme	X	
Syringodium sp.		X
Thalassia testudinum	X	X
ANIMAL KINDOM		
Phylum Mollusica		
Class Gastropoda		
Acmaea antillarum	X	
Astraea tuber	X	X
Bulla striata	X	

Table 35 (cont.)

	Station B1 22 March 1973	Station B2 22 March 1973
Plylum Mollusca (cont.)		
Class Gastropoda		
Cerithium veriabile		X
Columbella mercatoria		X
Diodora viridula	X	
Fissurella barbadensis	X	
Fissurella sp.	X	
Hemitoma octoradiata	X	
Hipponix antiquatus	X	
Littorina ziczac	X	
Nerita tessellata	X	
Nitidella laevigata	X	
Tegula excavata	X	
Class Pelecypoda		
Barbatia domingensis	X	
Codakia orbicularis	X	
Phylum Arthropoda		
Order Decapoda		
Suborder Brachyura		
Callinectes danae		X
Microphrys antillensis	X	X
Phylum Echinodermata		
Class Echinoidea		
Tripneustes esculentus	X	X

Table 36

Species and individuals per species collected in 1/4 m^2 quadrat at Cabo Mala Pascua

	S7 2/22/73	S1 2/22/73
PLANT KINGDOM		
Phylum Phaeophyta		
Dictyota sp.	X	
Phylum Rhodophyta		
Amphiroa sp.	X	
ANIMAL KINGDOM		
Phylum Sipunculida	24	20
Phylum Annelida	-	
Class Polychoeta		
Arabella opalina	1	
Eunice fucata	2	1
Eunice sp.	1	1
Hermenia verruculosa	1	
Laetmonice kinbergii		3
Lepidonotus sp.	2	1
Lumbrinereis sp.		2
Lysidice sulcata	3	3
Marphysa regalis	6	
Marphysa sp.		3
Nereis sp.		1
Nicidion kingergii		5
Nicidion sp.	2	
Phyllodoce papillosa	1	1
Family Sabellidae	1	1
Family Serpulidae	3	
Syllis sp.	1	1
Terebella sp.	2	
Family Terebellidae		2
Unid. polychaete	1	2

Table 36 (cont.)

	S7 2/22/73	S1 2/22/73
Phylum Mollusca		
Class Gastropoda		
Columbella mercatoria		1
Lucapina sowerbii		1
Class Pelecypoda		
Barbatia domingensis	2	3
Chama sarda		1
Coralliophaga coralliophaga		1
Lioberus castaneus	1	
Lithophaga bisulcata	1	
Lithophaga nigra		1
Unid. pelecypod		1
Phylum Arthropoda		
Order Stomatopoda		
Unid. stomatopoda	1	
Order Isopoda		
Cirolana parva	1	
Spaeroma walkeri		3
Unid. isopod	1	
Order Decapoda		
Suborder Natantia		
Family Alphaeida		
Unid. alphaeid	2	
Alpheus amblyonyx	1	
Pontonia mexicana		1
Synalpheus mcclendoni	1	
Synalpheus rathbunae	1	
Suborder Brachyura		
Mithrax pleuracanthus		1
Phylum Echinodermata		
Class Echinoidea		
Eucidarus tribuloides	1	
Class Asteroidea		
Asterinides sp.	1	
Class Ophiuroidea		
Unid ophiuroid	2	

Table 36 (cont.)

	S7 2/22/73	S8 2/22/73
Family Amphiuridae		
Unid. amphiurid	1	1
Ophiactis savignyi	1	
Ophiocoma echinata	4	
Ophiocoma pumila	1	
Ophionereis squamulosa	1	
Ophiophragmus sp.	1	
Ophiopsila sp.	1	
Ophiopsila riisei		1
Ophiothrix angulata	3	1
Ophiothrix orstedii	1	
Ophiothrix sp.		1
Phylum Chordata		
Class Ascidacea		
Styela partita	1	

3.2.2. Open Ocean Life

3.2.2.1. Productivity

Production rates in the open ocean show a general decrease from the coastal margins to the central basin areas (Davis, 1973). In general, tropical ocean waters have low production rates and show little variation with changing seasons of the year. Raymont (1963) states that two compounds, phosphate and nitrate (together with nitrite and ammonia to some extent) are clearly of extreme importance to marine plant growth. In general it may be said that values of both these essential nutrients in the upper photosynthetic zone, which is the only zone directly concerned with basic productivity, are very low and fairly constant in sub-tropical and tropical areas. It would appear, therefore, that only a rather low production is possible in the tropics and subtropics and that production proceeds at a fairly steady level. The overall production, considered on a yearly basis, may be considerably greater than would first appear, since the nutrients are probably more rapidly recycled at the higher sea temperature of the tropical regions and thus pass through several cycles during the course of a year. Nevertheless, over the tropical seas of the world, the standing phytoplankton crop tends to be low at any one time, but as Riley (1939) has pointed out, the thickness of the productive photosynthetic may be considerably greater in tropical seas, thus expanding the total crop more than expected.

Most of the detailed studies on productivity in the Caribbean Sea have been carried out in the Gulf of Cariaco and adjacent regions, off northern Venezuela. In accord with Margalef (1971) the primary production estimates, based on 14-C uptake (Fig. 51), are from 600 to 1000 mg C/m^2/day in the central productive area, going down to 50 to 200 mg C/m^2/day in the more offshore or peripheric positions. These values represent something between net and gross production (Ballester and Margalef, 1968) and they harmonize with the limited number of studies of inorganic carbon uptake in the Gulf of Mexico and the Caribbean.

3.2.2.2. Phytoplankton

The portion of the water column with sufficient sunlight to photosynthesize is called the <u>euphotic zone</u> (Duxbury, 1971). It reaches about 100 m in depth. At the OTEC plant site the euphotic zone corresponds closely with the Tropical Surface Water (TSW). This water mass may have a thickness of up to 100 m and its characteristics are studied in other sections of this report. Almost all the activities of the phytoplankton organisms take place in the first 100 m of depth off Punta Tuna.

No less than 450 species of phytoplankton have been observed in the Caribbean and the Gulf of Mexico (Margalef, 1971). Undoubtedly, a catalogue of those species would be defective in many aspects, especially in regard to the smaller and more delicate organisms.

The following species are more common offshore in stable environmental situations, and the meaning of their presence is perhaps more ecological than geographical: Amphisolenia, Peridinium fatulipes, P. pentagonum latissimum, Ceratium belone, C. (furca) hireus, C. incisum, C. lunula, C. vultur, Pyrocystis hamulus, Lauderia annulata, Rhizosolenia cylindrus, Chaetocerus coarctatus, Hemiaulus indicus and H. membranaceus.

Margalef (op. cit.), studying the pelagic ecosystem of the Caribbean, stated that Chaetoceros curvisetus, Ch. socialis, Asterionella japonica and Stephanopyxis (Skeletonema) costata are common species in the upwelled water. Perhaps these species will be identified when and if an upwelling is produced near an OTEC site.

3.2.2.3. Zooplankton

3.2.2.3.1. In the Water Column

As previously mentioned, there are some surface zooplankton data collected close to the benchmark stations (Wood et al., 1975). According to Michel, Foyo and Haagensen (1976), zooplankton and hydrographic data were collected at 105 stations during nine cruises, in the oceanic Caribbean and adjacent waters, from 1966 through 1969 (Fig. 54). However, of those stations, only two: Station "4", cruise G-6722, and Station "1", cruise P-6911, are closest to the proposed Puerto Rico OTEC site of Punta Tuna. Both stations are located about 120 km to the east.

Table 37 lists zooplankton species identified at Station "4" (Cruise G-6722). Three species of Siphonophora, four species of Euphausiacea, and 18 of Copepoda were encountered. No Chaetognatha are mentioned. Other species identified at Station "1" (Cruise P-6911) are registered in Table 38. There are six species of Siphonophora; 18 species of Copepoda; three species of Euphausiacea; 13 of Chaetognatha; and two of Salpidae. Two species of Siphonophora; 17 of Copepoda; and one of Euphausiacea are found at both stations. Also, Table 38 lists seven species of Thecosomata (pteropods) encountered near the island of Puerto Rico (Michel, Foyo and Haagensen, op. cit.)

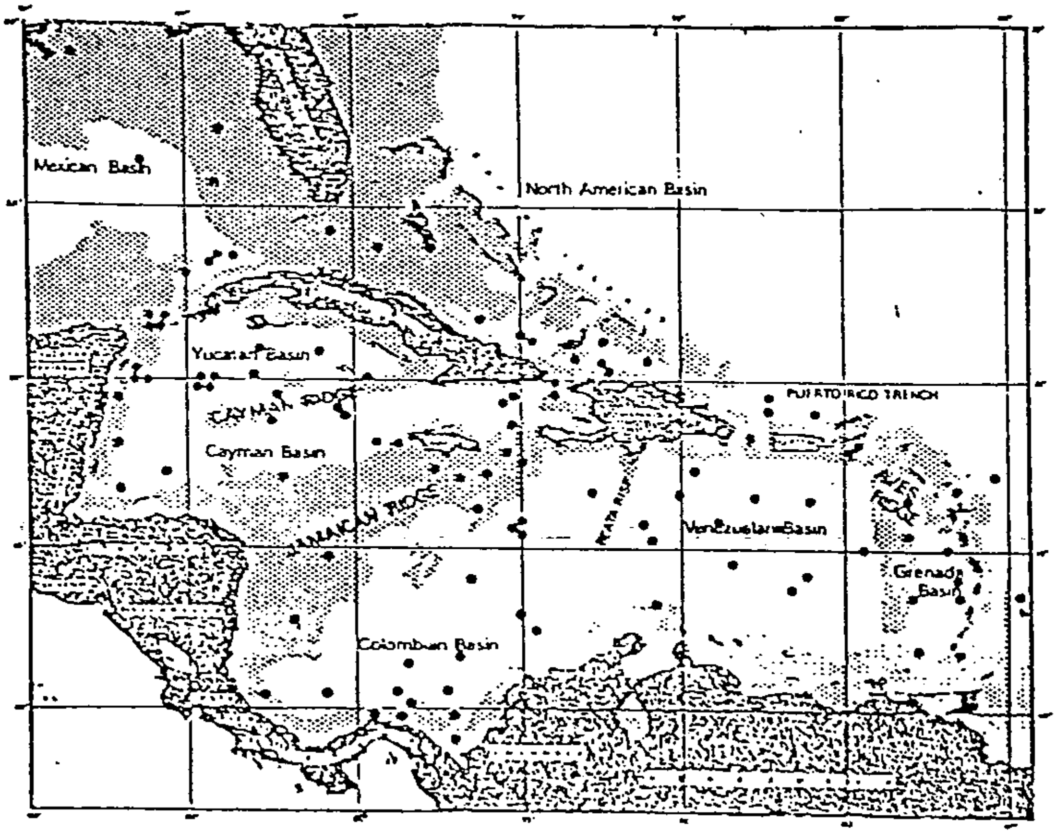


Figure 54. Locations of stations at which hydrographic data and complete series of plankton samples were obtained (Michel, Foyo and Hangensen, 1976).

Table 37

Zooplankton species at Station 4, Cruise G-6722, situated at 17° 52' N, 64° 49' W, with a bottom depth of 4026 m and a fishing depth of 0-1520 m on 1 December 1967 (Michel et al., 1976).

	Depth (m)	Estimated number
Phylum Coelenterate		
Class Hydrozoa		
Order Siphonophora		
1. _Abylopsis tetragona_	55	200
2. _Diphyes bojani_	0	750
3. _Eudoxoides mitra_	55	50
Phylum Arthropoda		
Class Crustacea, Subclass Copeoda		
Order Calanoida		
1. _Acrocalanus longicornis_	0	55
	55	600
2. _Clausocalanus furcatus_	0	2950
	55	2650
	335	5
3. _Euchaeta marina_	0	150
	335	10
4. _Haloptilus longicornis_	335	165
5. _Lucicutia flavicornis_	0	250
	55	150
6. _Mormonilla minor_	335	80
	581	3
	1040	2
	1520	6
7. _M. phasma_	581	1
	1520	1
8. _Paracalanus aculeatus_	0	500
	55	250
9. _Rhincalanus cornutus_	335	15
	581	3
	1040	1
	1520	3

Table 37(cont.)

10. *Undinula vulgaris*	0	100
Order Harpacticoida		
11. *Macrosetella gracilis*	55	150
	335	5
12. *Microsetella rosea*	0	750
	55	5050
	581	1
	1040	1
	1520	3
Order Cyclopoida		
13. *Conaea gracilis*	581	2
	1040	2
14. *Farranula carinata*	0	2650
	1520	3
15. *F. gracilis*	0	50
16. *Oithona plumifera*	0	6100
	55	4750
	335	65
	1520	2
17. *Oncaea mediterranea*	55	200
	335	10
18. *O. venusta*	0	1100
	55	500
Phylum Arthropoda		
Class Crustacea, Subclass Malacostraca		
Order Euphausiacea		
1. *Euphausia americana*	0	50
2. *E. brevis*	0	300
3. *E. tenera*	0	50
4. *Stylocheiron longicorne*	335	15

Table 38

Zooplankton species at Station 1, Cruise P-6911, situated at 18° 00' N, 64° 49' W, with a bottom depth of 3008 m and a fishing depth of 0-2337 m on 26 October 1969 (Michel et al., 1976)

	Depth (m)	Estimated number
Class Hydrozoa		
Order Siphonophora		
1. *Abylopsis eschscholtzii*	0	120
2. *A. tetragona*	65	300
3. *Chelophyes appendiculata*	0	570
4. *Dyphyes bojani*	0	390
5. *D. dispar*	0	60
6. *Eudoxoides mitra*	65	100
Phylum Arthropoda		
Class Crustacea, Subclass Copepoda		
Order Calanoida		
1. *Acrocalanus longicornis*	0	30
2. *Clausocalanus furcatus*	0	300
3. *Euchaeta marina*	2337	1
4. *Haloptilus longicornis*	250	100
	459	420
	911	30
5. *Lucicutia flavicornis*	65	300
	250	400
	1835	1
6. *Mormonilla minor*	250	5400
	459	600
	715	96
	911	141
	1371	50
	1835	24
	7	23

Table 38 (cont.)

7. *M. Phasma*	250	150
	459	20
	715	27
	911	75
	1371	6
	1835	10
	2337	3
8. *Paracalanus aculeatus*	0	90
9. *Rhincalanus cornutus*	459	40
	715	27
	911	48
	1371	42
	1835	5
	2337	8
10. *Undinula vulgaris*	0	150
Order Harpacticoida		
11. *Macrosetella gracilis*	0	30
	250	250
12. *Aegistus aculeatus*	911	9
	1371	4
	1835	1
13. *Microsetella rosea*	0	390
	65	750
	250	450
	459	60
	715	3
	911	3
	1371	4
	1835	5
Order Cyclopoida		
14. *Conaea gracilis*	459	160
	715	156
	911	327
	1371	22
	1835	11
	2337	21
15. *Farranula carinata*	0	270

Table 38(cont.)

16.	Oithona plumifera	0	180
		65	7150
		250	2200
		459	200
		715	6
		911	11
		1371	6
		1835	10
		2337	2
17.	Oncaea mediterranea	250	300
18.	O. venusta	65	200
		250	50
		1835	1

Phylum Arthropoda

Class Crustacea, Subclass Malacostraca

Order Euphausiacea

1.	Euphausia brevis	65	50
2.	Nematoscelis megalops	250	50
3.	Thysanopoda aequalis	65	50

Phylum Chaetognatha

1.	Eukrohnia bathyantarctica	1371	3
		1835	1
		2337	1
2.	E. fowleri	715	6
		911	5
3.	Krohnitta pacifica	0	5
		1835	1
4.	K. subtilis	250	2
		459	20
5.	Pterosagitta draco	65	35
6.	Sagitta decipiens	250	102
7.	S. enflata	0	55
		65	165
8.	S. hexaptera	0	5
		65	10

Table 38(cont.)

9.	*S. hispida*	0	20
10.	*S. lyra*	250	30
11.	*S. macrocephala*	715 911	3 13
12.	*S. serratodentata*	0 65	30 20
13.	*S. zetesios*	911	4
Phylum Chordata			
Subphylum Urochordata, Class Thaliacea			
Order Salpida, Family SALPIDAE:			
1.	*Thalia democratica*	65	800
2.	*Weelia cylindrica*	0	75

According to Michel, et al. (1976), seven species of Thecomosata (pteropods) were encountered at sites farther from the OTEC power plant studies, but near the island of Puerto Rico. The seven Thecomosata species are:

Mollusks
  Class Gastropoda
    Subclass Opisthobranchia
      Order Thecosomata
        Suborder Euthecosomata
          Family Limacinidae

1. *Limacina inflata*
2. *Limacina trochiformis*

Family Cavolinidae

3. *Creseis acicula*
4. *Styliola subula*
5. *Diacria trispinosa*
6. *Cavolina inflexa*

Suborder Pseudothecosomata
  Family Desmopteridae

7. *Desmopterus papilio*

Michel and Foyo (1971) identified and estimated 86 species within six zooplanktonic groups studied in the Caribbean Sea and adjacent areas. They are listed in Table 39.

3.2.2.3.2. Relative Abundance

Approximatley 450 species of oceanic calanoid, harpacticoid and cyclopoid copepods have been reported in the Caribbean. The most numerous of the metazoan planktonic groups and the most widely distributed vertically are the copepods, with chaetognaths ranking next. Although the number of calanoid species is far greater than that of cyclopoids, the latter nearly equalled calanoids in total number of individuals, with the most numerous cyclopoids, *Farranula carinata* and *Oithona plumifera*, being more than twice as abundant as the top ranking calanoids, *Clausocalanus furcatus* and *Mormonilla minor*. Harpacticoida, the smallest group of planktonic copepods, includes the third most numerous form counted, *Microsetella rosea*. The total number of Copepoda collected at 48 stations in the Caribbean selected to compare abundance in major areas are shown in Table 40 and Figure 55. (Michel, Foyo and Haagen, op. cit.)

The Chaetognatha consists of 15 species 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 total numbers of Chaetognatha are given in Table 40 and Figure 56.

Michel and Foyo (1977) stated that Euphausiacea were inadequately sampled but they listed 15 new records for the Caribbean Sea, with *Euphausia americana*, *E. brevis*, *E. tenera*, *E. gibboides*, *E. mutica*, *Nematocelis megalops*, *Stylocheiron longicorne*, *S. elongatum* and *Thysanopoda monacantha*, among the most abundant of this group. The relative abundance of euphausids is shown in Figure 57 and Table 40.

The most common Thecosomata (pteropods) encountered around Puerto Rico are listed in Table 38. They are: *Limacina inflata*, *L. trochiformis*, *Creseis acicula*, *Styliola subula*, *Diacria trispina*, *Cavolina inflexa* and *Desmopterus papilio*. Horizontal distribution of total Thecosomata for the Caribbean Sea is shown in Figure 58.

The siphonophores *Abylopsis tetragona*, *A. eschscholtzii*, *Diphyes bojani*, *D. dispar*, *Eudoxoides mitra*, and *Chelophyes appendiculata* (Tables 37 and 38) were identified close to Punta Tuna, Puerto Rico. Total number of Siphonophora

Table 39. Relative abundance of species of six zooplanktonic groups studied in the Caribbean Sea and adjacent areas (Michel and Foyo, 1977).

Group and Species	Total numbers
Siphonophora	
Abylopsis eschscholtzii	13 040
A. tetragona	15 608
Bassia bassensis	4
Ceratocymba leuckartii	1
Chelophyes appendiculata	7 482
Diphyes bojani	14 667
D. dispar	4 213
Eudoxoides mitra	4 250
E. spiralis	1 700
Heteropoda	
Atlanta fusca	1
A. inclinata	20
A. inflata	2
A. peroni	14
Cardiapoda placenta	1
Firoloida desmaresti	46
Protatlanta souleyeti	2
Pterotrachea coronata	1
Copepoda	
Calanoida	
Acrocalanus longicornis	28 856
Clausocalanus furcatus	169 191
Euchaeta marina	62 029
Haloptilus longicornis	50 990
Lucicutia flavicornis	54 219
Nannocalanus minor	159 076
N. obesa	14 270
Paracalanus aculeatus	70 543
Rhincalanus cornutus f. atlantica	53 206
Scolecithrix danae	22 414
Undinula vulgaris	66 514
Other Calanoida	2 905 723
Harpacticoida	
Aegisthus aculeatus	1 694
Macrosetella gracilis	80 563
Microsetella rosea	270 068
Other Harpacticoida	34 442
Cyclopoida	
Conaea gracilis	45 690
Farranula carinata	412 740
F. gracilis	12 895
Oithona plumifera	491 616
Oncaea mediterranea	56 584
O. venusta	124 782
Other Cyclopoida	2 254 529
Euphausiacea	
Euphausia americana	2 091
E. brevis	4 555
E. gibboides	310
a/ E. hemigibba	585
E. mutica	1 255
a/ E. pseudogibba	46
E. tenera	6 769
a/ Nematobrachion boopis	165
a/ N. flexipes	179
a/ Nematoscelis megalops	240
a/ N. microps/atlantica	405
a/ N. tenella	260
a/ Stylocheiron abbreviatum	35
a/ S. affine	1 720
a/ S. carinatum	2 695
S. elongatum	5
S. longicorne	2 416
a/ S. suhmii	875
a/ Thysanopoda aequalis	461
T. monacantha	6
a/ T. obtusifrons	230
a/ T. pectinata	1
a/ T. tricuspidata	54
Chaetognatha	
Bathybelos typhlops	1
Eukrohnia bathyantarctica	275
E. bathypelagica	270
E. fowleri	195
E. hamata	17
E. proboscidea	5
Krohnitta pacifica	4 762
K. subtilis	3 455
Pterosagitta draco	11 717
Sagitta bipunctata	2 162
S. decipiens	13 183
S. enflata	57 795
S. helenae	14
S. hexaptera	9 545
S. hispida	1 131
S. lyra	3 579
S. macrocephala	471
a/ S. megalophthalma	2
S. minima	165
S. planctonis	615
S. serratodentata	31 331
S. zetesios	69
Salpidae	
Ihlea punctata	1 636
Salpa fusiformis	2 617
Thalia democratica	[illegible]
Weelia cylindrica	6 513

a/ New record for the Caribbean Sea

Table 40

Relative abundance of five groups of organisms collected at stations selected to compare distribution in major Caribbean areas (Michel, Foyo and Haangensen, 1976).

Region	Station	Siphonophora	Copepoda	Euphausiacea	Chaetognatha	Salpidae	Total
Yucatan Channel	P6701, Sta. 2	215	39,874	569	2,544	20	43,222
	P6805, " 2	800	63,720	790	1,531	0	66,841
	P6811, " 20	230	46,400	40	947	0	47,617
	P6904, " 2	1,550	117,780	70	736	1,250	121,386
Western Caribbean	P6805, " 3	1,100	184,323	330	5,658	100	191,511
	" , " 4	700	74,928	150	838	800	77,416
	P6811, " 14	300	50,866	0	3,521	0	54,687
	" , " 15	120	40,752	100	1,865	350	43,187
	" , " 16	150	61,616	392	1,216	0	63,374
	" , " 17	170	81,372	20	918	0	82,480
	" , " 18	150	107,330	400	1,261	150	109,291
	" , " 19	300	50,188	465	1,266	0	52,219
Central Caribbean	P6606, " 4	400	72,970	1,160	855	300	75,685
	P6805, " 5	250	62,430	498	4,143	50	67,371
	" , " 7	1,550	88,298	360	9,257	55	99,520
	P6811, " 2	60	47,156	550	1,257	30	49,053
	" , " 3	600	124,259	170	1,314	200	126,543
	" , " 4	590	198,608	240	3,872	150	203,460
Eastern Caribbean	P6805, " 9	450	35,339	1,572	2,978	300	40,639
	" , " 10	1,350	25,193	811	2,619	350	30,323
	" , " 11	240	17,108	954	2,636	0	20,938
	P6911, " 1	1,540	77,672	150	586	1,550	81,498
	" , " 2	1,504	63,003	584	2,180	650	67,921
	" , " 3	150	99,664	720	1,926	150	102,610
	" , " 4	210	33,342	400	1,545	620	36,117
	" , " 5	570	52,164	302	1,598	30	54,664
	" , " 6	930	59,293	0	1,292	220	61,735
	" , " 7	124	35,861	600	728	312	37,625
	" , " 8	250	54,345	100	924	2,120	57,739
	" , " 9	1,150	106,716	357	5,293	1,650	115,168

Table 40 (cont.)

Region	Station	Siphonophora	Copepoda	Euphausiacea	Chaetognatha	Salpidae	Total
	P6911, Sta. 10	650	97,726	796	3,622	1,850	104,644
	" , " 11	1,210	66,921	112	6,276	550	75,069
Areas of Upwelling	P6606, " 11	0	29,724	0	910	0	30,634
	" , " 12	50	121,957	75	8,600	25	130,707
	" , " 13	50	52,133	270	980	25	53,458
	" , " 14	100	77,500	540	4,000	150	82,290
	P6811, " 5	2,650	112,029	800	7,595	1,000	124,074
	" , " 6	750	85,782	670	1,373	600	89,175
	" , " 7	1,254	94,730	690	3,128	0	99,802
	" , " 8	3,145	25,824	280	1,174	40	30,463
	" , " 9	1,300	129,204	3,350	3,225	105	137,184
	" , " 10	1,450	110,583	1,380	7,647	500	121,760
	" , " 11	625	177,904	2,750	4,617	650	186,546
	" , " 12	670	78,885	84	2,490	200	82,329
Windward Passage	" , " 1	100	90,261	450	2,019	100	92,930
Mona Passage	P6911, " 12	403	74,607	380	2,010	0	77,400
Grenada Passage	G6722, " 15	120	7,966	6	831	64	8,987
	" , " 17	370	33,639	230	1,042	10	35,291

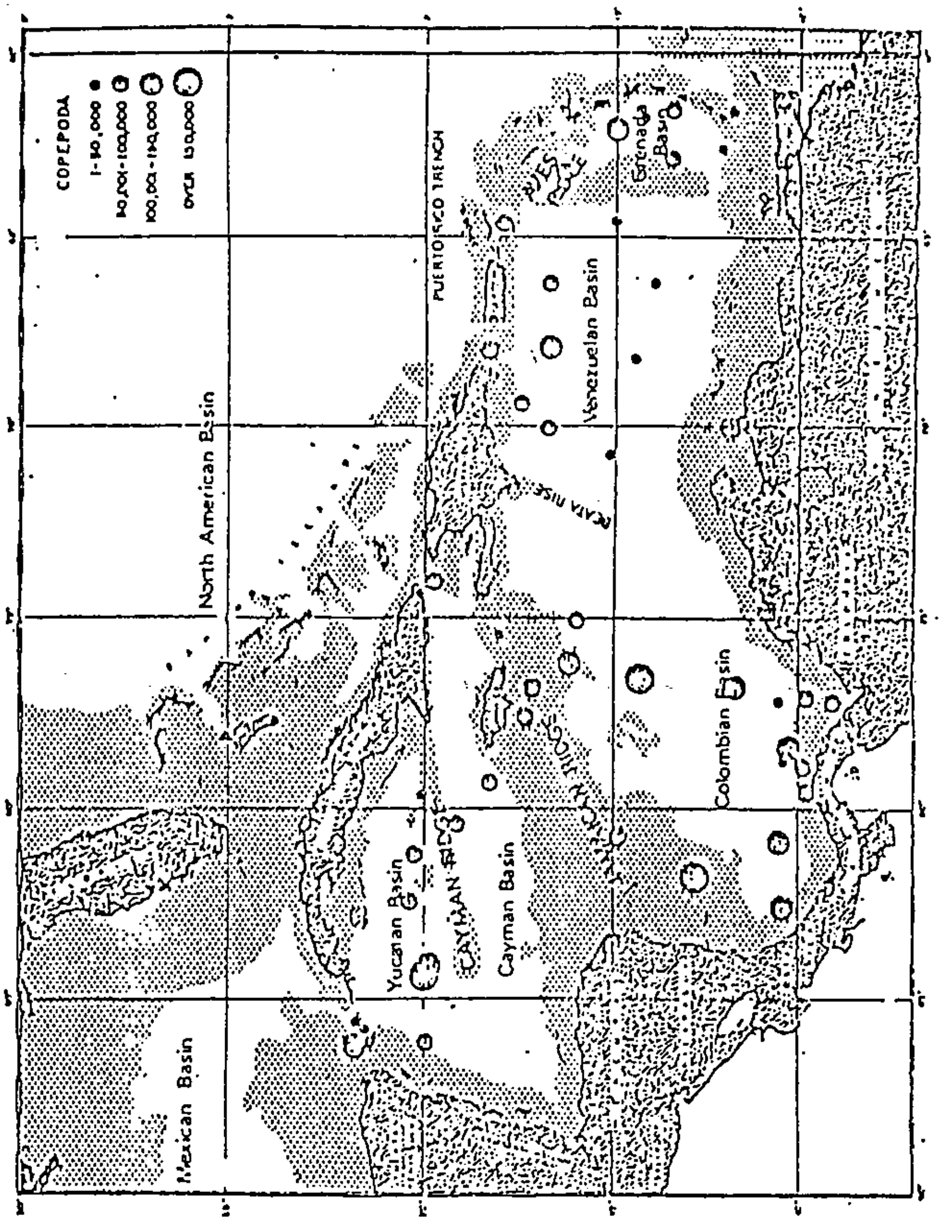


Figure 55 Total numbers of Copepoda collected at 48 stations selected to compare abundance in major Caribbean areas (Michel, Foyo and Haagensen, 1976).

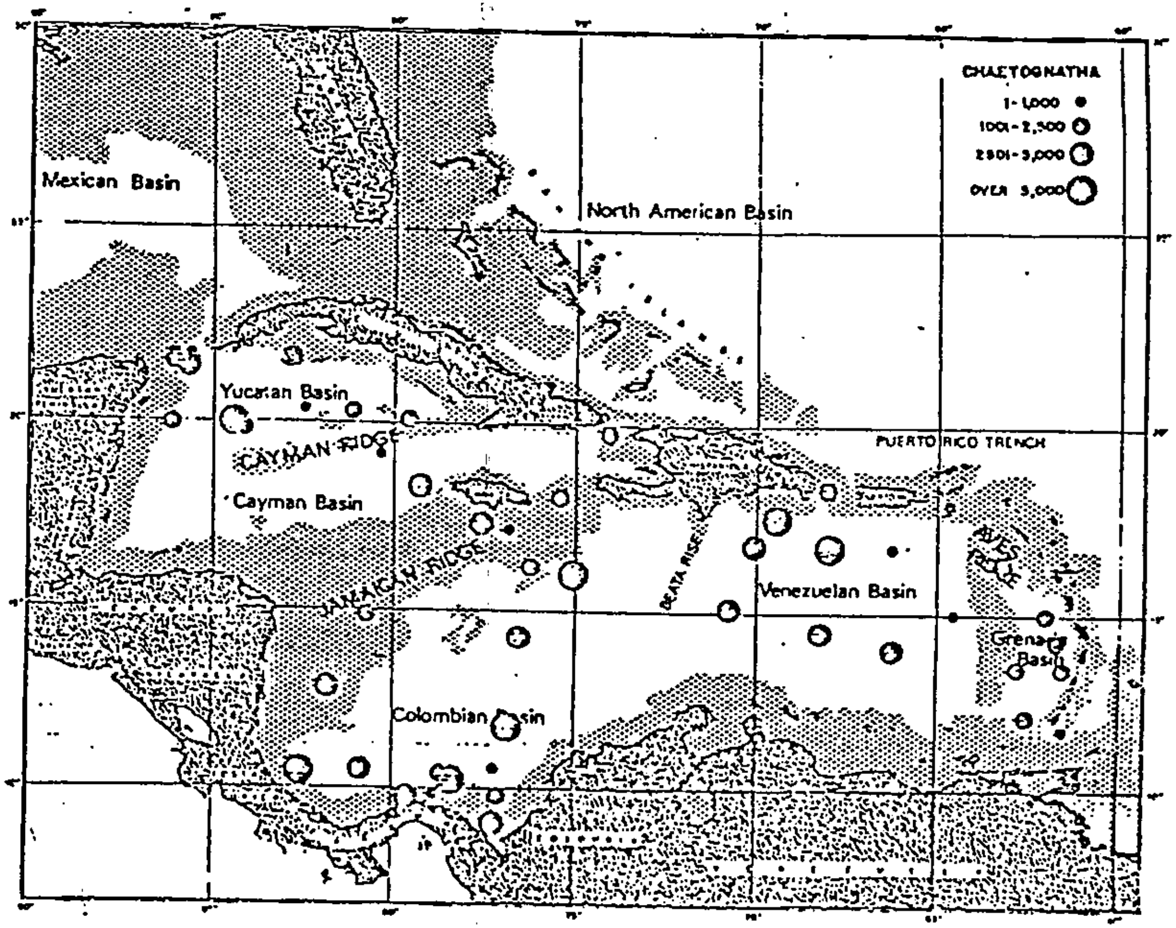


Figure 56. Total numbers of Chaetognatha collected at 48 stations selected to compare abundance in major Caribbean areas (Michel, Foyo and Haagensen, 1976).

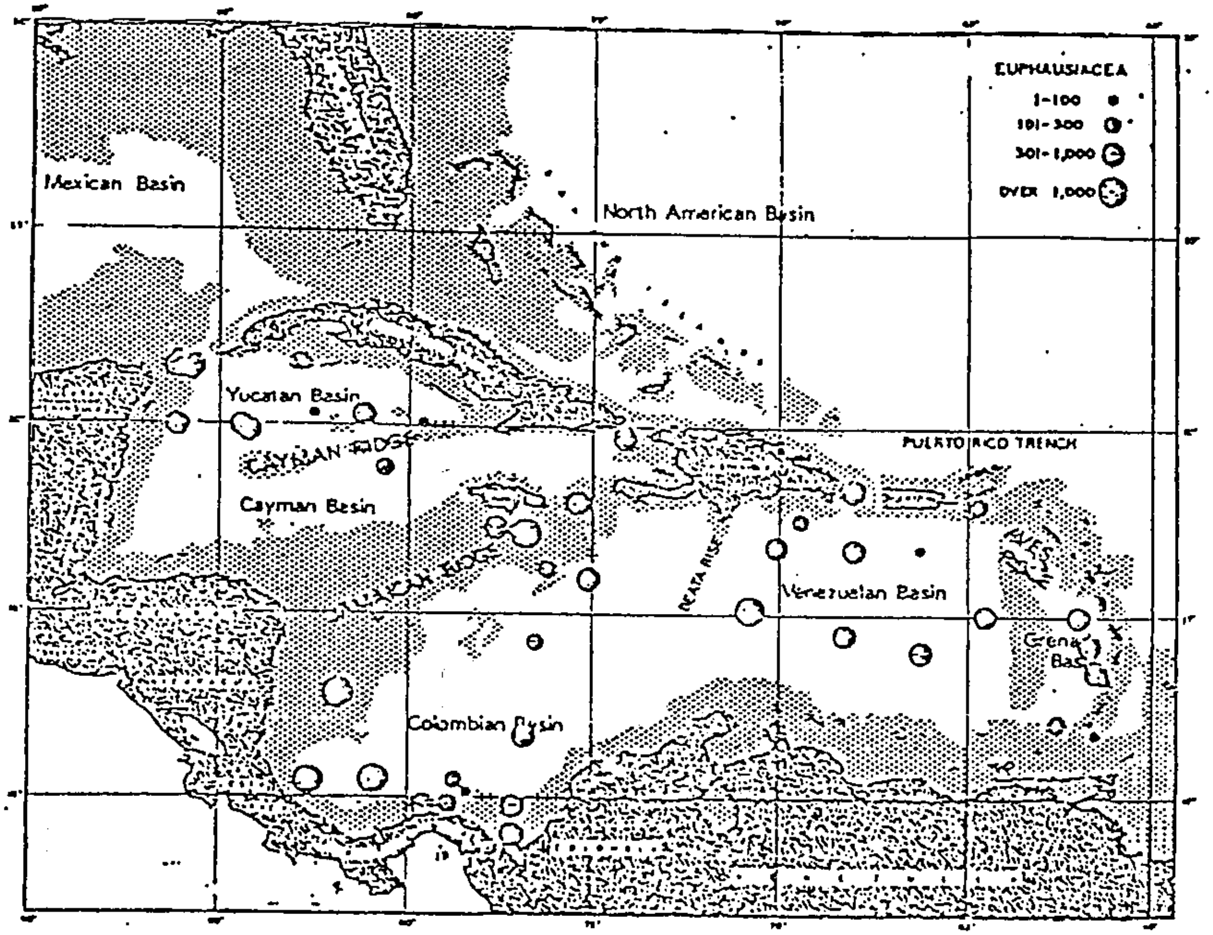


Figure 57. Total numbers of Euphausiacea collected at 48 stations selected to compare abundance in major Caribbean areas (Michel, Foyo and Haagensen, 1976).

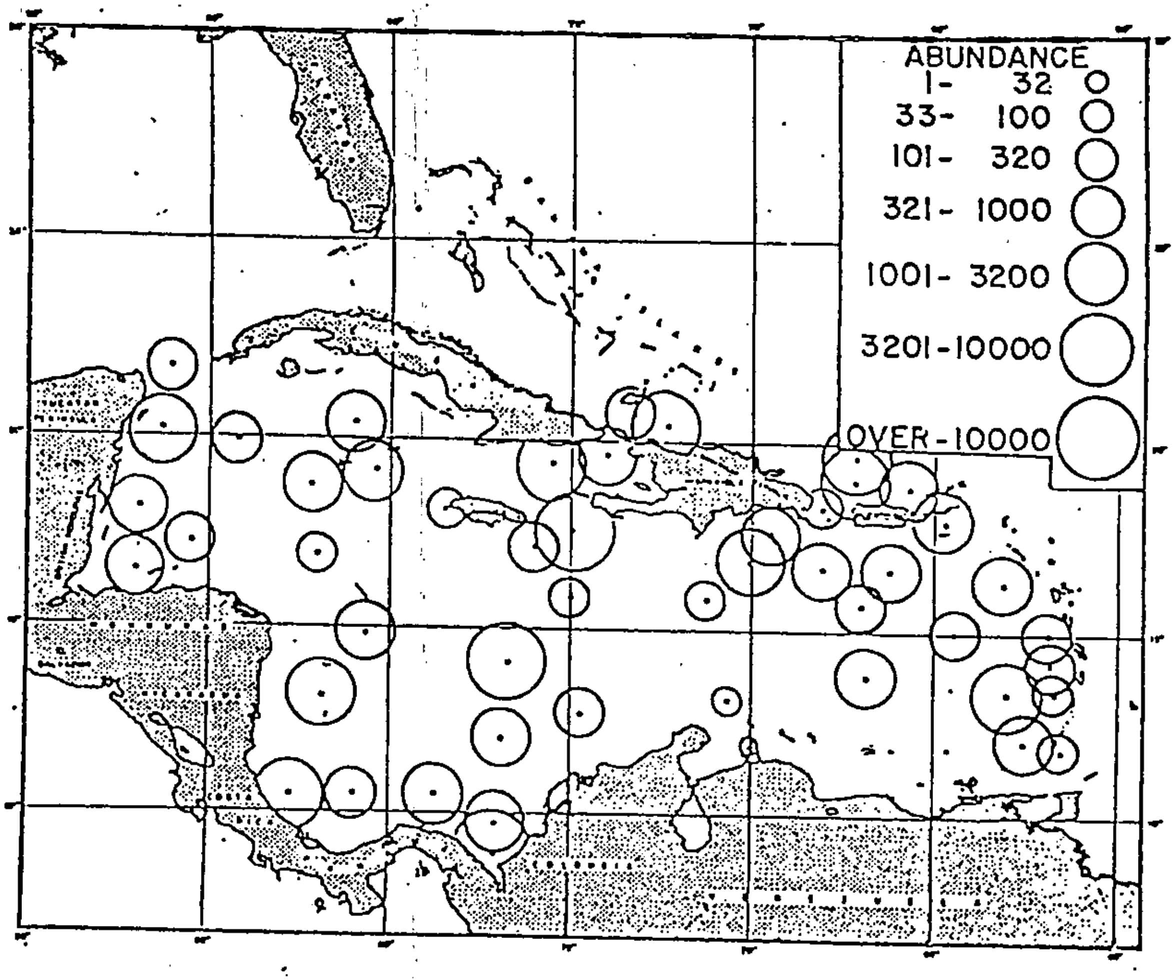


Figure 58. Horizontal distribution of total Thecosomata (Michel, Foyo and Haagensen, 1976).

collected from the Caribbean are listed in Table 40 and shown graphically in Figure 59.

The salps, *Thalia democratica* and *Weelia cylindrica*, found near Punta Tuna, are familiar inhabitants of the upper two water masses of the area, the Tropical Surface Water (TSW) and the Subtropical Underwater (SUW). These two water masses comprise the upper 200 m of the Caribbean Sea. The total numbers of salpidae collected from the Caribbean Sea are listed in Table 40 shown in Figure 60.

Michel and Foyo (1977) calculated affinity indices which show two groups with an index of 0.50. An epipelagic group consists of *Sagitta serratodentata*, *S. enflata*, *Paracalanus aculeatus*, *Clausocalanus furcatus*, *Krohnitta pacifica*, *Diphyes bojani*, *Acrocalanus longicornis* and *Farranula carinata*; species having affinity only with the preceding are *Abylopsis eschscholtzii*, *Undinula vulgaris*, *S. hispida* and *Euchaeta marina*. All these species are inhabitants of the TSW and the SUW.

Bathypelagic species comprising the second group are *Mormonilla minor*, *M. phasma*, *Rhincalanus cornutus*, *Conaea gracilis*, *Sagitta macrocephala* and *Aegisthus aculeatus*; species having affinity only with the preceding are *Eukrohnia fowleri* and *E. bathypelagica*. The bathypelagic region is located between 1000 to 4000 m depth. In the Caribbean Sea this region corresponds with the Venezuela Bottom Water (Wust, 1964; Sturges, 1965; Atwood et al., 1976).

3.2.2.3.3. Horizontal and Vertical Distribution

Michel and Foyo (1976) did not find a uniform distribution of abundance within any group or with all considered together. Instead, the greatest numbers of zooplankton were collected in the Central Caribbean and in the areas of upwelling in the Central American bight, very far from Puerto Rico. This is best illustrated by the distribution of copepods (Fig. 61, which also indicates a high level of productivity in the eastern Caribbean, suggested by earlier studies), as well as a massing of organisms in the far west, as waters approach the Yucatan Channel. Michel and Foyo (1977) state:

> "The vertical distribution of all species except very rare forms, e.g. *Stylocheiron elongatum*, *Thysanopoda pectinata*, *Sagitta planctonis* and heteropods, was diagrammed to show the relationship of abundance to temperature and salinity. Examples are given in Figures 62 and 63. Many species were found over a great range, the lower extremes of which cannot always be ascribed to contamination because of the frequency of

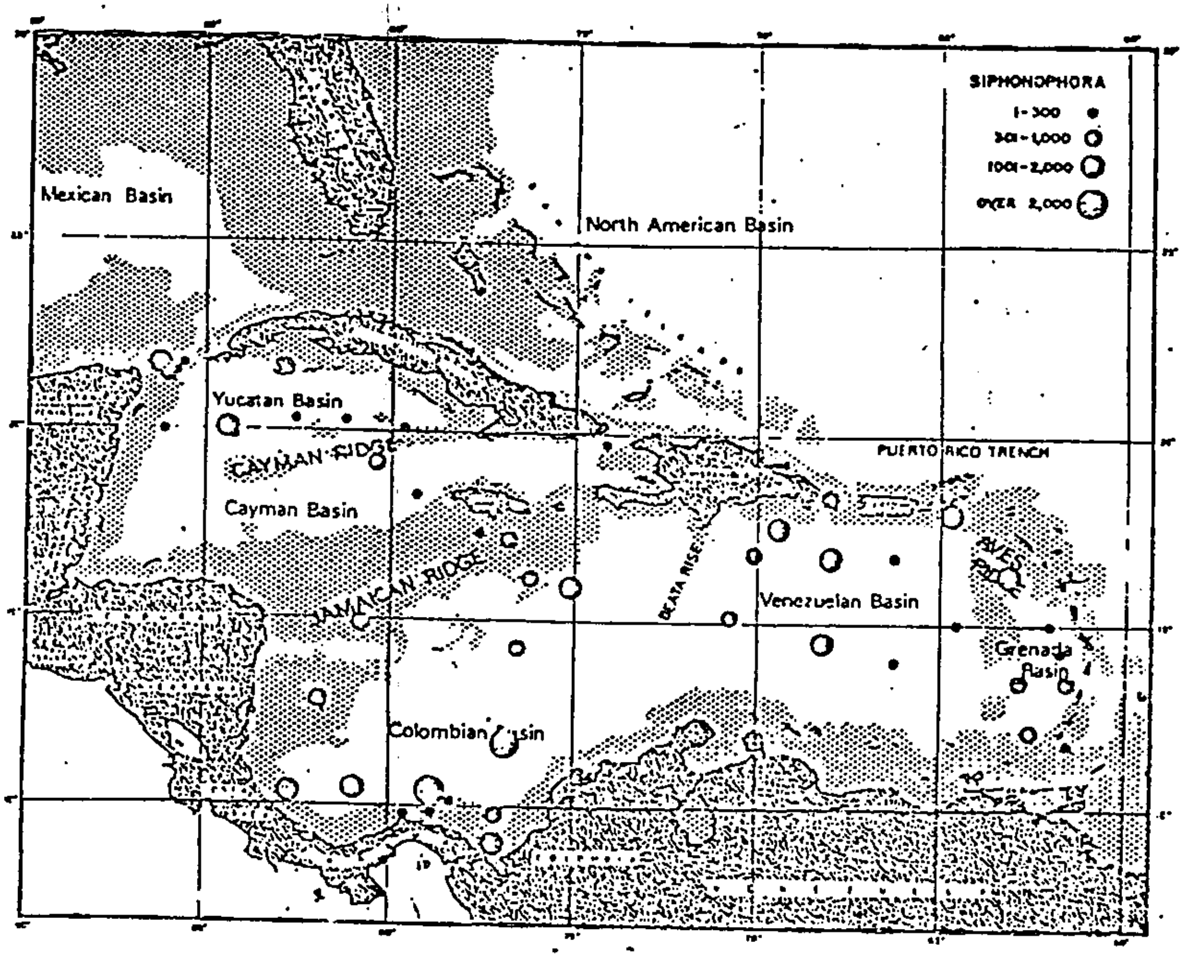


Figure 59. Total numbers of Siphonophora collected at 48 stations selected to compare abundance in major Caribbean areas (Michel, Foyo and Haagensen, 1977).

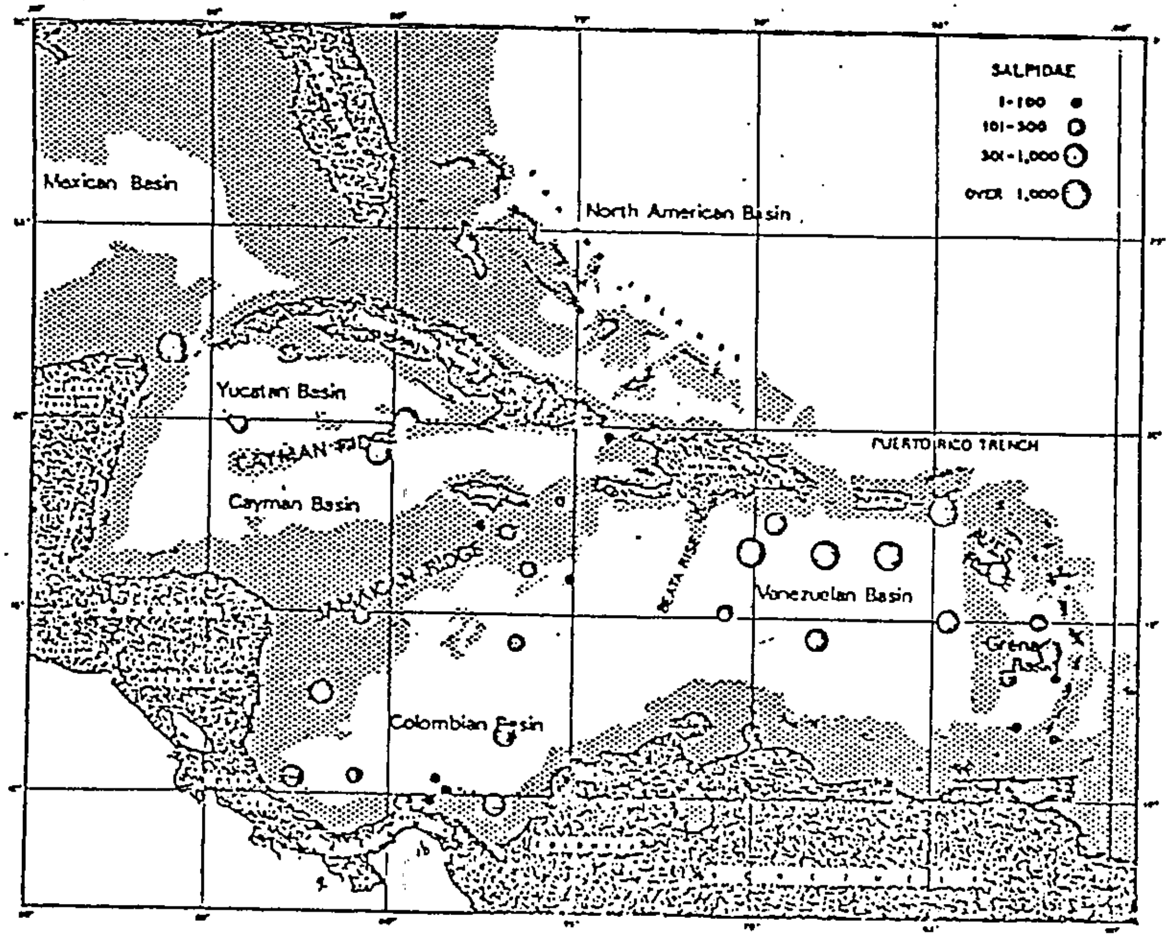


Figure 60. Total numbers of Salpidae collected at 48 stations selected to compare abundance in major Caribbean areas (Michel, Foyo and Haagensen, 1976).

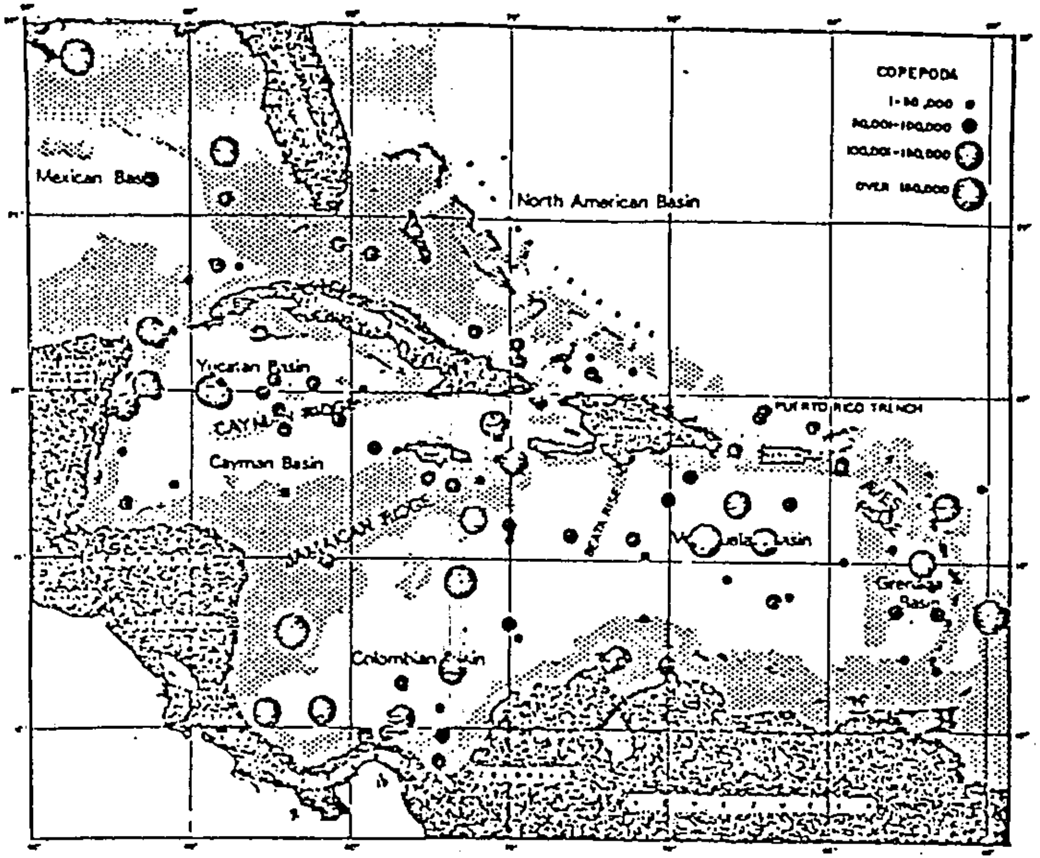


Figure 61. Total numbers of copepods collected at all depths combined at each station (Michel and Foyo, 1977).

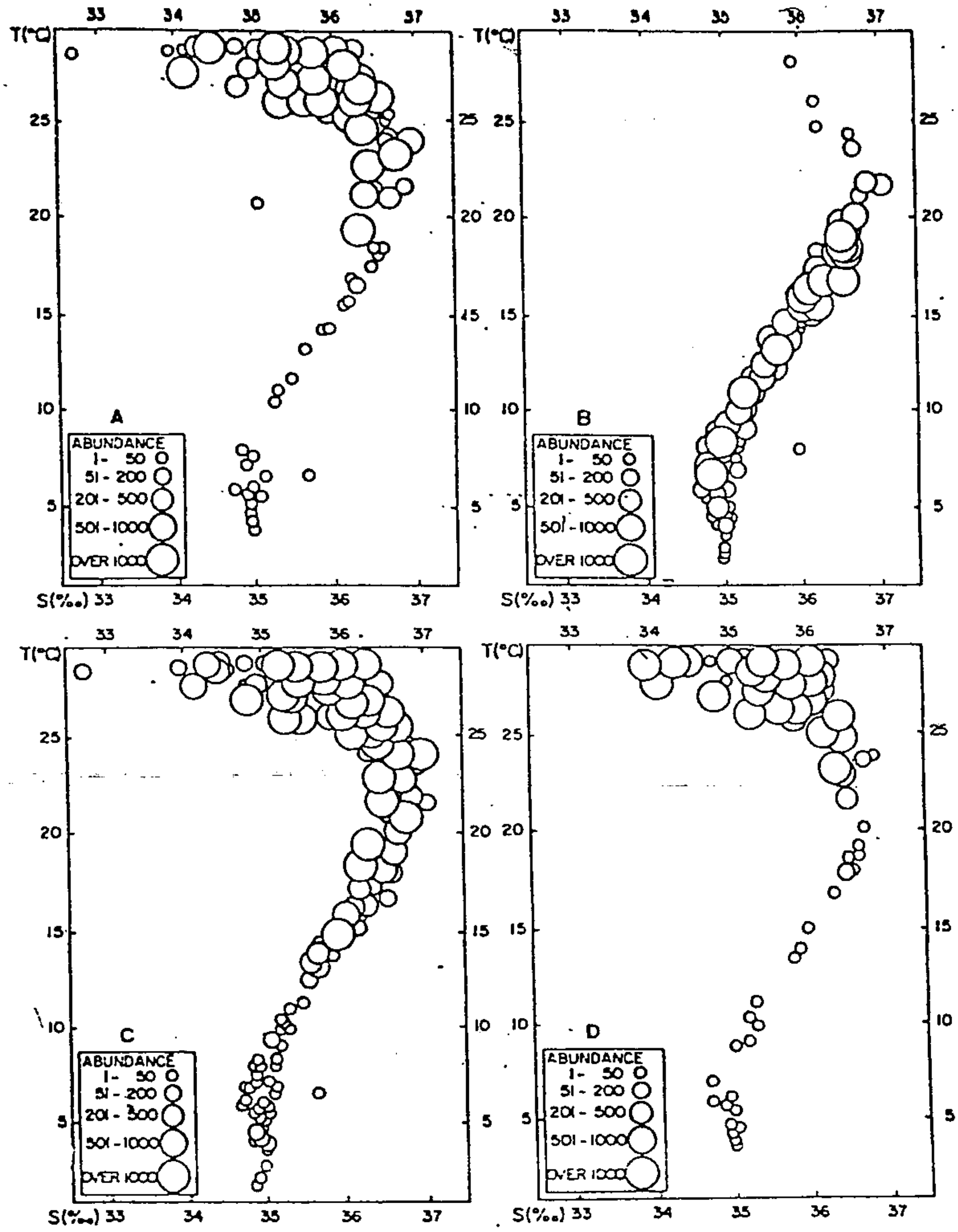


Figure 62. Temperature-salinity-plankton diagrams. A. *Clausocalanus furcatus*; B. *Mormonilla minor*; C. *Microsetella rosea*; D. *Farranula carinata*. (Michel and Foyo, 1977).

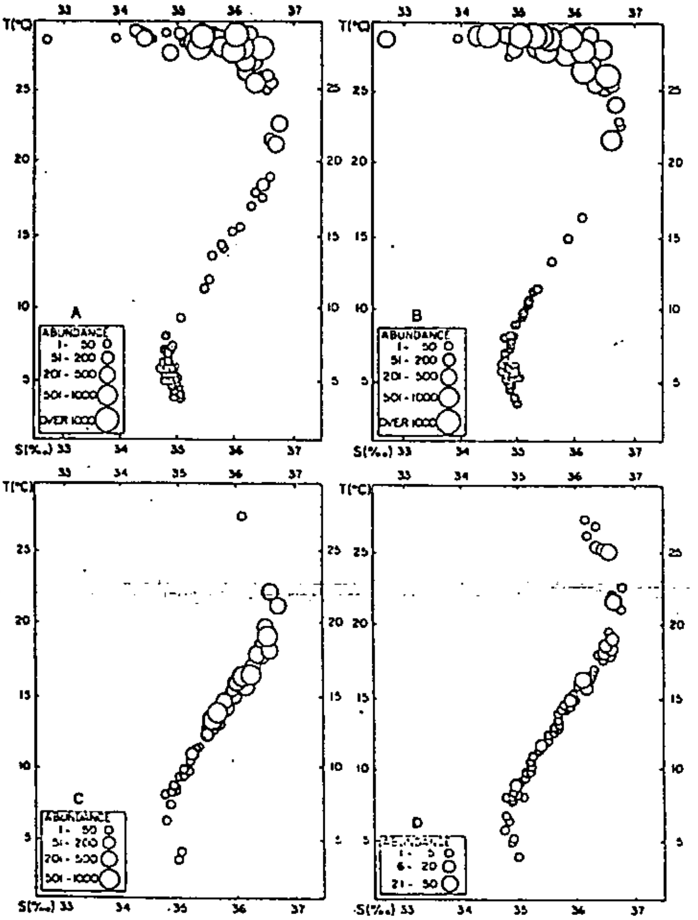


Figure 63. Temperature-salinity-plankton diagrams. A. *Sagitta serratodentata* (open circles) and *S. macrocephala* (stippled circles); B. *S. enflata* (open circles) and *Eukrohnia bathypelagica* (stippled circles); C. *S. decipiens*; D. *S. lyra* (Michel and Foyo, 1977).

records, and the efforts taken to wash nets and to eliminate desiccated specimens from consideration. However, the depths of major concentrations were usually clearly delimited. Thus the copepods *Acrocalanus longicornis* and *Clausocalanus furcatus* (Fig. 62A) live primarily in TSW and SUW, but the former is far more numerous in surface waters than the latter. *Euchaeta marina*, *Paracalanus aculeatus*, *Scolecithrix danae* and *Undinula vulgaris* are also found mainly in the upper 100 m, and *Farranula carinata* (Fig. 62D) and *F. gracilis* are most numerous in sub-surface swarms. *Haloptilus longicornis* is concentrated between approximately 100 and 250 m, day and night, occurring in lower TSW but most abundant in SUW and upper North Atlantic Central Water (NACW). *Lucicutia flavicornis* is distributed similarly, except that it is most numerous in TSW. *Rhincalanus cornutus f. atlantica* was common over a broader range than the others, being rare at the surface, but numerous in TSW and SUW, while the majority were living in NACW and Subantarctic Intermediate Water (SAIW). Others with similar extended distributions are *Macrosetella gracilis*, *Microsetella rosea* (Fig. 62C) *Oithona plumifera*, *Oncaea mediterranea* and *O. venusta*. In contrast, *Mormonilla minor* (Fig. 62B) was one of the few living in great abundance below SUW, common in SAIW and extending into North Atlantic Deep Water (NADW). The distribution of *M. phasma*, *Aegisthus aculeatus* and *Conaea gracilis* is similarly deep and the numbers fewer.

Distributional records of the more frequently caught euphausiid species indicate both migratory and non-migratory habits in that some occurred over a very broad vertical range in comparison with others. *Stylocheiron carinatum* and *S. suhmii* were collected only in TSW and SUW, *Nematobrachion boopis* only in NACW and SAIW, and *Nematocelis tenella* in NACW. Those found in TSW, SUW and NACW, but primarily in NACW, are *Euphausia hemigibba* and *Nematobrachion flexipes*; those more numerous in TSW were *E. americana*, *E. brevis*, *E. mutica*, *E. tenera* (also caught in SAIW), *Stylocheiron affine*, *S. longicorne* and *Thysanopoda aequalis*. Another group living mainly in NACW, but also collected in SUW, consists of *E. pseudogibba*, *Nematoscelis megalops*, *N. microps/atlantica*, *S. abbreviatum* and *T. obtusifrons*.

The vertical distribution of many chaetognath species is also extensive with however, the

> major concentrations clearly stratified. Most Sagitta serratodentata (Fig. 63A), S. enflata (Fig. 63B), S. bipunctata and Krohnitta pacifica live in warm surface waters of highly variable salinity, while S. hexaptera and Pterosagitta draco are usually associated with the more saline SUW. The least numerous epipelagic species were S. hispida, a natural inhabitant of inshore waters, and S. minima, of shelf and slope areas. Below these are four that span the greatest vertical range among chaetognaths in the Caribbean from SUW into SAIW and NADW: S. decipiens (Fig. 63C), S. lyra (Fig. 63D), S. zetesios and Krohnitta subtilis. The remaining four of the more abundant species were largely restricted to SAIW and NADW: Sagitta macrocephala (Fig. 63A), Eukrohnia bathyantarctica, E. bathypelagica (Fig. 63B) and E. fowleri."

Michel and Foyo, (op. cit.) also stated that changes

> "in distribution of some species, primarily copepods and chaetognaths, indicate upwelling, sinking, or admixture of coastal with oceanic waters. Farranula gracilis is a likely indicator of warm, saline waters of shallow equatorial origin when it is found in the Caribbean and the Florida Straits. The presence of Aegisthus aculeatus, which lives primarily in SAIW and NADW, in shallower water masses, indicates upwelling as does Morminilla minor, if numerous in TSW. Chaetognath species which mark an admixture of coastal waters when found in the open sea are Sagitta friderici and S. tenuis (not collected during this study), S. helenae and S. hispida. The presence of deep water species in relatively large numbers at unusually shallow depths indicates upwelling, e.g., S. lyra, S. macrocephala and E. bathyantarctica at 50, 635 and 230 m, respectively, at a station north of Panama. There is also the possibility that chaetognath species, rare in the Caribbean, may be indicators of waters entering the Sea from the North Atlantic, e.g., Eukrohnia hamata and Sagitta planctonis, known to be established in the North Atlantic, E. proboscidea, reported from southeast Africa, and S. magalopthalma, from the Mediterranean and the Gulf of Guinea. Locations at which specimens were collected are, in many cases, in or near the Windward and Anegada Passages and those between the Lesser Antilles. Intensive sampling in these areas might well show that there are biological labels to mark the influx of North Atlantic waters at various depths."

3.2.2.4. Fishes

Historical information regarding the fishes near Punta Tuna is such that the conditions in the water column can be understood.

3.2.2.4.1. Epipelagic Region

The epipelagic region of the oceanic zone is really a relatively thin, offhsore extension of the neritic zone, but it has permeable, water bottom, not a solid substrate. This region is well-lighted at the surface, dimming considerably towards its downward limit of about 200 m. Seasonal variations are shown in certain parameters such as temperature, light, salinity, oxygen, nutrients, and plant and animal populations (Lagler, et al., 1962). Of these parameters, light and temperature seem most important in determining animal distribution. Fish inhabitants include oceanward utilizers from the neritic zone, as well as some mackerels and tunas such as the following species: *Thunnus albacares* (Yellowfin tuna), *T. alalunga* (Albacore), *T. atlanticus* (Blackfin tuna), *T. thynnus* (Bluefin tuna), *Euthynnus pelamis* (Skipjack tuna), *E. alletteratus* (Little tuna), *Auxis thazard* (Frigate mackerel), *Acanthocybium solanderi* (Wahoo), *Scomberomorus cavalla* (King mackerel), and *S. regalis* (Cero). All these fishes belong to the family Scombridae (Erdman, 1974).

Other fishes in this division are as follows: from the family Xiphidae, Swordfish (*Xiphias gladius*); Istiophoridae, Sailfish (*Istiophorus platypterus*), Blue marlin (*Makaira nigricans*) and White marlin (*Tetrapturus albidus*). In the Coryphaenidae, Dolphin (*Coryphaena hippurus*) and Pompano dolphin (*C. equisetus*).

From the family Exocoetidae (Flying fishes) we have the Atlantic flyingfish (*Cypselurus heterurus*) and the Margined flyingfish (*C. cyanopterus*); and from the family Anguillidae, the American eel (*Anguila rostrata*). Also, Triggerfish and Filefishes of the family Balistidae (*Balistes vetula*, trigger fish) and needlefishes of the family Belonidae (*Strognylura* spp.) could come from nearshore. In addition to these fishes we may find different species of sharks of the following families: Rhincodontidae, Carcharhinidae, Lamnidae and Sphyrnidae; also Mantas such as the Atlantic manta (*Manta birostri*).

3.2.2.4.2. Mesopelagic Region

Occupants of the mesopelagic region of the ocean (between 200 to 1000 m) depend for food on a "rain" of plankton, detritus, and droppings from the overlying epipelagic region and on predatory relationships. There is little seasonal variation of temperature; water temperature is virtually constant, ranging from 5-20 °C, depending on depth. The pressure is high and what little light there is, is extremely dim, and in the blue and violet range. This region contains the uppermost aphotic waters of the oceans and is inhabited mainly by dark-adapted, or scotophilic, animals (Lagler et al., 1962). Many of the fishes in this zone are black or red and move upward to feed in the epipelagic region at night. The larval stages of these invaders also pass into epipelagic waters. An example of an inhabitant of this environment is the lanternfish (Myctophidae).

3.2.2.4.3. Bathypelagic Region

In the bathypelagic region of the oceanic zone most food gravitates downward from the waters above. There are no seasonal variations in physical factors of the environment; the water is very cold (between 2°and 4°C at 2000 m), the water pressure is very great, and darkness prevails except for the bioluminiscence arising from the light organs of some of the inhabitants. Fishes are greatly reduced in both number and kinds below those of the upper waters (Lagler et al., 1962). This division is also characterized by deep water species such as those of the families Zeidae (dories) and Scorpaenidae (scorpionfishes).

3.2.2.4.4. The Thermocline and the Fishes

Laevastu and Hela (1970) explain in detail the interpretation and use of the ocean thermal structure in relation to the distribution of fish. They stated that there are pelagic fish which are found above the thermocline, and others which frequent the layers of the thermocline, and still others which are found mainly in deep water (Fig. 64). According to Shanley (1972) the seasonal thermocline near Punta Tuna lies between 50 to 125 m deep. Under these conditions yellowfin tuna (Thunnus albacares) will remain above that depth, according to the seasonal changes. The bigeye tuna (Thunnus obesus) which is a species reported for the Atlantic and Pacific oceans could be found in the thermocline layers, and the Albacore (T. alalunga) would appear down to 50-125 m.

3.2.2.5. The Food Chain

The transfer of food energy from plants through a series of organisms repeatedly eating and being eaten is referred to as the "food chain." Fishes are tied to other forms of life in their environment by food webs. Each food organism is a part of the chain of life in which a fish species is merely another link or, if one considers the relative positions of the eaters and the

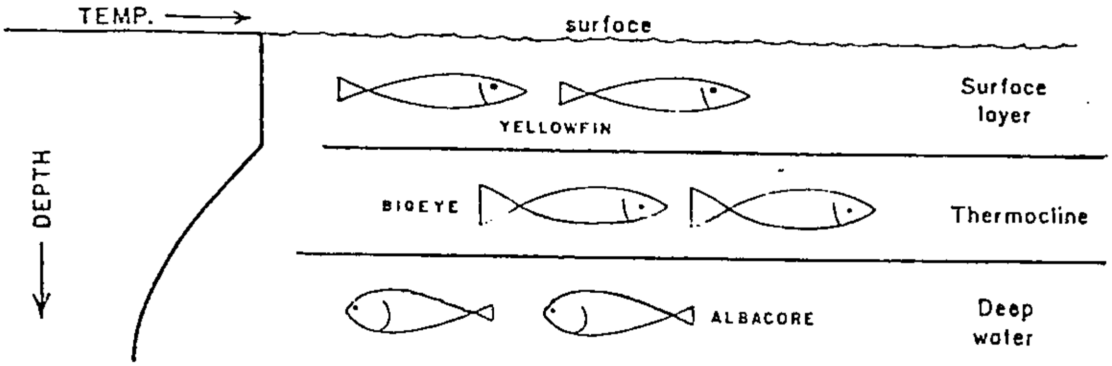


Figure 64. Schematic example of different depth and temperature preference by different species of tuna in tropical latitudes. (Laevastu and Hela, 1970).

eaten, herbivores and carnivores are at different vertical positions (trophic levels) of a food pyramid. Usually the largest carnivore or top predator can be placed at the apex of the pyramid, e.g., sharks such as Rhincodon typus (whale shark), Carcharhinus falciformis (silky shark) and C. longimanus (oceanic white tip shark). Also there are several species of fish of the families Scombridae, Xiphidae, Istiophoridae, Coryphaenidae, Exocoetidae, and Anguillidae, which have been mentioned above. Furthermore, we should include some sea mammals such as the bottlenosed dolphin (Tursiops truncatus), spinner dolphin (Stenella cf. longirostris, spotted dolphin (Stenella spp.), common dolphin (Delphinus delphis), humpback whale (Megaptera novaeangliae), fin whales, rorquals (Balaenoptera spp.), sperm whale (Physeter catodon), Cuvier's beaked whale (Ziphius cavirostris) and pilot whale (Globicephala macrorhyncha). All these species of mammals have been mentioned by Erdman, et al., (1973) and Erdman (1970). Some species of turtles such as leatherback (Dermochelys c. coriacea), loggerhead (Caretta c. caretta), green turtle (Chelonia m. mydas), and hawksbill (Eretmochelys i. imbricata), according to Rivero (1978), should also be mentioned.

The primary link or bottom trophic level is occupied by green plants which bind the sun's energy for further transfer through the living world. The phytoplankton, mainly diatoms and flagellates are part of this bottom level. Then comes an intermediate level composed of the herbivores, and crustaceans such as copepods and euphausids, chaetognaths, some mollusks, and fishes. Finally there is the highest trophic level, occupied by carnivores, in which there may be several tiers of fish and other big animals such as mammals and reptiles.

According to Erdman (1958, 1962) and Suárez-Caabro and Duarte-Bello (1961), there are many species of marine animals which, even though they usually live their adult life in the neritic province and in the littoral and sub-littoral zones, are present at least part of their lives in the oceanic province as larvae. Among those fish and shellfish which are a part of the food chain are the following: fishes such as Acanthurus spp. (Doctor fishes), Mulloidichthys martinicus (Goatfish), Holocentrus ascensionis (Squirrelfish), Caranx crysos (Blue runner), Hemiramphus brasiliensis (Ballyhoo) and Gempylus serpens (Snake mackerel); crustaceans which include Stomatopod (Flat white shrimps) larvae of several species of the family Squillidae; Decapoda (larvae), zoea and megalops stages of different species; Phyllosoma larvae of Panulirus spp. (Spiny lobster); some mollusks of the families Loliginidae and Enoploteuthidae; and Ommastrephidae (Squids) and Octopus spp. (Octopuses).

Altering the deep water layers, at an OTEC plant site would produce some alterations in the distribution of the organisms in the trophic levels because some of them would move to other areas looking for their appropriate environment. Nevertheless, the deep, cold water that is discharged near the surface is rich in nutrients and contains zooplankton which could be used by fish or plants depending on the need. For this reason we can predict that the upwelling of this cold water, along with the shadows cast by the plants, will entice greater numbers of fish to the area.

3.3. FISHERIES RESOURCES

Juhl (1971) mentioned that the Caribbean fishery resources could be grouped in three mayor zones: island arc and reefs, continental shelf, and pelagic. A fourth classification, midwater fishery, could be suggested but probably even today there is not enough information on this type of fishery.

In 1976, according to the Yearbook of Fishery Statistics FAO (1977), 47% of the regional production comes from island arc and reef resources. This includes the artisanal fisheries carried out by Puerto Rican local fishermen. The continental shelf resources reached 48% of the total production of the Caribbean. It is important to note that the most productive area, owing mainly to good hydrographical conditions for fisheries, lies from the Guianas to the Panama region, very far from Puerto Rico. The pelagic resources are the least productive, both in volume and number of species composition, with only 4% of the total production in 1976.

The most important Puerto Rico fishing centers close to Punta Tuna are located in the southern part of the island (Patillas, Maunabo, Yabucoa) and Vieques Island. In 1978 there were a total of about 100 artisanal fishermen, 70 fishing boats, and 1,400 units of fishing gear in this region. Most of the fishing activities are carried out in the narrow shelf from Patillas to Yabucoa, and south of Vieques Island. Very few fishermen go beyond the 20 m isobath. There are roughly 900 fishing pots, which represent 70% of the total fishing gear of the area. The total landings of fish and shellfish in these fishing centers in 1977 amounted to at least 225,000 Kg (Fig. 65).

Figure 65 . Commercial fishing area at the Benchmark site and adjacent waters.

REFERENCES

Ahlstrom, D. H. and J. R. Thraikill. 1962. Plankton volume loss with time of preservation. CAL-COFI Rept., 9:57:73.

Ballester, A. and R. Margalef. 1968. Estudios sobre el ecosistema pelágico del NE de Venezuela. Producción Primaria. Mem. Cienc. Nat. La Salle, 70, 71, 72, pp. 207-221.

Bogdanov, D. V. 1965. Algunos rasgos de la oceanografía del Golfo de Mexico y del Mar Caribe. Sovetko-Ku-binskii Rebojoziastvennie Issledovaniya, 1965, pp. 23-45.

Davis, R. A. 1973. Principles of Oceanography. Addison-Wesley, 434 pp.

Durán, M. 1957. Notas sobre algunos tintínnoideos del plancton de Puerto Rico. Inv. Pesq., 8:97-120.

Duxbury, A. C. 1962. Averaged dynamic topographies of the Gulf of Mexico. Limnol. Oceanogr., 7, pp. 428-431.

______ . 1971. The Earth and its Oceans. Addison-Wesley Publishing Co., 381 p.

Erdman, D. S. 1958. Food of pelagic fishes from Puerto Rico and the Bahama Islands. III Intl. Game Fish Conf., 12 p.

______ . 1962. The sport fishery for Blue Marlin off Puerto Rico. Trans. Amer. Fish. Soc. 91(2): 225-227.

______ . 1970. Marine Mammals from Puerto Rico to Antigua. Jour. Mammalogy, 51(3): 636-639.

______ . 1974. Common names of fishes in Puerto Rico. Cont. Agrop. Pesq., Dept. Agric., Puerto Rico, 6(2): 1-50.

Erdman, D. S., J. Harms and M. Marcial Flores. 1973. Cetacean Records from the Northeastern Caribbean Region. Cetology, 17: 1-14.

Fairbridge, R. W. (Edit) 1966. The Encyclopedia of Oceanography, Vol. I. Dowden, Hutchinson and Ross, Inc., Pennsylvania, 1021 p.

FAO 1977. Yearbook of fishery statistics. FAO Statistics Series, 42: 1-320.

Gordon, A. L. 1967. Circulation of the Caribbean Sea. Jour. Geophys., Res., 72, pp. 6207-6223.

Hart, T. J. 1959. A possible correlation between weather conditions and discoloured water phenomena in the Eastern Central basin of the Caribbean sea. The Marine Observer, 29, pp. 161-195.

Hulburt, E. M. 1963. Distribution of phytoplankton in coastal waters of Venezuela. Ecology, 44, pp. 169-171.

Ivanov, A. I. 1966. Some data of phytoplankton of the Gulf of Mexico and Florida Straits. Issledovaniya Chentralno Amerikanskij Morei, 1: 81-91.

Juhl, R. 1971. Status and potential of fishery in the Caribbean. In: Procc. Gulf and Caribb. Fish. Inst., 23rd. Ann. Sess., pp. 175-183.

Lavaestu, T. and I. Hela. 1970. Fisheries Oceanography. Fishing News (Book) Ltd., London, 238 p.

Lagler, K. F., J. E. Bardach and R. R. Miller. 1962. Ichthyology, The Study of Fishes. John Wiley and Sons, Inc. New York, 545 p.

Margalef, R. 1957. Fitoplancton de las costas de Puerto Rico. Inv. Pesq., 6: 39-52.

______ . 1960. Hidrografía y fitoplancton de un área marina de la costa meridional de Puerto Rico. Inv. Pesq., (en prensa).

______ . 1967. Ritmos, fluctuaciones y sucesiones. En: Fundación La Salle de Ciencias Naturales, Ecologís Marina, Caracas, Venezuela, Monografía 14· 485.

______ . 1971. The pelagic ecosystem of the Caribbean Sea. In: UNESCO-FAO Symposium on Investigations and Resources of the Caribbean Sea and Adjacent Regions. Curacao, November 1968. UNESCO, Paris, pp. 483-496.

Michel, H. B. and M. Foyo. 1977. Studies of Caribbean Zooplankton. In: Cooperative Investigations of the Caribbean Sea and Adjacent Regions, FAO, Fishery Report 200, pp. 275-289.

Michel, H. B., M. Foyo and D. A. Haagensen. 1976. Caribbean Zooplankton. Part I. -Siphonophora, Heteropoda, Copepoda, Euphausiacea, Chaetognatha and Salpidae. Part II - Thecosomata. Office of Naval Research, Dept. Navy, i-iv, 549 p.

Raymont, J. E. G. 1963. Plankton and Productivity in the Oceans. Pergamon Press, New York, 660 p.

Riley, G. A. 1939. Plankton studies II, The Western North Atlantic, May-June 1939. J. Mar. Res., 2: 145-162.

Rivero, J. A. 1978. Los Anfibios y Reptiles de Puerto Rico, Univ. of P. R., Edit. Univ., 300 p.

Shanley, G. E. (Rev. by C. P. Duncan) 1972. Hydrographic data for Caribbean Sea and for Pesca Serial Station at 17° 38'N, 67° 00'W for 171. Dept. Mar. Sci., UPR, Mayaguez, #72-1 (Rev).

Simmons, E. G. and W. H. Thomas. 1962. Phytoplankton of the Eastern Mississippi Delta. Publ. Inst. Mar. Sci., Univ. Texas, 8:269-298.

Suárez-Caabro, J. A. and P. P. Duarte-Bello. 1961. Biología Pesquera del Bonito (Katsuwonus pelamis) y Albacora (Thunnus atlanticus) en Cuba. I. Ser. Est. Inst. Cubano Inv. Technol., 15: 1-151.

Thomas, V. H. and E. G. Simmons. 1960. Phytoplankton production in the Mississippi Delta. Recent Sediments, Northwestern Gulf of Mexico. Am. Assoc. Petrol. Geol. Tulsa, pp. 103-116.

Wood, E., M. J. Youngbluth, P. Yoshioka and M. J. Canoy. 1975. Cabo Mala Pascua environmental studies. Puerto Rico Nuclear Enter, Univ. Puerto Rico, Mayaguez, PRNC-188, 95 p.

Wust, G. 1964. Stratification and circulation in the Antillean-Caribbean basins, I. Columbia Univ. Press, New York and London, 201 p.

Youngbluth, M. J. 1974a. Diel changes in the composition of a tropical, coastal zooplankton community. (In preparation).

______ . 1974b. Diel changes in the composition of tropical zooplankton assemblages from coastal waters around Puerto Rico. (Unpublished).

4.0. SUMMARY

This summary has for its basis, the literature and information that was discussed in this document, as well as the very prelimianry resutls of Puerto Rico's OTEC data-collection program for fiscal 1979. These latter results are not presented in this report, and shall only be referred to for confirmation or verification.

4.1. PHYSICAL ENVIRONMENT

The climate of Puerto Rico and its surrounding area is well documented as being typically tropical marine, with the superposition of predominant easterly winds. As is frequently found in similar situations, the windward side of the island usually receives more rainfall, with precipitation varying from 70-500 cm/year, depending on location. Again, as is often the case in tropical and subtropical latitudes, hurricanes and severe storms are experienced in the area. There is an annual expectation of such a storm being sufficiently near the area to be felt, and statistically every 3-5 years, a severe storm or hurricane may be expected to affect the weather and sea conditions for an extended time.

Historical wave statistics indicate that 99% of the time the seas are less than 3 m, and much of the time they range from 1-2 m.

The tidal excursion around the coast of Puerto Rico and her neighbors is small, ranging from virtually nothing to less than 1 m. In spite of this low tidal range, the tidal currents are seen as being significant components in the coastal circulation patterns of some areas.

There have been few measurements or even attempts to measure the water currents in the area. Some surface results show a predominant westerly drift, with occasional reversals. The subsurface results are even less definative, due to the few attempts. Usually a southwesterly drift is reported.

The salinity profile below the pycnocline (depth of most rapidly changing density-about 200 m maximum) along the south coast is documented fairly well. At and exceeding such depths, the variations due to atmospheric fluctuations are seldom seen. The upper waters are influenced by the atmosphere, the local weather and climate, and the degree of freshwater inflow from the major northeastern South American rivers. This relationship is now beginning to be understood. Typical upper water salinity may vary from

31-37 °/oo, with 34-36 °/oo most common. A salinity maximum of about 37 °/oo, is found immediately beneath the surface water mass (0-200 m). Below this salinity maximum, the salinity generally decreases to about 35 °/oo in the nearshore deep waters around the island.

Temperature values, and the resulting level of the thermal resource, are found frequently in the literature. The surface water temperature usually ranges from 26°C to 29°C. A sharply defined seasonal thermocline exists during part of the year, but the permanent thermocline, although present, is not well defined. Typical values of the temperature at the 1000 m depth is 6°C, with some small variation. The thermal resource available to an OTEC plant, using the surface and 1000 m depth values of temperature, is 20-23 C° throughout the year, except during severe weather conditions.

The Mixed Layer Depth, or isophycnic layer depth, varies from virtually zero to almost 150 m deep, with the usual range being 40-100 m, depending on the time of the year. These values are taken from various measurements made in the area over many years.

4.2. BIOLOGICAL ENVIRONMENT

The productivity of the Caribbean is known to be low due primarily to low available nutrient levels in the photic zone.

Not much has been reported about the phytoplankton, either nearshore, or in the open sea. The few exceptions include species lists (up to 450 species), and a brief description of the ecosystem near upwellings in the Caribbean.

Some zooplankton measurements have been taken both nearshore and in open water near Puerto Rico. Seasonal changes are seen in the nearshore waters, with most of the variations caused by fluctuations of holoplankton. These permanent plankton have accounted for 60-90% of the zooplankton collected near shore, with copepods comprising most of the organisms. About 450 species of copepods have been reported throughout the Caribbean water column. The greatest number of zooplankton were collected in the Central Caribbean and near areas of upwelling.

Overall, the biological resource of the Caribbean is scarcely being tapped, or understood, and therefore an accurate assessment of the ecosystem changes resulting from an OTEC plant being either present and/or operating can not necessarily be assessed at this time.

4.3. CONCLUSION

In conclusion, this survey shows that our present level of knowledge of the OTEC related oceanic parameters for the Puerto Rico area is low. Usually, the measurements, results, and citations used in this report were made with other purposes in mind. Therefore, the spatial and temporal scale of the measurements were not necessarily the most desirable for our purposes. It is hoped that during the next few years, this problem shall be corrected, with more OTEC-oriented measurement programs yielding more applicable and meaningful results.

5.0. RECOMMENDATIONS FOR FUTURE WORK

As there are few published and unpublished data available for the potential OTEC sites around the island of Puerto Rico, the results of this study lead to two recommendations; a more thorough historical data review, and future data collection.

5.1. HISTORICAL DATA REVIEW

Although the purpose of this study was to review the available physical and biological literature and unpublished information, there may still be more data as yet uncovered. One recommendation is to continue to be aware of any uncovered historical data sets that are pertinent to the area and to OTEC.

Most, if not all, of the available temperature and current data has been found for the Punta Tuna/Vieques area, but a more detailed study on salinity may be required. Furthermore, the geographical area of coverage should be expanded to include the remaining portion of the south coast of Puerto Rico, as well as the entire north and northwest coast. Although the physical differences measured at these locations should not vary considerably, they should be documented for the OTEC program.

This report does include a biological section, but the processing and reporting of biological results in the literature may lay behind the other data, due to longer processing and interpreting time. Therefore, an up-to-date interpretation of today's knowledge of the biota and their dynamics in this part of the world will probably not be available for some time. Continued literature monitoring will help minimize the time gap.

Chemical and geological revies were not part of this study, but certainly should not be overlooked. These reviews should be started as quickly as possible, since any environmental effect on the biota might well come about as a result of chemicals used in the cleaning of heat exchangers, or by trace metal erosion. An understanding of the dynamical structural interrelationships between the biota and their chemical environment might well predict or divert any future problems, or may suggest directions toward a more ecologically compatible design.

In summary, the following recommendations are being made with respect to the historical data:

1. Expand the geographical area of coverage of the literature review to include the entire south and north

coasts of Puerto Rico, including both the Atlantic and the Caribbean.

2. Continue to monitor the biological literature for updating of existing information that is pertinent.

3. Monitor all environmental studies completed in this part of the world for any usable information.

4. Use any available satellite sea surface temperature data to enhance the exisiting data bank and to develop better predictive capabilities.

5.2. FUTURE DATA COLLECTION

As so little applicable information is available, the greatest thrust toward understanding the oceanic region near Puerto Rico shall have to lie in the realm of combining the sparse historical information with an intensive data collection effort. This program must be developed at the specific benchmark site of Punta Tuna (where the present work is being conducted), and also along the remainder of the south coast and the entire north coast. The program must address itself to the questions of, "What effects will the ocean have on an OTEC power plant?" and "Waht effects will OTEC power plants have on the ocean?"

Possible OTEC scenarios include using intake water of up to 3000 m^3/sec from both the near surface and the terminus of a deep water pipe, many tens of meters in diameters, located as much as 1000 m deep. These two water intakes may or may not be mixed during their exhaust cycle. Therefore, design and environment planners must understand the physical, chemical, and biological dynamics of the entire water column and the geology of the bottom. The upper waters must be studied for mooring and stress effects, safety, thermal resource, biofouling, entrainment, productivity, and contamination. The mid-depths must be studied for contamination, stress effects, and the movement of the deep scattering layer. The bottom depths must be studied for thermal resource, entrainment, nutrient levels, and mooring problems. Furthermore, predictive relationships for these and other parameters must be responsive to both real and temporal variations. These are but a few of the considerations taken into account in the development of the recommendations which follow:

There is a need for further data collection at potential Puerto Rico OTEC sites to measure the following parameters - those considered most urgent are indicated by an asterisk (*):

1. Temperature

*a) of the mixed layer, using thermometers, STD, or XBT (daily), when possible, for short term variations.

*b) to 200 m, using recorded monitoring equipment, for upper water thermal structure during severe weather events.

*c) in the water column to 1000 m, using thermometers, STD, or XBT (monthly), for ecological structuring and plant design purposes.

d) of the actual sea surface and the mixed layer, using thermomenters, STD, XBT, and satellite (whenever the satellite data will be available) to correlate the satellite sea surface temperature monitoring with the mixed layer temperature.

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

2. Thermocline depth

*a) using XBT (daily, when possible, otherwise weekly), to anticipate discharge dynamics.

3. Salinity

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

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

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

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

4. Mixed layer depth

*a) using STD or XBT (daily, if possible), for engineering design requirements.

*b) using recording equipment with thermister strings, to monitor thermal resource variation during severe weather events.

5. Internal waves

*a) 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, to determine the effect of the variation of the horizontal thermal structure (due to large amplitude long waves) on intake and outlet.

6. Wave spectra surface

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

7. Water currents

*a) using current profilers, (4 per day on a weekly basis), to supplement the moored data, with emphasis 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 2-5 days), to determine the trajectory diffusion and plume dynamics of the plant discharge.

9. Zooplankton

*a) at the sites and downstream, using a net of 64 micron mesh at discrete depth intervals, (2 per day monthly), to determine the population structure of small and medium-sized zooplankton.

*b) at the sites and downstream, using a net of 330 micron mesh at discrete depth intervals, (2 per day monthly), to determine the population structure of medium zooplankton and meroplankton.

*c) at the sites and downstream, using a net of 1000 micron mesh at discrete depth intervals, (2 per day monthly), to determine some of the structure of the meroplankton and large zooplankton population.

d) at the benchmark site, using the above 3 nets with larger diameter openings and longer scope, through the entire water column, (hourly for 48 hours, twice per year), to gather statistics describing the patchiness of various sizes of plankton in the area.

e) using a very large multimesh net pulled through the water at various depths in the upper waters (bimonthly), for closer estimation of possible organism entrainment.

10. Chlorophyll

*a) either at discrete depths or by pumping throughout the upper 200 m (bihourly 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 to determine the spatial distribution and species present for ecological structuring.

*b) at discrete depths in the upper 200 m (bihourly, quarterly), for counting and identification to determine statistics related to patchiness.

12. Nutrients

*a) downstream along the 200 m isobath, at discrete depths, (bimonthly), to determine if normal upwelling exists, for ecological structuring.

*b) downstream in the plume from the sites, at discrete depths throughout the water column, (monthly), for ecological structuring.

*c) at the benchmark site, at discrete depths (bihourly for 48 hours, quarterly) to determine temporal variation.

13. Fish attraction

a) in upper waters from a moored structure, to determine attraction effects of a floating pelagic structure.

APPENDIX A

SUMMARY OF COASTAL CURRENTS CHARACTERISTICS ALONG THE SOUTH COAST

Guayanilla - Punta Ventana Sector
Guayama Sector
Guánica Sector
Ponce Sector
La Parguera Sector
Summary of South Coast Nearshore Currents

SUMMARY OF COASTAL CURRENTS CHARACTERISTICS ALONG THE SOUTH COAST

The offshore surface currents of the south coast of Puerto Rico have been described by many investigators. Published reports from dift bottles studies, ship drift measurements and wind regime analyses and observations indicate that the main dift is in a west-northwesterly direction as shown in Figure A1. This is the north Equatorial current which dominates the entire Antilles. Figure A2 summarizes in vectorial and statistical methods the general distribution pattern of the currents on the south coast during winter and summer according to the data published in the Sea and Swell Oceanographic Atlas of the North Atlantic (U.S. Naval Oceanographic Office, 1969). The figure also shows the wave regime statistical characteristics during the two most significant seasons.

Close to shore, however, this general current varies considerably, owing to the variations in depth. Surface and water column currents are deflected and influenced by submarine topography, tidal processes and shoreline morphology.

GUAYANILLA - PUNTA VENTANA SECTOR

Table A1 shows the range of current speed at various depths as found in three previous studies on the area. The variability of the currents at different times of the year is apparent. Minimum surface current speeds ranged from 7 to 22.6 cm/sec, both values having been measured in the May, 1969 study by Kamel and Hadjitheodorou. Maximum surface current speeds are relatively more consistent, ranging from 22.5 to 38.7 cm/sec. Speed range at a depth of 5 meters is less variable, the greatest difference measured on June 10, 1971 and reported in the Oceanographic Baseline Data (1971-72) report. Maximum speed range at depths varies significantly in contrast to the current speed at the surface; there is a definite velocity gradient with depth.

Kamel and Hadjitheodorou (1969) concluded from their study that wind-drift and tidal currents are the predominant types in the Guayanilla Bay and Punta Verraco areas. The report of the "First Survey of the Guayanilla Disposal Site (Area G)" Oceanographic Baseline Data (1971-72) study indicates that wind-drift currents are predominant since "the total rise and fall of the tide is well under a foot therefore, so not a great deal of tidal component to the current would be expected." Both studies conclude that

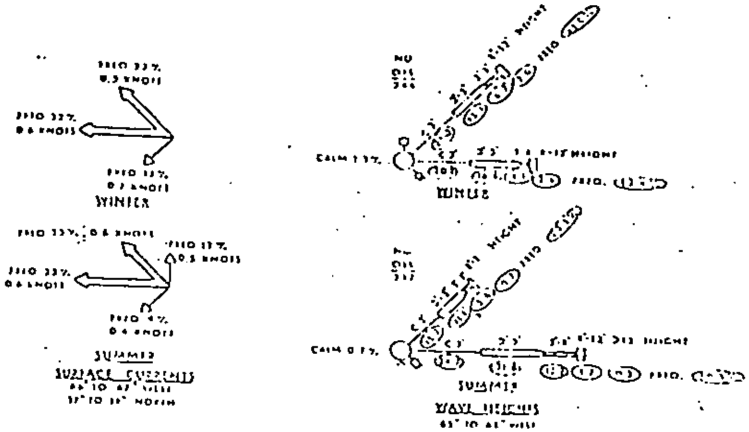


Figure A-1. Typical summer surface currents and wave heights.

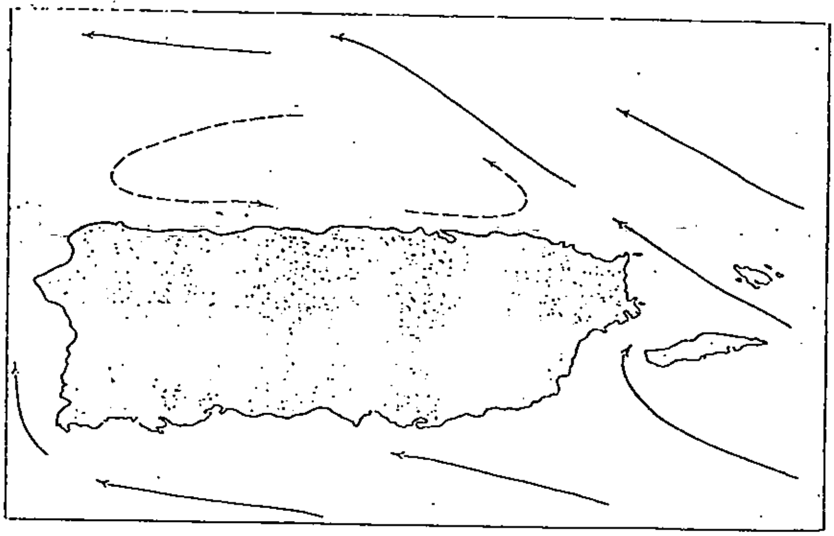


Figure A-2. Principal oceanic currents of Puerto Rico, showing hypothetical eddy off north coast during certain times of the year (after Kaye, 1959).

TABLE A-1

RANGE OF CURRENT SPEEDS FOUNDS ON PUNTA VENTANA-GUAYANILLA BAY AREA

Date	Investigator	Method	Depth (Meters)	Min. Speed (cm/sec)	Max. Speed (cm/sec)	No. of days of Invest.	No. of stations
May 1969	Kemal and Hadjitheodorou	Floats	Surface	22.5	33.7	7	1
	Kemal and Hadjitheodorou	Floats	3	8.5	10.4	7	1
	Kemal and Hadjitheodorou	Floats	6.1	.9	6.8	7	1
	Kemal and Hadjitheodorou	Dye	Surface	7.0	29.6	1	23
June 10, 1971	Dept. Natural Resources, Area G, Cruise 1	Ekman-Merz Current Meter	4	6.7	30.3	1	1
			12	7.8	23.5	1	1
			24	6.8	30.2	1	1
July 27, 1974	*	Dye	Surface	8.5	26.3	1	7
		Drogues	5	10.7	11.5	1	1
Aug. 23, 1974	*	Dye	Surface	16.4	23.6	1	3
		Drogues	5	15.3	16.7	1	1
Sept. 21, 1974	*	Dye	Surface	17.2	22.5	1	1
		Drogues	5	8.0	14.0	1	1
July 17 to		Drogues	12	5.0	11.5	1	2
July 17, to July 23, 1974	*	General Oceanic Current Meter (inclinometer)	45	0	13.0	12	1

* Our Study

surface wind-drift current becomes insignificant at a depth of about 1 meter.

The results of investigations performed by the Department of Marine Sciences personnel (Hernández-Avila and Morelock, 1975) suggest a third possible current-generation process: a wave-induced surface and subsurface current affecting, mainly, the direction of flow. Table A2 of the original report (Caribtec Lab., 1975) shows results on current speeds at surface and intermediate layers as measured by dye and drogues methods.

The Oceanographic Baseline Data (1971-72) reported current speeds in the Guayanilla sector ranging from 9 cm/sec at a depth of 20 m to 28.7 cm/sec at 5 meters depth, as measured with an Ekman-Merz current meter. Variability of current can be seen in Table F-1 (page 7.113). Range of speeds varied from 7.7 to 28.3 at a depth of 11 meters (Table F-3 of the report) as recorded by an in-situ current meter. Drogues measured a maximum surface speed of approximately 35 cm/sec and a minimum of 2.1 cm/sec. (Table F-2).

GUAYAMA SECTOR

Current structure and patterns in the Guayama sector have been reported in the Oceanographic Baseline Data Project (1971-72). Muñoz (1967), a study carried out by PRASA (1967), and Heres (1971), reported data on currents made by employing drifting drogues and wood blocks. The general flow of water in all cases was found to be to the west at varying speeds, although variations to the east were encountered. These studies, according to the Oceanographic Baseline Data Project reviewers, were not reported in proper form for more comprehensive analyses.

The current meter data reported by the Oceanographic Baseline Data Project study is listed in tabular form in Appendix F of their final report; graphs of the data are shown in Figures GM-2 through GM-7 of the same report. Speeds ranged from a maximum of 28.7 cm/sec at a depth of 5 meters to a minimum of 7.7 cm/sec at 20 meters depth as recorded with an Ekman-Merz meter. Recording meters at a depth of 11 meters showed current speeds from about 10 to 27 cm/sec. Drogues gave velocities from 35 cm/sec at the surface to a minimum of 1 cm/sec at a depth of 10 meters. Tables and figures of current meter data and drogues studies are given in pages 7.113 of Vol. II of the final report.

GUANICA SECTOR

The current patterns in the Guánica sector, as investigated by Hernández-Avila (1977, unpublished), were similar to those at Punta Ventana, with the exception of the

TABLE A-2
DYE AND DROGUES CURRENT DATA

Date	Dye or Drogue No.	No. of Obsv.	Approx. Depth (m)	Time In	Time Last Measure	Approx. Total Dist. (Km.)	Mean Speed (cm/sec)	Max. Speed (cm/sec)	Min. Speed (cm/sec)	Std. Devi-ation	Tide	Main Wave Charac-teristics T(sec)	H(ft)	D	Remarks
07-27-74	A-1	2	5	1239	1404	.567	11.2	11.5	10.7	.57	Rising	4	2	SE	
08-23-74	A-2	2	5	1341	1424	.415	16.0	16.7	15.3	.99	Rising	6	4	SE	
08-21-74	A-3	9	5	1030	1349	1.507	12.7	14.0	8.0	1.04	Rising	4	2	SE	) Small
	A-4	6	12	1040	1546	1.610	8.8	11.5	7.2	1.25	Rising	4	2	SE	}— Wave
	A-5	4	12	1600	1750	.457	6.9	8.1	5.0	1.37	Falling	4	2	SE	) from 4 s
07-26-74	D-1	3	0	1004	1208	1.10	14.8	15.2	14.4	.40	Rising	4	2	SE	
	D-2	4	0	1007	1426	2.29	14.7	15.6	13.8	.75	Rising	4	2	SE	
	D-3	3	0	1010	1256	1.66	16.6	16.0	15.8	1.15	Rising	4	2	SE	
	D-4	3	0	1014	1253	1.45	15.2	16.5	14.3	1.15	Rising	4	2	SE	In-shore
	D-5	2	0	1018	1137	1.14	24.1	24.9	23.6	.92	Rising	4	2	SE	In-shore
	D-6	2	0	1023	1224	.73	10.0	10.7	8.5	1.6	Rising	4	2	SE	In-shore
	D-7	1	0	1054	1202	.62	15.3	-	-	-	Rising	4	2	SE	In-shore
08-23-74	D-8	4	0	1010	1252	1.78	18.4	20.0	16.4	1.5	Rising	6	4	SE	
	D-9	4	0	1105	1233	1.17	22.1	23.6	20.1	1.5	Rising	6	4	SE	
	D-10	2	0	1115	1215	.61	17.0	17.3	16.6	.5	Rising	6	4	SE	
09-21-74	D-11	5	0	1213	1355	1.16	19.0	22.5	17.2	2.07	Rising	4	2	E	

funneling effect of the canyon. Drifting drogues and dye traces indicated that surface currents are a function of the wind stresses from the east and southeast. The tidal forces are observed to have an effect on the direction of the deeper drogues as shown in the 4, 6 and 7 meters drogue-tracks. Net mass transport in the water column was toward the west and west-north-west. Current velocity ranged from about 1 cm/sec to approximately 30 cm/sec at the surface.

Circulation at depths greater than 9 meters was determined to be a function of water reflection from the coast and the tidal excursion forces. Net mass transport was in a south and southeastern direction. East flow was also dominant at intervals.

The reversal effect of the tides was observed in the progressive vector diagrams. Velocity histograms indicated that the velocity ranged from 1.5 to a measured maximum of about 14 cm/sec. Mean velocities ranged from 2 to 7 cm/sec depending on the station's location.

The data shown from this study has not been fully analyzed as yet. Currents were monitored during the four seasons of the year; wave refraction diagrams are in the process of analysis, as are salinity, temperature, climatological, and other dynamic parameters that have been measured periodically. Comparisions between the current structure in the same station during two seasons of the year will be made.

PONCE SECTOR

The available ocean current measurements in the Ponce area have been reported by Colón (1971a) of the Water Resourses Research Institute, University of Puerto Rico, Mayaguez Campus. Measurements were made at three different water depths employing Hydro-Products in-situ current meters, Model 502. The data has not been completely analyzed, at least with the methods usually employed.

Current roses are shown in Figures 1 to 4 of the aforementioned study. Figure 1 of the Colón study illustrates the frequency of direction of water flow at a depth of 1.5 meters in station 1. Dominant current direction was towards the north-east, east, and southeast quadrants. At station 2 (Figure 2) the dominant direction was shown to be towards the north-west quadrant at a depth of 1.5 meters, although reversals towards the east were also observed. The same pattern, but with stronger current speeds toward the east, were found at station 3, as illustrated in Figure 3 of the publication. Currents seemed to be dominant toward the southwest and east quadrants. Current velocities ranged from 0 to a maximum of about

11 cm/sec (2 knots). Surface vectorial properties were not observed or measured in this investigation.

Colón (1971b) made another study at Punta Cuchara in the Ponce area at a much deeper water depth. Variations of the current were immediately observed. Velocities at this depth, according to Colón, varied from .1 to .2 knots (5 to 10 cm/sec).

LA PARGUERA SECTOR

Surface and subsurface currents in La Parguera offshore and nearshore areas have been monitored throughout the year by students and personnel of the Department of Marine Sciences. Directions and speed patterns in this area are similar to those found at Guánica, Guayanilla-Punta Ventana and at Ponce offshore-nearshore sectors. Current divergence by submarine morphological differences are evident. Surface speeds ranged from zero (at slack time with no wind blowing) to a maximum of 30 cm/sec.

Surface resultant velocities vary according to the strength and variations of the wind patterns. At night the wind blows offshore, from the land, reducing the tidal current velocities if the flood tide is flowing.

Figure 13 in Roberts and Hernández (1976, unpublished) shows the results of a study performed with radiotracked current drogues offshore La Paraguera. Two radio drogues were tracked for an interval of four days. These drogues were later recovered in Mona Passage, one in the El Negro Reef complex, off Mayaguez, and the other in the vicinity of Desecheo Island.

Colón (1971c) installed three in-situ current meters at different locations off the reefs near La Parguera. Relative quantity of water and direction of flow were illustrated by means of current roses (Figures 1 to 3 of the report). Western directions of flow are dominant in the locations closer to land. Northeastern flow directions were found at a depth of 7.5 meters in the outer station. Velocities of the currents ranged from 5 to 20 cm/sec.

Circulation patterns around Laurel Reef, La Parguera, Puerto Rico, have also been specifically determined by Glynn (1973, pages 309 to 315). Table 4 of this publication tabulates the current speeds and directions. The resultant vector diagrams are shown in Figure 12 of the published paper. Maximum velocities of around 10 cm/sec were measured.

SUMMARY OF SOUTH COAST NEARSHORE CURRENTS

Conclusions (after Hernández-Avila, 1977, unpublished) from the general review of the available literature on nearshore-offshore currents of the south coast are as follows:

A. Surface drift is a function of the relative strength of the wind, waves and tidal patterns. There are marked diurnal variations.

B. During daylight hours the wind direction and speed are dominant, overpowering the ebb tidal flow or aiding the flood tide if these coincide. The land-sea breeze effect at night has the reverse effect: it opposes the flood tides and aids the ebb tides.

C. Measured surface velocities during daylight hours can reach a maximum of about 40 cm/sec toward the shoreline owing to wind stress coupled with flood tidal conditions and wave mass transport direction. Storm conditions have not been monitored.

D. Current velocities usually decrease at night during the flood tide to values below 5 cm/sec in an offshore direction.

E. Surface current statistics:

1. Range: Minimum measured speed: 2.1 cm/sec

   Maximum measured speed: 40 cm/sec

   Approximate mean value: 18 cm/sec

2. Dominant direction: WNW

F. Tidal currents statistics:

1. Range: Mean Ebb: 6 cm/sec*

   Mean Flood velocities: 10 cm/sec**

   * = after wind stress has been cancelled out.

   ** = velocities vary as a function of submarine and coastal morphologic.

2. Direction of tidal flow:

   Ebb tide: SSE

   Flood tide: WNW

completely negligible, but wave-induced stresses are still a dominant effect. The variability, owing to the reversing tidal effect, will affect to a certain extent the speed distribution and flow direction towards shore on a WNW azimuth. Wave refraction effects are still present.

M. Current speed and direction at a depth of 45 meters, 5 meters above the bottom of Punta Ventana Canyon, as measured with an in-situ mechanical current meter.

1. Range: Minimum measured speed: 0 cm/sec (?)

   Maximum measured speed: 19 cm/sec

   mean speed: 3.6 cm/sec

2. Dominant Direction: ESE (mean direction) in Punta Ventana; S and SE in La Parguera and Guánica during the ebb tide cycle.

CONCLUDING REMARKS

1. General water mass movement at the surface and subsurface is in a western direction, at an angle to the shoreline. This circulation pattern minimizes any hydraulic back-flow from shore to the offshore areas. Mass transport at the shoreline will be along the shore in a western direction. Longshore current speeds ranging from 17 to 25 cm/sec have been measured at the Punta Ventana and Guánica shorelines. At La Parguera these currents are usually on the order of 5 to 10 cm/sec inside the reefs.

2. Surface circulation is expected to be nearly the same for long periods of time. This statement is supported by the location of the coast in a constant energy environment determined by steady trade wind incidence, mean wave regime, and meteorological data as shown in the tables of the text. Changes will occur during different seasons of the year, but the wind-driven, wave-induced mechanisms from an almost constant direction will be dominating the surface circulation. Overall it can be concluded that parameter variations are mainly significant during the winter-summer seasons.

REFERENCES

Caribtec Lab. 1975. Punta Ventana ocean sewage outfall planning oceanographic study. Prepared for Puerto Rico Aqueduct and Sewage Authority, Commonwealth of Puerto Rico.

Colón, E. F. 1971. Estuaries, bags and coastal currents around Puerto Rico. Water Resources Research Institute, WRRI-PR-71-31-8. Technical Reports Series. Ponce, La Parguera, and Punta Cuchara reports. University of Puerto Rico, Mayaguez Campus.

Environmental Quality Analysts, Inc. 1972. Supplementary oceanographic and hydrographic surveys. Guayama submarine outfall sewer. Puerto Rico Aqueduct and Sewer Authority, Commonwealth of Puerto Rico.

Gynn, P. W. 1973. Ecology of a Caribbean coral reef. The Porites reef-flat biotope. Part I. Meteorology and Hydrography. Marine Biology, 20: 297-318.

Heres-González, A. 1971. Preliminary wastewater management report: Guayama subregion. Puerto Rico Aqueduct and Sewer Authority, Commonwealth of Puerto Rico.

Hernández-Avila, M. L. 1977. Survey of ooastal currents on the south coast of Puerto Rico. Report prepared for the Environmental Quality Board, Commonwealth of Puerto Rico, San Juan, P.R. (unpublished).

Hernández-Avila, M. L. 1976. Coastal currents and water circulation in Guánica Bay. Water Resources Research Institute, Univ. of Puerto Rico, Mayaguez Campus. Unpublished report under Grant A-051-PR.

Hernández-Avila, M. L. and J. Morelock. 1975. Report on waves, current patterns and geological oceanography off Punta Ventana Outfall project. Caribtec Laboratories, Inc., San Juan, P.R.

Kamel, A. M., and P. E. C. Hajitheodorou. 1970. Report on the current conditions in Guayanilla Bay, In: Study of the Guayanilla Bay. Contract between Texaco Co. and WRRI, University of Puerto Rico, Mayaguez, P.R., 7 p.

Kaye, C. A. 1959. Shoreline features and quaternary shoreline changes, Puerto Rico. U.S. Geological Survey Prof. Paper 317-B. U.S. Government Printing Office, Wash., D.C.

Muñoz, R. 1967. Report of sanitary quality of Guayanez Bay. Study under sponsorship of the Department of Health, Commonwealth of Puerto Rico.

P.R. Department of Public Works. 1974. Oceanographic Baseline data (1971-72) for the formulation of marine waste disposal alternatives for Puerto Rico. Prepared for the Environmental Quality Board, Commonwealth of Puerto Rico, Final Report.

Roberts, H. H., M. L. Hernández-Avila and W. T. Whelan. 1976. Meso-and macroscale temperature telemetry using over-the-horizon radio direction-finding techniques. Paper to be submitted to a scientific journal, unpublished.

APPENDIX B

LISTINGS AND CURVES OF NODC DATA FOR THE PUERTO RICO AREA

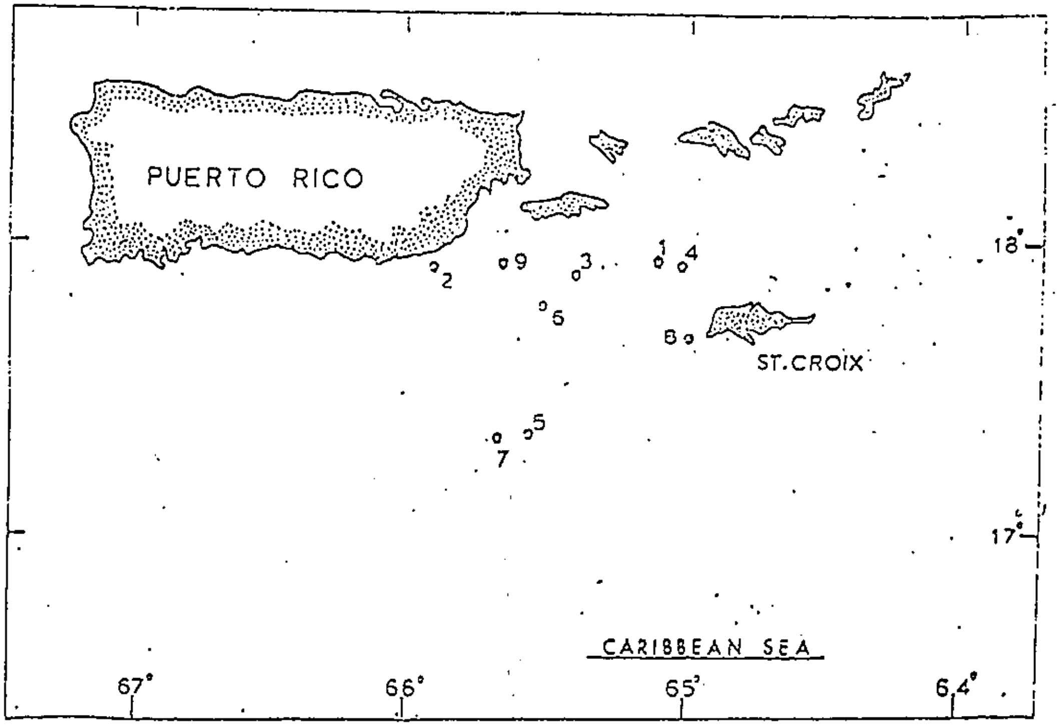


Figure B-1. Station locations of the hydrographic data presented for the Puerto Rico site.

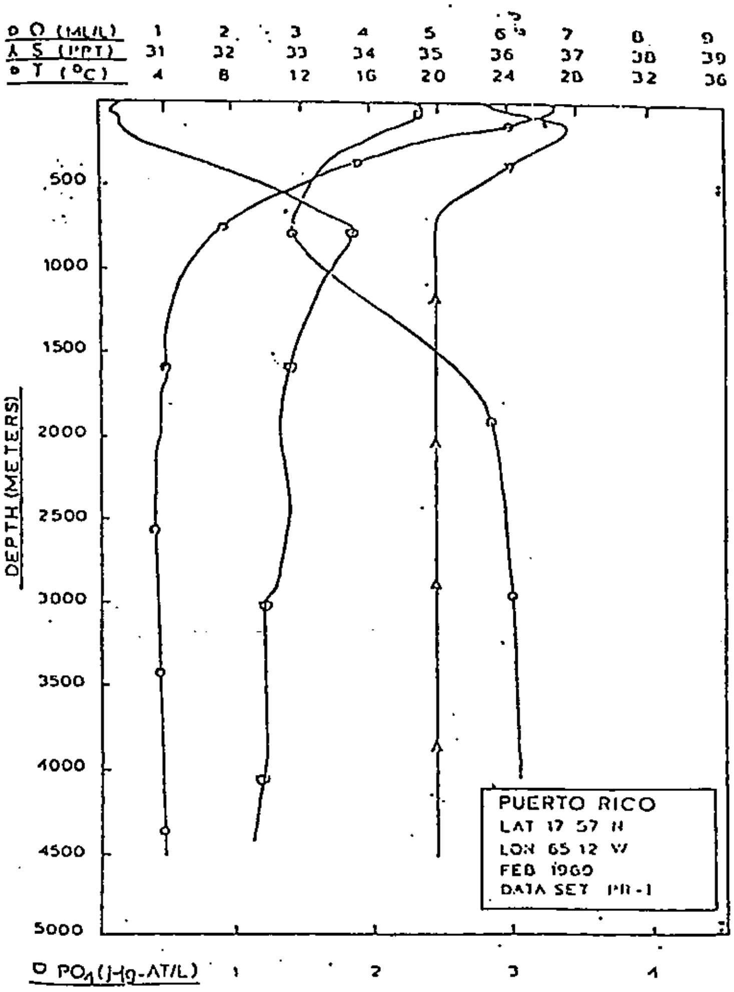


Figure B-2. Vertical profiles of dissolved oxygen, temperature, salinity and phosphates for Puerto Rico, February, 1960.

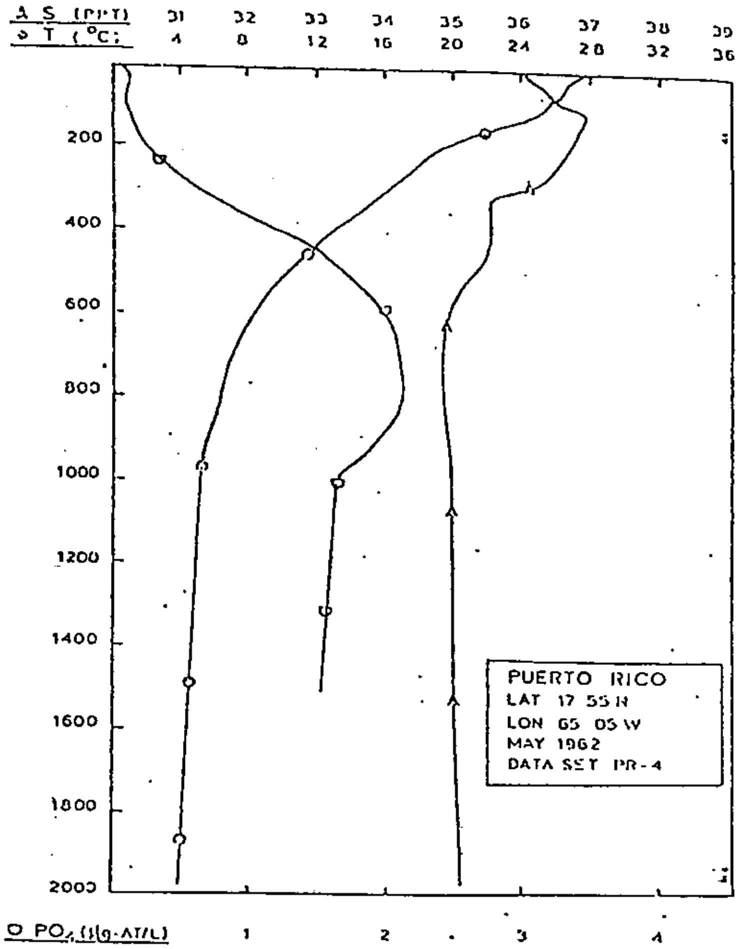


Figure B-3. Vertical profiles of temperature, salinity and phosphates for Puerto Rico, May, 1962.

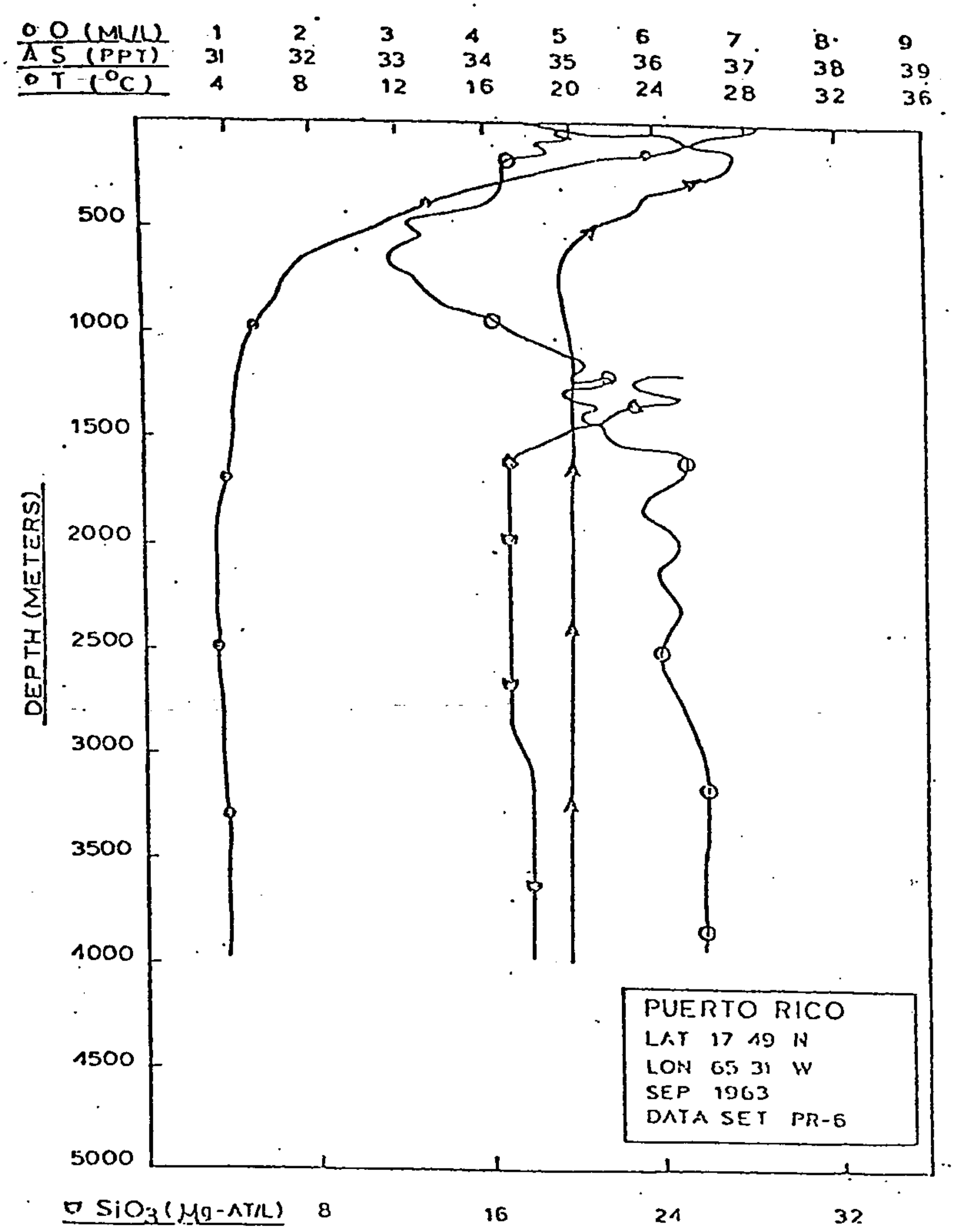


Figure B-4. Vertical profiles dissolved oxygen, temperature, salinity and silicates for Puerto Rico, September, 1963.

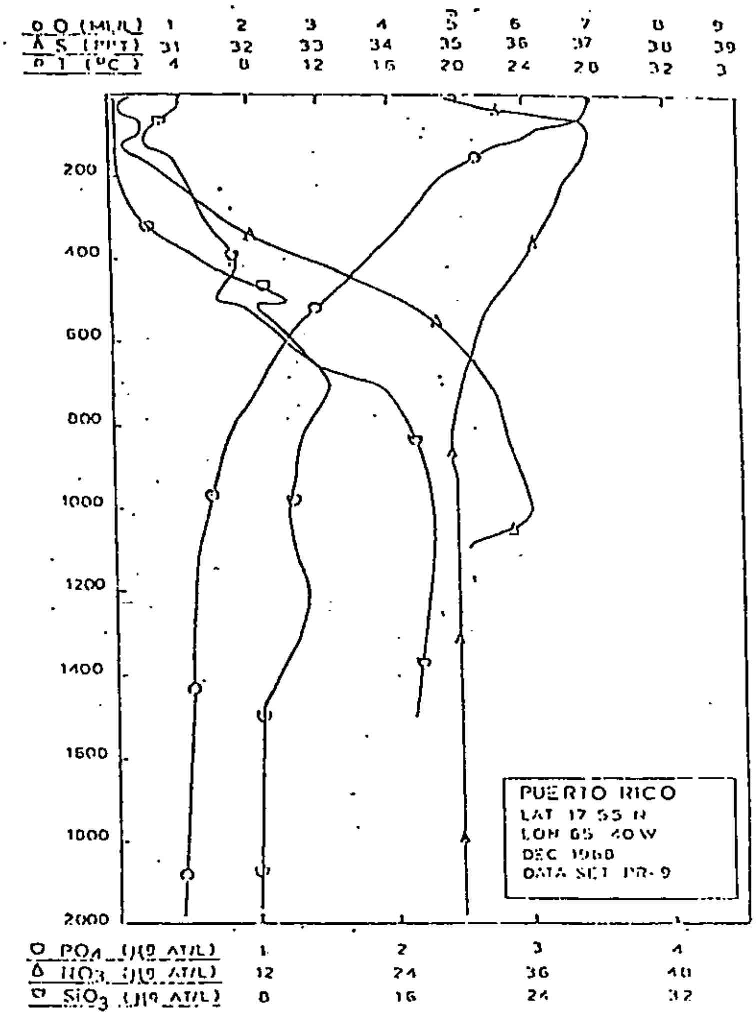


Figure 8-5. Vertical profiles of dissolved oxygen, temperature, salinity, phosphates, nitrates and silicates for Puerto Rico, December, 1968.

Table B-1. Hydrographic data for Puerto Rico for February, 1960.

NODC NANSEN CAST DATA

SITE: PUERTO RICO　　NUMBER: PR 1　　MONTH: FEBRUARY

LATITUDE: 17 57 N
LONGITUDE: -65 12 W
BOTTOM DEPTH: N/A M
DATE: 1960-02-19　10H
REFID: 31 0271-0046

STD='S'
OBS='O'

DEPTH (M)	TEMP (DEG C)	SALINITY (PPT)	OXYGEN (ML/L)	PHOS (UG-AT/L)	NITRATE (UG-AT/L)	SILICATE (UG-AT/L)
0000 S	26.57	35.72	4.64			
0000 O	26.57	35.72	4.69	0.17		
0010 S	26.61	35.77	4.72			
0020 S	26.65	35.84	4.74			
0030 S	26.70	35.92	4.77			
0050 S	26.70	36.11	4.82			
0055 O	26.80	36.16	4.83	0.10		
0075 S	26.56	36.49	4.76			
0095 O	25.95	36.73	4.69	0.16		
0100 S	25.66	36.77	4.68			
0125 S	24.27	36.93	4.61			
0130 O	[illegible]	36.94	4.59	0.11		
0150 S	23.02	36.94	4.46			
0185 O	21.39	36.80	4.28	0.13		
0200 S	20.73	36.81	4.26			
0250 S	18.74	36.57	4.21			
0280 O	17.70	36.43	4.18	0.41		
0300 S	17.15	36.34	4.12			
0370 O	15.27	36.24	3.04	0.73		
0400 S	14.49	35.91	3.65			
0465 O	12.88	35.65	3.32	1.10		
0500 S	12.10	35.53	3.20			
0560 O	10.74	35.32	3.06	1.48		
0600 S	09.67	35.17	3.03			
0655 O	08.50	35.01	2.98	1.66		
0700 S	07.80	34.95	2.86			
0750 O	07.26	34.93	2.85	1.00		
0800 S	06.76	34.91	3.16			
0900 S	05.92	34.91	3.72			
0940 O	05.63	34.91	3.91	1.75		
1000 S	05.28	34.93	4.18			
1100 S	04.81	34.95	4.52			
1135 O	04.63	34.95	4.62	1.59		
1200 S	04.50	34.86	4.72			
1300 S	04.29	34.97	4.65			
1330 O	04.24	34.97	4.89	1.52		
1400 S	04.20	34.98	4.93			

Table B-1. (Cont.)

MODE HANSEN CAST DATA

SITE: PUERTO RICO NUMBER: PR 1 MONTH: FEBRUARY

DEPTH (M)	TEMP (DEG C)	SALINITY (PPT)	OXYGEN (ML/L)	PHOS (UG-AT/L)	NITRATE (UG-AT/L)	SILICATE (UG-AT/L)
1500 S	04,14	34,98	5,01			
1625 O	04,06	34,98	5,17	1,41		
1750 S	03,95	34,99	5,54			
2000 S	03,80	34,99	6,04			
2420 O	03,79	34,99	6,06	1,31		
2420 O	03,78	34,98	6,10	1,41		
2500 S	03,78	34,99	6,10			
2915 O	03,79	34,98	6,10	1,30		
3000 S	03,79	34,98	6,10			
3410 O	03.82	34,97	6,10	1,22		
3910 O	03,88	34,97	6,06	1,23		
4000 S	03,89	34,98	6,06			
4405 O	03,94	34,98	6,04	1,19		
4430 O	03,95	34.98	6,05			
4455 O	03,95	34,98	6,17			
4480 O	03,95	34,97	6,12			
4505 O	03,95	34,97	6,08			

Table B-2. Hydrographic data for Puerto Rico for March, 1955.

NODC HANSEN CAST DATA

SITE: PUERTO RICO NUMBER: PR 2 MONTH: MARCH

LATITUDE: 17 54 N
LONGITUDE: 65 51 W
BOTTOM DEPTH: 1955 M
DATE: 1955-03-12 15H
REFID: 31 2206-0020

STD='S'
OBS='O'

DEPTH (M)		TEMP (DEG C)	SALINITY (PPT)	OXYGEN (ML/L)	PHOS (UG-AT/L)	NITRATE (UG-AT/L)	SILICATE (UG-AT/L)
0000	S	25,00	35,78	4,22			
0001	O	25,00	35,78	4,22		00,0	002.
0010	S	25,01	35,80	4,24			
0020	S	25,02	35,81	4,26			
0024	O	25,02	35,81	4,26		00,6	002.
0030	S	25,00	35,81	4,26			
0047	O	24,97	35,80	4,26		00,2	002.
0050	S	25,00	35,77	4,25			
0071	O	25,01	35,77	4,22		00,0	002.
0075	S	24,97	35,83	4,20			
0094	O	24,62	36,15	4,08		00,5	002.
0100	S	24,39	36,32	3,99			
0125	S	23,35	36,84	3,69			
0141	O	22.63	37,01	3,57		00,5	002.
0150	S	22,13	36,97	3,56			
0188	O	20,23	36,81	3,51			002.
0200	S	19,77	36,75	3,50			
0250	S	18,00	36,51	3,48			
0283	O	16,95	36,35	3,47		00,0	003.
0300	S	16,61	36,25	3,37			
0400	S	14,46	35,71	2,90			
0472	O	12,77	35,40	2,70		22,0	011.
0500	S	11,83	35,30	2,70			
0600	S	09,05	35,03	2,69			
0660	O	07,82	34,92	2,68		20,0	020.
0700	S	07,39	34,89	2,81			
0800	S	06,45	34,85	3,11			
0849	O	05,86	34,84	3.25		29,0	024.
0900	S	05,75	34,86	3,39			
1000	S	05,21	34,90	3,65			
1038	O	05,09	34,91	3,75		25,0	020.
1100	S	04,81	34,94	3,92			
1200	S	04,51	34,97	4,15			
1300	S	04.20	35,00	4,35			
1326	O	04,23	35,00	4,40		22,0	027.
1400	S	04,20	35,00	4,44			
1500	S	04,15	35,01	4,55			

Table B-2. (Cont.)

NODC NANSEN CAST DATA

SITE: PUERTO RICO NUMBER: PR 2 MONTH: MARCH

DEPTH (M)	TEMP (DEG C)	SALINITY (PPT)	OXYGEN (ML/L)	PHOS (UG-AT/L)	NITRATE (UG-AT/L)	SILICATE (UG-AT/L)
1625.0	04.05	35.01	4.74		07.0	022.
1750.5	03.91	35.00	5.02			
1810.0	03.82	34.99	5.26		09.0	017.

Table B-3. Hydrographic data for Puerto Rico for April, 1953.

NODC NANSEN CAST DATA

SITE: PUERTO RICO NUMBER: PR 3 MONTH: APRIL

LATITUDE: 17 51 N
LONGITUDE: 65 26 W
BOTTOM DEPTH: 4114 M
DATE: 1953-04-12 12H
REFID: 31 0309-0026

SID='S'
OBS='O'

DEPTH (M)	TEMP (DEG C)	SALINITY (PPT)	OXYGEN (ML/L)	PHOS (UG-AT/L)	NITRATE (UG-AT/L)	SILICATE (UG-AT/L)
0000 S	26.16	36.45	4.71			
0000 O	26.16	36.45	4.71			
0010 S	26.10	36.40	4.68			
0010 O	26.10	36.40	4.60			
0020 S	26.13	36.38	4.73			
0020 O	26.13	36.30	4.73			
0030 S	25.78	36.34	4.76			
0030 O		36.42	4.76			
0050 S	25.32	36.29	4.73			
0050 O	25.32	36.29	4.73			
0075 S	25.18	36.32	4.83			
0075 O	25.18		4.83			
0100 S	24.02	36.36	4.81			
0100 O	24.02	36.36	4.81			
0125 S	24.07	37.03	4.51			
0133 O	23.76	37.14	4.42			
0150 S	22.85	37.08	4.25			
0177 O	21.49	36.91	4.03			
0200 S	20.35	36.63	3.92			
0222 O	19.42	36.42	3.83			
0250 S	18.52	36.41	3.75			
0266 O	18.04	36.70	3.73			
0300 S	17.21	36.34	3.92			
0356 O	15.80	36.20	4.00			
0400 S	14.60	36.01	3.73			
0445 O	13.40	35.02	3.49			
0500 S	11.60		3.27			
0534 O	10.90	34.88	3.16			
0600 S	09.43		3.10			
0700 S	07.59		3.02			
0714 O	07.30	35.43	3.01			
0800 S	06.44		3.28			
0894 O	05.77	35.00	3.46			
0900 S	05.76		3.48			
1000 S	05.53		3.02			
1018 O	05.40	34.85	3.00			
1100 S	05.07		4.15			

Table B-3. (Cont.)

NODC NANSEN CAST DATA

SITE: PUERTO RICO NUMBER: PR 3 MONTH: APRIL

DEPTH (M)	TEMP (DEG C)	SALINITY (PPT)	OXYGEN *(ML/L)	PHOS (UG-AT/L)	NITRATE (UG-AT/L)	SILICATE (UG-AT/L)
1200 S	04,65		4,47			
1270 U	04,39	34,92	4,71			
1370 S	04,35	34,92	4,81			
1402 S	04,21	34,94	5,18			
1500 S	04,09	34,95	5,49			
1690 U	03,89	34,97	5,92			
1750 S	03,80	34,97	5,95			
2000 S	03,85	34,96	6,05			
2154 U		34,96	6,08			
2500 S	03,78	35,01	6,07			
2610 U	03,76	35,03	6,05			

Table B-4. Hydrographic data for Puerto Rico for May, 1962.

NODC NANSEN CAST DATA

SITE: PUERTO RICO NUMBER: PR 4 MONTH: MAY

LATITUDE: 17 55 N
LONGITUDE: 65 05 W
BOTTOM DEPTH: N/A M
DATE: 1962-05-02 07H
REFID: 31 0290-0041

STD='S'
OBS='O'

DEPTH (M)		TEMP (DEG C)	SALINITY (PPT)	OXYGEN (ML/L)	PHOS (UG-AT/L)	NITRATE (UG-AT/L)	SILICATE (UG-AT/L)
0000	S	27,33	35,96				
0001	O	27,33	35,96		0,08		
0010	S	26,98	36,01				
0010	O	26,98	36,01		0,09		
0020	S	26,59	36,20				
0025	O	26,43	36,27		0,12		
0030	S	26,35	36,31				
0050	S	26,05	36,44				
0058	O	26,05	36,44		0,16		
0075	S	25,70	36,61				
0075	O	25,70	36,60		0,08		
0099	O	25,23	36,93		0,11		
0100	S	25,16	36,93				
0125	S	23,39	36,06				
0150	S	21,75	36,77				
0199	O	18,92	36,50		0,25		
0200	S	18,88	36,50				
0250	S	17,12	36,28				
0300	S	15,47	36,00				
0397	O	12,60	35,53		1,30		
0400	S	12,51	35,52				
0500	S	09,92	35,12				
0596	O	08,06	34,87		2,02		
0600	S	08,01	34,88				
0700	S	06,98	34,83				
0794	O	06,20	34,01		2,15		
0800	S	06,16	34,82				
0900	S	05,59	34,88				
0993	O	05,13	34,92		1,66		
1490	O		34,96		1,58		
1986	O	04,06	35,14				

Table B-5. Hydrographic data for Puerto Rico for August, 1967.

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                 NODC HANSEN CAST DATA

STN: PUERTO RICO          NUMBER:  PR 5   MONTH:  AUGUST

        LATITUDE:  17 23 N                  STD='S'
       LONGITUDE:  65 35 W                  OBS='O'
    BOTTOM DEPTH:  4392 M
            DATE:  1967-08-27   14H
           REFID:  31 1145-0012

DPTH     TEMP     SALINITY  OXYGEN      PHOS   NITRATE   SILICATE
(M)     (DEG C)    (PPT)    (ML/L)  (UG-AT/L)(UG-AT/L) (UG-AT/L)
----     ----    --------   ------      ----   -------   --------
0000 S   28,37     33,51
0000 O   28,37     33,51
0009 O   28,38     33,53
0010 S   28,29     33,71
0019 O   28,16     34,84
0020 S   28,15     34,85
0028 O   28,01     35,08
0030 S   28,03     35,17
0036 O   27,86     35,75
0050 S   27,75     35,82
0070 O   27,38     36,15
0075 S   27,20     36,25
0093 O   26,25     36,54
0100 S   26,21     36,59
0125 S   25,07     36,74
0143 O   24,31     36,81
0150 S   23,69     36,86
0187 O   21,59     36,95
0200 S   20,44     36,87
0250 S   18,71     36,59
0283 O   17,86     36,42
0300 S   16,98     36,33
0391 O   14,84     35,97
0400 S   14,42     35,91
0424 O   13,82     35,82
0461 O   12,11     35,55
0500 S   11,76     35,49
0510 O   11,56     35,46
0596 O   09,62     35,47
0600 S   09,52     35,14
0682 O   07,76     34,95
0700 S   07,57     34,94
0800 S   06,68     34,98
0854 O   06,15     34,89
0900 S   05,82     34,91
1000 S   05,21     34,94
1021 O   05,07     34,95
```

Table D-5. (Cont.)

NODC NANSEN CAST DATA

SITE: PUERTO RICO NUMBER: PR 5 MONTH: AUGUST

DEPTH (M)	TEMP (DEG C)	SALINITY (PPT)	OXYGEN (ML/L)	PHOS (UG-AT/L)	NITRATE (UG-AT/L)	SILICATE (UG-AT/L)
1100 S	04,81	34,95				
1200 S	04,52	34,96				
1286 D	04,32	34,96				
1300 S	04,31	34,96				
1400 S	04,24	34,97				
1500 S	04,19	34,97				
1720 D	04,16	34,98				
1750 S	04,16	34,98				
2000 S	04,08	34,99				
2172 D	04,07	34,99				
2500 S	04,07	34,99				
2632 D	04,08	34,99				
3000 S	04,14	34,99				
3504 D	04,20	34,99				
3076 D	04,22	34,98				

Table 8-6. Hydrographic data for Puerto Rico for September, 1963.

NODC NANSEN CAST DATA

SITE: PUERTO RICO NUMBER: PR 6 MONTH: SEPTEMBER

LATITUDE: 17 49 N
LONGITUDE: 65 31 W
BOTTOM DEPTH: N/A M
DATE: 1963-09-13 11H
RCF ID: 31 0754-0809

STD='S'
OBS='O'

DEPTH (M)	TEMP (DEG C)	SALINITY (PPT)	OXYGEN (ML/L)	PHOS (UG-AT/L)	NITRATE (UG-AT/L)	SILICATE (UG-AT/L)
0000 S	28,67	34,46				
0001 O	28,67	34,46				
0010 S	28,65	34,46				
0010 O	28,65	34,45				
0020 S	28,76	35,17				
0020 O	28,80	35,40	4,96			
0030 S	28,70	35,66	4,85			
0040 O	28,48	36,20	4,70			
0050 S	28,41	36,24	4,07			
0072 O	27,55	36,48	5,29			
0075 S	27,41	36,50	5,19			
0096 O	26,33	36,61	4,60			
0100 S	26,10	36,65	4,68			
0125 S	24,62	36,64	4,69			
0144 O	23,46	36,90	4,70			
0150 S	23,03	36,90	4,63			
0192 O	20,43	36,81	4,27			
0200 S	20,13	36,70	4,27			
0250 S	18,37	36,53	4,25			
0289 O	17,09	36,33	4,23			
0300 S	16,75	36,26	4,22			
0385 O	14,31	35,00	4,17			
0400 S	13,93	35,02	3.92			
0481 O	11,87	35,40	3,69			
0500 S	11,35	35,41	3,18			
0577 O	09,47	35,12	3,27			
0600 S	08,96	35,05	3,09			
0673 O	07,60	34,86	2,82			
0700 S	07,20	34,83	2,90			
0770 O	06,45	34,78	3,14			
0800 S	06,38	34,82	3,25			
0866 O	06,09	34,87	3,57			
0900 S	05,77	34,90	3.81			
0962 O	05,32	34,92	4,19			
1000 S	05,10	34,93	4,37			
1058 O	04,96		4,64			
1100 S	04,70	34,95	4,92			

Table B-6. (Cont.)

NODC NANSEN CAST DATA

SITE: PUERTO RICO   NUMBER: PR 6   MONTH: SEPTEMBER

DEPTH (M)	TEMP (DEG C)	SALINITY (PPT)	OXYGEN (ML/L)	PHOS (UG-AT/L)	NITRATE (UG-AT/L)	SILICATE (UG-AT/L)
1154 O	04.61	34.95	5.11			
1200 S	04.53	34.98	5.08			
1202 O	04.53	34.97	5.40			025.
1251 O	04.44	34.96	4.93			023.
1300 S	04.38	34.96	4.98			
1301 O	04.38	34.98	4.98			025.
1351 O	04.29	34.98	5.27			023.
1400 S	04.27	34.99	5.19			
1401 O	04.26	34.98	5.19			022.
1452 O	04.25	34.98	5.39			020.
1500 S	04.29	34.99	5.46			
1504 O	04.28	34.98	5.47			019.
1555 O	04.25	35.01	5.68			018.
1607 O	04.04	34.99	6.30			015.
1710 O	03.89	35.00	6.25			015.
1750 S	03.82	35.00	6.08			
1815 O	03.79	34.99	5.82			015.
1892 O	03.77	34.98	5.95			015.
1989 O	03.77	34.98	6.26			015.
2000 S	03.77	34.99	6.29			
2183 O	03.77	34.98	6.05			015.
2375 O	03.77	34.98	6.25			015.
2500 S	03.77	34.99	6.08			
2570 O	03.77	34.99	6.05			015.
2862 O	03.79	34.98	6.37			015.
3000 S	03.81	34.98	6.48			
3155 O	03.81	34.97	6.56			016.
3545 O	03.84	34.97	6.58			016.
3936 O	03.89	34.97	6.58			016.

Table 8-7. Hydrographic data for Puerto Rico for October, 1964.

```
                         NODC HANSEN CAST DATA

SITE:  PUERTO RICO          NUMBER:  PR 7    MONTH:  OCTOBER

          LATITUDE:  17 20 N                      STD='S'
         LONGITUDE:  65 40 W                      OBS='O'
      BOTTOM DEPTH:  4786 M
              DATE:  1964-10-29   23H
             REFID:  31 1365-0031

DEPTH      TEMP     SALINITY  OXYGEN     PHOS     NITRATE    SILICATE
 (M)     (DEG C)     (PPT)    (ML/L)  (UG-AT/L)(UG-AT/L)  (UG-AT/L)
-----      ----    ---------  ------     ----     -------    --------
 0000 S   28,54      34,39     4,66
 0001 O   28,54      34,38     5,20     0,06
 0005 O   28,52      34,37     4,66     0,04
 0010 S   28,32      34,61     4,64
 0020 S   27,92      35,04     4,62
 0030 S   27,54      35,43     4,59
 0050 S   26,81      36,07     4,56
 0053 O   26,71      36,15     4,56     0,00
 0075 S   26,17      36,52     4,57
 0100 S   25,29      36,81     4,59
 0105 O   25,08      36,85     4,59     0,00
 0125 S   23,94      36,90     4,45
 0150 S   22,56      36,96     4,28
 0159 O   22,08      36,97     4,22     0,08
 0160 O              36,97     4,37     0,09
 0755 O   06,92      34,86     3,39     2,04
 0800 S   06,57      34,86     3,64
 0900 S   05,04      34,93     4,01
 1000 S   05,20      34,92     4,36
 1070 O   04,76
 1095 O   04,77      34,94     4,63     1,71
 1610 O   04,14      35,01     5,07     1,52
 1750 S              35,00     5,08
 2000 S              34,98     5,11
 2164 O   04,07      34,96     5,12     1,54
 2500 S   04,10      34,96     5,15
 3000 S   04,15      34,96     5,18
 3232 O   04,17      34,96     5,20     1,44
 3246 O   04,16      34,98     5,19     1,47
 3676 O   04,26      34,97     5,23     1,53
 4000 S   04,25      34,97     5,33
 4265 O   04,27      35,00     5,32     1,55
 4389 O   04,30      34,96     5,41     1,44
 4555 O   04,32      35,00     5,35     1,59
 4624 O   04,32      34,97     5,35     1,52
 4697 O   04,32      34,96     5,36     1,57
 4651 O   04,34      34,97               1,59
```

Table B-8. Hydrographic data for Puerto Rico for November, 1962.

NODC NANSEN CAST DATA

SITE: PUERTO RICO   NUMBER: PR 8   MONTH: NOVEMBER

LATITUDE: 17 41 N   SIO='S'
LONGITUDE: 65 01 W   OBS='O'
BOTTOM DEPTH: 1189 M
DATE: 1962-11-03 19H
REFID: 31 0034-0116

DEPTH (M)	TEMP (DEG C)	SALINITY (PPT)	OXYGEN (ML/L)	PHOS (UG-AT/L)	NITRATE (UG-AT/L)	SILICATE (UG-AT/L)
0000 S	28.59	34.42				
0000 O	28.59	34.42				
0010 S	28.57	34.02				
0020 S	28.55	34.41				
0022 O	28.55	34.09				
0030 S	28.56	34.41				
0031 O	28.56	34.41				
0045 O	28.67	35.00				
0050 S	28.25	35.42				
0075 S	25.66	36.68				
0091 O	24.73	37.09				
0100 S	24.58	37.12				
0114 O	24.21	37.14				
0125 S	23.76	37.11				
0137 O	23.23	37.07				
0150 S	22.51	37.01				
0183 O	20.77	36.83				
0200 S	19.86	36.72				
0230 O	18.49	36.54				
0250 S	17.99	36.46				
0300 S	16.69	36.25				
0324 O	16.04	36.15				
0400 S	13.79	35.88				
0418 O	13.30	35.72				
0500 S	11.26	35.39				
0514 O	10.95	35.34				
0600 S	09.30	35.11				
0700 S	07.90	34.95				
0705 O	07.84	34.94				
0800 S	06.88	34.93				
0898 O	06.11	34.92				
0900 S	06.10	34.92				
1000 S	05.56	34.93				
1092 O	05.27	34.94				

Table B-9. Hydrographic data for Puerto Rico for December, 1968

NODC NANSEN CAST DATA

SITE: PUERTO RICO   NUMBER: PR 9   MONTH: DECEMBER

LATITUDE: 17 55 N
LONGITUDE: 65 40 W
BOTTOM DEPTH: 1994 M
DATE: 1968-12-14   02H
REFID: 31 1352-0001

STD='S'
OBS='O'

DEPTH (M)	TEMP (DEG C)	SALINITY (PPT)	OXYGEN (ML/L)	PHOS (UG-AT/L)	NITRATE (UG-AT/L)	SILICATE (UG-AT/L)
0000 S	27,78	34,78				
0000 O	27,78	34,78		0,00	01,7	004.
0010 S	27,81	34,77				
0010 O	27,81	34,77		0,01	00,0	004.
0020 S	27,78	34,75				
0020 O	27,78	34,75		0,00	00,6	004.
0030 S	27,80	34,76				
0030 O	27,80	34,76				003.
0050 S	27,19	36.29				
0050 O	27,19	36,29				003.
0075 S	25,25	36,77				
0075 O	25,25	36,77		0,03	02,7	003.
0099 O	24,21	36,91		0,04	02,6	002.
0100 S	24,15	36,40				
0124 O		36,01		0,02	01,0	002.
0125 S	22,66	36,81				
0149 O	21,34	36,80		0,00	02,5	003.
0150 S	21.20	36,80				
0198 O	18,96	36,61		0,06	05,1	004.
0200 S	18,92	36,61				
0250 S	17,97	36,49				
0298 O	16,98	36,34		0,22	10,2	005.
0300 S	16,94	36,33				
0397 O	14,71	35,93				007.
0400 S	14,64	35,92				
0496 O	12,30	35,53		1,24		006.
0497 O	12,17	35,50		1,04	25,7	007.
0500 S	12,10	35,49				
0595 O	10,04	35,26		1,20		010.
0600 S	09,97	35,25				
0695 O	08,48	35,06		1.55	33,0	015.
0700 S	08,38	35,05				
0796 O	06,78	34,88		1,36	34,3	016.
0800 S	06,73	34,88				
0900 S	05,91	34,90				
0992 O	05,31	34,92		1,25	36,6	018.
1000 S	05,27	34,92				

Table B-9. (Cont.)

NODC HANSEN CAST DATA

SITE: PUERTO RICO NUMBER: PR 9 MONTH: DECEMBER

DEPTH (M)	TEMP (DEG C)	SALINITY (PPT)	OXYGEN (ML/L)	PHOS (UG-AT/L)	NITRATE (UG-AT/L)	SILICATE (UG-AT/L)
1100 S	04.80	34.94				
1190 O	04.48	34.95		1.34	30.1	018.
1200 S	04.47	34.95				
1300 S	04.33	34.95				
1400 S	04.21	34.95				
1480 O	04.12	34.96		1.07	30.5	017.
1500 S	04.11	34.96				
1750 S	03.94	34.97				
1984 O	03.89	34.97		1.00		014.

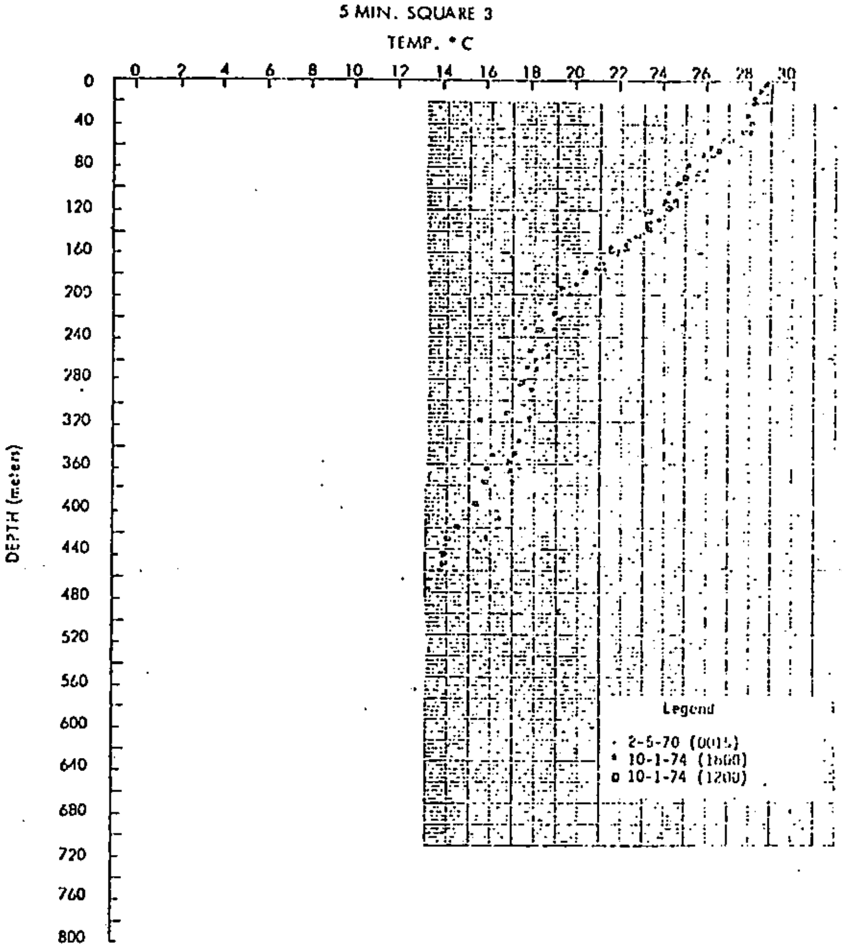

Figure B-6. Temperature versus depth for 5-minute Square 3.

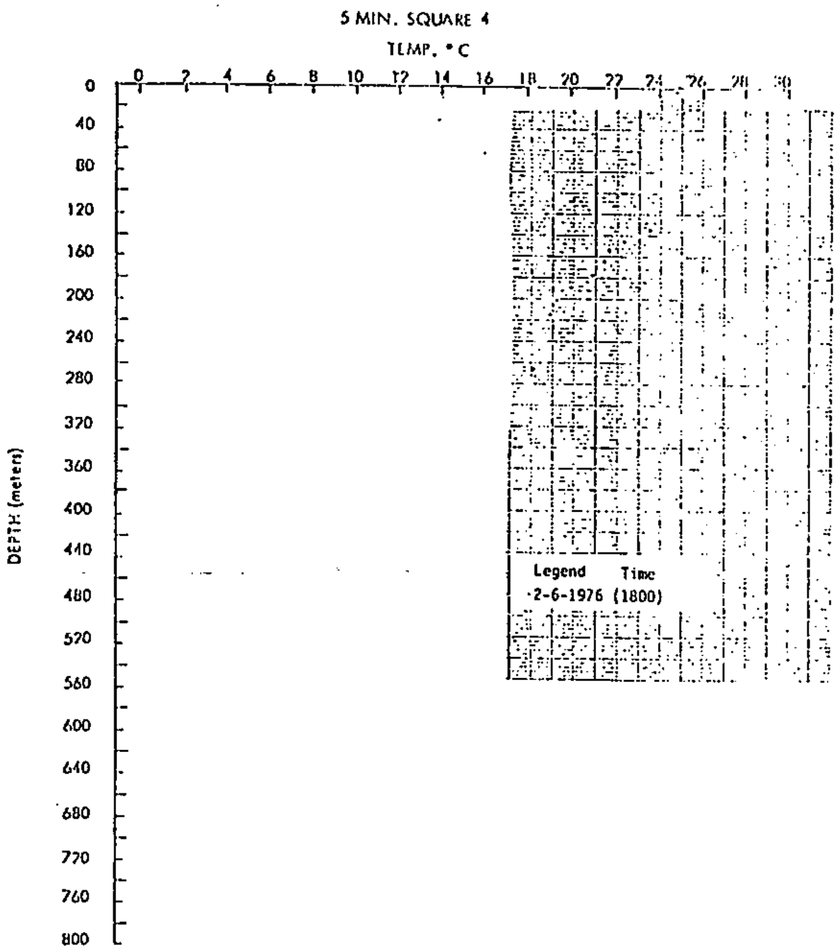

Figure B-7. Temperature versus depth for 5-minute Square 4.

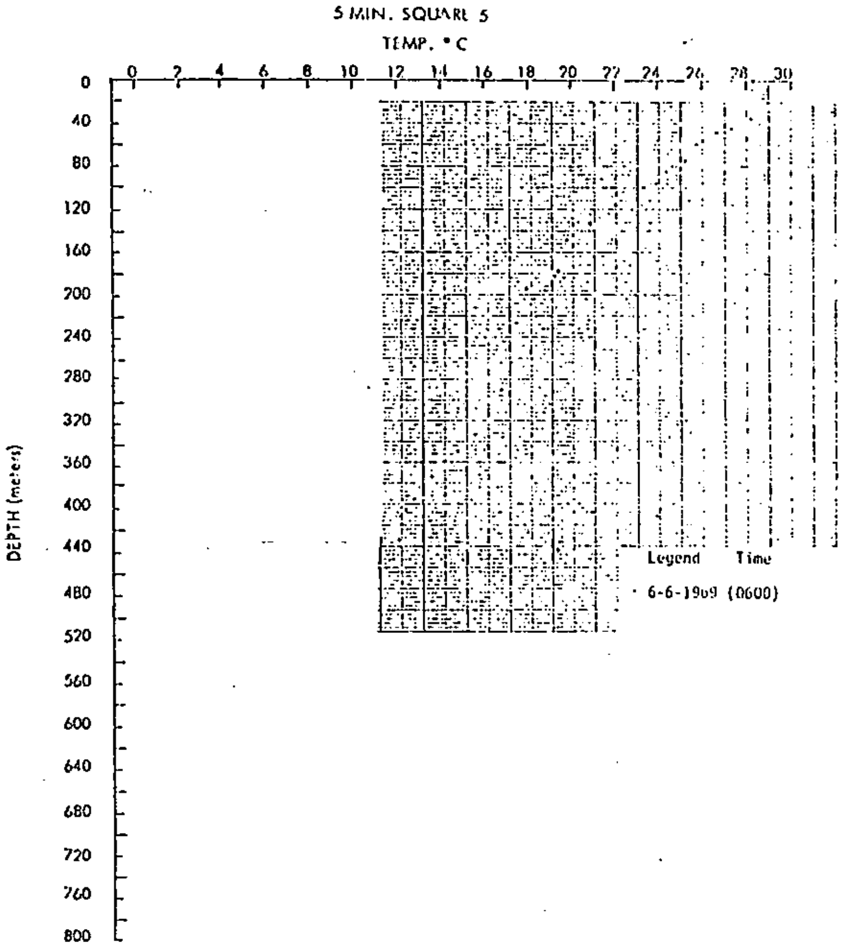

Figure B-8. Temperature versus depth for 5-minute Square 5.

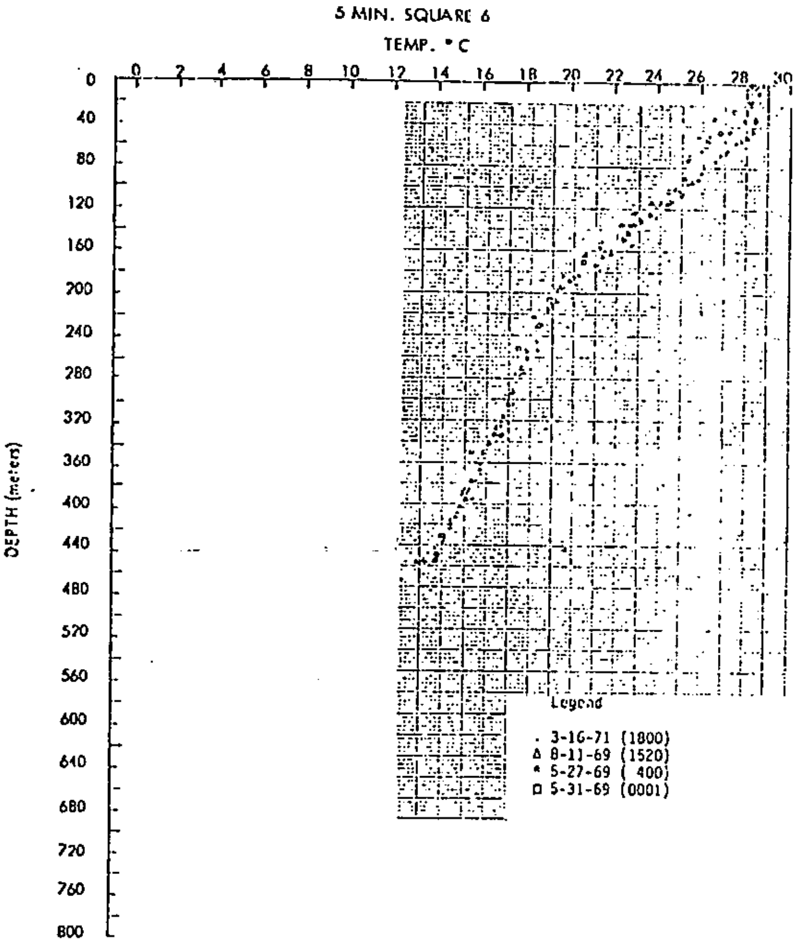

Figure B-9. Temperature versus depth for 5-minute Square 6.

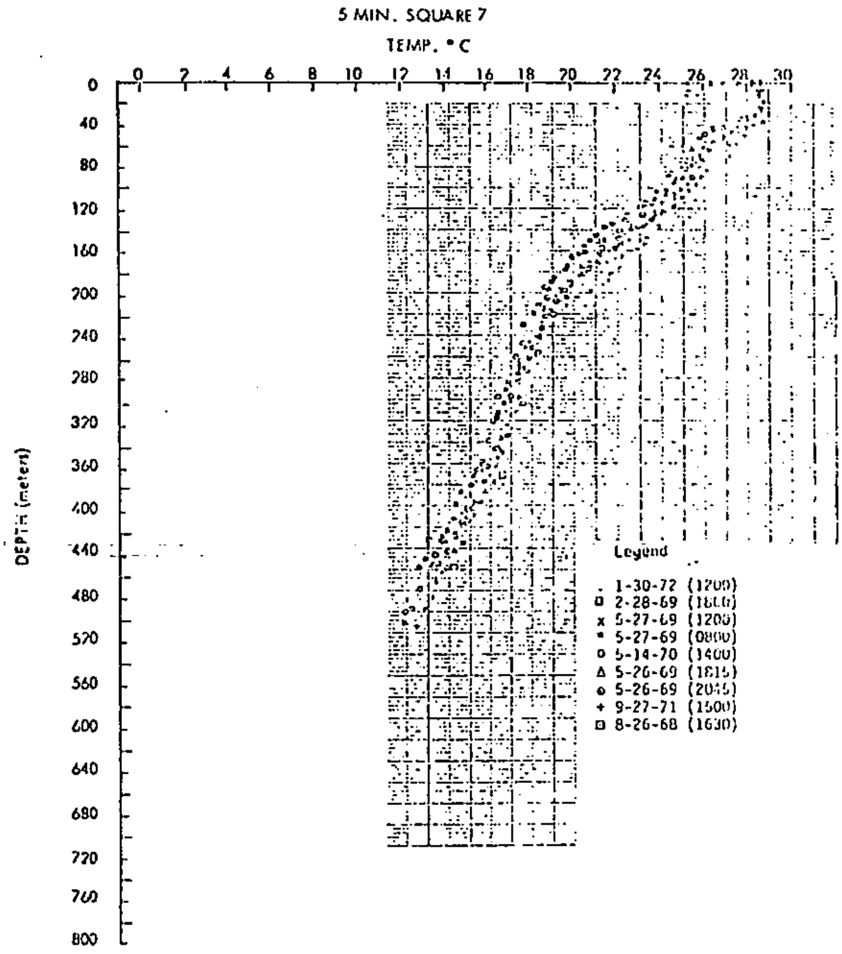

Figure B-10. Temperature versus depth for 5-minute Square 7.

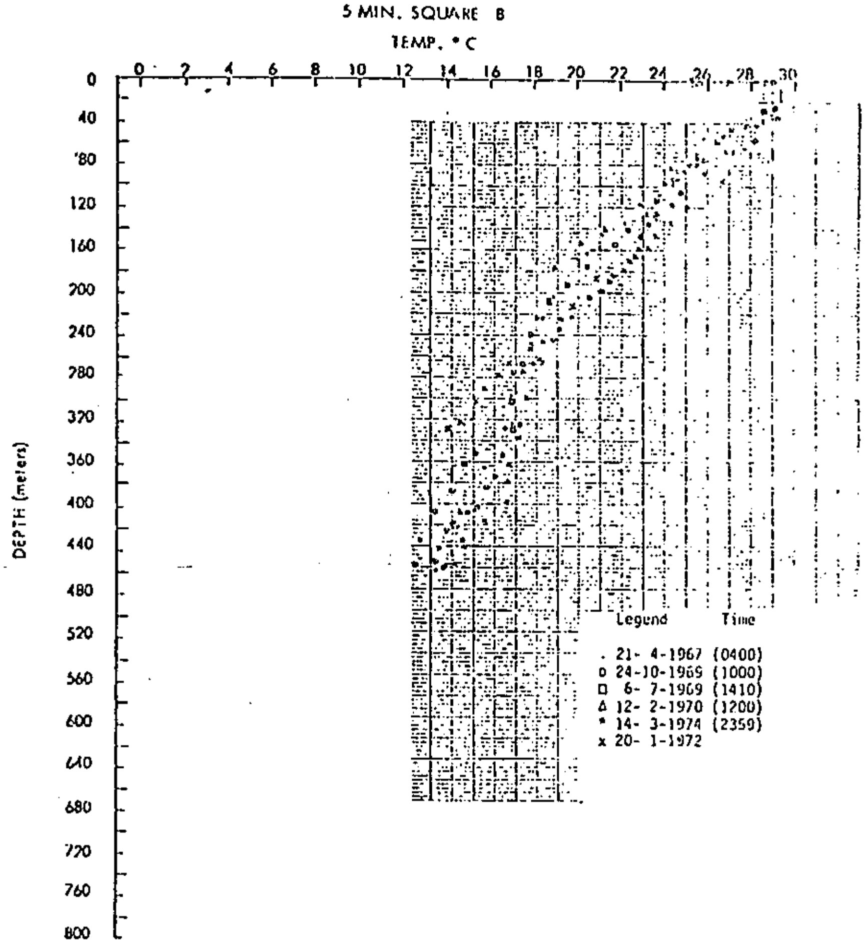

Figure B-11. Temperature versus depth for 5-minute Square B.

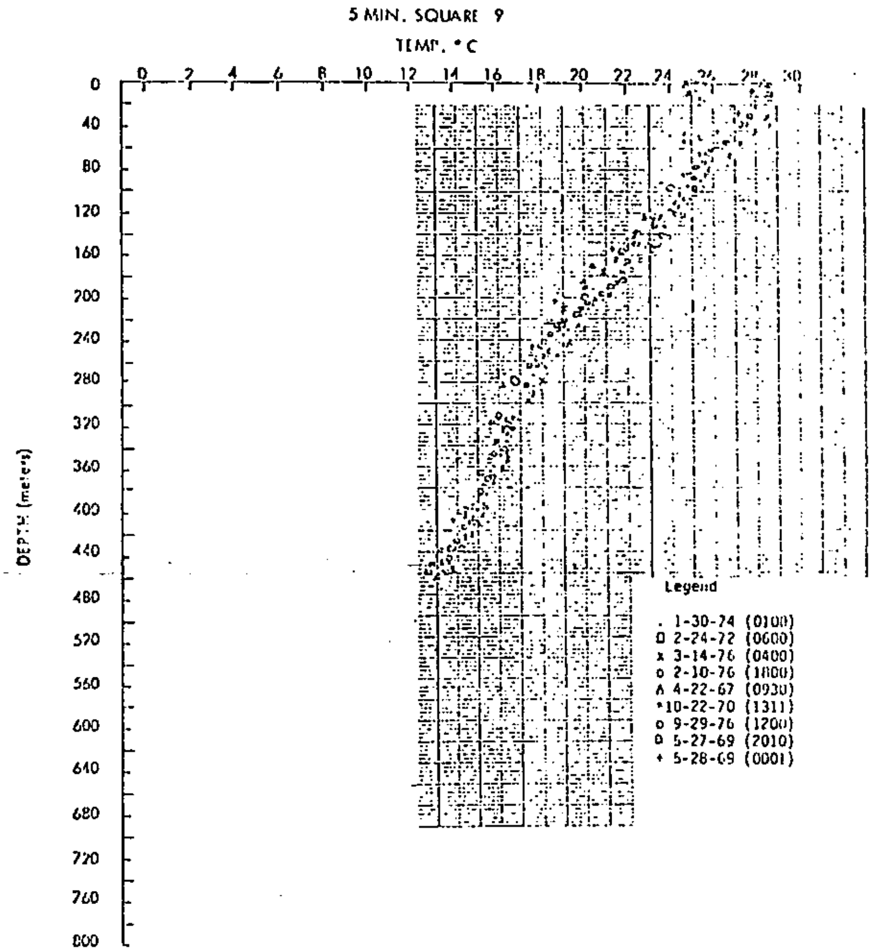

Figure 8-12. Temperature versus depth for 5-minute Square 9.

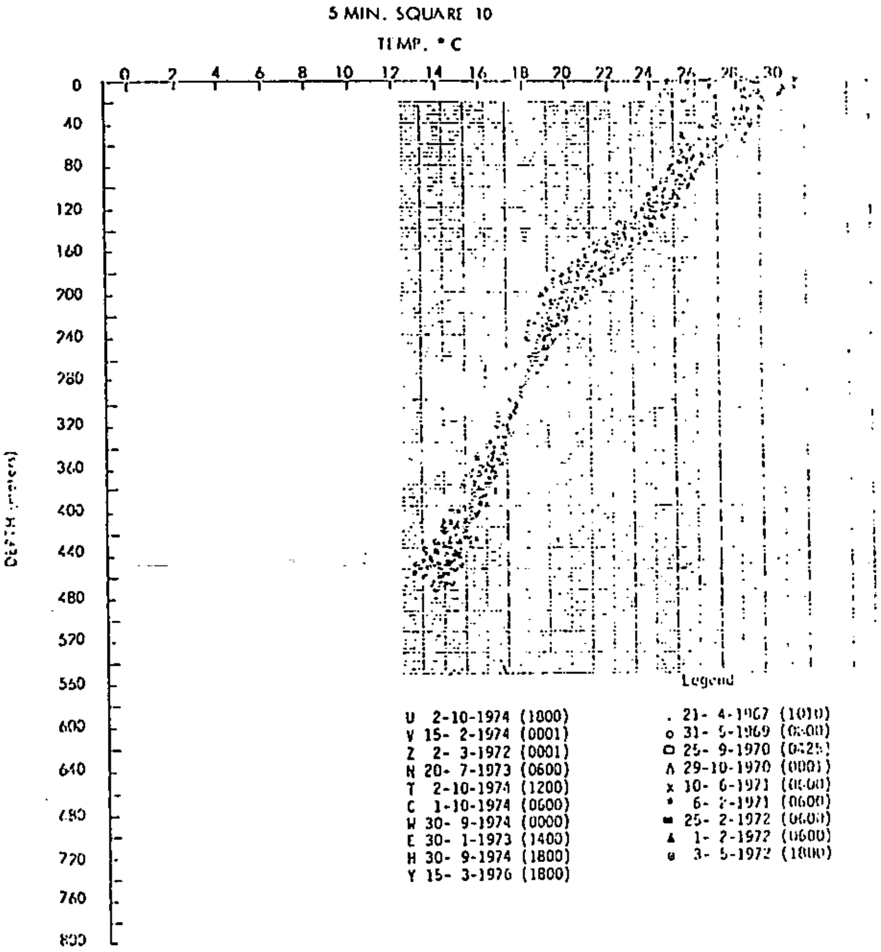

Figure B-13. Temperature versus depth for 5-minute Square 10.

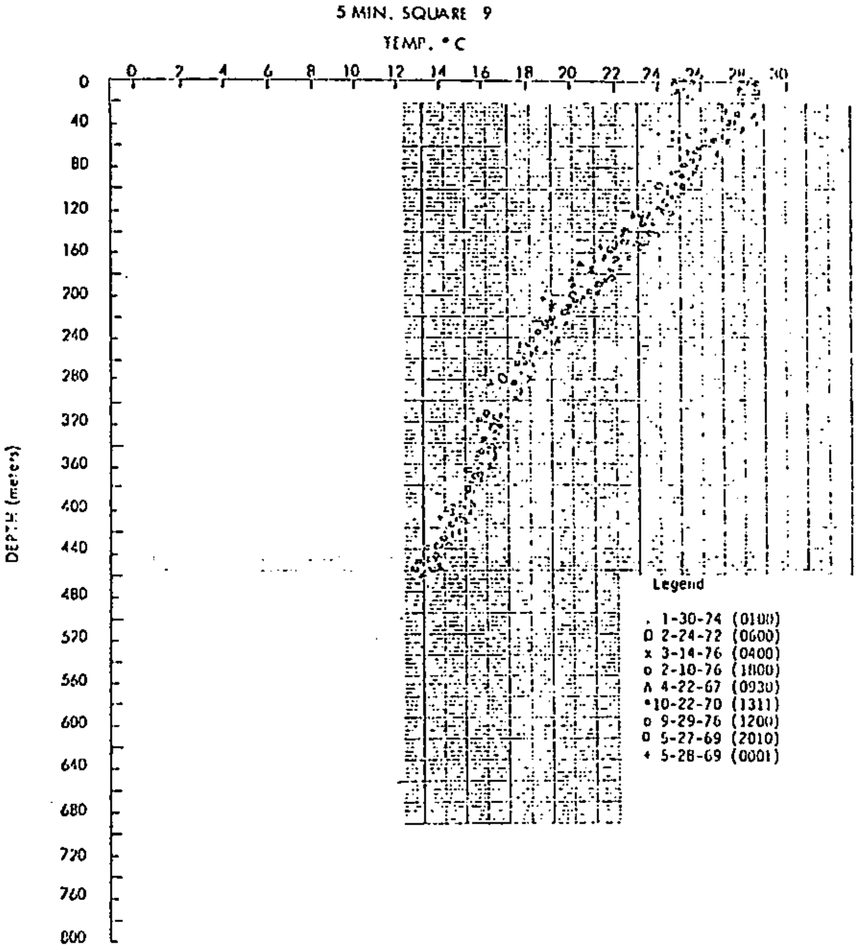

Figure 8-12. Temperature versus depth for 5-minute Square 9.

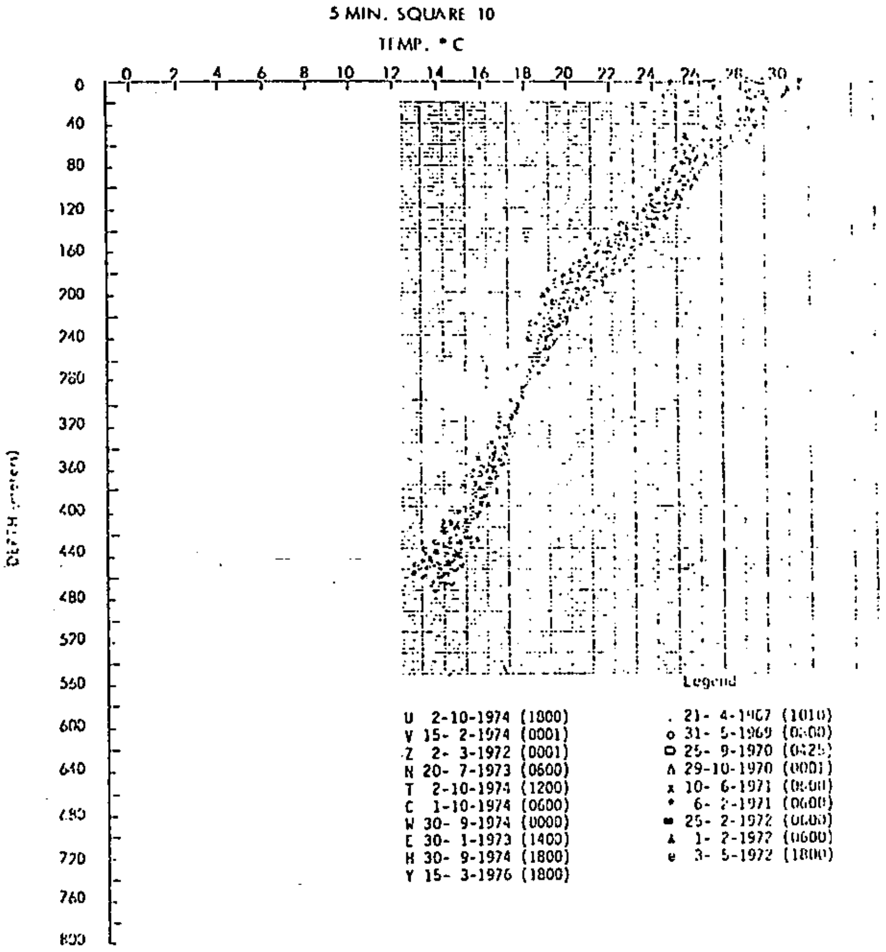

Figure B-13. Temperature versus depth for 5-minute Square 10.

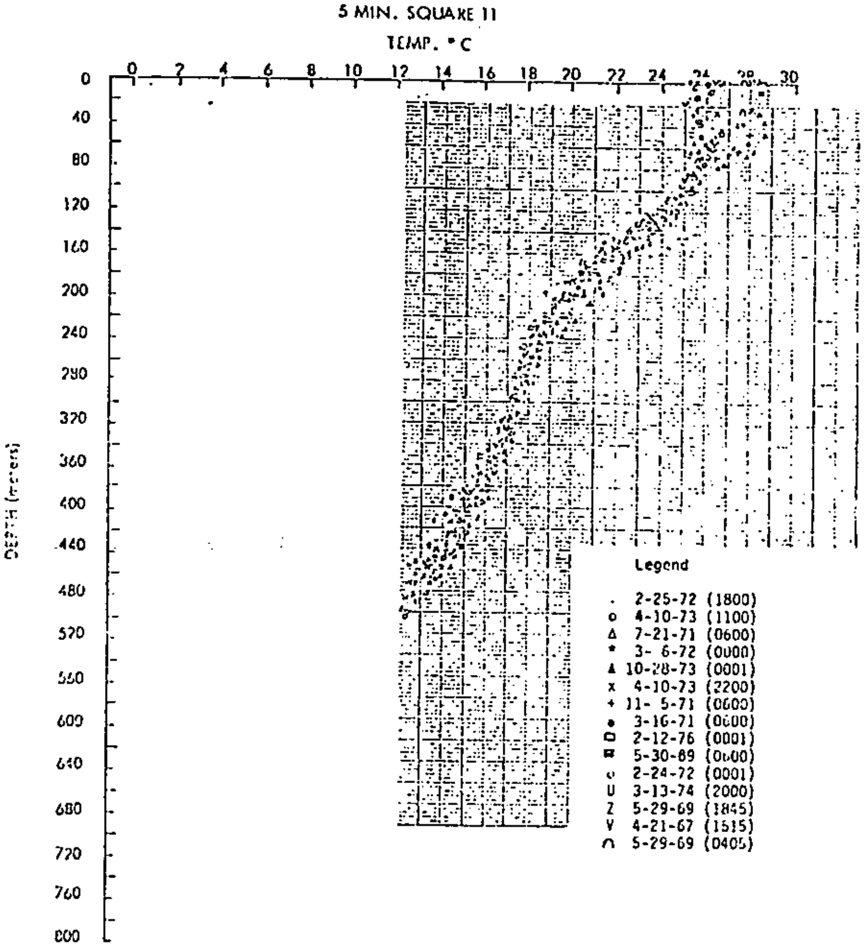

Figure B-14. Temperature versus depth for 5-minute Square 11.

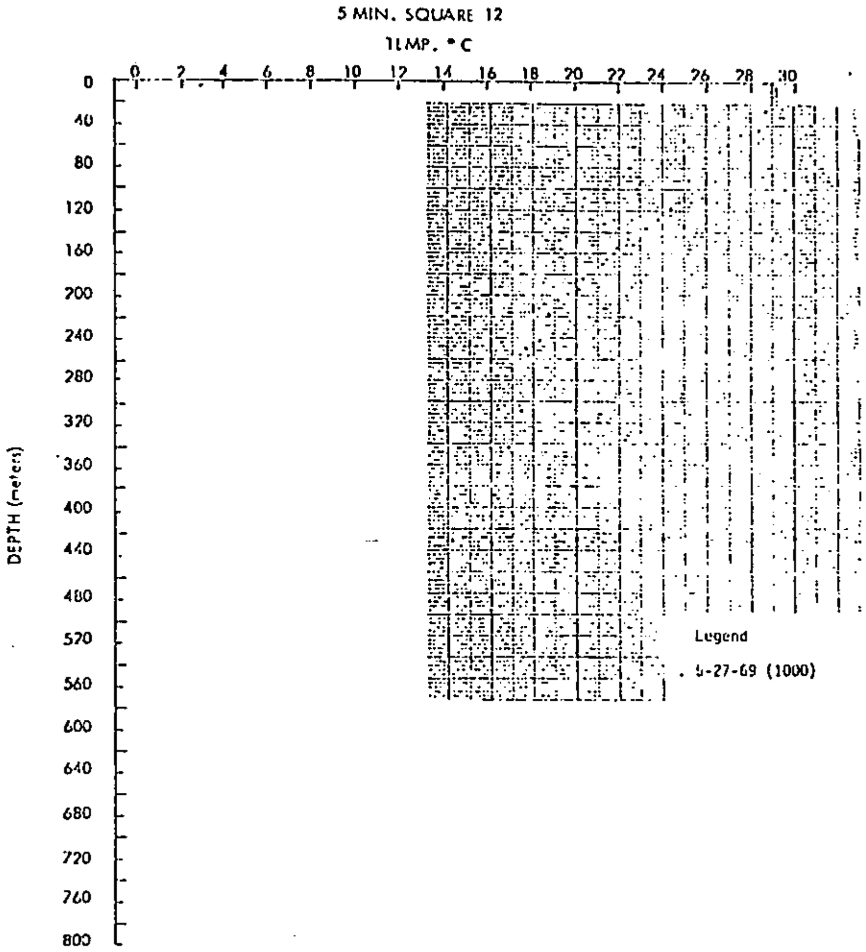

Figure B-15. Temperature versus depth for 5-minute Square 12.

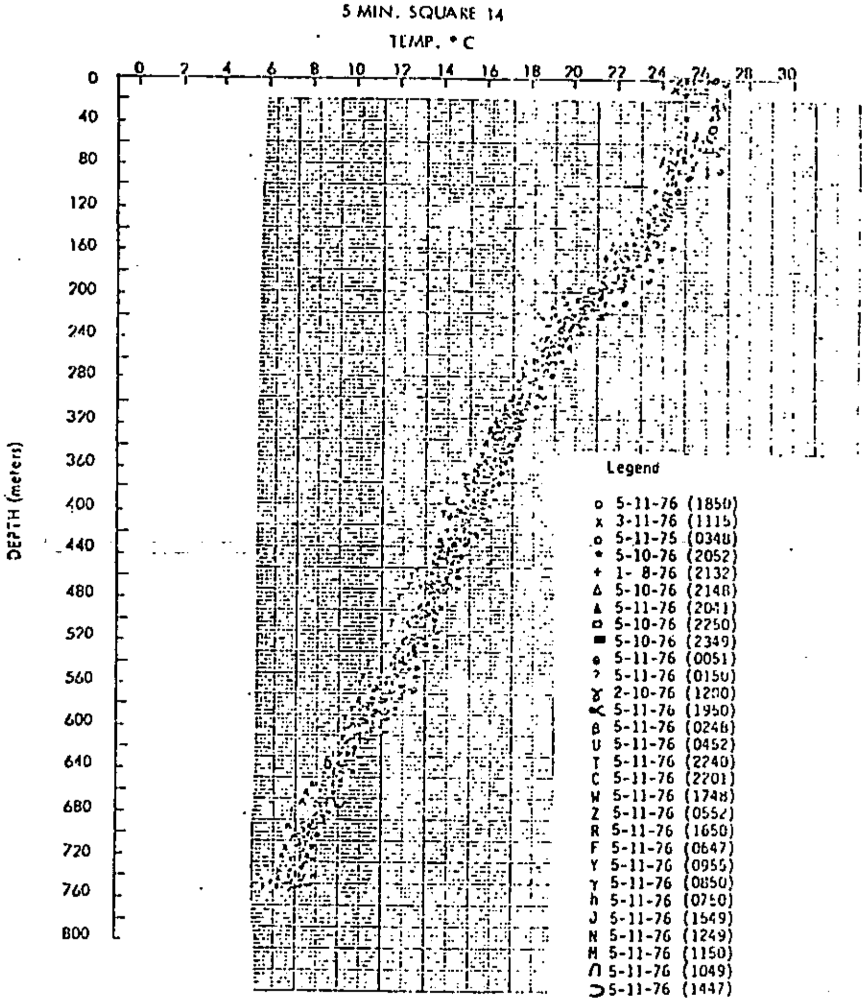

Figure B-16. Temperature versus depth for 5 minute Square 14.

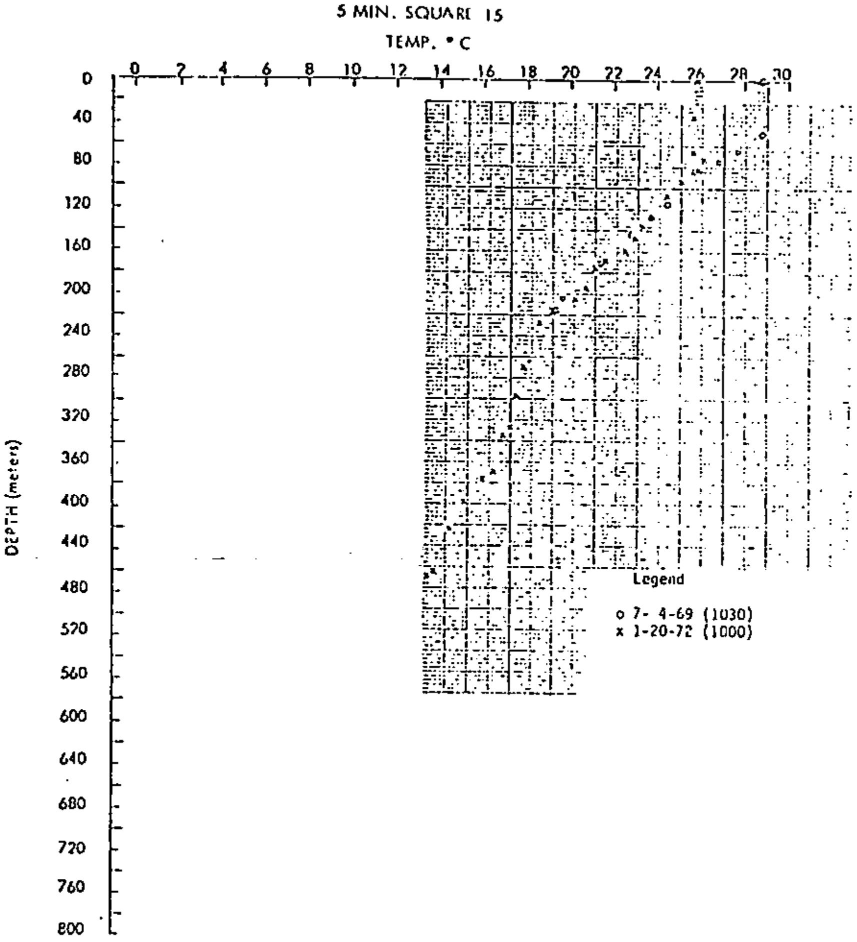

Figure B-17. Temperature versus depth for 5-minute Square 15.

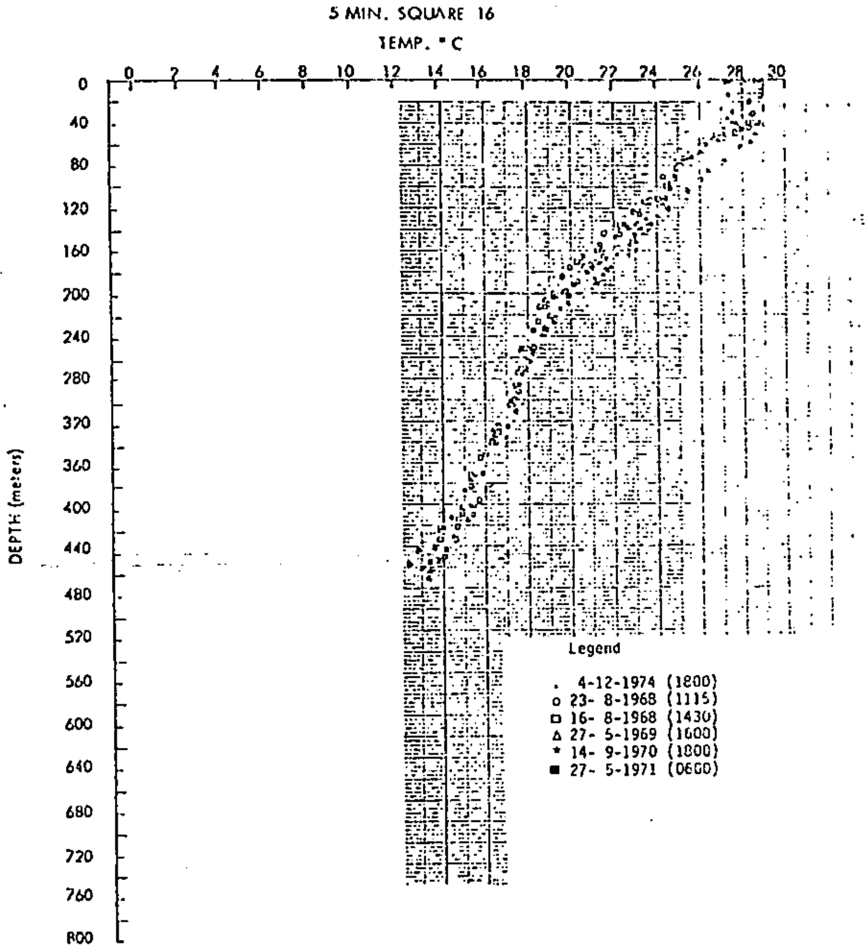

Figure B-18. Temperature versus depth for 5-minute Square 16.

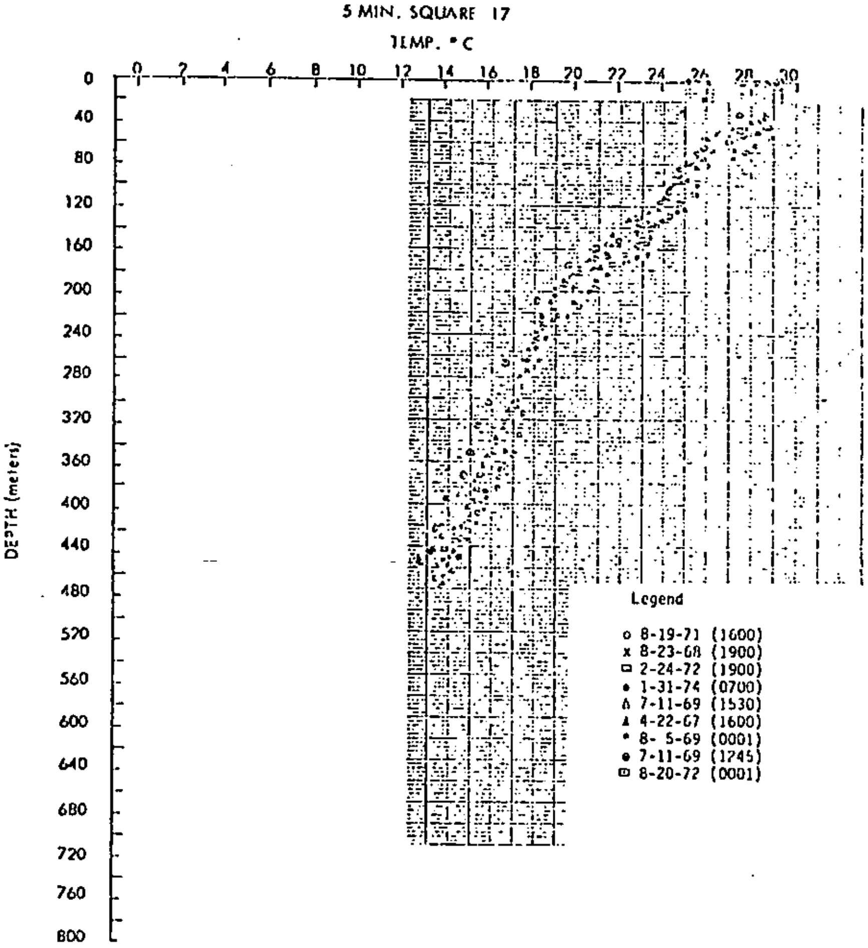

Figure B-19. Temperature versus depth for 5-minute Square 17.

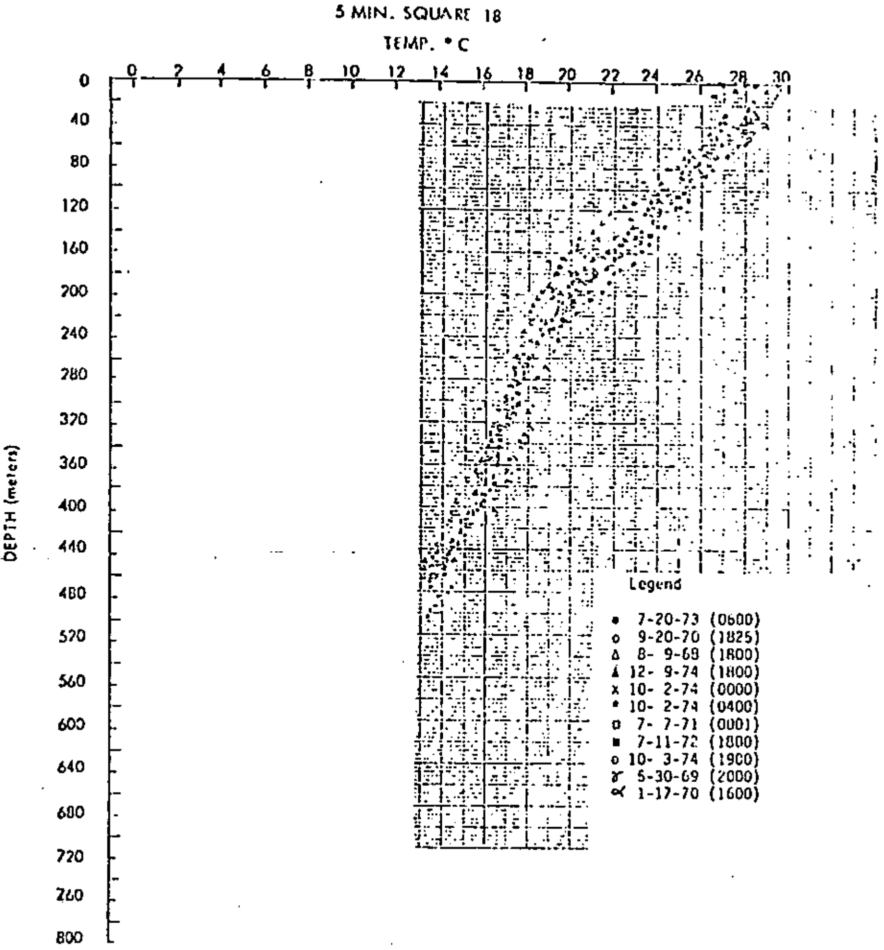

Figure B-20. Temperature versus depth for 5-minute Square 18.

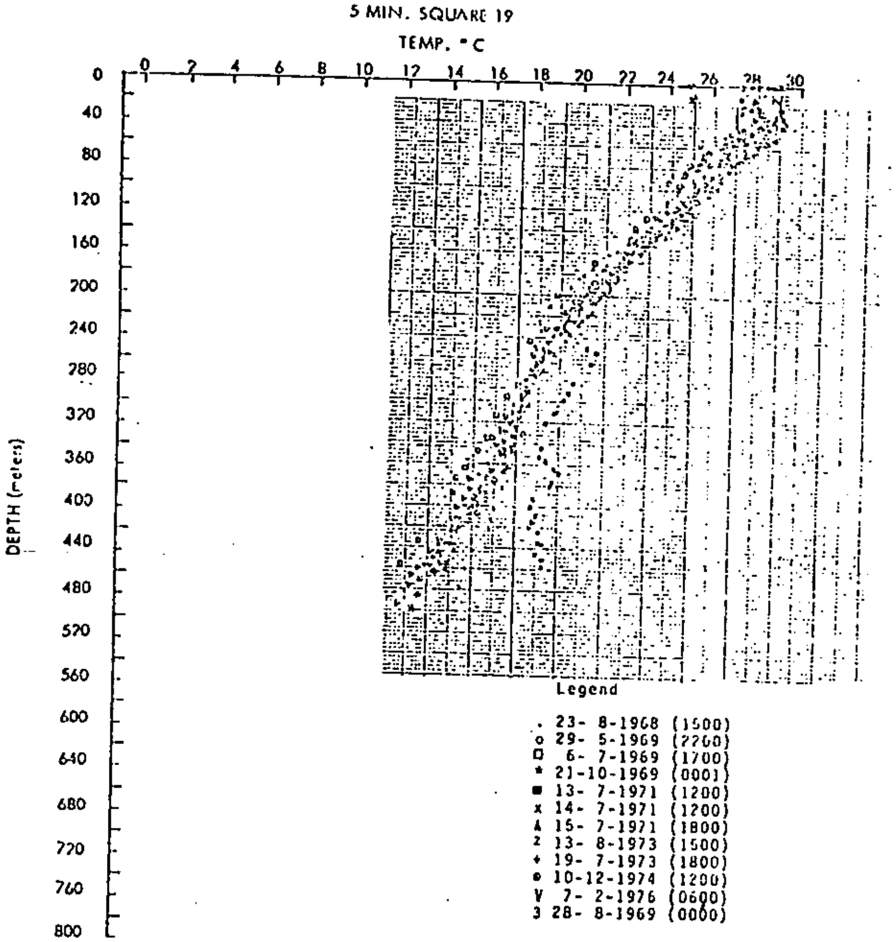

Figure B-21. Temperature versus depth for 5-minute Square 19.

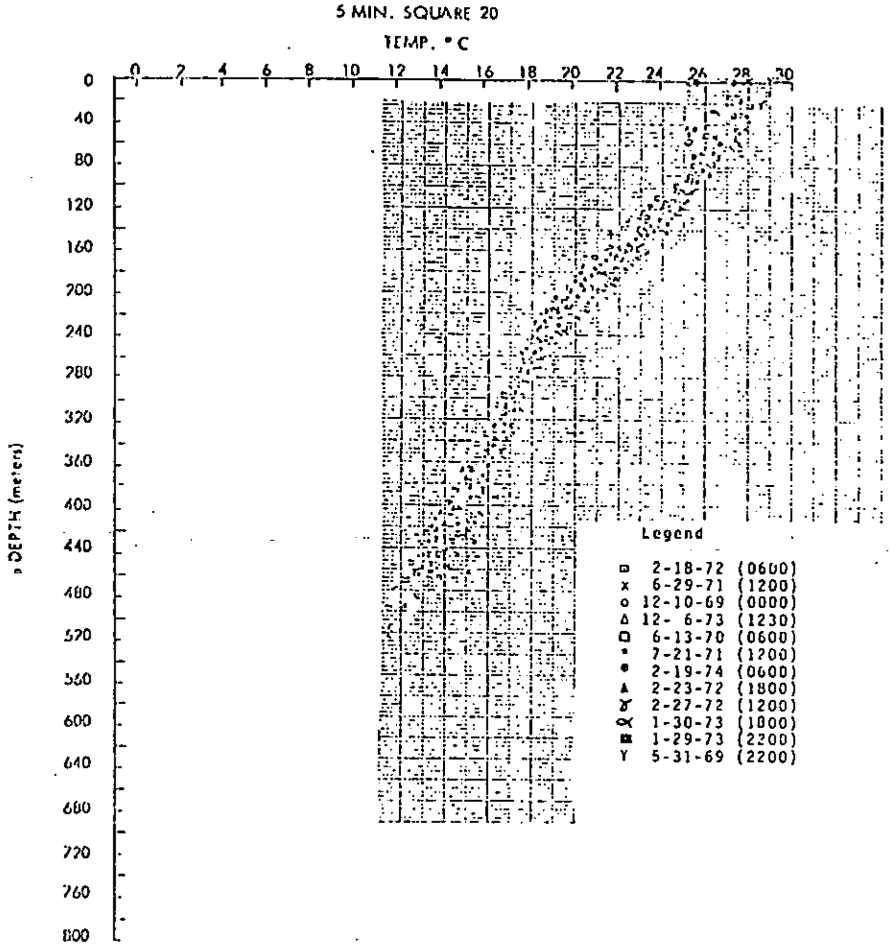

Figure B-22. Temperature versus depth for 5-minute Square 20.

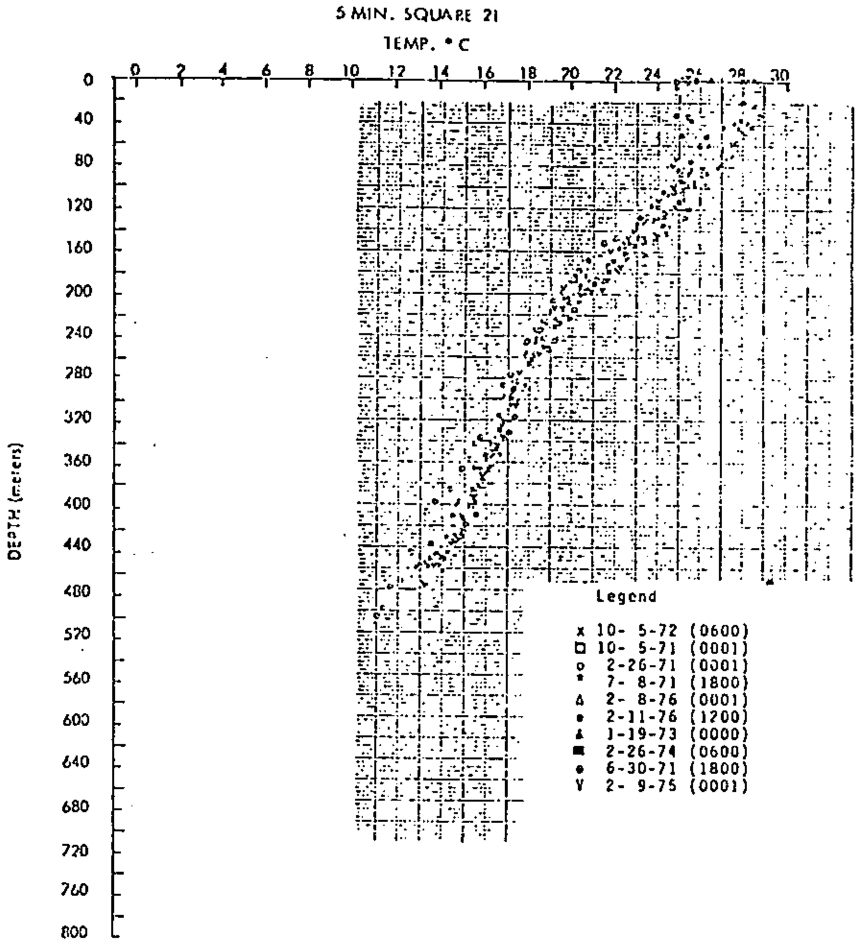

Figure 8-23. Temperature versus depth for 5-minute Square 21.

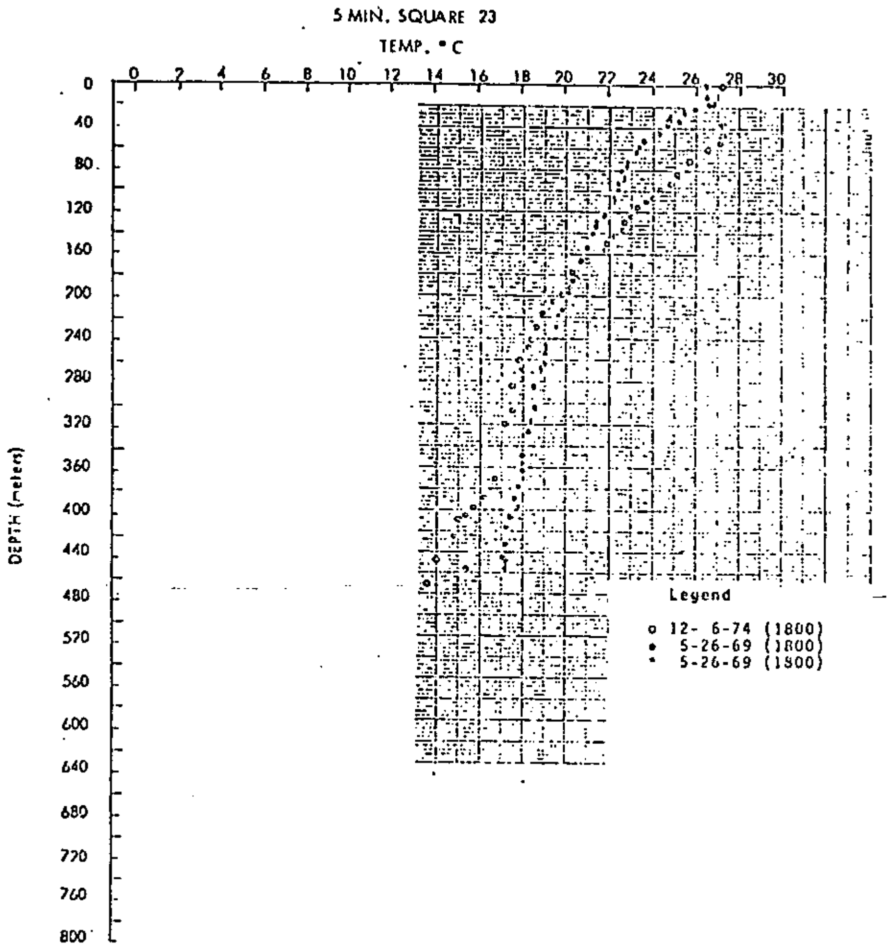

Figure B-24. Temperature versus depth for 5-minute Square 23.

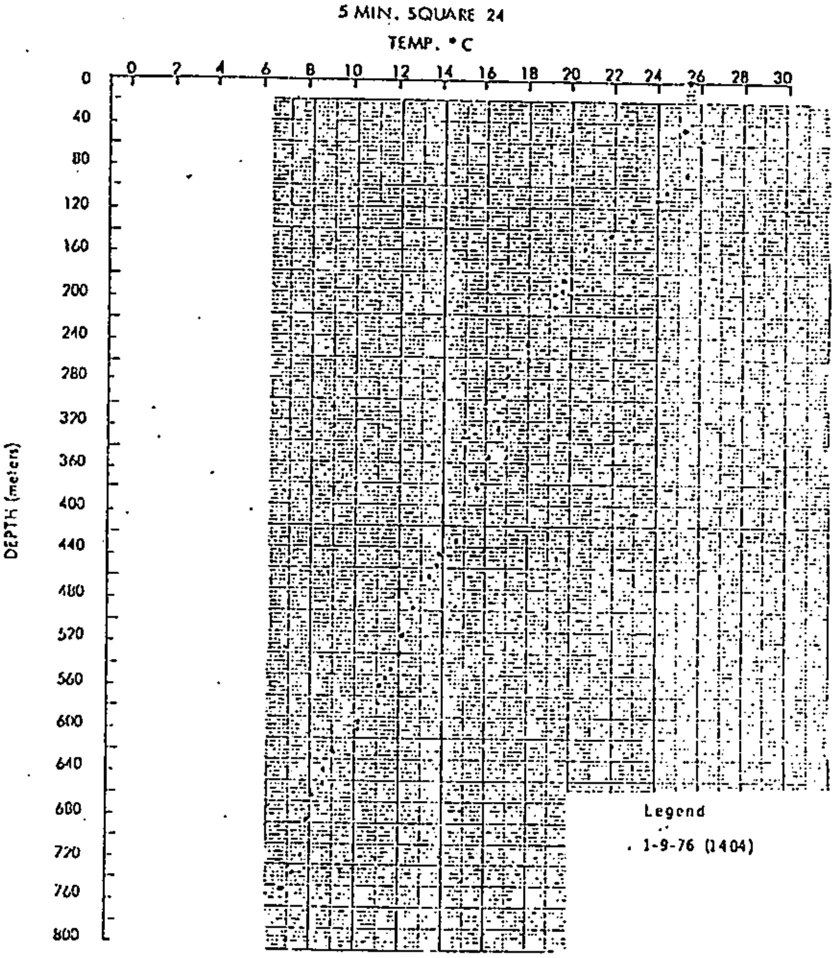

Figure B-25. Temperature versus depth for 5-minute Square 24.

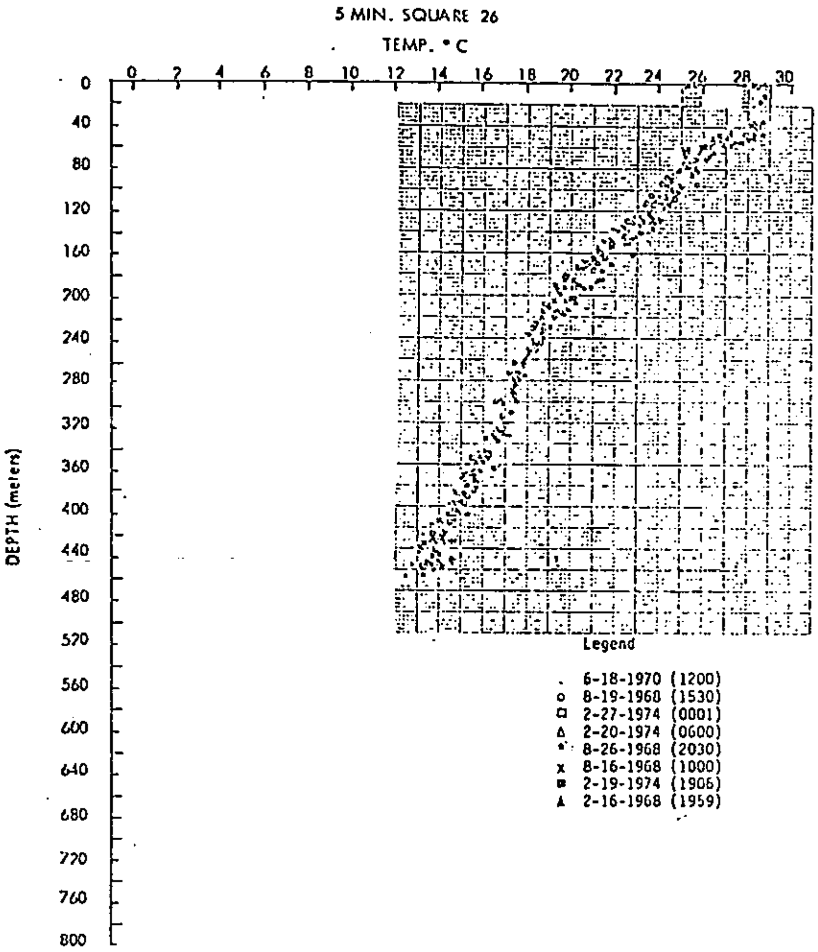

Figure B-26. Temperature versus depth for 5-minute Square 26.

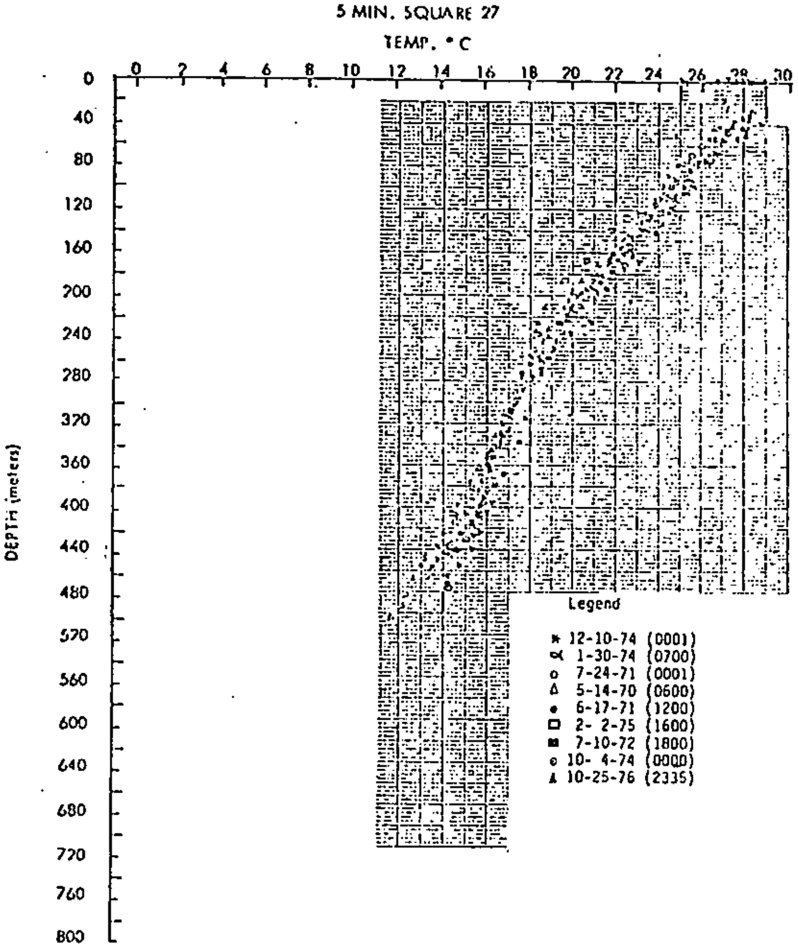

Figure B-27. Temperature versus depth for 5-minute Square 27.

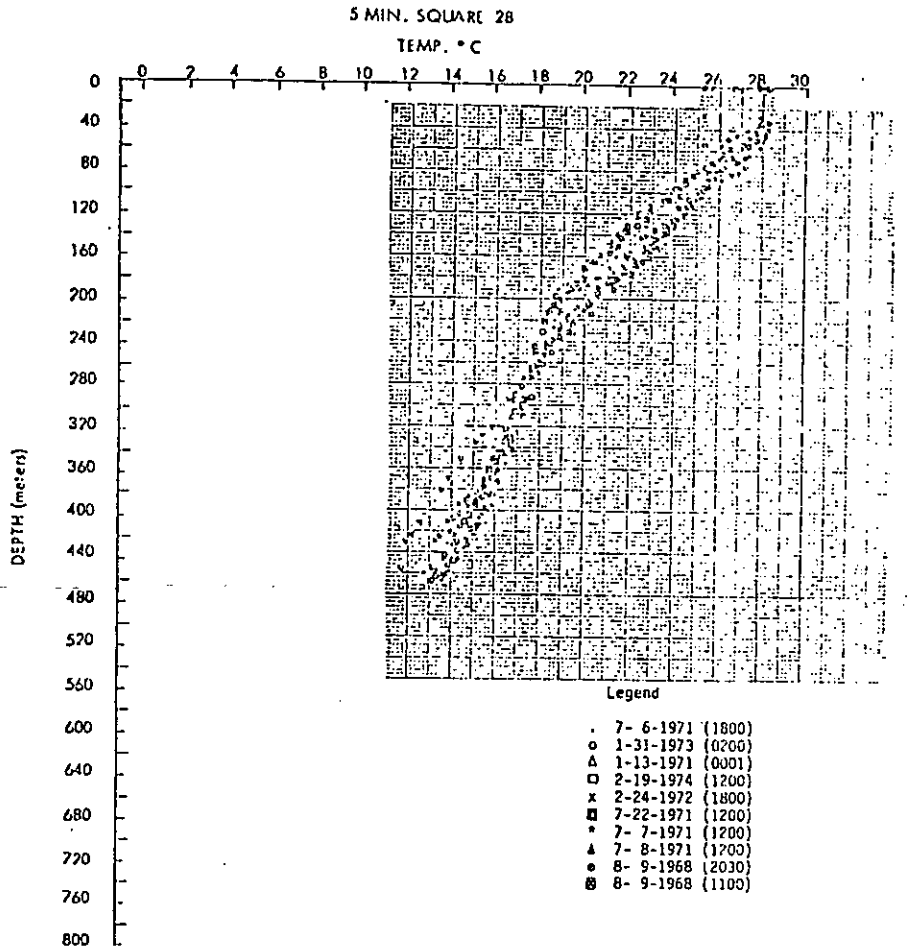

Figure B-28. Temperature versus depth for 5-minute Square 28.

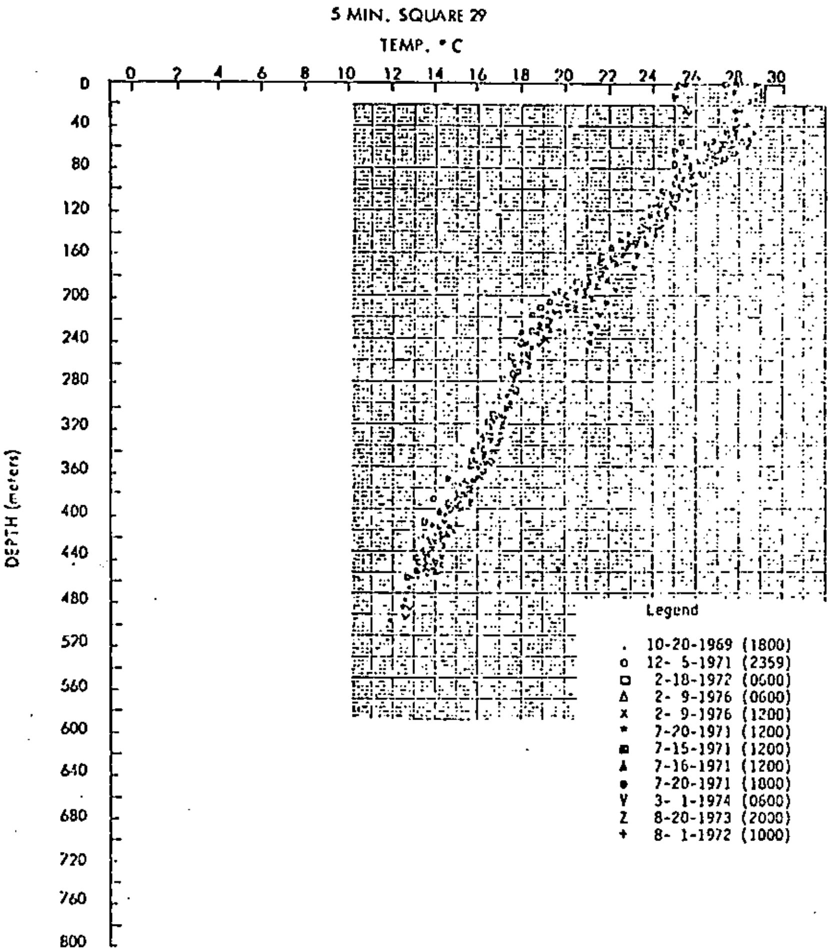

Figure B-29. Temperature versus depth for 5-minute Square 29.

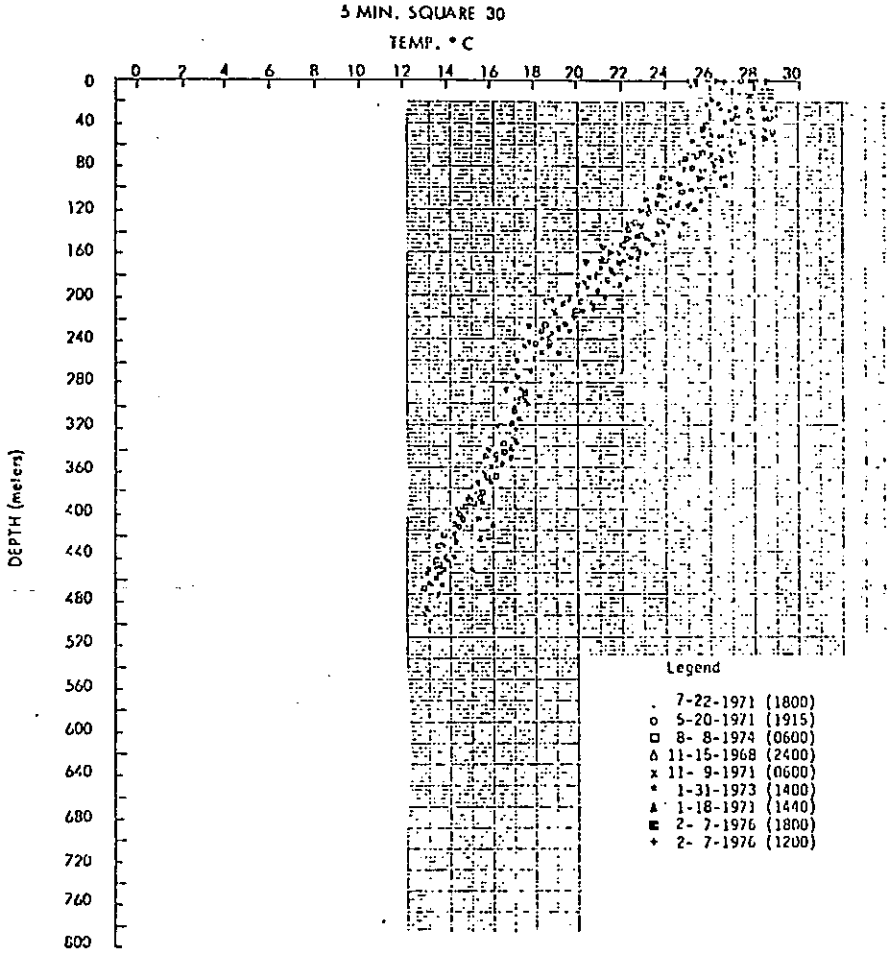

Figure B-30. Temperature versus depth for 5-minute Square 30.

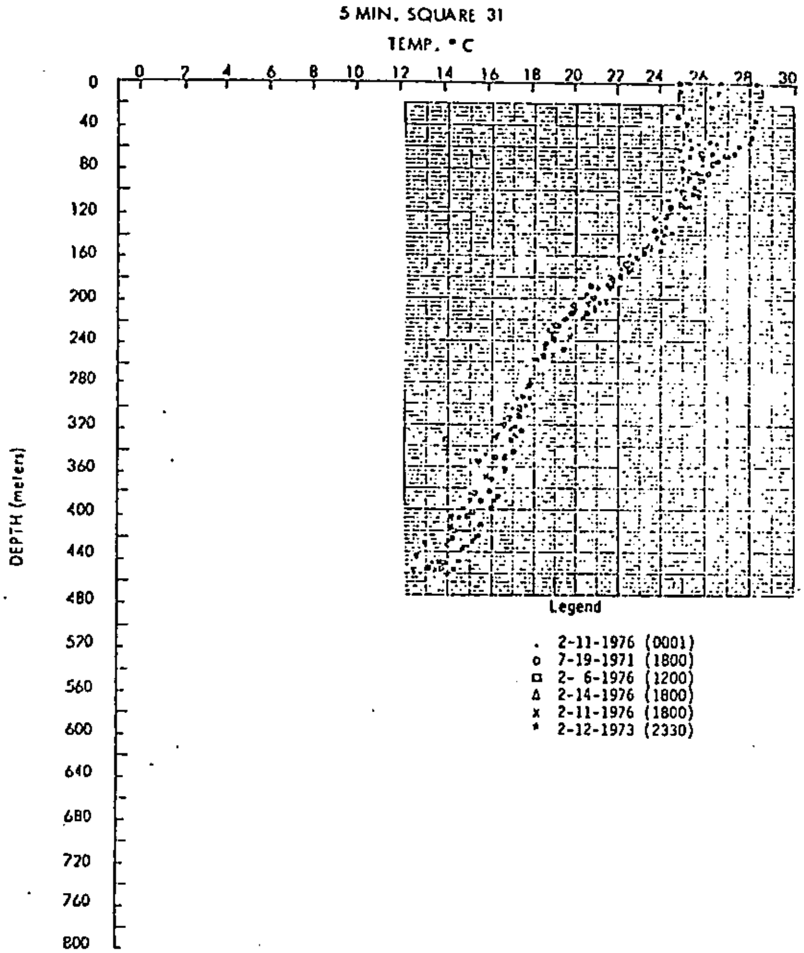

Figure B-31. Temperature versus depth for 5-minute Square 31.

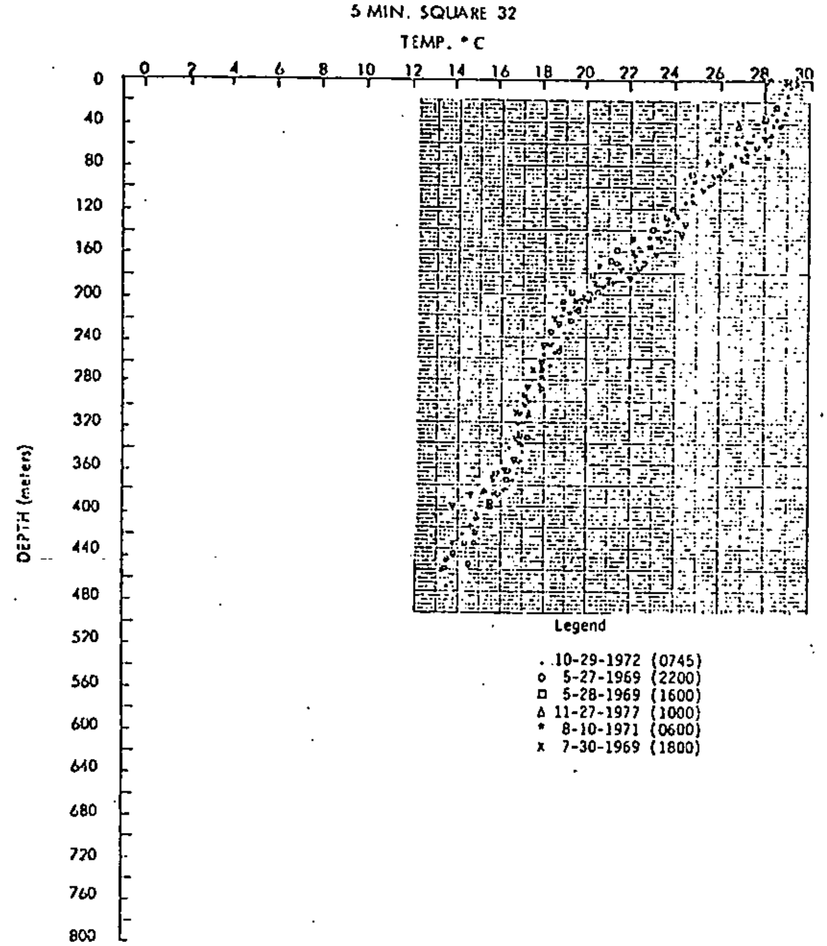

Figure B-32. Temperature versus depth for 5-minute Square 32.

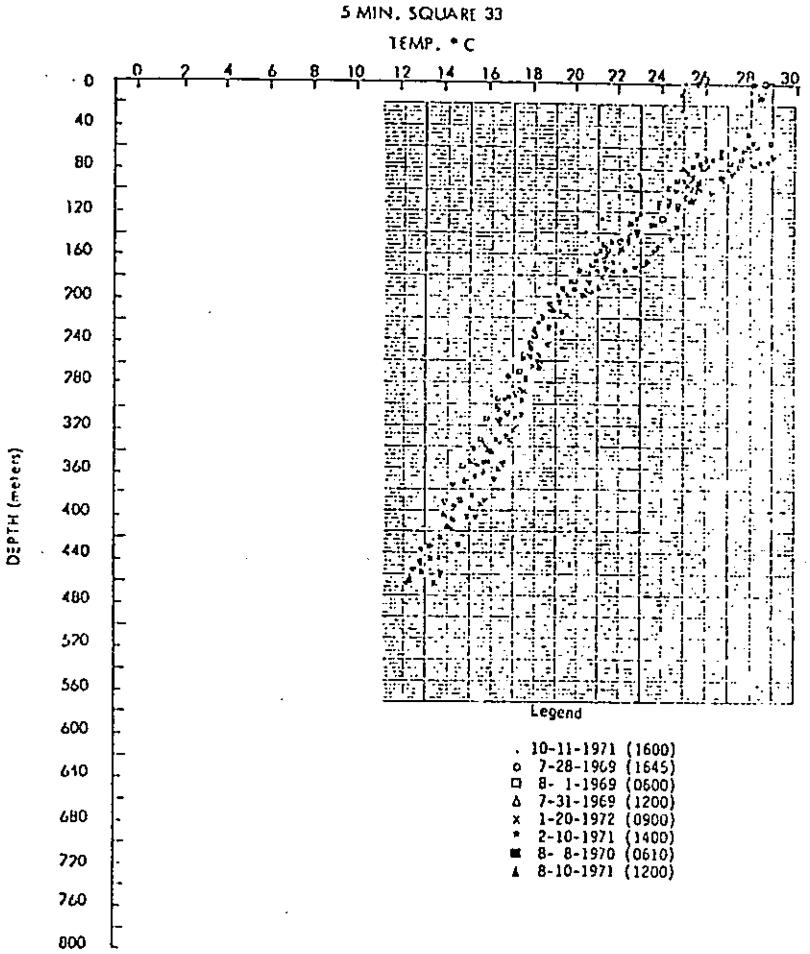

Figure B-33. Temperature versus depth for 5-minute Square 33.

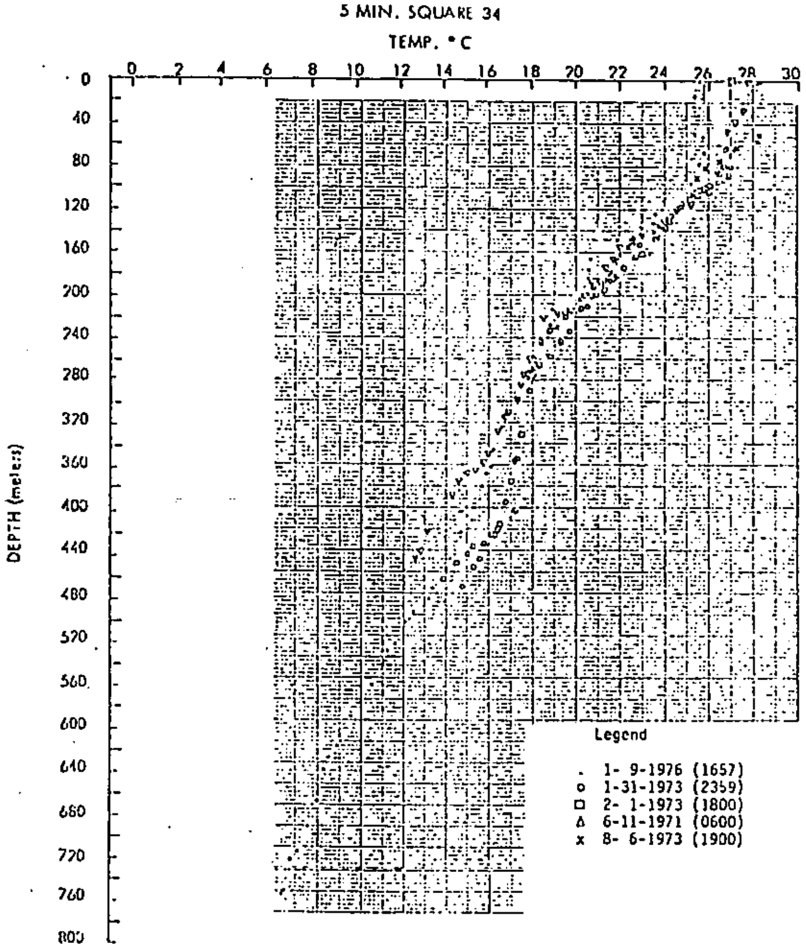

Figure B-34. Temperature versus depth for 5-minute Square 34.

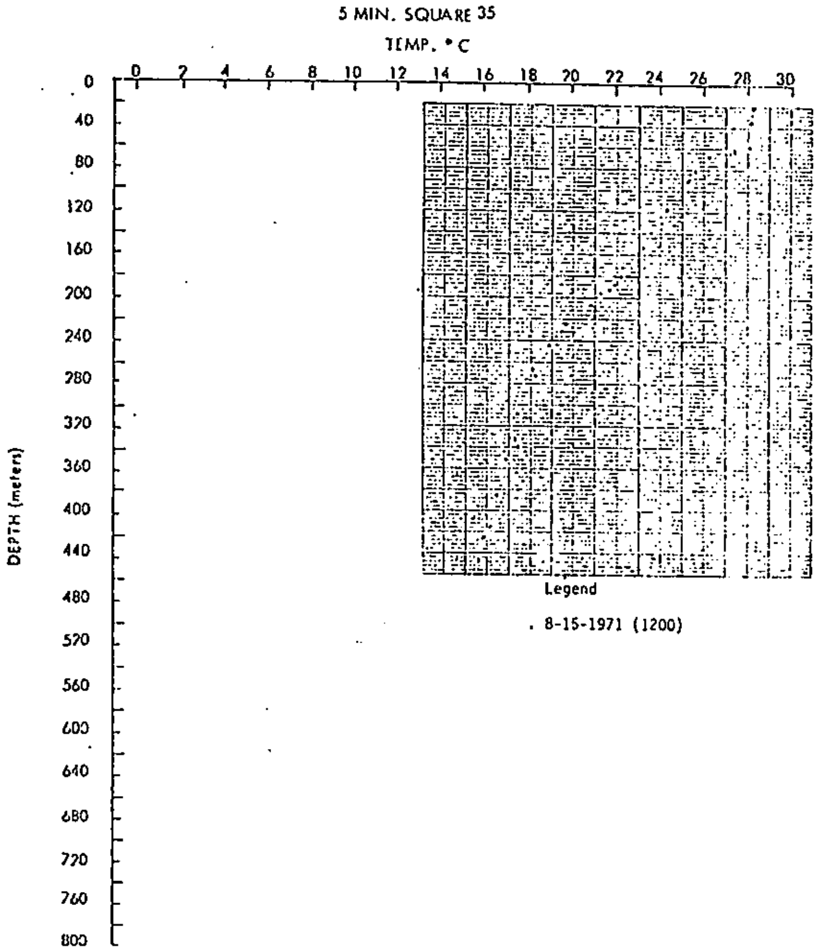

Figure B-35. Temperature versus depth for 5-minute Square 35.

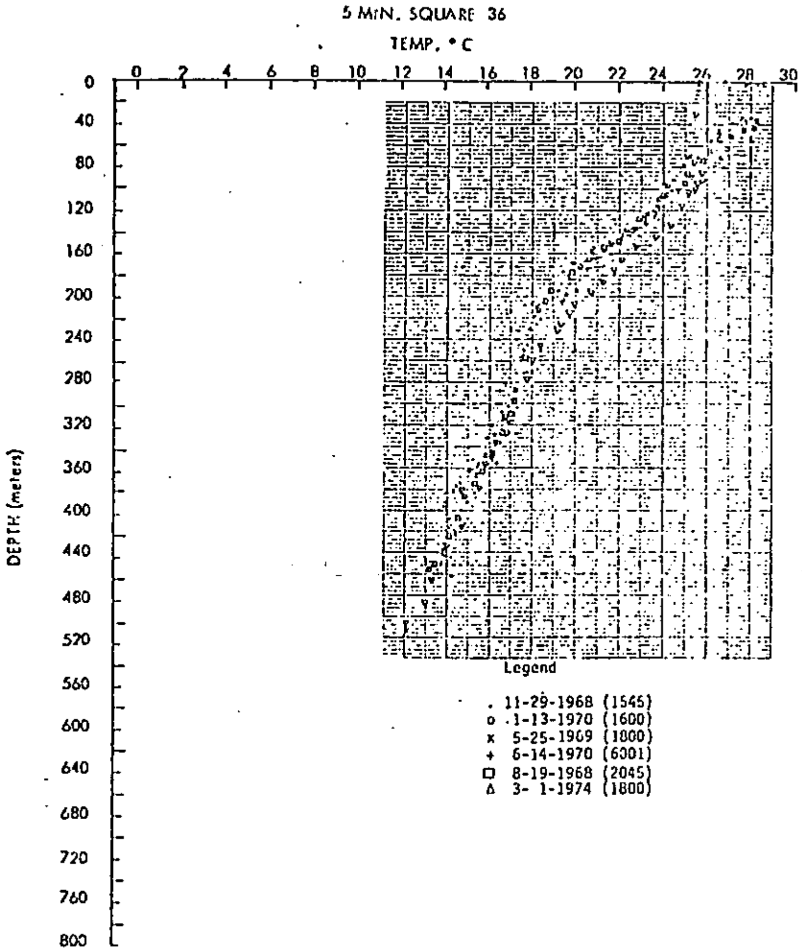

Figure B-36. Temperature versus depth for 5-minute Square 36.

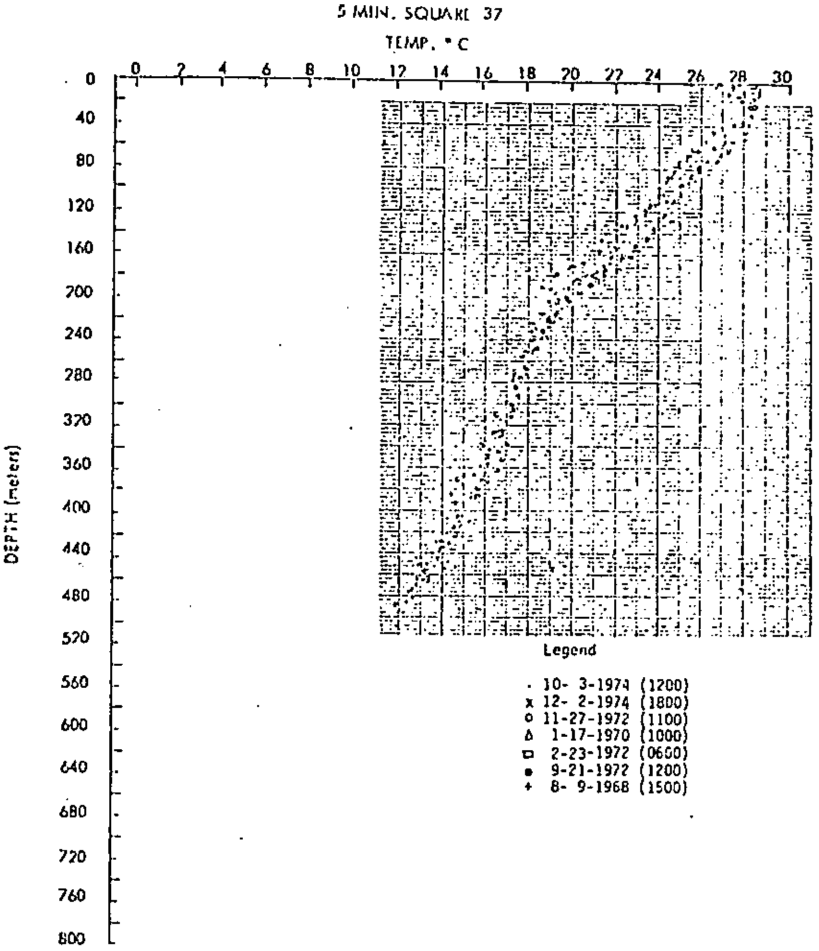

Figure B-37. Temperature versus depth for 5-minute Square 37.

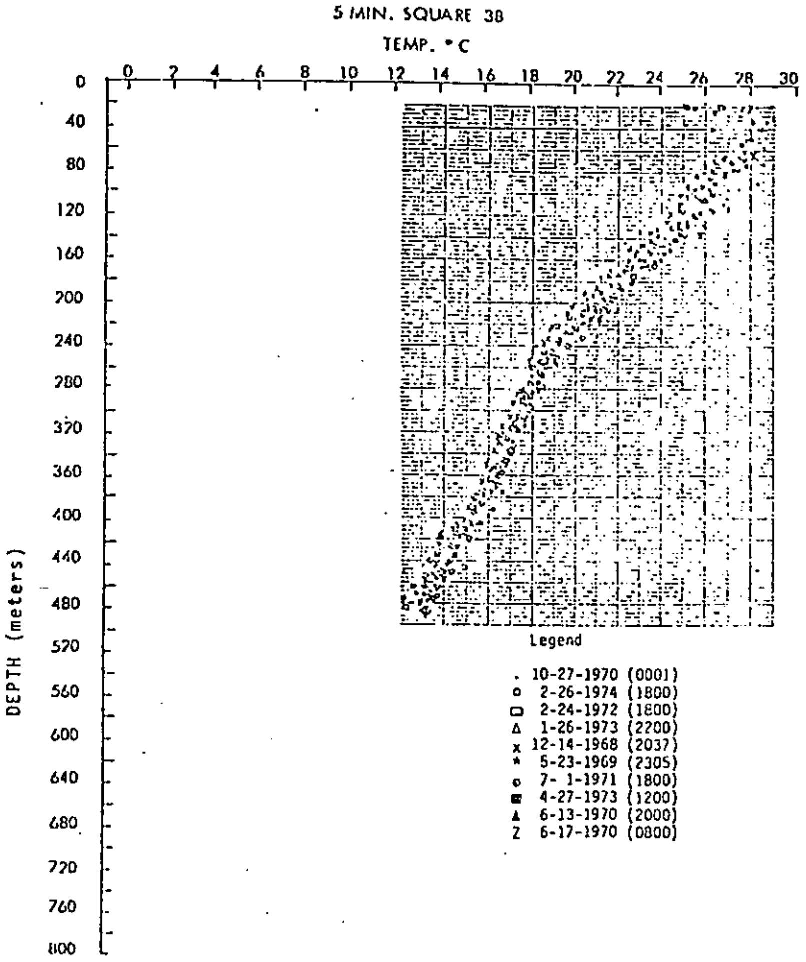

Figure B-38. Temperature versus depth for 5-minute Square 38.

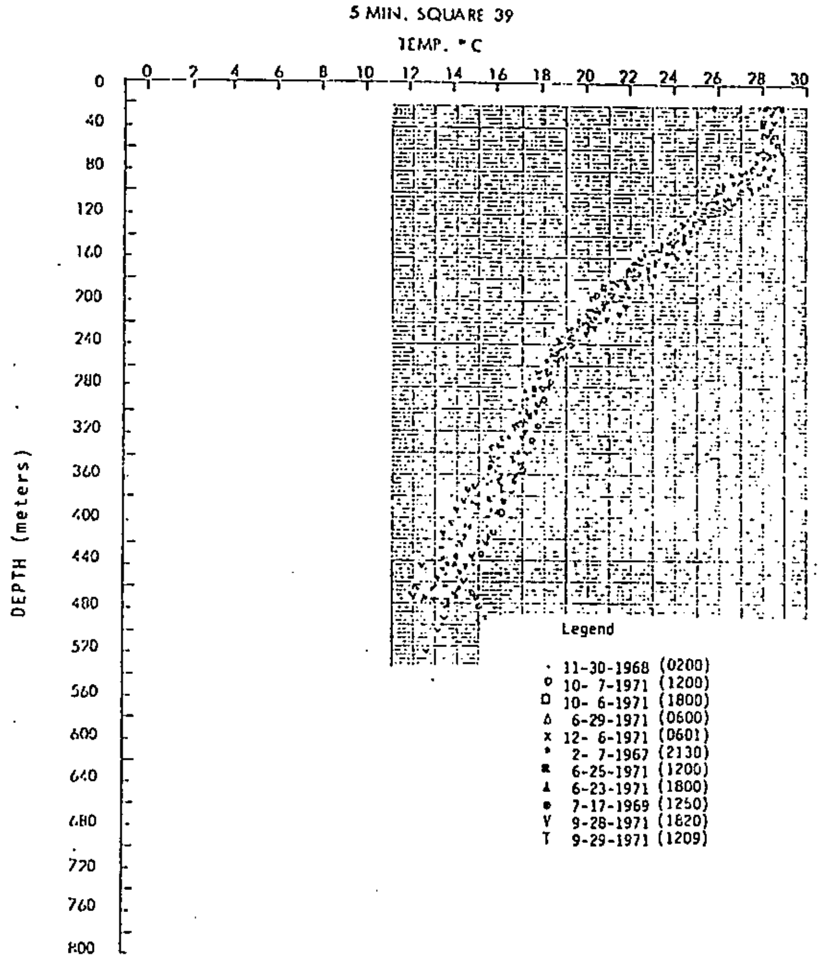

Figure B-39. Temperature versus depth for 5-minute Square 39.

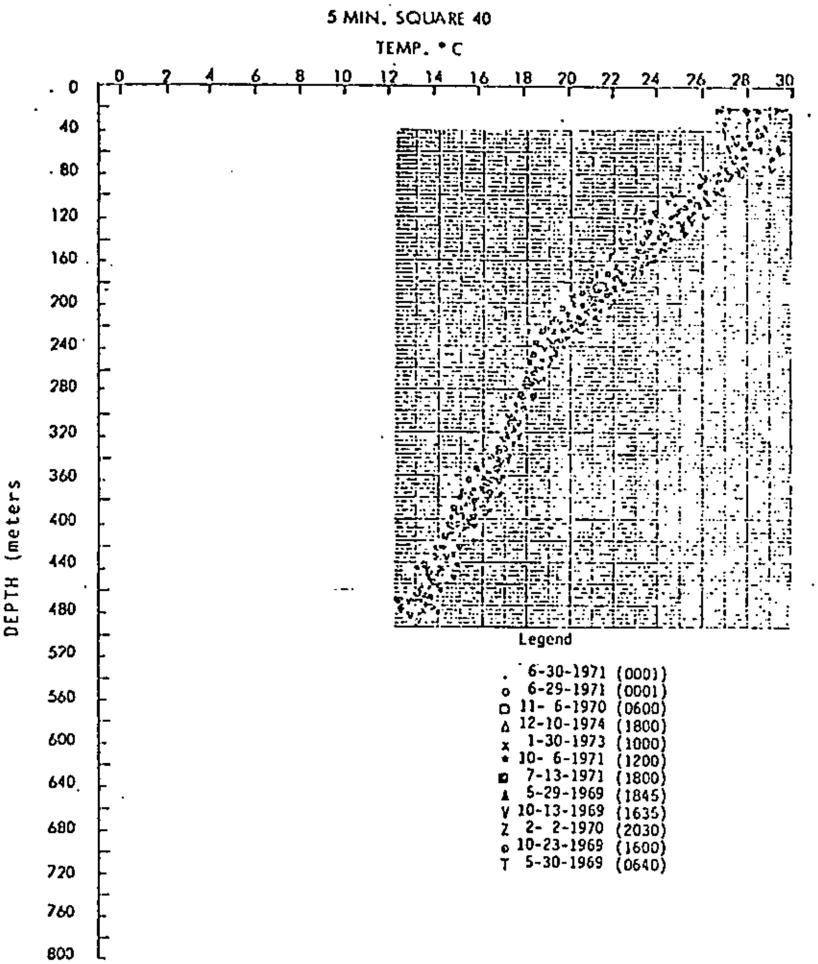

Figure B-40. Temperature versus depth for 5-minute Square 40.

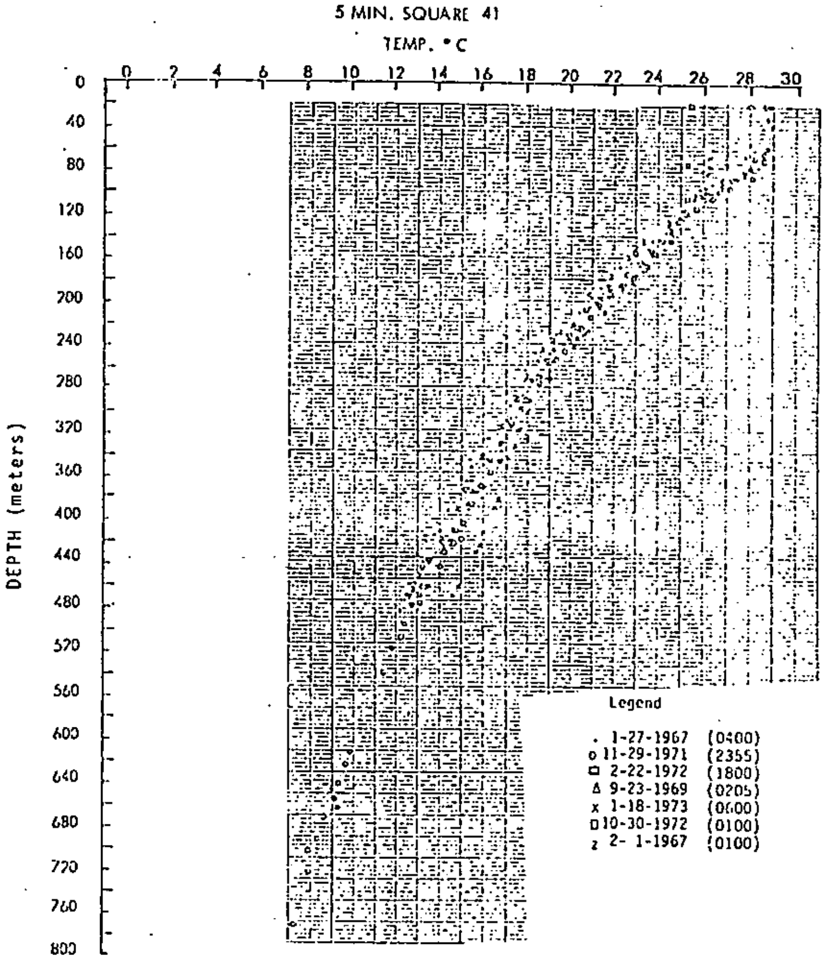

Figure B-41. Temperature versus depth for 5-minute Square 41.

APPENDIX C

BIBLIOGRAPHY OF OTEC/PHYSICAL OCEANOGRAPHY REFERENCES FOR PUERTO RICO

Allender, J.N., J.D. Ditmars, R.A. Paddock, K.D. Saunders. 1978. OTEC physical and climatic environmental impacts: An overview of modeling efforts and needs. In Proceedings of Fifth Ocean Thermal Energy Conference, 20-22 Feb. 1978, Miami. Clean Energy Research Institute, Univ. of Miami. pp III 165-185.

The present overview of studies of the effects of ocean thermal energy conversion (OTEC) plant operation on the physical environment of the ocean includes a review of the pertinent results of past and contemporary model efforts in terms of their implications for OTEC development and suggestions for future research consistent with OTEC timetables. Particular consideration is given to the areas of utilization of the thermal resource, effects of a single OTEC plant, and aggregate effects of many OTEC plants. These potential effects include modification of the local temperature, salinity, and nutrient distributions, induced changes in mixed-layer depths and sea-surface temperatures, and dispersal of biocides or working fluids (due to leaks).

Atwood, D.P., P. Duncan, M. Stalcup & M. Barcelona. 1976. Ocean thermal energy conversion: Resource assessment and environmental impact for proposed Puerto Rico site. Final Report - NSF Grant #AER75-00145, U.P.R., Dept. of Marine Sciences, Mayaguez, P.R. 104 p.

This report was produced as a pre-environmental/ assessment report for OTEC work off the southeastern coast of Puerto Rico. The report evaluated present field data, as well as historical data, where available. The information analyzed concerned bathymetry, bottom quality, seismicity, climate, winds, hurricanes, tides, sea and swell, water masses, temperatures, salinity, currents, nutrients, and oxygen. This and other pertinent OTEC criteria are evaluated and compared to other sites in the world.

Atwood, D.K., C.P. Duncan, M.C. Stalcup, M.J. Barcelona. 1977. Resource assessment of a high potential OTEC site near Puerto Rico. In Proceedings of Fourth Annual Conference on Ocean Thermal Energy Conversion, 22-24 March 1977, New Orleans, University of New Orleans, pp IV 74-78.

Environmental assessment of potential OTEC sites near Puerto Rico indicates that a high-potential site exists off the southeast coast. The Δ T to 1000 meters can be as high as 24°C (43°F) and is never less than 20°C (36°F). The insular slope at the site is steep, and water depths of 1000 meters exist within 1-1/2 miles off shore. Geostrophic conditions guarantee a warm, thick mixed layer with surface currents in the order of 1/3 of a knot. The supply of cold water can be considered limitless. The site is protected from north and northeast swell, and a mild sea state exists all year round (except during hurricanes). The salinity, temperature and nutrient distributions at the site are typical of open tropical seas, making the site ideal for a prototype OTEC plant.

Bathen, K. 1977. A further evaluation of the oceanographic conditions found off Keahole Point, Hawaii, and the environmental impact of nearshore Ocean Thermal Energy Conversion plant on the subtropical Hawaiian waters. In Proceedings of Fourth Annual Conference on Ocean Thermal Energy Conversion, 22-24 March 1977, New Orleans, Univ. of New Orleans, pp IV 79-99.

Environmental analyses, as detailed in the previous 15-month NSF/RANN report, repeated for the case of a 100 MW and a 240 MW nearshore floating power plant located 2 km off Keahole Point. Both summer and winter conditions were considered. The intent was to evaluate just the approximate scale of impact for each case. Based on the temperature and discharge rate of cold water from the OTEC plant, the local meteorological and oceanographic data estimates were made of changes in surface heat exchange, alteration in heat content of the mixed layer, and rates of spreading of the discharged work. Work was completed using the surface heat exchange equations and the two-dimensional heat conservation equation. Given then an estimate of the plume outfall characteristics and local biological data, the degree of nutrient addition and the extent of possible biostimulation were estimated.

Bretschneider, C.L. 1977. Operational sea state and design wave criteria: State-of-the-art of available data for U.S.A. coasts and the equatorial latitudes. In Proceedings of the Fourth Annual Conference on Ocean Thermal Conversion at New Orleans, 22-24 March 1977. Univ. of New Orleans, pp IV 61-73.

This was a "state-of-the-art" investigation on the availability of published material on the subjects of winds, waves, and surface currents for possible use in the determination of operational and design criteria for potential OTEC sites. It included the offshore areas of the U.S. East Coast, the Gulf Coast and the West Coast, the Hawaiian Islands, and all the equatorial oceanic areas between 20°S and 20°N latitude. No additional measurements and no generation of new data were made for increasing the "state-of-the-art". The sources of data are referenced and classified into one of four classes according to a pre-determined set of rules and opinions.

Brekhouskikh, L.M., K.N. Fedirov, L.M. Fomin, M.H. Koshlyakov, & A.D. Yampolsky. 1971. Large Scale multi-buoy experiment in the Tropical Atlantic. Deep Sea Res. 18(12):189-1206.

A large-scale hydrophysical experiment aimed at studying ocean currents variability was conducted at a selected site (polygon) centred at 16°30´W in the Tropical Atlantic. The experiment involved six U.S.S.R. research vessels and a cross-shaped network of buoy-stations laid out within a square 113 x 113 nautical miles. Currents and water temperature were continuously recorded by this network at various depths. Each of the buoys was replaced every 25 days, special arrangement being made to have overlapping records during each replacement operation. Additional research programmes were conducted from participating ships.

Current records revealed an extremely high variability both in time and in space even after filtering out the inertial and tidal oscillations from these records. Density stratification seems to affect the mean current vector rotation with depth as well as the inertial and tidal currents which, as a result, have qualities of large-scale three-dimensional internal waves.

Among other studies measurements of small-scale thermohaline structure deserve particular attention. It is likely that the observed thermohaline microstructure is related to an intermittent mixing regime in which double-diffusivity convection interplays with larger scale turbulence of both convective and dynamical origin.

Bunker, A.F. & L.V. Worthington. 1976. Energy exchange charts of the North Atlantic Ocean. Bull. Amer. Meter. Soc. 57(6):670-678.

Charts of calculated energy exchange across the the surface of the North Atlantic Ocean have been constructed. Wind and temperature observations obtained from 8 million ship weather reports were entered individually into the bulk aerodynamic equations with exchange coefficients that varied with wind speed and stability. The individual fluxes were averaged to obtain monthly and annual means of latent and sensible heat momentum. Net radiation fluxes were calculated using Budyko's (1963) formulas. Monthly and annual averages for 32 years have been formed for 500 subdivisions of the ocean. Averages for each month from 1941 through 1972 were computed for 66 10° squares to study the variations and anomalies of the fluxes, meteorological variables, and sea temperature. Charts giving annual averages of the net heat gain by the ocean, evaporation, sensible and radiational heat exchange, wind stress components, and meteorological variables are presented. A graph of the monthly variations for Marsden Square 116 and an anomaly chart for January 1958 show the variability of the fluxes and the large-scale anomaly pattern.

Burns, D.A., M. Car. 1975. Current data report for the eastern part of the Caribbean Sea. Naval Oceanographic Office, Washington, D.C. Tech. Note, TN6110-6-75 146 pp.

Preliminary analysis of 36 current meter records, from 18 arrays in the eastern Caribbean Sea, showed wide variation in mean speed ranging from less than 1 cm/sec near St. Croix and Vieques, to a maximum of about 90 cm/sec between St. Lucia and St. Vincent at a depth of 45 meters. Ten of the records had significant tidal current signatures with maximum amplitude of the M2 constituent attaining approximately 24 cm/sec at 590 meters between St. Lucia and St. Vincent. Data were recorded during all four seasons at depths ranging from 45 meters to 1910 meters.

Chew, F., K.L. Drennan, & W.J. Demoran. 1962. Drift-bottle return in the wake of Hurricane Carla, 1961. J. Geoph. Res. 67(7):2773-2776.

Most of the drift bottles released off the Mississippi delta three weeks before hurricane Carla entered the Gulf of Mexico were recovered from the vicinity where Carla crossed the Texas coast. The pattern of the recovered bottles is presented together with a discussion of some possible interpretations.

Clarks, G.L. 1938. Light penetration in the Caribbean Sea and the Gulf of Mexico. J. Mar. Res. VI, (2):84-94.

Measurements of light penetration using Photox rectifer cells were made at 8 stations in the Caribbean Sea region and in the Gulf of Mexico. At the stations in shallow water east of the Mississippi Delta, considerable turbidity was encountered in the surface layers. But at the offshore station in the Gulf and at all the other stations the water was found to be highly uniform and extremely transparent. The value of the transmissive exponent from 95 to 185 m at the station in the Cayman Sea west of Jamaica was $k = .038$, indicating the presence of the clearest ocean water ever measured.

Colon, J.A. 1963. Seasonal variations in heat flux from the sea surface to the atmosphere over the Caribbean Sea. J. Geoph. Res., 68(5):1421-1430.

The annual variations in the heat flux to atmosphere over the Caribbean Sea are studied through a computation of the monthly heat balance of the oceanic body. Various components of the heat balance are computed from available climatological information; the heat flux is obtained as a residual. A sample of bathythermograph observations accumulated through the years and compiled at the Woods Hole Oceanographic Institution was used in evaluating the rate of change of the heat content of the water body-the heat storage term. The results for this term indicate maximum cooling rates of about 141 ly day^{-1} in December and maximum warming of 82 ly day^{-1} in April and August. The warming from winter to summer is spread over a 7-month period. The cooling from summer to winter takes only 5 months. The divergence of heat transport by the ocean current is computed, but the procedures are, of necessity, rather crude and uncertain. There are indications that this term changes sign, with export of heat observed in summer and import in winter, but the largest magnitudes are only of the order of 5 to 10 percent of the radiation absorption. The maximum heat flux to the atmosphere, about 369 ly day^{-1}, is observed in November; the minimum is 196 ly day^{-1} in August. The corresponding evaporation rates are 0.58 cm day^{-1} in December and 0.31 cm day^{-1} in August. The annual range and annual average are higher than previous estimates. A separate evaluation using turbulence transfer formulas with data for a section of the Caribbean Sea was also made; the results compared well with the heat balance computations.

Crease, J. 1962. Velocity measurements in the deep water of the western North Atlantic. J. Geoph. Res., 67(8):3173-3176.

Water velocity measurements are reported in the western North Atlantic using Swallow floats. The floats were moving at depths of 2000m and 4000m. Typical speeds seen were of the order of 10 cm/sec.

Cuchrane, J.D. 1968. Currents and waters of the eastern Gulf of Mexico and western Caribbean, of the western tropical Atlantic Ocean and of the eastern tropical Pacific Ocean. Texas A&M, Tech. Report 68-8T pp 19-28.

Fisher, E.L. 1958. Hurricanes and the sea-surface temperature field. J. of Meteor., 15(3):328-333.

The behavior of hurricane tracks and the variations of the intensity of hurricanes are investigated in a study of the seasurface temperatures around eleven hurricanes. By the use of several methods of analysis, it is found that there is distinct, although not conclusive, evidence that hurricanes tend to form near relatively warm ocean areas, that they tend to follow tracks along the areas of warmest water, and that they tend to weaken when they move over pronouncedly colder water.

Forristall, G.Z. 1974. Three-dimensional structure of storm - generated currents. J. Geoph. Res., 79(18): 2721-2729.

Previous studies of wind-driven currents have naturally concentrated on the prediction of destructive storm surges. However, the present and planned construction of large facilities in offshore waters makes study of the currents themselves equally important. Here we show that it is possible to model three dimensional time-dependent currents by numerical integration over a two-dimensional grid followed by an evaluation of convolution integrals over the sea slope and wind stress. Solutions for idealized cases are compared with analytical results, and a study of a hurricane in the Gulf of Mexico is presented.

Forristall, G.Z., R.C. Hamilton, & V.J. Cardone. 1977. Continental shelf currents in Tropical Storm Delia: Observations and theory. J. Phys. Ocean., 7(4): 532-54

Storm currents are a significant part of the design hydrodynamic flow field in areas subject to tropical storms. In September 1973, Tropical Storm Delia passed over the instrumented Buccaneer platform located in 20 m of water 50 km south of Galveston, Tex. Current meter records from three depths show the storm produced currents on the order of 2 m s^{-1} which persisted to near the bottom. A mathematical model of wind-driven current generation was successful in hindcasting the observed current development after a linear slip condition bottom was incorporated in the model.

Frassetto, R. & J. Northrop. 1957. Virgin Island bathymetric survey. Deep Sea Res., 4:138-146.

A bathymetric survey in the vicinity of the Virgin Islands showed that Anegada and Jungfern Passages, which connect the Atlantic Ocean with the Caribbean Sea between the Virgin Islands Platform and St. Croix Island, are the deepest charted passages between the two seas. The 1,072-fathom sill depth of Jungfern Passage is the limiting factor in the exchange of deep water between the Atlantic Ocean and the Caribbean sea.

Furthermore, it was found that the Virgin Islands Basin, which lies between Anegada and Jungfern Passages, has a flat floor 2,400 fathoms deep. It is bounded on the north and south by sea scarps having apparent slopes of 9 to 43 degrees. The eastern end of the basin is divided into two arms which embrace a 420-fathom sea knoll. Both these arms terminate at sills which separate them from Anegada Passage and St. Croix Basin. The western end of the basin is connected with a smaller basin, 2,200 fathoms deep, which is bordered by Jungfern Passage on the south and by Grappler Bank on the west.

Froelich, P.N., D.K. Atwood. 1974. New evidence for sporadic renewal of Venezuela Basin water. Deep-Sea Res. 21(11):969-975.

Diagrams of silicate versus potential temperature from two years of data at a hydrographic station on the southern Puerto Rican insular slope 190 km west-southwest of Jungfern Passage sill indicate the presence of minor amounts of North Atlantic Deep water (NADW) below 1600 m. Time-dependent sections of silicate indicate that this water is present only sporadically. Time-dependent sections of salinity display no variation below 1600 m. These observations are consistent with sporadic overflow of NADW into the Venezuela Basin over Jungfern sill, accompanied by mixing and geostrophic spreading at intermediate depths westward along the Puerto Rico-St. Croix ridge.

Froelich, P., D.A. Atwood, J. Polifka. Seasonal variations in the salinity-silicate structure of the upper Venezuela Basin, Caribbean Sea. Trans. Amer. Geop. Union, 55(4):309. 1974.

Recent temporal hydrographic studies in the Venezuela Basin have yielded new information concerning variations in the upper 400 meters. Seasonal low-salinity surface water during October-November is characterized by high silicates, indicative of runoff, probably Amazonian. Linear regressions of silicate versus salinity yield excellent correlations ($r > .9$). STD traces during the low-salinity season display homogeneous low-salinity, high-silicate water underlain by a steep thermocline, the top of which shows a 2‰ increase in salinity and a 2 ug-at/l decrease in silicate within 15 m. Salinity and silicate sections across the eastern Caribbean display temporal variations in the lateral position and strength of the Subtropical UnderWater (SUW) core. The SUW can be characterized by a weak silicate minimum as well as a strong salinity maximum.

Fry, D.J., E.E. Adams, G.H. Jirka. 1978. Evaluation of mixing and recirculation in generic OTEC discharge designs. In Proceedings of the Fifth Ocean Thermal Energy Conversion Conference, 20-22 Feb. 1978, Univ. of Miami, Clean Energy Research Institute. pp III 104-116.

This paper has two parts. The first summarizes the results of an experimental and analytical study of the external fluid mechanics of generic OTEC designs, which was conducted at M.I.T.'s R.M. Parsons Laboratory for Water Resources and Hydrodynamics from March 1976 to July 1977. In this study it was concluded that plants of 100-200 MW, utilizing mixed evaporator and condenser discharges, could be designed to operate with no recirculation under typical ocean conditions. The primary design variables affecting recirculation were identified and recommendations for future research were made. The second half of the paper outlines a continuing research effort. This effort consists of further study of near-field mixing processes currently underway at M.I.T. and study of the intermediate field disturbances of the ambient ocean now underway at Cornell University.

Fukaoka, J.A., A. Ballester & F. Cervigon. 1964. An analysis of hydrographical conditions in the Caribbean Sea-III-Especially about upwelling and sinking. Studies on Oceanography. Hidaka Commemoration, Univ. of Washington Press, Seattle. pp. 145-149.

Gordon, A.L. 1967. Circulation of the Caribbean Sea.
J. Geoph. Res. 72,(24):6207-6223.

The geostrophic method was applied to six north-south hydrographic profiles across the Caribbean Sea and one across the Yucatan Strait. An access of flow exists in the southern third of the Caribbean Sea. It flows directly over the steep slope in the reference layer found by DEFANT's method. This condition is similar to that of the Gulf Stream. The baroclinic mass distribution extends to approximately 1200 meters. Below this, the flow is weak (5 cm/sec) except in the depths of the Cayman and Yucatan basins, where currents of over 10 cm/sec occur. The deep and bottom flow may fluctuate in phase with overflow through the Windward and Anegada passageways. The main axis of flow corresponds closely with the main axis of spreading found by the core method in both the salinity maximum and the salinity minimum layers. The volume transport across the meridional section in the Caribbean is about 31 x 10^6 m^3/sec toward the west. The northern passageways contribute only a small part of this water. The major outlet is the Yucatan Strait, where the calculated geostrophic volume transport corresponds to the transport through the Strait of Florida. The surface flow is directly affected by the wind. The upper baroclinic field mass is produced by the Ekman transport of the light surface water toward the northern boundary. It is expected that divergences occur to the south of the main flow, and convergences occur to the north. This is supported by salinity and temperature sections. The upwelling in the south is calculated to be of the order of 10^{-1} cm/sec at the bottom of the Ekman layer.

Gould, W.J., W. J. Schmitz, & C. Wunsch. 1974. Preliminary field results for a Mid-Ocean Dynamics Experiment (MODE-0). Deep-Sea Res. 21(11):911-931.

Three arrays of moored instruments were placed in the western part of the Sargasso Sea in 1971-1972 to provide pilot data for a Mid-Ocean Dynamics Experiment (MODE-I). Current, current-temperature, temperature-pressure, and acoustic positioning sensors were deployed on these moorings. The acoustic positioning instrumentation, in combination with conductivity, temperature, and pressure sensors, was also used in free-fall mode to obtain 12 vertical profiles of temperature and horizontal currents with a vertical resolution of 20 m over a 36-h period during deployment of the first array. These observations were collectively designed to provide estimates of energy levels and space and time scales for mesoscale motions. For frequencies less than 1 cycle day^{-1}, velocity and temperature records are dominated by 50-100 day fluctuations, with apparent horizontal spatial scales of the order of 100 km. The vertical structure of the mesoscale motions appears to be dominated by the barotropic and first few baroclinic modes. Estimates of kinetic energy from current meter records were found to depend upon the type of mooring used. Records from moorings with surface buoyancy yield kinetic energies that are higher than those from moorings with subsurface buoyancy. This effect occurs over the entire frequency spectrum. A special purpose experiment, with current meters at the same depths on the two different mooring types and separated horizontally by only a few hundred meters, yielded the same type of result. The vertical and horizontal displacements of a mooring with subsurface buoyancy at 500-m depth (water depth of about 5400 m) observed over a 4-day duration during the retrieval of the third array were ± 1 and ± 50 m, respectively. Pressure measurements at other depths on this mooring yielded the same ± 1 m bound on the magnitude of vertical excursions. The vertical displacements obtained from a 4 1/2 - month pressure record at 2000-m depth for a similar mooring configuration were ± 6 m.

Hastenrath, S.L. 1966. On general circulation and energy budget in the area of the Central American Seas. J. Atmosph. Sci. 23:694-711.

The field of large-scale vertical motion and the atmospheric oceanic energy budget in the areas of the Caribbean Sea and the Gulf of Mexico are studied with emphasis on seasonal and regional variations, using the available radiosonde data of the entire year 1960. The atmosphere over the Caribbean Sea exports latent heat during the winter half of the year, changing to import during summer, while divergence of the latent heat flux prevails over the Gulf of Mexico during most of the year with the exception of midsummer. The troposphere as a whole imports geopotential energy and sensible heat during winter in the Caribbean, and during most of the year in the Gulf area, this being effected by the upper-tropospheric westerly current originating over the equatorial regions of the eastern Pacific. During the summer half of the year, an export of geopotential energy and sensible heat takes place over the Caribbean Sea, being concentrated in the uppertropospheric easterlies, this pattern also including the area of the Gulf of Mexico in midsummer. Regarding the total energy budget, the troposphere over the Caribbean Sea acts as an exporter of energy to other parts of the globe throughout the year, while import is indicated for the Gulf of Mexico during some winter months. Ocean currents export heat from the Caribbean Sea during the summer half of the year while conspicuous import is indicated for the Gulf of Mexico throughout the year, with the exception of midsummer. The tropospheric energetics are discussed with respect to their role in the general circulation.

Hastenrath, S.L. 1968. Estimates of the latent and sensible heat flux for the Caribbean Sea and the Gulf of Mexico. Limn. & Ocean. 13(2):322-331.

Monthly mean values of the latent and sensible heat flux at the sea-air interface (Q. + Q.) are derived for the areas of the Caribbean Sea and the Gulf of Mexico, separately: 1) from the multiannual mean of the oceanic heat budget: 2) from the atmospheric energy budget, on the basis of the available radiosonde data for the entire year 1960; and 3) by the bulk-aerodynamic method, using 1960 ship observations.

The annual average of the latest and sensible heat transfer in the area of the Central American Seas is of the order of 270 ly/day. Making allowance for the propagation of errors and the different time periods used, the results of the three independent approaches are in fair agreement. The shortcomings inherent in all the procedures make various independent approaches desirable wherever possible.

Hazelworth, J.B. 1968. Water temperature variation resulting from hurricanes. J. Geoph. Res. 73(16):5105-5123.

Daily variations in sea surface temperature at several coastal and lightship stations and the Nomad buoy during the passages of ten hurricanes are presented. The temperature variations are given for the coastal stations and Nomad buoy for a period from 10 days before to 36 days after the hurricane passed. Generally, marked cooling of the sea surface occurred during the passage of a hurricane. However, examples are noted where a rise in temperature occurred. A comparison was made of the daily temperature variation due to hurricanes as recorded at the coastal and deep water sites. The mean temperatures decrease for the eleven coastal examples and for the thirteen lightship examples was 3.1°F, and for the three Nomad samples was 6.4°F. The extent of cooling of the surface water appears to be related to storm density and orientation with respect to the recording station. The temperature decreases at the Nomad buoy during the passage of hurricanes were quite large compared with the changes at other times during the 47-day periods, but factors other than hurricanes appear to cause larger temperature variations at the coastal sites. The length of time for the water temperature to return to normal after passage of a hurricane was computed for all stations. For the coastal and lightship stations the temperature returned to normal in less than one month with mean time of 13 and 10 days, respectively. At the Nomad buoy, near prehurricane surface temperature conditions were recorded within 19 days. These observations indicate the rapidity with which hurricane effects are modified by subsequent environmental events.

Hidaka, K. & A. Yoshio. 1955. Upwelling induced by a circular wind system. Records of Oceano. 2:7-18.

Jirka, G.H., D.J. Fry, R.P. Johnson, D.R.F. Harleman. 1977. Investigations of mixing and recirculation in the vicinity of an Ocean Thermal Energy Conversion plant. In Proceedings of the Fourth Annual Conference on Ocean Thermal Energy Conversion, 22-24 March 1977, University of New Orleans, pp IV 35-41.

Experimental and analytical studies on the external fluid mechanics in the vicinity of an Ocean Thermal Energy Conversion (OTEC) plant are conducted. Schematic OTEC conditions defined by a mixed discharge model and a discreetly stratified ocean are assumed. The interaction of several fluid mechanical regions, a jet entrainment zone, an intermediate buoyant layer and an intake flow zone, is simulated in a shallow laboratory basin representing the upper layer of the stratified ocean. A concurrent analytical model development gives satisfactory agreement with the experiments and allows to define an approximate criterion for the existence of recirculation of discharge water back into the plant intake.

Jordon, C.L. 1964. On the influence of tropical cyclones on the sea surface temperature field. Proc. Symp. Trop. Meteor. New Zealand Meteor. Vol. 7, Service Wellington, pp. 614-622.

Kinard, W.F., D. Atwood and G.S. Giese. 1974. Dissolved Oxygen as Evidence for 18°C Sargasso Sea Water in the Eastern Caribbean Sea. Deep-Sea Res. 21(1): 71-82.

Dissolved oxygen measurements at a serial hydrographic station in the eastern Caribbean and along a hydrographic transect between La Parguera, Puerto Rico and La Guaira, Venezuela (67°W) indicate an intermediate oxygen maximum at about 300 m in the north gradually rising to 175 m in the south. The water at the oxygen maximum has a temperature of about 18°C and a salinity of about 36.5°/ₒₒ indicating it is 18°Sargasso Sea Water.

Korgen, B.J., G. Bodvarsson, and L.D. Kulm. 1970. Current speeds near the ocean floor west of Oregon. Deep-Sea Res. 17(2):353-357.

Near-bottom current speeds were measured at distances of from 1-3 meters above the ocean floor west of Oregon. The instrument used was a temperature-current probe designed to measure temperatures at 8 levels and current speeds at either 1 or 2 levels near the sea floor.

Sampling was carried out at six selected positions. A distribution of recorded current speed versus water depth (from 725 to 2900m) reveals a systematic and significant increase in current speed with decreasing depth.

Mean current speeds for depths from 2700 to 2900 meters were approximately 2 cm/sec with maxima of up to 6 cm/sec. Mean current speeds for continental slope stations, with depths from 725 to 1700 meters, range from 5 to 20 cm/sec with maxima of 20-40 cm/sec depending on water depth.

LaFond E.C. 1962. Temperature structure of the upper layer of the sea and its variation with time. Temperature, its measurement and control in science and industry, Vol. I. Reinhold, N.Y. pp. 751-762.

Description of equipment necessary to measure the temperature structure versus time is discussed. Also, factors controlling the sea temperature are described, as well as cycles in sea temperatures. Short period temperature fluctuations are also described.

Lee, T.N., R.S.C. Munier, S. Chin. 1978. Water mass structure and variability north of St. Croix, U.S. Virgin Islands, as observed during the summer of 1977, for OTEC assessment. UM-RSMAS #78004, Univ. of Miami, Rosentiel School of Marine and Atmos. Sci. 80 pp.

Variability of the water mass structure north of St. Croix in the Virgin Islands Basin was observed during a 2.5 month study of corrosion and biofouling on OTEC heat exchanger performance in the summer of 1977. Daily STD profiles and weekly hydrocasts were taken of the upper 1500 m from a Tracor Marine barge moored 15 km north of St. Croix in 3600 m water depth. The largest temporal fluctuation in water properties occurred in the Tropical Surface Waters of the upper 100 m due primarily to advection of this spatially inhomogeneous water mass past the moor. Currents in the upper layer were also highly variable with speeds ranging from 0 to 50 cm/sec and numerous direction reversals. Subsurface currents appeared to be more steady and toward the west at 10 to 15 cm/sec.

The water used in the heat exchanger test was pumped continuously from the Tropical Surface Waters at a depth of 20 m, which is within the surface mixed layer defined by temperature, but at the base of the surface salinity mixed layer. Intake salinity variations of 1.7°/₀₀ over a one-month period were coherent with similar changes in the upper 60 m of TSW. Variation in water properties below the Tropical Surface Water was small. The mean and ranges of temperature and salinity at 1000 m were only 5.4 ± 0.5°C and 35.0 ± 0.06 °/₀₀, respectively. Temperature of the surface mixed waters was also quite steady with a total range of only 0.9°C from 27.8 to 28.7°C during the experiment. The thermal resource available for OTEC power plants defined as the vertical temperature difference ΔT between the surface mixed waters and subsurface water averaged 23°C at a depth of 1000 m with a standard deviation of ± 0.2°C. The depth to reach a ΔT of 20°C varied from a minimum of 660 m to a maximum of 740 m. Historical data indicate that the maximum depth to reach a ΔT of 20°C would occur in the winter and would not exceed 956 m. Thus, from thermal resource considerations, the waters north of St. Croix are considered an excellent location for an OTEC site.

Leipper, D.F. 1967. Observed ocean conditions and Hurricane Hilda, 1964. J. Atmos. Sci. 24:182-196.

Hurricane Hilda crossed the Gulf of Mexico in the period 30 September to 4 October 1964, developing into a very severe hurricane in the central Gulf. Sea temperature data available prior to the storm indicated what was probably a typical late summer situation with some surface temperatures running above 30C. Beginning 5 October 1964, a 7-day cruise was conducted over the area where hurricane winds had been observed. Using the GUS III of the Galveston Biological Laboratory of the Bureau of Commercial Fisheries, four crossings of the hurricane path were made. Bathythermograph observations were taken regularly to 270 m and hydrographic casts to 125 m. The data on all four crossings indicated similar patterns. The observed temperature-depth structures after the storm indicated that the warm ocean surface layers were transported outward from the hurricane center, cooling and mixing as they moved; that these waters converged outside of the central storm area with the result that downwelling to some 80 to 100 m in depth took place there; and that cold waters upwelled along the hurricane path from depths of approximately 60 m. Sea surface temperatures decreased by more than 5C over an area of some 70 to 200 mi. A cyclonic current system was observed around the area of greatest hurricane intensity. It is estimated that the total heat loss from the ocean to the atmosphere in the area of hurricane force winds was 10.8×10^{18} cal with the transfer per unit area being 4500 cal cm^{-2}. The data collected on the GUS III cruise are the first systematic observations available immediately after a severe hurricane in deep water.

Leming, T.D. & M.C. Ingham. Oceanic conditions in the eastern Caribbean Sea and Adjacent Atlantic, 6 August to 6 October 1965.

Marine Sciences Department. 1976. Oceanographic data of the University of Puerto Rico; January 1971-June 1973, Vol. I. University of Puerto Rico, Mayaguez, Puerto Rico. Collection maintained at the Hall of Puerto Rico Documents, General Library, University of Puerto Rico, Mayaguez.

Tables showing depth, temperature, salinity, density, Dynamic height, oxygen, phosphate, silicate, and potential temperature for both observed and interpolated data collected by the Department of Marine Science, University of Puerto Rico, Mayaguez, and funded by the National Science Foundation and the Commonwealth of Puerto Rico.

Marine Sciences Department. 1976. Oceanographic data of the University of Puerto Rico; January 1971-June 1973, Vol. II. University of Puerto Rico, Mayaguez, Puerto Rico. Collection maintained at the Hall of Puerto Rico Documents, General Library, University of Puerto Rico, Mayaguez.

Tables showing depth, temperature, salinity, density, dynamic height, oxygen, phosphate, silicate, and potential temperature for both observed and interpolated data collected by the Department of Marine Science, University of Puerto Rico, Mayaguez, and funded by the National Science Foundation and the Commonwealth of Puerto Rico.

Marine Sciences Department. 1976. Oceanographic data of the University of Puerto Rico; July 1973-November 1975, Volumes I and II. University of Puerto Rico, Mayaguez, Puerto Rico. Collection maintained at the Hall of Puerto Rico Documents, General Library, University of Puerto Rico, Mayaguez.

Tables showing depth, temperature, salinity, density, dynamic height, oxygen, phosphate, silicate, and potential temperature for both observed and interpolated data collected by the Department of Marine Science, University of Puerto Rico, Mayaguez, and funded by the National Science Foundation and the Commonwealth of Puerto Rico.

Martin, P.J., G.O. Roberts. 1977. An estimate of the impact of OTEC operating on the vertical distribution heat in the Gulf of Mexico. In Proceedings of the Fourth Annual Conference on Ocean Thermal Energy Conversion, 22-24 March 1977, Univ. of New Orleans. pp V 26-34.

The effect of OTEC operation on the thermal structure of the Gulf of Mexico is estimated by using a one-dimensional z-t heat conservation equation to predict the horizontal mean temperature. The surface heat fluxes are parameterized in terms of the observed air-sea temperature difference and the predicted sea surface temperature (SST). Advection of heat into the Gulf by the Yucatan Current is treated as a heat source for the surface layer of the Gulf. A constant mean upwelling is calculated to balance the overall heat budget. Within the mixed layer, the vertical diffusivity is calculated using the Mellor-Yamada Level 2 turbulent diffusion model. Below the mixed layer, a constant diffusivity is determiend from a balance between vertical advection and diffusion to yield a realistic mean temperature profile.

The operation of 1000 OTEC plants in the Gulf is parameterized by the addition to the model of a mean vertical velocity profile required to complete the circulation between the near-plant intake and discharge flows. The result is a surface cooling and a warming at depth. The SST drops about 0.3°C during the first two years and then remains fairly constant. However, the deep water in the region above the cold water intake warms continuously at the rate of about 0.3°C per year. This rate of deep warming is about the worst that could be expected since the model does not allow the removal of this heat from the Gulf by the currents. For the operation of only 100 OTEC plants, the impact is correspondingly reduced. After 30 years, the model predicts a drop in SST of 0.05°C and a warming in the region above the cold water intake of 0.8°C.

McFadden, J.D. 1967. Sea-surface temperatures in the wake of Hurricane Betsy (1965). Monthly Weather Review, 95(5):299-302.

Following the passage of Hurricane Betsy (1965) through the Gulf of Mexico two flights were made

the current pattern associated with the origin of the Equatorial undercurrent. The temperature/oxygen relationship indicates that most of the Undercurrent water comes from the South Atlantic by way of the North Brazilian Coastal Current and that the contribution of North Atlantic water is very minor.

Metcalf, W.G., M.C. Stalcup. 1974. Drift bottle returns from the eastern Caribbean. Bulletin of Marine Science, 24(2):393-395.

On oceanographic cruises to the eastern Caribbean Sea in the spring of 1970 and again in 1972, 1750 drift bottles were released. A total of 65 returns (3.7 per cent) were recorded. During the 1972 cruise, a small but distinct shift in the drift pattern with time was observed in a group of bottles released in a period of 1 1/2 months in a relatively small area near St. Croix island. It is inferred from the results that the major part of the surface water crossing the Caribbean Sea from east to west enters that sea through the southeastern and not the northeastern passages.

Miller, A.R. 1978. Ranges and extremes of the natural environment in and about the Hawaiian Archipelago (related to design criteria for Ocean Thermal Energy Conversion plants). Report #COO-4293-5 (WHOI-78-74). Woods Hole Oceanographic Inst. for U.S. Dept. of Energy. Contract #EG-77-S-02-4293, ADOO. 56 pp.

Examination of data from the water areas surrounding the Hawaiian Islands leads to the conclusion that Hawaii is suitably situated for ocean thermal energy conversion. Historical records of surface temperature for the Hawaiian area and the tropical and sub-tropical Pacific suggest that the proposed site may be vulnerable to significant epochal changes and yearly shifts in base temperatures but the site should still remain within the limits of operational parameters. Annual and monthly charts have been prepared for sea surface temperature, surface windspeeds and directions, and reported storm severities.

Miller, A.R. 1978. A preliminary comparative study of historical sea surface temperatures at potential OTEC sites. In Proceedings of the Fifth Conference on Ocean Thermal Energy Conversion, 20-22 Feb. 1978,

Univ. of Miami, Clean Energy Research Inst. pp. III 214-230.

Analyses of surface temperature averages and anomalies focusing on the 25-year period 1945-1969 show long-term systematic fluctuations varying on a hemispherical scale. A 180-degree phase correspondence seems to exist between the fluctuations of temperature in the Gulf of Mexico and the Caribbean Sea. Another time-connected coincidence, based on a 50-year record, suggests a relationship between Hawaiian temperatures and Japanese surface temperature phenomena. A breakdown of annual surface temperatures into their monthly anomalous components identified cold seasons from warm seasons and warrants further study.

Molinari, R.I., and J.F. Festa. 1978. Ocean thermal and velocity characteristics of the eastern Gulf of Mexico relative to the placement of an OTEC plant: A progress report. In the Proceedings of the Fifth Ocean Thermal Energy Conversion Conference, 20-22 Feb. 1978. Univ. of Miami, Clean Energy Research Inst. pp III 64-83.

Historical temperature and current data collected in the Gulf of Mexico are reviewed to produce data representations needed in the design and placement of an OTEC plant and the evaluation of the impact of the plant on the environment. Specific products include horizontal plots of mean monthly vertical temperature differences and mixed layer depths. Regions selected by the Department of Energy as potential OTEC sites are subdivided into smaller regions, for which annual and seasonal exceedence diagrams of these thermal properties are computed. Synoptic cruise data are reviewed to ascertain those regions which warrant further study, and to determine the cause of the variability in the smaller regions. Finally, a method to obtain crude estimates of the distribution of surface speeds is presented.

Molinari, R.L., and J.F. Festa. 1978. Ocean thermal and velocity characteristics of the Gulf of Mexico relative to the placement of a moored OTEC plant. NOAA Tech Memo ERL AOML-33. NOAA Atlantic Oceano. and Meteorological Lab., Miami 105 pp.

This report presents the results of the second stage of a four stage effort designed to provide ocean thermal and velocity data in the Gulf of Mexico for OTEC. The four stages are:

(1) define ocean thermal and velocity data requirements for OTEC design and impact studies,

(2) review the historical data-set and literature for relevant information,

(3) design a measurement and/or data reanalysis program, and

(4) conduct the measurement and/or reanalysis program.

Murray, S.P. 1970. Bottom currents near the coast during Hurricane Camille. J. Geoph. Res. 75(24):4579-4582.

A ducted current meter, which was mounted on the bottom in 6.3 meters of water off the coast of the Florida panhandle, was operative during much of the activity of Hurricane Camille. Before the arrival of the storm an unexpected outward extension of the wave-driven longshore current was recorded. During the storm bottom current speeds ranged up to 160 cm/sec, and their direction rotated from alongshore parallel to the wind to seaward against the wind.

Oser, R.K. and L.J. Freeman. 1969. Oceanographic cruise summary Vieques Island, Puerto Rico area December 1968 to March 1969. Naval Oceanographic Office, Washington, D.C. Informal Report IR#69-66. 16 pp.

This informal report is a summary of an oceanographic and geophysical survey in the proposed Deep Oceanographic Survey Vehicles (DOSV) Test and Evaluation (TEV) Site southwest of Vieques Island, Puerto Rico. Included in the survey were Nansen casts, bathymetry, sub-bottom profiling, current measurements, marine fouling studies, bottom photography, geomagnetic measurements, and sediment sampling.

Ostericher, C. 1967. Oceanographic cruise summary Atlantic Fleet Tactical Underwater Range; Southeast Puerto Rico-1967. Naval Oceanographic Office, Washington, D.C. Informal Report IR#67-76 44 pp.

An oceanographic survey of a proposed Fleet Tactical Underwater Range off the southeast coast of

Puerto Rico was conducted during March - April 1967. Data collected included: temperature and salinity, surface currents, moored current meter measurements, bottom sediments, bottom sterco photographs, and ambient noise. Preliminary analysis of the data indicates that the distribution of physical properties is as expected for this time of the year, but current speeds may be somewhat higher than anticipated. The bottom was revealed to be exceedingly flat in the basin, which is an area of ponded sediments.

Included in the report are the ocean station data listings and the calculations used in the analysis of the moorings.

Parr, A.E. 1937. A contribution to the hydrography of the Caribbean and Cayman Seas. Bull. Bingham Oceano. Coll. 5(4):1-110.

Parr, A.E. 1938. Further observations on the hydrography of the Eastern Caribbean and adjacent Atlantic waters. Bull. Bingham Oceano. Coll. 6(4):1-29.

Perlroth, I. 1971. Distribution of mass in the near surface waters of the Caribbean. SIRCSAR, UNESCO, Paris. pp 147-152.

Historical oceanographic data have been used in this study to achieve a better understanding of the physical processes in the near surface waters of the Caribbean. It is believed that climatological studies of this type may lead toward a deeper understanding of the complexities in the oceanographic media.

The advantage of setting up a historical model to depict average physical environmental conditions in the ocean are manifold. Surveys of water mass structure and transport could be planned more intelligently; a more complete procedure for quality control and processing of data could be established and, consequently, a better understanding of the air-sea interaction would result. Furthermore, the historical model would enable the synoptic oceanographer to review vast ocean areas.

Piacsek, S.A., P.J. Martin, J. Toomre and G.O. Roberts. 1976. Recirculation and thermocline perturbations from ocean thermal power plants. NRL, NRL-GFD/OTEC 2-76, ERDA contract E(49-26)1003 to NRL.

Numerical experiments were performed on the fluid motions resulting from the pumping action of ocean thermal power plants. In particular, the resulting thermocline distortions, sea surface temperature decrease and corresponding heat flow change were investigated. The object was to find engine discharge configurations and pumping rates that would minimize these alterations. This would result in both a minimal environmental impact and preservation of the temperature gradient across the engine, i.e. the energy resource.

The results obtained to date use 2-D turbulent flow calculations. Near the engine, the sea surface temperature reduction ranges from 0.01°F to 3°F, depending on design, flow rate, season and location. The mean temperature of the warm inflow water is reduced by up to 4°F from the mean temperature at the depth, for certain designs and flow rates, due to recirculation and turbulence. The far-field surface heat calculations applied to the Puerto Rico area shows that a depression of the sea surface temperature by 0.1 °C leads to an increased heat flow from air to sea of 9.6 cal/cm^2/day, serving to replenish the heat removed from the surface layers by the plant. Accepting 0.1 °C as a permissible environmental perturbation, the area requirement for a typical 100 MW plant is 2500 km^2, with a radius of 28 km. The corresponding estimates for Hawaii are 4 cal/cm^2/day, an area of 6000 km^2, and a radius of 44 km.

Piacsek, S.A. and A.C. Warn-Varnas. 1977. Air-sea interaction perturbations by plant operations. In Proceedings of the Fourth Annual Conference on Ocean Thermal Energy Conversion, 22-24 March 1977, University of New Orleans. pp IV 3-6.

The readjustment in the air-sea heat flow and the air-sea temperature contrast following a possible sea surface temperature lowering by OTEC operations has been calculated in the areas of Puerto Rico, Gulf of Mexico, and Hawaii. The net heat and the perturbations due to OTPP operations are found to be 96, 81 and 67 cal/cm^2-day-°C.

Puerto Rico Nuclear Center. March 1973. Aguirre power project environmental studies 1972, Annual Report and Appendix, Puerto Rico Nuclear Center, U.P.R., Mayaguez, PRNC 162, 464 in 2 Vols.

This report of two volumes is an environmental report of Jobos Bay on the south coast of Puerto Rico. Many types of data were taken, with no conclusions indicated. Some of the data taken and discussed are: plankton, foraminifers, algae, turtle grass, mangrove root community, coral reef ecology, fish and birds.

Puerto Rico Nuclear Center. June 1975. Aguirre environmental studies Jobos Bay, Puerto Rico Final Report, Puerto Rico Nuclear Center, U.P.R. Mayaguez, Puerto Rico. PRNC 196 VI (95 p), VII (184 p).

This report of two volumes is an environmental report of the Jobos Bay on the south coast of Puerto Rico. Many types of data were taken, with conclusions mentioned for some of them. The data taken include: microzooplankton, zooplankton, seagrasses, mangrove community, fish, fish egg entrainment, and foraminifera.

Richards, F.A. and R.F. Vaccaro. 1956. The Cariaco Trench, an anaerobic basin in the Caribbean Sea. Deep-Sea Res. 3:214-228.

The Cariaco Trench is a basin in the Caribbean Sea which is anaerobic below depths of about 375 meters to the bottom at 1,400 meters. Below ea. 250 meters the water is essentially isothermal at about 16.9 C and has practically uniform salinity and density. Hydrogen sulphide reaches maximum concentrations of .03 mgA sulphide S per litre, which is about 10% of the concentration found in the depths of the Black Sea. Inorganic phosphate is linearly related to the oxygen and sulphate consumption in a ratio equivalent to 235 atoms of oxygen utilized for the production of 1 atom of phosphate. The anaerobic zone is free of nitrate and nitrite, but some ammonia is present. It is suggested that most of the nitrogen arising from decomposition of organic matter is present as elementary N_2 in solution. The age of the water is estimated to be between 100 and 2,000 years. The physical properties of the trench are compared with those of other isolated basins.

Riehl, H. 1962. Radiation measurements over the Caribbean during the autumn of 1960. J. Geoph. Res. 67(10): 3935-3942.

Observations made over the Caribbean Sea with the Suomi-Kuhn infrared radiometer during 1960 are analyzed. About 120 soundings released at five stations ascended to the 100-mb level or beyond. Compared with Elsasser's results they show greater cooling below 800 mb and much smaller cooling higher up. In the high troposphere a radiational heat source due to long-wave radiation alone is found. It follows that vertical heat transport requirements from the surface by convective means, for heat balance, are much less than was previously estimated. Fragmentary observations above 100 mb indicate that the outward radiative flux increases above the tropopause and gradually approaches the values obtained from Explorer 7 measurements. Strong cooling of the air above the tropopause is computed, as much as 5 times that of the troposphere. Day-to-day fluctuation of net radiation from the troposphere was large, as was the range of observed fluxes. Statistical analysis indicated that the control of the net radiation from the troposphere lies mainly in the high troposphere, in the layer of maximum wind. It is

shown that a cirrus hypothesis of this control is at least plausible and that differential radiation can be sufficiently strong to be of considerable possible importance in the growth and evolution of daily weather systems.

Roberts, G.O. 1977. Stratified turbulence modeling for new field external flow. In Proceedings of the Fourth Annual Conference on Ocean Thermal Energy Conversion, 22-24 March 1977. Univ. of New Orleans. pp IV 7-25.

A simplified two dimensional model is used to calculate the turbulent flow near the two outflows and the warm inflow associated with one power module of the Lockheed baseline OTPP design. A rectangular domain of depth 500 ft has three horizontal slots of height 72 ft on its left boundary, centered respectively at depths of 75, 150 and 315 ft, to represent the inflow and outflows. Four separate computations assume statistical uniformity across widths of 50 ft, 100 ft, 200 ft and 400 ft; we believe that the results for widths of 100 ft and 200 ft essentially bracket the results for the three-dimensional prototype flow. The assumed ambient temperature profile has a surface temperature of 80°F, and a thermocline at depth 300 ft where the temperature is 61.5°F. The temperature at 500 ft is 44.4°F. The assumed temperature at the cold inflow, at depth 1550 ft, is 42.6°F; this water is warmed by 2.4°F in the condenser and leaves the cold outflow at 45°F.

The numerical results for the average warm inflow temperature are 75.7°F, 77.2°F, 77.9°F and 78.6°F in the four cases. This inflow water is cooled by 3°F in the condenser before leaving the warm outflow. In all four cases, the far-field flow leaves or enters tne computational domain horizontally, with temperature equal to the ambient profile. In the 50 ft and 100 ft computations, there is significant recirculation (4000 cu ft/sec and 1300 cu ft/sec, respectively) from the warm outflow back into the warm inflow, contributing to the reduced inflow temperatures. In all cases, the OTPP-generated turbulence is negligible at distances greater than 350 ft from the inflow and outflows.

Ross, C.K. and C.R. Mann. 1971. Oceanographic observations in the Jungfern Passage and over the sill into the Venezuela Basin, February 1968. SIRCSAR, UNESCO, Paris. pp 171-174.

According to previous work, the 3.84°C isotherm lies at a depth of 3000 m in the Venezuela Basin. These results show the same isotherm at a depth of only 1700 m in the Jungfern Passage, and at the bottom in the basin. As no water with potential temperature less than the above was found at stations within the basin, it is not certain to infer that the Venezuela Basin bottom water is continually being renewed through the Jungfern Passage. Possibly the cold dense water is prevented from moving down into the basin by the dynamics of deep water near the sill.

Rossby, T., and D. Webb. 1971. The four month drift of a Swallow float. Deep-Sea Res. 18(10):1035-1039.

A Swallow float at 1100 m depth was tracked by SOFAR in the region between Bermuda, Bahamas and Puerto Rico. During the four month life of the float it drifted 300 km to the west, a displacement which corresponds to an average drift rate of 2.8 cm/sec. This is consistent with previous studies and suggests that the transport to the west between Bermuda and the West Indies is well in excess of 100 x 10^6 m^3/sec. The shape of the trajectory is such that it may have been governed by planetary wave dynamics.

Inertial oscillations were observed with unexpected clarity. It is evident that they can remain stable for weeks, but on one occasion when the temperature of the water dropped 0.5°C, a sudden change in the oscillation phase and frequency was observed, a transition that is consistent with the float moving from one relatively well-mixed layer to another.

Sands, M.D. 1978. Progress report for the environmental impact assessment program for the 1-MWe early OTEC test platform. In Proceedings of the Fifth Ocean Thermal Energy Conversion Conference, 20-22 Feb. 1978. Univ. of Miami, Clean Energy Res. Inst. pp III 186-202.

The 1-MWe Ocean Thermal Energy Conversion Early Testing Platform (EOTP) has a projected test date in mid-1979 in the Gulf of Mexico, Hawaii or Puerto Rico. With the implementation of the National Environmental Policy Act of 1969, all government funded activities must consider potential environmental consequences of the activity and prepare an environmental impact assessment and bring environmental considerations into the decision making process. This presentation summarizes the progress to date for the environemntal impact assessment program for OTEC-1, the Early Ocean Testing Platform.

The considerations in assessing impact for OTEC-1 first require a detailed description of the physical system design. Included in the design description are the depth of intake and discharge pipes, volumes discharged, and applicable safety regulations and procedures. The detailed site descriptive information including the biological, chemical, physical, oceanographic, and meteorogical data must be gathered from all available sources. Particular study areas include the effects of impingement and entrainment, biocide effectiveness and toxicity to non-target biota, working fluid release effects, climatological impacts, and worker safety. Also, the International, Federal, State, and local legal implications of siting will be considered. While socioeconomic impacts of OTEC-1 now appear to be minimal, there is potential later for substantial benefits to the resident community serviced. When all relevant data is at hand the predictive process for assessing environmental impact is underway.

Sandusky, J. and P. Wilde. 1978. Preliminary bio-ecologic investigations at the OTEC Gulf of Mexico site - 29°N 88°W. In Proceedings of the Fifth Ocean Thermal Energy Conversion Conference, 20-22 Feb. 1978. Univ. of Miami, Clean Energy Res. Inst. pp III 83-103.

Bio-ecologic measurements important for environmental assessment of the impact of an operating Ocean Thermal Energy Conversion Plant have been initiated in July 1977 and November 1977 at the proposed Gulf of Mexico site off the coasts of Louisiana, Mississippi, Alabama, and Florida with physical oceanographic measurements on the OSS Researcher in a joint effort with the Atlantic Ocean Marine Laboratory (AOML) of the National Oceanic and Atmospheric Administration (NOAA). The measurements in July included 16 formal hydrocast stations of various depths of 1000 meters. Water was analyzed for trace metals, nutrients, and phytoplankton biomass as estimated by chlorophyll and ATP. Physical data were supplied by NOAA-AOML. In addition, two surface net casts were taken to obtain zooplankton at the site and tow ^{14}C bioassays were made to measure productivity. The Deep Scattering Layer (DSL) was monitored at the site by a continuously recording 12 KHZ depth sounder. Measurements in November were made from the RV Virginia Key (AOML). They included 4 hydrocasts, 7 net tows for zooplankton (samples analyzed by Gulf Coast Research Laboratory), 1 STD trace, 20 XBT's and one ^{14}C phytoplankton bioassay.

Seiwell, H.R. Application of the distribution of oxygen to the physical oceanography of the Caribbean Sea region. Pap. Phys. Oceanog. Meteorol. 6(1):1-60.

Shanley, G. 1972. Hydrographic data for Caribbean Sea and Pesca Serial Station at 17°38'N, 67°00'W for 1971. Dept. Mar. Sci., U.P.R., Mayaguez #72-1.

Shanley, G.E., Rev. by C.P. Duncan. 1972. Hydrographic data for Caribbean Sea and for Pesca Serial Station at 17°38'N, 67°00'W for 171. Dept. of Marine Sci. U.P.R. Mayaguez #72-1 (REV).

Smith, N.P. 1978. Longshore currents on the fringe of Hurricane Anita. J. Geoph. Res. 83(C12):6047-6051.

Subsurface current data from a 2-week period in August and September 1977 are compared with coastal wind stress and water level data to describe longshore motion in response to the passage of Hurricane Anita across the northern Gulf of Mexico. Current meters 2 and 10 m above the bottom 21.5 km off the central Texas Gulf coast indicate strongest speeds of approximately 70 and 80 cm/s, respectively coinciding closely with the time of maximum wind stress. A qualitative comparison of the variations in sea surface slope and wind stress with the recorded longshore current suggests that both wind stress and the longshore pressure gradient combined to produce the strong flow recorded during the storm but that the pressure gradient was primarily responsible for decelerating the current after the storm made landfall.

Stalcup, M.C. and W.G. Metcalf. 1972. Current measurements in the passages of the Lesser Antilles. J. Geoph. Res. 77:1031-1049.

Direct-current measurements during March and April 1970, in the four major passages through the Lesser Antilles show a westward transport of about 26×10^6 m^3 sec^{-1}. This transport is divided between the Grenada, St. Vincent, and St. Lucia passages with, respectively, 10, 10 and $6^2 \times 10^6$ m^3 sec^{-1} flowing to the west. The transport through Dominica passage was less than 2×10^6 m^3 sec^{-1} during these measurements. This flow pattern is consistent with the distribution of variables as shown by data from hydrographic stations to the east and west of each passage. On the basis of the temperature-oxygen relationship, water taht enters the Caribbean with a temperature between 16°-23°C comes from a broad band of water found east of the area.

Stalcup, M.C. and W.G. Metcalf. 1973. Bathymetry of the sills for the Venezuela and Virgin Islands Basin. Deep-Sea Res. (20(8):739-742.

Recent bathymetric surveys using a precision radar ranging navigation system in the Anegada-Jungfern Passage reveal that the depth of the Jungfern Passage sills is 1815 m. As described by the 1800 m isobath it is 3 km wide and 10 km long and contains a central depression with depths exceeding 1970 m. In agreement with earlier data the Jungfern Passage (Virgin Passage) sill is shown to be the deepest or controlling one between the Venezuela and Virgin Islands basins.

The Anegada Passage sill found during the recent surveys, is not that found by FRASSETTO and NORTHRUP (1957). The one described here is located near Barracuda Bank and, with a depth of 1915 m, is 300 m shallower than the one previously described.

Stevensen, R.E. and R.S. Armstrong. 1965. Heat loss from the waters of the northwest Gulf of Mexico during Hurricane Carla. Geofisica International, 5:49-57.

The temperature and salinity of an area off Galveston and Corpus Christi, Texas was measured about one month after Hurricane Carla passed by. In general, surface water was seen to be cooler along the hurricane's path, and warmer elsewhere. Heat was lost from up to 100 meters depth. An estimate of the heat loss at each station yields about 2.5×10^{17} cal/day. This value seems to compare with those determined for Hurricane Daisy in 1961.

Sturges, W. 1965. Water characteristics of the Caribbean Sea. J. Mar. Res. 23(2):147-162.

The volume of Caribbean Sea water in bivariate classes of potential temperatures vs. salinity has been estimated from 76 hydrographic stations. The resulting statistics are presented on a pair of characteristic diagrams. The outstanding feature of the diagrams is the strong mode; nearly half of all Caribbean water lies within 0.1°C and 0.02 per mil of the mode, and 3.9°C and 34.98 per mil. An envelope of all samples has been determined. The waters below 2900 m in each of the four large basins are compared by using only data from a single CRAWFORD cruise. In each basin the deep water is remarkably homogeneous, but the deep waters are different in the eastern (Yucatan and Cayman) and western (Colombia and Venezuela) basins. There appears to be no inflow of deep water through Jungfern Passage, the deepest connection with the Atlantic Ocean, but there may be sporadic inflow through Windward Passage into the western basins. There appears to be no inflow of water at mid-depth above either sill.

Sundaram, T.R., E. Sambuco, A.M. Sinnarwalla and S.K. Kapur. 1977. The external flow induced by an Ocean Thermal Energy Conversion (OTEC) power plant. In Proceedings of the Fourth Thermal Conference on Ocean Thermal Energy Conversion, 22-24 March 1977, Univ. of New Orleans. pp IV 42-49.

As an essential part of its operation, the OTEC plant withdraws large amounts of water (typically 6×10^4 gpm per MW of capacity) from both the surface layers and the deeper layers of the ocean and discharges them at intermediate levels. The circulations induced in the ambient ocean of these large withdrawals and discharges are of paramount importance, since any adverse changes in the ambient stratification will directly influence the operational efficiency of the plant itself. Specifically, any "short circuit" between the outflows and the inflows will direclty lead to a decrease in power production. Because of this direct "feed back" effect, the external flow induced by an OTEC plant has to be considered as an essential part of its operation. The present paper describes the interim results from an on-going experimental study to assess the recirculation potential under various design and environmental conditions. The method used is a "building block" approach in which "dissected" parts of the overall problem are isolated and studied experimentally. Specifically, experiments are described on two classes of problems, the first in which an ambient current is present but not ambient stratification, and the second in which the opposite is true. Recirculation is measured directly by introducing dye into the discharges and by measuring the dye concentration in the intake flow. Maps of the distributions in the jet flow of the mean and turbulent quantities are also given; such detailed measurements being of relevance to the "tuning" mathematical (turbulence) models of the flow field.

The similitude parameters governing the problem are identified and the manner in which the results of the "dissected" studies can be used to construct results for the overall problem is discussed.

Swallow, M. 1961. Deep currents in the open ocean. Oceanus, VII(3):2-8.

Water currents were measured at 2000 m and 4000 m in the western North Atlantic Ocean. Speeds seen were on the order of 10 cm/sec.

Thompson, J.P., H.E. Hurlburt, and L.B. Lin. 1977. Development of a numerical ocean model of the Gulf of Mexico for OTEC environmental impact and resource availability studies. In Proceedings of the Fourth Annual Conference on Ocean Thermal Energy Conversion, 22-24 March 1977, Univ. of New Orleans. pp IV 50-56.

Short of actual operations the complex interactions of OTPP's and the environement can only be assessed using numerical ocean models and laboratory experiments. The best strategy for OTPP far-field modeling of the ocean is the selection of a single, well-observed ocean basin with well-defined boundary and surface input data with conditions in the basin representative of those to be encountered in the tropical and subtropical oceans. The basin should be large enough to represent open ocean conditions, but small enough for economical computer modeling. The Gulf of Mexico is therefore appropriate for initial model studies.

We are developing a hierarchy of numerical models of the Gulf of Mexico for use in studies of OTPP operations. The first model is nonlinear, time-dependent, and retains both barotropic and first baroclinic modes. The model uses primitive equations on a β-plane and the external and internal gravity waves are treated implicitly. The model uses uniform rectangular grid with $\Delta x = \Delta y = 16\ 2/3$ km and Δt up to 1/7 day. The numerical model was driven for five years by an idealized wind field consistent with observational data presented by Franceschini and by Hellerman. The statistically steady-state model results show periods of upwelling along all the boundaries and downwelling in the interior. Baroclinic boundary currents of varying strength are found along all the boundaries, but are strongest along the western and northern boundaries. Eddies associated with nonlinear recirculation are found in the northwest and southwest corners with additional eddies representing baroclinic Rossby waves found throughout the model basin. A significant result of the model is the existence of strong baroclinic eddies in the Gulf even in the absence of the Loop Current.

Thompson, J.D., H.E. Hurlburt, and P.J. Marint. 1978. Results from the Gulf of Mexico - OTEC far-field numerical model. In Proceedings of the Fifth Ocean

Thermal Energy Conversion Conference, 20-22 Feb. 1978. Univ. of Miami, Clean Energy Research Inst. pp. III 141-164.

One reasonable strategy for predicting the complex interactions between OTEC and the far-field environment is to develop a numerical model of a single well-observed ocean basin and reproduce observed aspects of its physical oceanography. Then OTEC can be inserted as a perturbing influence on the basin. The impact of OTEC operations on the circulation and thermal structure of the basin can then be assessed.

The Gulf of Mexico was chosen for initial model studies by virtue of its potential for OTEC utilization, its size, and relatively well-defined boundary conditions and well-observed features. The second model in the hierarchy of increasingly complex models of the Gulf of Mexico has now been developed. Simplified but realistic bottom topography and wind-forcing have been incorporated in a two-layer primitive equation model. The model is 900 km x 1600 km with a grid resolution of 20 km and a time step as large as 1/12 day. The model retains a free-surface and treats internal and external gravity waves implicitly. Forced inflow through the Yucatan Straits and outflow through the Florida Straits has been included.

A nine-year integration to statistical equilibrium was performed with both wind and Loop-Current forcing included. The circulation characteristics for a mid-Gulf site, a site just south of New Orleans, and a site corresponding to the OTEC Gulf test-site are described, based on model results. Near-surface and sub-surface scalar discharges from each plant are traced for ten months and concentration maps presented. The relevance of these model predictions to OTEC siting in the Gulf is discussed in detail.

Underwood, J.W. 1967. Oceanographic cruise summary SALVOPS Vieques, U.S.S. Hoist (ARS-40). Naval Oceanographic Office, Washington, D.C. Informal Report IR#67-16. 44 pp.

An oceanographic survey was conducted off the eastern tip of Vieques Island during August 1966. The purpose of the survey was to obtain current, bottom sediment, and underwater photographic data for immediate use by U.S. Navy divers working in the area. Only current data were predominantly tidal with a nearly constant phase relationship between maximum flood and ebb and predicted high and low tides. Observed currents also were significantly stronger than predicted currents and times of maximum flood and ebb occurred later than predicted.

Vukovich, F.M. 1978. Analysis of sea-surface temperature variations in the Gulf of Mexico using satellite data for OTEC siting. In Proceedings of the Fifth Ocean Thermal Energy Conversion Conference, 20-22 Feb. 1978. Univ. of Miami, Clean Energy Res. Ins. pp III 38-63.

Sea-surface temperature variations were investigated using NOAA infrared data in the northern portions of the eastern Gulf of Mexico. The region was characterized by sea-surface temperature variations produced by cold intrusions of warm Loop Current water. The central portion of this region was most affected, but the results of the analysis suggested that this entire region was a difficult place to site OTEC.

Webster, F. 1969. Vertical profiles of horizontal ocean currents. Deep-Sea Res. 16(1):85-98.

Data collected from moored current meters at a single site (Site D) in the western North Atlantic are used to define vertical profiles of steady and time-dependent horizontal ocean currents. The mean velocity profile shows currents systematically flowing towards the west, with amplitude which decreases with depth. Time-dependent currents have a vertical profile of kinetic energy which is proportional to the vertical profile of Brunt Vaisala frequency, N(2). Since the mean speed is dominated by time-dependent components, its profile is approximately proportional to N 1/2.

At frequencies lower than I cycle per day, the time-dependent motion is not horizontally isotropic at all depths. In the surface layer, north-south (v) components have a larger variance than east-west (u) components; at mid-depths, the u-variance is greater; at great depths the variances are approximately equal. At frequencies higher than one cycle per day, the motions are horizontally isotropic. The pattern of an isotropy may be due to the interaction between low-frequency processes and the nearby continental shelf.

Eddy momemtum fluxes have a profile which reverses sign at the approximate depth of the continental shelf.

Webster, F. 1971. On the intensity of horizontal ocean currents. Deep-Sea Res. 18(9):885-893.

Ocean currents on both the east and west sides of the Atlantic, near Bermuda, and in the Mediterranean Sea show similar mean kinetic energy and mean speeds from long-term current measurements. At a given depth, there is less than a factor of two in the range of speeds and a factor of four in kinetic energy. In spite of intermittency in time and location in space there is remarkable uniformity in the intensity of the currents. A notable exception is a set of high values of speed and kinetic energy NNE of Bermuda that are possibly associated with a Gulf Stream meander.

Both moored current meters and neutrally buoyant (Swallow) floats have been used for measurement of currents. Speed and total kinetic energy are similar with the two methods, but estimates of the kinetic energy of the fluctuating component of motion are generally lower when Swallow floats are used.

Wolff, P.M. 1978. Temperature difference resource. In Proceedings of the Fifth Ocean Thermal Energy Conversion Conference, 20-22 Feb, 1978. Univ. of Miami, Clean Energy Res. Inst. pp III 11-37.

The continuous operation of OTEC plants requires the availability of a consistent temperature difference resource. The requirements of such a consistent OTEC T resource are examined and related to other parameters.

Ocean Data Systems, Inc. has examined all temperature soundings in the archive for possible OTEC sites in the following areas: Hawaii, Puerto Rico, Gulf of Mexico, Florida Straits, and Florida East Coast. This investigation produced most probable monthly soundings for each of 60 one-degree latitude and longitude squares.

The Hawaiian and Puerto Rico areas are characterized by homogeneous temperature conditions and small variability at all depths. In the Eastern Gulf of Mexico and off Key West and Miami there are stronger currents and greater space and temporal variability. The Loop Current in the Eastern Gulf of Mexico causes additional difficulties in analysis. A bi-modal temperature structure can exist.

Plans for additional resource analysis are discussed.

Wolff, P.M. and L. Lewis. 1977. Monthly assessment of temperature resource for three potential OTEC sites. In Proceedings of the Fourth Annual Conference on Ocean Thermal Energy Conversion, 22-24 March, 1977. Univ. of New Orleans, pp IV 57-60.

During 1975 Ocean Data Systems, Inc. assembled an ocean temperature data set for OTEC purposes from available soundings in Navy and NOAA files. In this study the OTEC data file was summarized monthly for three possible sites. The depth necessary to achieve a T of 18°C, 20°C and 22°C was determined for each area for the most probable monthly temperature structure.

The data are presented in plan view and in tabular form. For each site the existence of a T of 20°C at a depth less than 1500 meters was demonstrated for each month of the year.

Some information was provided on plans for expanded investigation of this type.

Wood, E., M.J. Youngbluth, P. Yoshioka, M. Canoy. 1975. Cabo Mala Pascua Environmental Studies. Puerto Rico Nuclear Center, U.P.R., Mayaguez, PRNC-188. 95 p.

This report is an environmental study of the area just south of Cabo Mala Pascua, Puerto Rico, with no conclusions or results, only data collected and presented. These data collected were: currents, temperature, salinity, dissolved oxygen, nutrients, sediments, zooplankton, benthos, and terrestrial vegetation.

Worthington, L.V. 1955. A new theory of Caribbean bottom-water formation. Deep-Sea Res. 3:82-87.

A recent section across the Caribbean Sea shows that in the Caribbean deep water oxygen values have dropped 0.3 ml/l in the last twenty years, a loss closely corresponding to that in the North Atlantic deep water. Study of the surrounding Atlantic water suggests that the Caribbean deep water has not been renewed since the end of the eighteenth century, coincident with a cold climatic variation at high latitudes in the North Atlantic. It is further deduced that the Windward Passage was the sill over which this water originally came from the Atlantic, and that both the Jungfern and Windward Passage sills must be considerably shallower than Dietrich's(1939) estimates.

Worthington, L. V. 1956. The temperature increase in the Caribbean deep water since 1933. Deep-Sea Res. 3. (3): 234-235.

Observations of temperature of the deep Caribbean water are made from 1500m to 3000m. The dates discussed are 1933 and 1954. Using some estimation of the temperature increase, an attempt is made to date the deep water in the Caribbean.

Worthington, L. V. 1966. Recent oceanographic measurements in the Caribbean Sea. Deep-Sea Res. 13: 731-739.

Two oceanographic sections were made across the two deepest sills of the Caribbean Sea in September 1963. One ran from the Atlantic Ocean into the Venezuela Basin through the Anegada and Virgin Islands Passages; the second ran from the Cayman Basin into the Atlantic through the Windward Passage. These sections differ from WUST's (1963, 1964) sections in that there is no evidence that bottom water is entering the Caribbean at the present time. The Cayman Basin bottom water appears to have been warmed about 0.-03°C since the surveys made by PARR in 1933 and 1937.

Worthington, L. V. 1971. Water circulation in the Caribbean Sea and its relationship to North Atlantic circulation. SIRSCAR, UNESCO Paris. pp 181-191.

Using data from two oceanographic sections, one from the Cayman Basin to the Atlantic, through the Windward Passage, and the other through the Virgin Islands Passage, tests were made to determine the origin of the bottom water in the Caribbean. Potential temperature profiles through the Windward Passage and the Virgin Islands Passage both indicate no renewal. Also, the dissolved silicate is different from the basin to the Atlantic. There is no evidence for renewal of the bottom water taking place at present.

The question of the main circulation in the Caribbean was also studied. The present work indicates that most of the circulation is to the south, while water mass distribution studies of others indicate the circulation maximum is to the north.

Wright, W. R. 1970. Northward transport of antarctic bottom water in the western Atlantic Ocean. Deep-Sea Res., 17: (2) 367-371.

The volume transport of Antarctic Bottom Water in the western basin of the Atlantic Ocean has been determined by dynamic calculations for seven oceanographic sections made during the International Geophysical Year between 32°S and 16°N. The reference level was based on the sharp bend, seen in both temperature-depth and salinity-depth traces, that marks the transition from North Atlantic Deep Water to Antarctic Bottom Water. The northward transport decreases from 5-6 x 10 m /sec in the southern sections to about 10 m /sec in the northern sections. The results are consistent with those obtained by solving a set of conservation equations for a simple box medel of the deep circulation in the western Atlantic.

Wust, G. 1963. On the stratification and circulation in the cold water sphere of the Antillian-Caribbean Basins. Deep-Sea Res. 10: 165-187.

The cold water circulation is discussed for the Antillean-Caribbean Basins. The three water masses investigated were the Subantarctic Intermediate Water, the North Atlantic Intermediate Water, and the Caribbean Bottom Water. The Subantarctic Intermediate Water is formed at the southern polar front, having a salinity minimum, and extends throughout the whole breadth of the Atlantic at depths of 700-900 m. This water finds its way into the Antillean Caribbean Basin, retaining its identity. The North Atlantic Deep Water is formed near south Greenland. This water makes its way to the 2000-2500 m level, and is characterized by an oxygen maximum. This water ultimately spills over the sills into the Caribbean, and changes character enough to have a slightly separate identity, the Caribbean Bottom Water.

Wust, G. 1964. Stratification and circulation in the Antillean-Caribbean Basins. Part 1. Columbia Univ. Press., N.Y. pp 1-201.

The Caribbean and Antillean Basins are described as of the available information for this data. The circulation and stratification for all depths are discussed, and are related to the surrounding waters.

APPENDIX D

BIBLIOGRAPHY OF MARINE BIOLOGY REFERENCES FOR PUERTO RICO AND OTHER TROPICAL WATERS

Almodóvar, L. R. and H. L. Blomquist. 1959. The benthic algae of Bahía Fosforescente. *Quarterly Jour. Fla. Acad. Sci.*, 22(3): 163-168.

Alvariño, A. 1965. Chaetognaths. *Oceanogr. Mar. Biol. Ann. Rev.* 3: 115-194.

______. 1968. Los quetognatos, sifonóforos y medusas en la región del Atlántico equatorial bajo la influencia del Amazonas. *An. Inst. Biol. Univ. Mac. Auton. Mex.* (*Cienc. Mar. Limnol.*), 39(1): 41-76.

______. 1969. Los quetognatos del Atlántico. Distribución y notas esenciales de sistemática. *Trab. Inst. Esp. Oceanogr.*, 37: 290.

______. 1974. Distribution of siphonophores in the regions adjacent to the Suez and Panama Canals. *Fish. Bull. NMFS/NOAA*, 72: 527- 46.

Anderson, W. W., and J. W. Gehringer. 1958. Physical oceanographic, biological, and chemical data-South Atlantic coast of the United States, M/B Theodore N. Gill Cruise 6. *U.S. Fish Wildlife Serv., Spec. Sci. Rept.-Fish.*, 265: 1-99.

______. 1959a. Idem, M/B Theodore N. Gill Cruise 8. *U.S. Fish Wildlife Serv., Spec. Sci. Rept.-Fish.*, 303: 1-227.

______. 1959b. Idem, M/B Theodore N. Gill Cruise 9. *U.S. Fish Wildlife Serv., Spec. Sci. Rept.-Fish.*, 313: 1-226.

Anonymous. 1971-1974. Puerto Rico Nuclear Center Guayanilla Bay Environmental Report, 1971-1974. *PRNC* 179, 157 pp.

______. 1974. Punta Higuero Power Plant Environmental Studies 1973-1974. *PRNC* 174, 330 pp.

______. 1975a. Tortuguero Bay Environmental Studies. *PRNC* 181, 227 pp.

______. 1975b. Punta Manatí Environmental Studies. *PRNC* 182, 225 pp.

______. 1975c. Punta Higuero Environmental Studies. *PRNC* 183, 181 pp.

______. 1975d. Aguirre Environmental Studies Jobos Bay, Puerto Rico, Final Report. Vols. I and II, *PRNC* 196, 279 pp.

______. 1975e. Environmental Studies of the Proposed North Coast Nuclear Plant Unit No. 1, Final Report. Vols. I and II, *PRNC* 197, 412 pp.

Austin, H. B. 1972. Contouring zooplankton as a funciton of temperature and salinity. New York Ocean Science Laboratory Tech. Rep. No. 12: 1-12.

Austin, H. M. 1971. The characteristics and relationships between the calculated geostrophic current component and selected indicator organisms in the Gulf of Mexico Loop Current System. Ph.D. Dissertation, Florida State Univ. 369 pp. Univ. Microfilms, Ann Arbor, Mich.

Austin, H. M. and J. I. Jones. 1974. Seasonal variation of physical oceanographic parameters on the Florida middle ground and their relation to zooplankton biomass on the west Florida shelf. Fla. Sci., 37: 16-32.

Balech, E. 1967. Microplankton of the Gulf of Mexico and Caribbean Sea. Texas A & M Res. Found. 67-10-T, 144 pp.

Barnes, H. and M. Marshall. 1951. On the variability of replicate plankton samples and some applications of "contagious" series to the statistical distribution of catches over restricted periods. Jour. Mar. Biol. Assn. U.K., 30: 233-263.

Bary, B. M. 1959. Species of zooplankton as a means of identifying different surface waters and demonstrating their movements and mixing. Pacific Sci., 13(1): 14-54.

______. 1963. Temperature, salinity and plankton in the eastern North Atlantic and coastal waters of Britain, 1957. II. The relationships between species and water bodies. J. Fish. Res. Bd. Canada, 20(4): 1031-1065.

______. 1964. Temperature, salinity, and plankton in the eastern North Atlantic and coastal waters of Britain, 1957. IV. The species' relationship to the water body; its role in distribution and in selecting and using indicator species. J. Fish. Res. Bd. Canada, 21(1): 183-202.

Bé, A., C. MacClintock, and D. Currie. 1972. Helical shell structure and growth of the pteropod Cuvierina columnella (Rang) (Mollusca, Gastropoda). Biomineralization Res. Rep., 4: 47-79.

Beers, J. B., D. M. Steven and J. B. Lewis. 1968. Primary productivity in the Caribbean Sea off Jamaica and the tropical North Atlantic off Barbados. Bull. Mar. Sci., 18(1): 86-104.

Bernard, M. 1958. Révision des Calocalanus (Copépodes Calanoida), avec description d' un genre nouveau et deux espéces nouvelles. Bull. Soc. Zool. Fr., 83: 185-199.

______. 1963. Rectifications des noms donnés á deux genres de Calocalanides (Copépodes Calanoida). Crustaceana, 5(2): 160.

Bigelow, H. B. 1911. The siphonophorae. *Mem. Mus. Comp. Zool. Harv. Univ.*, (38): 171-401.

______. 1915. Exploration of the coast water between Nova Scotia and Chesapeake Bay, July and August 1913, by the U.S. Fisheries schooner Grampus. *Bull. Mus. Comp. Zool. Harv.*, 59: 149-359.

______. 1917. Explorations of the coast water between Cape Cod and Halifax in 1914 and 1915, by the U.S. Fisheries schooner Grampus. Oceanography and plankton. *Bull. Mus. Comp. Zool.* Harv., 61(8): 163-357.

______. 1918. Some Medusae and Siphonophorae from the Western Atlantic. *Bull. Mus. Comp. Zool. Harv. Univ.*, (62): 363-442.

______. 1922. Exploration of the coastal water off the northeastern United States in 1916 by the U.S. Fisheries schooner Grampus. *Bull. Mus. Comp. Zool. Harv.*, 65(5): 87-188.

______. 1926. Plankton of the offshore waters of the Gulf of Maine. *Bull. U.S. Bur. Fish.*, 40(2): 1-509.

Bigelow, H. B. and M. Sears. 1937. Siphonophorae. *Rep. Dan. Oceanogr. Exped. 1908-1910 Mediterr. Adj. Seas (Biol.)*, 11: 1-144.

______. 1939. Studies of the waters of the continental shelf, Cape Cod to Chesapeake Bay, III: A volumetric study of the zooplankton. *Mem. Mus. Comp. Zool. Harvard College*, 54(4): 183-378.

Bjornberg, T. K. S. 1963. On the marine free-living copepods off Brazil. *Bol. Inst. Oceanogr., Sao Paulo*, 13: 3-142.

______. 1964. Copépodos. *In Historia Natural de Organismos Aquáticos do Brasil.* Bibliografia Comentada, P. E. Vanzolini, Ed., pp. 207-222. Sao Paulo, Brasil.

______. 1971. Distribution of plankton relative to the general circulation system in the area of the Caribbean Sea and adjacent regions. *In UNESCO-FAO Symposium on Investigations and Resources of the Caribbean Sea and Adjacent Regions, Curacao*, November 1968. *UNESCO, Paris*, pp. 343-356.

Bjornberg, T. K. S. and L. Forneris. 1955. Resultados Científicos do Cruzeiro do: "Baependí" e do "Vega" a ilha de Trindade. Copelata I. *Cont. Avul. Inst. Oceanogr. U. Sao Paulo* (1): 1-67, pls. I-XVII.

Boas, J. E. V. 1886. Spolia Atlantica. Bidrag til Pteropodernes Morfologi og Systematik samt til Kundskaben om deres geografiske udbredelse. *Vidensk. Selsk. Skr.*, *6 Raekke, Naturvidensk. og Math. Afd.* IV, 1: 1-231.

Boden, B. P. 1954. The euphausiid crustaceans of southern African waters. Trans. R. Soc. S. Afr., 34: 181-243.

Boeck, A. 1864. Oversigt over de ved Norges Kyster iagttagne Copepoder, henhorende til Calanidernes, Cyclopidernes og Harpactidernes Familier. Forh. Vid. Selsk., Christiania, 1864: 226-282.

______. 1872. Nye Slaegter og Arter af Saltvands-Copepoder. Forh. Vid. Selsk., Christiania, 14: 35-60.

Bogdanov, D. V. 1965. Some oceanographic features of the Gulf of Mexico and the Caribbean Sea. In Soviet-Cuban Fishery Research, A. S. Bogdanov, Ed., pp. 13-35. Translated from Russian by Israel Program for Scientific Translations, Jerusalem, 1969.

Bogdanov, D. V., V. A. Sokolov and N. S. Khromov. 1969. Regions of high biological and commercial productivity in the Gulf of Mexico and Caribbean Sea. Oceanology, 8: 371- 81.

Bogorov, B. G. 1955. Regularities of plankton distribution in northwest Pacific. Proc. Unesco Symposium on Phys. Oceanogr. Tokyo, pp. 260-276.

Boltovskoy, D. 1971. Pterópodos thecosomados del Atlántico Sudoccidental. Malacologia, 11(1): 121-140.

Boltovoskoy, D. and E. Mostajo. 1974. Quetognatos del mar Argentino y adyacencias consideraciones a cerca de su utilización en calidad de indicadores hidrológicos. Physis. B. Aires, 33: 239- 55.

Bonnevie, K. 1913. (Reprint 1933). Pteropoda from the "Michael Sars" North Atlantic deep-sea expedition 1910. Rep. Sci. Res. "Michael Sars" North Atlantic Deep-Sea Exped. 1919, 3(1): 1-69.

Bowman, T. E. 1955. A new copepod of the genus Calanus from the northeastern Pacific with notes on Calanus tenuicoruis Dana. Pacif. Sci., 9(4): 413-422.

______. 1957. A new species of Calanopia (Copepoda: Calanoida) from the Caribbean Sea. Proc. U.S. Nat. Mus., 107(3382): 39-45.

______. 1958. A new species of Acrocalanus (Copepoda: Calanoida) from off the southeastern coast of the United States. Bull. Mar. Sci., 8(2): 118-124.

______. 1961. The copepod genus Acartia in Chesapeake Bay. Chesapeake Sci., 2(3-4): 206-207.

______. 1971. The distribution of calanoid copepods off the southeastern United States between Cape Hatteras and southern Florida. Smithson. Contrib. Zool., 96: 58.

Bowman, T. E. and J. G. González. 1961. Four new species of *Pseudocyclops* (Copepoda: Calanoida) from Puerto Rico. *Proc. U.S. nat. Mus.*, 113(3452): 37-59.

Bowman, T. and J. McCain. 1967. Distribution of the planktonic shrimp, *Lucifer*, in the western North Atlantic. *Bull. Mar. Sci.*, 17(3): 660-671.

______. 1971. Distribution of plankton relative to the general circulation system in the area of the Caribbean Sea and the adjacent regions. *Symp. Inv. Res. Carib. Sea Adj. Reg.*, *UNESCO*, 14 p.

Bradshaw, J. 1959. Ecology of living planktonic Foraminifera in the North and Equatorial Pacific Ocean. *Cont. Cushman Foundation for Foram. Res.*, 10(2): 25-64.

Brady, G. S. 1880a. *Copepoda of the British Islands*. A Monograph of the Free and Parasitic, 2: 182.

______. 1880b. A monography of the free and semi-parasitic Copepoda of the British Islands, 3:32-37.

______. 1883. Report on the Copepoda obtained by H. M. S. Challenger during the years 1873-76. *Rep. Sci. Res. Challenger, Zool.*, 8: 1-142.

______. 1899. On the marine Copepoda of New Zealand. *Trans. zool. Soc. Lond.*, 15(2): 31-54.

______. 1914a. On some pelagic Entomostraca collected by Mr. J. Y. Gibson in Durban Bay. *Ann. Durban Mus.*, 1: 1-9.

______. 1914b. On some pelagic Entomostraca collected by Mr. J. Y. Gibson in Durban Bay. *Ann. Durban Mus.*, 1: 25-28.

Brady, G. S. and D. Robertson. 1873. Contributions to the study of Entomostraca. 8. On marine Copepoda taken in the west of Ireland. *Ann. Mag. nat. Hist.*, ser. 4, 12: 126-142.

Brinton, E. 1962. The distribution of Pacific euphausiids. *Bull. Scripps Inst. Ocean.*, 8(2): 51-270.

Bsharah, L. 1957. Plankton of the Florida Current. V. Environmental conditions, standing crop, seasonal and diurnal changes at a station 40 miles east of Miami. *Bull. Mar. Sci. Gulf & Carib.*, 7(3): 201-251.

Burkenroad, M. D. 1933. Pteropoda from Louisiana. *Nautilus*, 47(2): 54-57.

Cervigón, F. 1963. Contribución al conocimiento de los copépodos pelágicos de las costas de Venezuela. *Mem. Soc. Cienc. nat. La Salle*, 22(63): 181-188.

______. 1964. Los Corycaeidae del Caribe Suroriental (Copepoda, Cyclopoida). Mem. Soc. Cienc. nat. La Salle, 24(68): 163-201.

Cervigon, F. and P. J. Marcano. 1965. Zooplankton. In Estudios sobre el ecosistema pelagico del N.E. de Venezuela. Mem. Soc. de Cienc. nat. La Salle, 25(70-72): 263-287.

Chace, F. A., Jr. 1956. In S. Springer and H. R. Bullis, Jr., Collections by the OREGON in the Gulf of Mexico. Spec. Sci. Rep. USFWS (Fish.), (196): 134.

Chen, C. 1962. Ecological studies of shell-bearing pteropods from the western part of the North Atlantic Ocean. Ph.D. Dissertation, Boston University. 177 p. Univ. Microfilms, Ann Arbor, Mich.

Chen, C. and A. Bé. 1964. Seasonal distribution of euthecosomatous pteropods in the surface waters of five stations in the western North Atlantic. Bull. Mar. Sci. Gulf Caribb., 14(2): 185-220.

Chen, C. and N. S. Hillman. 1970. Shell-bearing pteropods as indicators of water masses off Cape Hatteras, North Carolina. Bull. Mar. Sci., 20(2): 350-367.

Chiba, T. 1953a. Studies on the pelagic Copepoda from the Japan Sea, 3: On the genus of Temora Baird 1850. Bull. Japanese Soc. Sci. Fisheries, 18(12): 695-697.

______. 1953b. On the distribution of the plankton in the East China Sea and Yellow Sea, 8: Description on the male of the pelagic Copepoda, Temora stylifera and T. discaudata. Bull. Japanese Soc. Sci. Fisheries, 19(6): 722-725.

Clarke, G. L. 1934. The diurnal migration of copepods in St. Georges Harbor, Bermuda. Biol. Bull., Woods Hole, 67: 456-460.

Claus, C. 1863. Die Freilebenden Copepoden mit besonderer Berucksichtigung der Fauna Deutschlands, der Nordsee und des Mittelmeeres. Leipzig. 230 p.

______. 1866. Die Copepoden-Fauna von Nizza, Ein Beitrag zur Charakteristik der Formen und deren Abanderungen "im Sinne Darwin's". Marburg & Leipzig. 34 p.

Cleve, P. T. 1900. The seasonal distribution of Atlantic plankton organisms, 369 p.

______. 1901. Plankton from the Indian Ocean and the Malay Archipelago. Kongl. Svenska Vetensk. Akad. Handl., 35(5): 58, 8 pls.

______. 1904a. Report on plankton collected by Mr. Thorild Wulff during a voyage to and from Bombay. Ark. Zool., 1: 329-381, pls. 16-19.

______. 1904b. The plankton of the South African seas. I. Copepoda. *Mar. Invest. S. Afr.*, 3: 177-210.

Coker, R. E. and J. G. González. 1960. Limnetic copepod populations of Bahía Fosforescente and Adjacent Waters, Puerto Rico. *Jour. Elisa Mitchell Scient. Soc.*, 76(1): 8-28.

Collier, A. 1958. Gulf of Mexico physical and chemical data from *Alaska* cruises. *U.S. Fish Wildlife Serv., Spec. Sci. Rept.-Fish.*, *(249)*: 1-417.

Colman, J. S. 1959. The Rosaura Expedition 1937-1938. Chaetognatha. *Bull. Br. Mus. Nat. Hist. (Zool)* 5: 221- 53.

Conant, F. S. 1896. Notes on the chaetognaths. *Ann. Mag. Nat. Hist.*, 18: 201- 14.

Conover, R. J. 1956. Oceanography of Long Island Sound, 1952-1954. VI. Biology of *Acartia clausi* and *A. tonsa*. *Bull. Bingham Oceanographic Collection*, 15: 156-233.

______. 1957. Notes on the seasonal distribution of zooplankton in Southampton waters with special reference to the genus *Acartia*. *Ann. Mag. Nat. Hist., serv.* 12, 10: 63-67.

Conseil Permanent International Pour L'Exploration de la Mer, 1948-1952. -*Fiches d'Identification du Zooplancton*, Nos. 1-17, 30-40 y 41-49.

Cruz, S. A. de la. 1972. Zooplancton de la región sureste del Golfo de Mexico. *Cienc. Biol. Univ. Luanda*, 4: 55.

Dahl, F. 1893. *Pleuromma*, ein Krebs mit Leuchtorgan. *Zool. Anz.* 16(415): 104-109.

______. 1894a. Die Copepodenfauna des untern Amazonas. *Ber naturf. Ges. Freiburg*, 8: 10-23.

______. 1894b. Uber die horizontale und verticale Verbreitung der Copepoden im Ozean. *Verh. Deutsch. zool. Ges. Munchen*, 4: 61-80.

______. 1895. Die Schwarmbildung pelagischer Thiere. *Zool. Anz.*, 18: 168-172.

Dahl, M. 1912. Die Copepoden der Plankton-Expedition. I. Die Corycaeinen. *Plankton-Expedition der Humboldt-Stiftung*, 2: 1-135.

Dall, W. H. 1889. A preliminary catalogue of the shell-bearing marine mollusks and brachiopods of the southeastern coast of the United States, with illustrations of many of the species. *Bull. U.S. Nat. Mus.*, (37): 1-229.

Dall, W. H. and C. T. Simpson. 1901. The Mollusca of Porto Rico. *Bull. U.S. Fish. Comm.*, 20(1): 351-524.

Dana, J. D. 1845. *Corycaeus*, nov. gen. Entomostracum. *In Proc. Acad. nat. Sci. Phila.*, 2: 285-286.

______. 1846. Notice of some genera of Cyclopacea. *Amer. J. Sci. Arts*, ser. 2, 1(2): 225-230 (reprinted in *Ann. nat. Hist.*, 18(118): 181-185).

______. 1848 (1847). Conspectus Crustaceorum, in orbis terrarum circumnavigatione, C. Wilkes e classe Reipublicae Foederdtae duce, collectorum. *Proc. Amer. Acad. Arts Sci.*, 1: 149-155.

______. 1852 (1849). *Ibid.*, 2: 9-61.

______. 1853. Crustacea. Part 2. *In U.S. Exploring Expedition during the years 1838-1842, under the command of Charles Wilkes, U.S.N.*, 14: 1019-1262; 1855, Atlas, 96 pls.

Dautzenberg, P. 1900. Mollusques. Croisiéres du yacht "Chazalie" dans l'Atlantique. *Mem. Soc. Zool. de France*, 13: 145-265.

Davis, C. C. 1944. On four new species of Copepoda new to Chesapeake Bay, with a description of a new variety of *Paracalanus crassirostris* Dahl. *Chesapeake Biol. Lab. Publ.*, (61): 1-11.

______. 1948. Notes on the plankton of Long Lake, Dade County, Florida, with descriptions of two new copepods. *Quart. J. Fla. Acad. Sci.*, 10(2-3): 79-88.

______. 1949. The pelagic Copepoda of the northeastern Pacific Ocean. *Univ. Wash. Publ.* (*Biol.*), 14: 1-118.

______. 1950. Observations of plankton taken in marine waters of Florida in 1947 and 1948. *Q. J. Fla. Acad. Sci.*, 12: 67-103.

Deevey, G. B. and A. L. Brooks. 1971. The annual cycle in quantity and composition of the zooplankton of the Sargasso Sea off Bermuda. II. The surface to 2,000 m. *Limnol. Oceanog.*, 16(6): 927-943.

Dragovich, A. 1961. Relative abundance of plankton off Naples, Florida, and associated hydrographic data, 1956-57. *U.S. Fish* Wildlife Serv., Spec. Sci. Rept.-Fish., (372): 1-41.

Duran, M. 1957. Notas sobre algunos tintinnoideas del plankton de Puerto Rico. *Inv. Pesquera* 8: 97-120.

Erdman, D. S. 1958. Food of Pelagic Fishes from Puerto Rico and the Bahama Islands. III Int. Game Fish Conf., 12 pp.

______. 1962. The Sport Fishery for Blue Marlin off Puerto Rico. Trans. Ame. Fis. Soc., 91(2): 225-227.

______. 1974. Common Names of Fishes in Puerto Rico. Cont. Agrop. Pesq., Dept. Agric. Puerto Rico, 6(2): 1-50.

Eschscholtz, F. 1829. Zoologischer Atlas, enthaltend Abbildungen und Beschreibungen neuer Thierarten, wahrend des Flottcapitans von Kotzebue zweiter Reise um die Welt. *Reimer, Berlin*, 3: 1-18.

Essenberg, C. 1919. The pteropod *Desmopterus pacificus* sp. nov. *Univ. Calif. Pubs. in Zoology*, 19(2): 85-88.

Esterly, C. O. 1905. The pelagic Copepoda of the San Diego region. *Univ. Calif. Publ. Zool*., 2(4): 113-233.

______. 1906. Additions to the copepod fauna of the San Diego region. *Univ. Calif. Publ. Zool*., 3(5): 53-92.

______. 1911a. Calanoid Copepoda from the Bermuda Islands. *Proc. Amer. Acad. Arts Sci*., 47(7): 219-226.

______. 1911b. Third report on the Copepoda of the San Diego region. *Univ. Calif. Publ. Zool*., 6(14): 313-352.

______. 1911c. The vertical distribution of *Eucalanus elongatus* in the San Diego region during 1909. *Univ. Calif. Publ. Zool*., 8(1): 1-7.

______. 1912. The occurrence and vertical distribution of the Copepoda of the San Diego Region with particular reference to nineteen species. *Univ. Calif. Publ. Zool*., 9(6): 253-340.

______. 1913. Fourth taxonomic report on the Copepoda of the San Diego region. *Univ. Calif. Publ. Zool*., 11(10): 181-196.

______. 1923. Preliminary statistical report on the occurrence of marine Copepoda in the plankton at La Jolla, California. *Univ. Calif. Publ. Zool*., 22(10): 417-433.

______. 1924. The free-swimming Copepoda of San Francisco Bay. *Univ. Calif. Publ*. Zool., 26(5): 81-129.

Fagetti, E. 1962. Catálogo de los copépodos planctónicos. Chilenos. *Gayana, Zoología* 4: 59.

______. 1968. New record of *Eukrohnia bathyantarctica* David, 1958, from the Gulf of Mexico and Caribbean Sea. *Bull. Mar. Sci*., 18: 383-7.

FAO. 1977. Yearbook of Fishery Statistics. FAO Statistics Series, 42: 1-320.

Farran, G. P. 1903. Record of Copepoda taken on the mackerel fishing grounds off Cleggan, Co. Galway, in 1901. *Sci. Invest. Fish. Br. Ire*., 1901, pt. 2, app. 7, 18 p.

______. 1905. Report on the Copepoda of the Atlantic Slope off Counties Mayo and Galway. Sci. Invest. Fish. Br. Ire., 1902-03, Pt. 11, App. 11: 23-52.

______. 1908. Second report on the Copepoda of the Irish Atlantic Slope. Sci. Invest. Fish. Br. Ire., 1906, (2): 104.

______. 1911. Plankton from Christmas Island, Indian Ocean. I. On Copepoda of the Family Corycaediae. Proc. zool. Soc. Lon., 1911: 282-296.

______. 1913. Plankton from Christmas Island, Indian Ocean. II. On Copepoda of the genera *Oithona* and *Paroithona*. Proc. zool. Soc. Lond., 1913: 181-193.

______. 1926. Biscayan plankton collected during a cruise of H.M.S. "Research." 1900, XIV. The Copepoda. J. Linn. Soc. (Zool.), 36:219-310.

______. 1929. Curstacea. Park X. Copepoda. Nat. Hist. Rep. Terra Nova Exped. 1919, 8(3): 203-306.

______. 1936. Copepoda. Great Barrier Reef Exped., 1928-1929, 5(3): 73-142.

______. 1939. Note on the nomenclature of the copepod genus *Megacalanus* Wolfenden and allied genera. Ann. Mag. nat. Hist. (II), 4:355-361.

______. 1948a. Copepoda. Calanoida. Fam. Centropagidae. Gen. Centropages. Fich. Ident. Zoopl. Cons. Int. Explor. Mer, 11.

______. 1948b. Copepoda. Calanoida. Fam. Acartiidae. Gen. *Acartia*. Fich. Ident. Zoopl. Cons. Int. Explor. Mer. 12.

______. 1948c. Copepoda. Calanoida. Fam. Candaciidae. Gen. *Candacia*. Fich. Ident. Zoopl. Cons. Int. Explor. Mer., 13.

______. 1948d. Copepoda. Calanoida. Fam. Metridiidae. Gen. *Metridia*. Fich. Ident. Zoopl. Cons. Int. Explor. Mer., 14.

______. 1948e. Copepoda. Calanoida. Fam. Heterorhabdidae. Gen. *Heterostylites*, *Hemirhabdus*, *Mesorhabdus*, *Disseta*. Fich. Ident. Zoopl. Cons. Int. Explor. Mer., 15.

______. 1948f. Copepoda. Calanoida. Fam. Heterorhabdidae. Gen. *Heterorhabdus*. Fich. Ident. Zoopl. Cons. Int. Explor. Mer., 16.

______. 1948g. Copepoda. Calanoida. Fam. Metridiidae. Gen. *Pleuromamma*. Fich. Ident. Zoopl. Cons. Int. Explor. Mer., 17.

______. 1949. The seasonal and vertical distributions of the Copepoda. Great Barrier Reef Expedition 1928-29. Scientific Reports. British Museum Natural History, 2(9): 292-312.

Farran, G.P. and W. Vervoort. 1951a. Copepoda. Calanoida. Fam. Calanidae. *Fich, Ident. Zoopl. Cons. Int. Explor. Mer*., 32.

______. 1951b. Copepoda. Calanoida. Fam. Megacalanidae. *Fich. Ident. Zoopl. Cons. Int. Explor. Mer.,* 33.

______. 1951c. Copepoda. Calanoida. Fam. Eucalanidae. *Fich. Ident. Zoopl. Cons. Int. Explor. Mer*., 34.

______. 1951d. Copepoda. Calanoida. Fam. Paracalanidae. Gen. *Paracalanus*. *Fich. Ident. Zoopl. Cons. Int. Explor. Mer*., 35.

______. 1951e. Copepoda. Calanoida. Fam. Paracalanidae. Gen. *Calocalanus*. *Fich. Ident. Zoopl. Cons. Int. Explor. Mer*., 36.

______. 1951f. Copepoda. Calanoida. Fam. Pseudocalanidae. Gen. *Pseudocalanus*, *Microcalanus*. *Fich. Ident. Zoopl. Cons. Int. Explor. Mer*,37.

______. 1951g. Copepoda. Calanoida. Fam. Pseudocalanidae. Gen. *Clausocalanus*, *Drepanopus*, *Drepanopsis*, *Ctenocalanus*. *Fich. Ident. Zoopl. Cons. Int. Explor. Mer.*, 38.

______. 1951h. Copepoda. Calanoida. Fam. Sponocalanidae. Gen. *Spinocalanus*. *Fich. Ident. Zoopl. Cons. Int. Explor. Mer.*, 39.

______. 1951i. Copepoda. Calanoida. Fam. Spinocalanidae. Gen. *Mimocalanus*, *Monacilla*. *Fich. Ident. Zoopl. Cons. Int. Explor. Mer*, 40.

Fish, A.G. 1962. Pelagic copepods from Barbados. *Bull. Mar. Sci. Gulf & Carib*., 12(1): 1-38.

Fish, C.J. 1955. Observations on the biology of *Microsetella norvejica*. Deep-Sea Res., suppl. vol. 3 (*Papers in Marine Biology and Oceanography*), pp. 242-249.

Fleminger, A. 1956. Tazonomic and distributional studies on the epiplanktonik calanoid copepods (Crustacea) of the Gulf of Mexico. Doctoral Dissertation, *Harvard University Library*.

Fleminger, A. 1957a. New calanoid copepods of *Pontella* Dana and *Labidocera* Lubbock with notes on the distribution of the genera in the Gulf of Mixico. *Tulane Studies in Zoology*, 5(2): 19-34.

______. 1957b. New genus and two new spedies of Tharybidae (Copepoda Calanoida) from the Gulf of Mexico with remarks on the status of the family. *Fish. Bull., U.S.*, 116: 347-354.

______. 1957c. New calanoid copepods of the families Aetideidae, Euchaetidae, and Stephidae from the Gulf of Mexico. *Fish. Bull*., U.S., 117: 355-363.

Fleminger, A. and T.E. Bowman. 1956. A new species of *Candacia* (Copepoda: Calanoida) from the western North Atlantic Ocean. Proc. U.S. nat. Mus., 106 (3370): 331-337.

Flores, C. 1965. Notas preliminares sobre la identificación de las apendicularias de las aguas veracruzanas. Ana. Inst. Biol. U.N.A.M. 36(1-2): 293-296.

Fol, H. 1875. Études sur le developpement des mollusques. Premier mémoire. Sur le developpement des ptéropodes. Arch. Zool. Exp. Gen., 4: 1-214.

Fontaine, M. 1955. The planktonic copepods (Calanoida, Cyclopoida, Monstrilloida) of Ungave Bay, with special reference to the biology of Pseudocalanus minutus and Calanus finmarchicus. J.Fish. Res. Bd. Can. 12(6): 858-898.

Foster, E. 1903. Notes on the free-swimming Copepoda of the waters in the vicinity of the Gulf Biological Station. 2nd Rep. Bull. Gulf biol. Sta., 2: 69-79.

Frontier, S. 1963a. Héteropodes et ptéropodes récoltes dans le plankton de Nosy-Bé. Cahiers O.R.S.T.O.M., sér. Océanogr., 1(6): 213-227.

______. 1963b. Présence de Cresies chierchiae (Boas) dans l'Océan Inden. Cahiers O.R.S.T.O.M., sér. Océanogr., 1(6): 229-232.

______. 1965. Le probleme des Creseis. Cahiers O.R.S.T.O.M., sér Océanogr., 3(2): 11-17.

______. 1966a. Liste complémentaire des ptéropodes du plancton Nosy-Bé (Madagascar). Cahiers O.R.S.T.O.M., sér. Océanogr., 4(2): 141-146.

______. 1966b. Zooplancton de la région de Nosy-Bé. I. Programme des récoltes et techniques d'études. II. Plancton de surface aux stations 5 et 10. Cahiers O.R.S.T.O.M., sér. Océanogr., 4(3): 3-37.

______. 1973a. Deuxiéme liste complémentaire des ptéropodes du plancton de Nosy-Bé (Madagascar) et notes morphologiques. Cahiers O.R.S.T.O.M., sér. Océanogr., 11(3): 253-257.

______. 1973b. Zooplancton de la région de Nosy-Bé (VI) Ptéropodes, hétéropodes--Première partie: espèces holoneritiques et neritiques--internes. Contribution à l'étude d'une baie eutrophique tropicale. Cahiers O.R.S.T.O.M., sér Océanogr., 11(3): 273-289.

______. 1973c. Zooplancton de la region de Nosy-Bé (VII) Ptéropodes, hétéropodes--deuxieme partie: especes neritiques--externes et océanogr., Cahiers O.R.S.T.O.M., sér Océanogr., 11(3): 291-302.

Frutchl, F. 1923. Cladocera und Copcpoda der Aru-Insein. (Vourlaufige Mitteilung: Artenlist und kurze diagnosen der neuen Formen). Abh. Senck. Naturf. Ges., 37(4): 449-457, pl. 26.

______. 1924. Die Cladoceren-und Copepoden-Fauna des Aru-Archipels. Arb. zool. Inst. Univ. Innsbruck, 2(2): 23-136.

Furnestin, M.L. 1961a. Morphologie et ecologie de Candacia aethiopica Dana des eaux Atlantiques Marocaines. Rev. Trav. Inst. Pêches marit., 25(3): 327-337.

______. 1961b. Ptéropodes et hétéropodes du plancton Marocain. Rev. Trav. Inst. Pêches Marit., 25(3): 293-326.

Gaudy, R. 1963. Campagne du navire ocenaographique Calypso dans les eaux cotieres du Bresil (Janvier-febrier 1962). Copepodes pelagiques, en: Rec. Trav. St. Mar. d'Endoume, 30: 15-42.

Gianferrari, L. 1923. Die Acartien der Deutschen Tiefsee-Expedition. Arb. zool. Inst. Univ. Innsbruck, 1(4): 73-88.

Giesbrecht, W. 1888. Elenco die Copepodi pelagici raccolti dal tenente di vascello Gaetano Chierchia durante el viaggio della R. Corvetta "Vettor Pisani" negli anni 1882-1885, e dal tenente di vascello Francesco Orsini nel Mar Rosso, nel 1884. R.C. Accad. Lincei, 4(2): 284-287, 330-338.

______. 1889. Ibid., 5(1): 811-815, (2): 24-29.

______. 1891a. Ibid. 7(1): 474-481.

______. 1891b. Elenco deo Copepodi pescati dalla R. Corvetta "Vettor Pisani" secondo la loro distribuzione geografica. R.C. Accad. Lincei, 7(2): 63-68, 276-282.

______. 1892. Systematik und faunistik der pelagischen copepoden des Golfes von Neapel und der angrezednden meeres-abschnitee. Fauna u. Flora Neapel, monogr. 19: 1 - 831 54 pls.

______. 1895. Reports on the dredging operations off the west coast of Central America to the Galapagos, to the west coast of Mexico, and in the Gulf of California, in charge of Alexander Agassiz, carried on by the U.S. Fish Commission steamer "Albatross," during 1891, Lieut. Commander Z.L. Tanner, U.S.N., commanding XVI. Die Pelagischen Coppoden. Bull. Mus. comp. Zool. Har., 25(12): 243-263.

______. 1896. Ueber pelagische Copepoden des Rothen Meeres, gesammelt vom Marinestabsarzt Dr. Augustin Krmaer. Zool. Jber., 9: 315-328+ 2 pls.

______. 1897. Notizen zur Systematik der Copepoden. Zool. Anz., 20: 253-255.

______. 1902. Copepoden. In Expedition antarctique Belge. Resultats du voyage du D.Y. Belgica en 1897-1898-1899, Zoologie, 49 pp. + 13 pls.

______. 1903. In S. Lo Bianco, Le pesche abissali eseguite da F.A. Krupp col Yacht Puritan nelle adiacenze di Capri ed in altre localita del Mediterraneo. Mitt. Zool. Sta. Neapel, 16: 200-206.

Giesbretch, W. and O. Schmeil. 1898. Copepoda. I. Gymnoplea. Tierreich, 6: 1-169.

Gilmer, R.W. 1972. Free-floating mucus webs: a novel feeding adaptation for the open ocean. Science, 176(4040): 1239-1240.

González, J.G. and T.E. Bowman. 1965. Planktonic copepods from Bahía Fosforescente, Puerto Rico and adjacent waters. Proc. U.S. Natl. Mus., 117:241:304.

Gordon, A.L. 1967. Circulation of the Caribbean Sea. Jour. of Geophys. Res., 72(24): 6207-6223.

Graham, H.W. 1954. Dinoflagellates of the Gulf of Mexico. U.S. Fish Wildlife Serv., Fish. Bull., (89): 223-226.

Grice, G.D. 1956. A qualitative and quantitative seasonal study of the Copepoda of Alligator Harbor. Stud. Fla. Univ., (22): 37-76.

______. 1959. A new species of Haloptilus (Copepoda: Calanoida) from equatorial and subtropical waters of the east-central Pacific Ocean. J. Wash. Acad. Sci., 49 (6): 193-195.

______. 1960a. Calanoid and cyclopoid copepods collected from the Florida Gulf coast and Florida keys in 1954 and 1955. Bull. Mar. Sci. Gulf & Carib., 10(2): 217-226.

______. 1960b. Copepods of the genus Oithona from the Gulf of Mexico. Bull. Mar. Sci. Gulf & Carib., 10(4): 485-490.

______. 1961a. Candacia ketchumi, a new calanoid copepod from the northwestern part of the Sargasso Sea. Crustaceana, 2(2): 126-131.

______. 1961b. Calanoid copepods from equatorial waters of the Pacific Ocean. Fish. Bull., U.S., 61: 171-246.

______. 1962. Copepods collected by the nuclear submarine Seadragon on a cruise to and from the North Pole, with remarks on their geographic distribution. J. Mar. Res., 20(1): 97-109.

______. 1963a. A revision of the genus Candacia (Copepoda: Calanoida) with an annotated list of the species and a key for their identification. Zool. Meded., 38(10): 171-194.

______. 1963b. Deep water copepods from the western North Atlantic with notes on five species. Bull. Mar. Sci. Gulf Caribb., 13: 493-501.

______. 1964. Two new species of calanoid copepods from the Galapagos Islands with remarks on the identity of three other species. Crustaceana, 6 (4): 255-264.

______. Calanoid copepods from the Caribbean Sea and Gulf of Mexico. 1. New species and new records from midwater trawl samples. Bull. Mar. Sci., 19: 466-55.

Grice, G.D. and E.C. Jones. 1960. Two new species of Candacia (Copepoda: Calanoida) from the Central Pacific, with notes on two other species. Pacif. Sci., 14(3): 280-291.

Grice, G.D. and A.D. Hart. 1962a. The abundance, seasonal occurrence and distribution of the epizooplankton between New York and Bermuda. Ecol. Monogr., 32: 287-309.

______. 1962b. The abundance, seasonal occurrence and distribution of the epizooplankton between New York and Bermuda. Appendix to Ref. 62-4, Woods Hole Oceanographic Institution (unpublished manuscript).

Grice, G.D. and K. Hulsemann. 1965. Abundance, vertical distribution and taxonomy of calanoid copepods at selected stations in the northeast Atlantic. J. Zool., 146: 213-62.

Grice, G.D. and W. Vervoort. 1963. Candacia Dana, 1846 (Crustacea: Copepoda): proposed preservation under the plenary powers and designation of a type-species for the genus in accordance with common usage. Z.N. (S) 1520. Bull. zool. Nom., 20(2): 150-152.

Gurney, R. 1927. Report on the Crustacea: Copepoda nad Cladocera of the plankton. Zoological Results of the Cambridge Expedition to the Suez Canal, 1924. Trans. zool. Soc. Lond., 22: 139-172.

______. 1944. Some notes on the copepod genus Saphirella Scott. Ann. Mag. nat. Hist. (Series 11), 11 (83): 825-829.

Haagensen, D.A. 1975. Thecosomata (Gastropoda, Opisthobranchiata) of the Caribbean Sea and Adjacent Areas. Master's Thesis. University of Miami. Also Scientific Report to ONR Project NR-083-060. 342 p.

Haeckel, E. 1864. Beitrage zur Kenntnis der Corycaeiden. Zeitschr. fur Med. und Naturwiss., Jena. 1: 61-112.

Hansen, H.J. 1910. The Schizopoda of the Siboga Expedition. Siboga Expedition, 37: 1-123.

______. 1915. The Curstacea Euphausiacea of the United States National Museum. Proc. U.S. Natl. Mus., 48: 59-114.

Harant, H. and P. Vernieres. 1938. Tuniciers. Fasc. 2. Appendiculaires et thaliaces. Faune Fr., 33: 1-56.

Hartmann, J. and H. Wiekert. 1969. Tagesgang eines Myctophiden (Pices) und zweier von ihm gefressener Mollusken des Neustons. Kieler Meeresforschungen, 25: 328-330.

Hasle, G.R. and E. Nordli. 1951. Form variation in Ceratium fusus and tripos populations in cultures and from the sea. Avh. Norske Vidensk. Akad., Klasse (4): 1-25.

Heinrich, A.K. 1960. Horizontal distribution of copepods in the Central Pacific and the determinant factors. Acad. Sci. U.S.S.R., Trud. Inst. Okeanol., 41: 31-41.

Henderson, J.S. 1958. Preliminary study of distribution of some copepods in upper Laguna Madre. Master's thesis, A&M College of Texas. 41 p.

Herbst, H.V. 1955. Cyclopida Gnathostoma (Crustacea Copopoda) von der brasilianischen Atlantikkuste. Kieler Meeresf., 11(2): 214-229.

Heron, G.A. 1964. Seven species of *Eurytemora* (Copepoda) from northwestern North America. Crustaceana, 7(3): 199-211.

Hida, T.S. 1957. Chaetognaths and pteropods as biological indicators in the North Pacific. Fish and Wildlife Service Special Scientific Rep.--Fisheries, (215): 1-13.

Hilsemann, K. 1966. A revision of the genus *Lucicutia* (Copepoda: Calanoida) with a key to its species. Bull. Mar. Sci., 16: 702-47.

Hoffman, H. 1932-40. Opisthobranchia. In Dr. H.G. Bonn's Klassen und Ordnungen des Tierreichs, Bd. 3, Abt. 2, Buch 3, Teil I (1-7): 1-1247 and Teil II(1): 1-90.

Hopkins, T.L. 1973. Zooplankton. In A summary of knowledge of the eastern Gulf of Mexico. Report to the Committee on Exploration of the American Petroleum Institute (Mimeo).

Hosoe, K. and J.A. Súarez Caabro. 1955. Biometría de los quetognatos. Bol. UNESCO, Cent. Coop. Cient. América Latina, Montevideo, Uruguay pp. 85-92.

Hughes, W.A. 1968. The thecosomatous pteropods of the Gulf of Mexico. Master's Thesis, Texas A & M. 59 p.

Hulsemann, K. and G.D. Grice. 1963. A new genus and species of bathypelagic calanoid copepod from the North Atlantic. Deep-sea Res., 10: 729-734.

Issel, R. 1913. Molluschi--III. Pteropodi. Raccolte planctoniche fatte dalla R. Nave "Liguria" nel viaggio di circonnavigazione del 1903-05 sotto il comando di S.A.R. Luidi di Savoia duca degli abruzzi. Pub. del R. Istituti di studi Superiori Pratici e di Perfezionamento in Firenze Sezione di Scienzefisiche e Naturali, 2(4): 71-83.

James, B.M. 1970. Euphausiacean Crustacea. In Contributions on the Biology of the Gulf of Mexico, edited by W.E. Pequegnat and F.A. Chace, Jr. Tex. A & M Univ. Oceanogr. Stud., 1: 205-29.

Jespersen, P. 1934. The Godthaab Expedition, 1928. Copepoda. Medd. Gronland 79(10): 1-166.

______. 1940. Non-parasitic Copepoda. Zool. Iceland, vol. 3, pt. 33, pp. 1-116.

Johnson, M.W. 1934. The life history of the copepod Tortanus discaudatus (Thompson and Scott). Biol. Bull., Woods Hole, 67(1): 182-200.

______. 1935. The developmental stages of Labidocera. Biol. Bull., Woods Hole, 68(3): 397-421.

______. 1936. Pachyptilus pacificus and Centraugaptilus porcellus, Bull. Scripps Instn. Oceanogr. tech., 4(2): 65-70.

______. 1937a. The developmental stages of the copepod Eucalanus elongatus Dana var. bunjii Giesbrecht. Trans. Amer. micr. Soc. 56(1): 79-98.

______. 1937b. Notes on the final metamorphosis of the male Aegisthus mucronatus Giesbrecht, and its bearing on the status of some uncertain species. Trans. Amer, micr. Soc., 56(4): 505-509.

______. 1939. Pseudodiaptomus (Pseudodiaptallous) euryhalinus a new subgenus and species of Copepoda, wiht preliminary notes on its ecology. Trans. Amer. micr. Soc. 58(3): 349-355.

______. 1942. Concerning the hitherto unknown males of the copepods Microsetella rosea (Dana), Vettoria granulosa(Giesbrecht) and Corissa parva Farran. Trans. Amer. micr. Soc., 56(4): 430-437.

______. 1953. The copepod Cyclops dimorphus Kiefer from the Salton Sea. Amer. Midl. Nat. 49(1): 188-192.

______. 1958. Bathycalanus sverdrupi, n. sp., a copepod crustacean from great depths in the Pacific Ocean. Proc. Calif. Acad. Sci., 29(6): 257-265.

Johnson, M.W. and E. Brinton. 9162. Biological species, water masses and currents. In The Sea, M.N. Hill, Ed., 2: 381-414.

Johnson, M.W. and J.B. Olson. 1948. The life history and biology of a marine harpacticoid copepod, Tisbe furcata (Baird). Biol. Bull. Woods Hole, 95(3): 320-332.

Jones, E.C. 1952. A preliminary survey of the copepods of the Florida Current. Master of Science Thesis, University of Miami, Coral Gables, Florida. 76 pp.

Juhl, R. 1971. Status and Potential of Fishery in the Caribbean. Procc. Gulf Carib. Fish. Inst. 23rd. Ann. Sess., pp. 175-183.

Kiefer, F. 1929. Cyclopoida Gnathostoma. Tierreich, 53: xvi + 102.

______. 1935. Zur Kenntnis der Oithonidae (Crustacea Copepoda Cyclopoida). Zool. Anz., 112(11-12): 322-327.

______. 1936. Brasilianische Ruderfusskrebse (Crustacea Copepoda), gesammelt von Herrn Otto Schubart, 3: Zur Kennetnis der Oithona hebes. Giesbrecht. Zool. Anz., 114(11-12): 320-322.

King, J.E. 1950. A preliminary report on the plankton of the west coast of Florida. Quart. J. Fla. Acad. Sci., 12(2): 109-137.

Klie, W. 1949. Harpacticoida (Cop.) aus dem Bereich von Helgoland und der Kieler Bucht 1. Kieler Meeresf., 6: 90-128.

Kolesnikov, A.N. 1968. Zooplankton distribution in the southwest Caribbean basin. In investigations of the Central American Seas. Ukranian Soviet Socialist Republic, Academy of Sci., 2:46-61.

Kornicher, L.S. 1959. Observations on the behavior of the pteropod Creseis acicula Rang. Bull. Mar. Sci. Gulf Carib., 9(3): 331-336.

Kramer, A. 1895. On the most frequent pelagic Copepods and Cladoceres of Hauraki Gulf, In Trans. Proceed. New Zealand Inst. (1894). 27: 214-223.

Krishnawamy. S. 1952. Some new species of copepods from Madras Coast. Rec. Indian Mus., 49(3-4): 321-336.

Kromov, N.S. 1969. Distribution of plankton in the Gulf of Mexico and some aspects of its seasonal dynamics. In Soviet-Cuban fishery research, edited by A.S. Bogdanov, Jerusalem, Israel Program for Scientific Translations, IPST Catalog No. 5514: 36-56. Transl. from VNIRO Sovetsko-Kubinskei rybokhozyaistvennye issledovaniya. Moskva, Pishchevaya Promyshlennost', pp. 47-70 (1965).

______. 1969a. Distribution of plankton in the Carivvean Sea. In Societ-Cuban fishery research, edited by A.S.Bogdanov. Jerusalem, Israel Program of Scientific Translation. IPST Catalog No. 5514: 57-61. Trans. from VNIRO Sovetsko-Kubinskie rybokhozyaistvennye issledovaniya. Moskva, Pishchevaya Promyshlennost', pp. 71-6(1965).

Lalli, C.M. and F. E. Wells, Jr. 9173. Brood protection in an epipelagic thecosomatous pteropod, Spiratella ("Limacina") inflata (D'Orbigny). Bull. Mar. Sci., 23(4): 933-941.

Lang, L. 1948. Monographie der Harpacticiden. I and II. Lund, Hakan Ohissons Boktryckeri. 1682 p.

Leavitt, B.B. 1935. A quantitative study of the vertical distribution of the larger zooplankton in deep water. Biol. Bull., Woods Hole, 68(1): 115-130.

______. 1938. The quantitative vertical distribution of macrozooplankton in the Atlantic Ocean Basin. Biol. Bull., Woods Hole, 74(3): 376-394.

Lebour, M.V. 1925. The dinoflagellates of the northern seas. Marine Biological Association of the U.K., Plymouth, England, 250 p.

Lebour M. 1932. Limacina retroversa in Plymouth waters. Jour. Mar. Biol. Assoc. U.K., 18: 123-129.

Legaré, J.E.H. 1961a. Algunos eufausiáceos del Golfo de Paria, Golfo de Cariaco y delta del Orinoco, al Oriente de Venezuela. *Bol. Inst. Oceanogr. Univ. Oriente*, Cumana, 1: 131-48.

______. 1961b. Estudios preliminares del zooplancton en la región de Cariaco. *Bol. Inst. Oceanogr. Univ. Oriente, Cumaná*, 1(1): 191-218.

______. 1964. The pelagic Copepoda of eastern Venezuela. 1. The Cariaco Trench. *Bol, Inst. Oceanogr. Univ. Oriente, Cumaná*, 3: 15-81.

Legaré, J.E.H. and E. Zoppi. 1961. Notas sobre la abundancia y distribución de Chaetognatha en las aguas del Oriente de Venezuela. *Bol. Inst. Oceanogr. Univ. Oriente, Cumaná,* 1: 149-71.

Lehnhofer, K. 1926. *Copilia* Dana 1849 der Deutschen Tiefsee-Expedition. *Wiss. Ergebn. 'Valdivia,'* 23(3): 113-177.

______. 1929. Copepoda 5: *Sapphirina* J.V. Thompson 1829. *Wiss. Ergebn. 'Valdivia*,' 1898-1899, 22(5): 269-346.

Leloup, E. 1933. Siphonophores calycophorides provenant des campagnes du Prince Albert 1^er^ de Monaco. *Result. Camp. Sci. Prince Albert I* Monaco, 87: 1-66.

______. 1934. Siphonophores calycophorides de l'Océan Atlantique tropical et austral. *Bull. Mus. Hist. Nat. Belg*., 10: 1-87.

Leloup, E. and E. Hentschel. 1935. Die Verbreitung der calycophoren Siphonophoren im Sudatlantischen Ozean. *Wiss. Ergeb. Dtsch. Atl.* Exped., 12: 1-31.

Lewis, J.B. 1954. The occurrence and vertical distribution of the Euphausiacea of the Florida Current. *Bull. Mar. Sci. Gulf. Carib*. 4: 265-301.

Lewis, J.B. and A.F. Fish. 1969. Seasonal variation of the zooplankton fauna of surface waters entering the Caribbean Sea at Barbados. *Carib. Jour. Sci*., 9:(1-2): 1-24.

Light, S.F. and O. Hartman. 1937. A review of the genera *Clausidium* Kossmann and *Hemicyclops* Boeck (Copepoda, Cyclopoida) with the description of a new species from the Northeast Pacific. *Univ.* Calif. Publ. Zool., 41(14): 173-188.

Lindberg, K. 1940. Cyclopoids (Crustacés Copépodes) de l'Inde. Rec. Indian Mus., 42(3); 519-526.

______. 1950. Cyclopoides nouveaux ou peu connus (Crustaces Copepodes). *Mém. Mus. Hist. nat., Paris*, 29(3): 259-298.

Lindquist, A. 1959. Studien uber das Zooplankton der Bottensee II. Zur Verbreitung und Zuammensetzung des Zooplanktons. *Inst. mar. Res., Lysekil, Ser. Biol, Rep. 11, Fishery Board of Sweden*, 136 p.

______. 1961. Untersuchugen an Limnocalanus (Copepoda, Calanoida). Inst. mar. Res. Lysekil, Ser. Biol., Rep. 13, Fishery Board of Sweden, 124 p.

Lubbock, J. 1853. Description of a new genus of Calanidae. Ann. Mag. nat. Hist., ser. 2, 11: 25-29.

______. 1856. On some Entomostraca collected by Dr. Sutherland in the Atlantic Ocean, Trans. ent. Soc. Lond., ser. 2, 4: 8-39.

Lubny-Gertsyk, Y.A. 1972. Plankton in the western tropical Atlantic in relation to hydrologic conditions. Oceanology. Wash., 12: 309-12.

Lucas. C.E. 1942. Continuous plankton records: Phytoplankton in the north Sea, 1938-39. Part II. Dinoflagellates, Phaeocystis, etc. Hull Bull. Mar. Ecology, 2: 47-70.

______. 1955. External metabolities in the sea. In Papers in Marine Biology and Oceanography (Suppl. to vol. 3 of Deep-Sea Res.), pp. 139-148. Pergamon Press, London and N.Y.

Margalef, R. 1957a. Fitoplancton de las costas de Puerto Rico. Investigación Pesquera, 6: 39-52.

______. 1957b. La teoría de la información en ecología. Memorias de la Real Academia de Ciencias y Artes de Barcelona, 23: 373-449.

______. 1960. Hidrografía y fitoplancton de un área marina de la costa meridional de Puerto Rico. Investigación Pesquera. (In Press).

______. 1962. Comunidades Naturales. Pub. Esp., Ints. Biol., Univ. Puerto Rico. 469 pp.

______. 1971. The pelagic ecosystem of the Caribbean Sea. In UNESCO-FAO Symposium on Investigations and Resources of the Caribbean Sea and Adjacent Regions, Curacao, November 1968. UNESCO, Paris, pp. 483-496.

Massy, A.L. 1920. Eupteropoda (Pteropoda Thecosomata) and Pterota (Pteropoda Gymnosomata). Brit. Ant. ("Terra Nova") Exp. 1910, Nat. Hist. Rep., Zoology, 2(9), (Mollusca 3): 203-232.

Mattlin, R.H., Jr. 1974. Chaetognaths of the Caribbean Sea. Master's Thesis, University of West Florida, Pensacola, Florida, 81 p. (Unpublished).

McGowan, J.A. 1960. The systematics, distribution, and abundance of the Euthecosomata of the North Pacific. Ph.D. Dissertation, Univ. of Calif. at San Diego. 212 pp.

McGowan, J.A. and V. Fraundorf. 1966. The relationship between size of net used and estimates of zooplankton diversity. Limnol. Ocean., 11(4): 456-469.

Meisenheimer, J. 1905. Pteropoda. Wiss. Ergebn. Deutschen Tiefsee-Exp. auf dem Dampfer "Valdivia" 1898-1899, 9(1): 1-314.

______. 1906a. Die tiergeographischen Regionen des Pelagials, auf Grund der Verbreitung der Pteropoden. Zool. Anz., 29: 155-163.

______. 1906b. Die Pteropoda der deutschen Sudpolar-Expedition in 1901-1903. Deutsche Sudpolar-Expedition 1901-1903, 9 (Zoology), 1(2): 95-152.

Menzies, R.J. 1958. Shell-bearing pteropod gastropods from Mediterranean plancton (Cavoliniidae). Pub. Staz. Zool. Napoli, 30(3): 381-401.

Merrill, A.S. 1963. Mollusks from a buoy off Georgia. Nautilus. 77(2): 68-70.

Michel, H.B. and M. Foyo. 1977. Studies of Caribbean Zooplankton, In: Cooperative Investigations of the Caribbean and Adjacent Regions. FAO, Fisheries Report 200, pp. 275-289.

Michel, B.H., M. foyo and D.A.Haagensen. 1976. Caribbean Zooplankton, Part I - Siphonophora, Heteropoda, Copepoda, Euphausiacea, Chaetognata and Salpidae, Part II - Thecosomata. Office of Naval Research, Dept. Navy, i-v, 549 p.

Miller, S.M., J.B. Moore and K.R. Kvammen. 1953. Plankton of the Florida Current. I. General conditions. Bull. Mar. Sci. Gulf & Carib., 2(3): 465-485.

Milne-Edwards, H. 1840. Histoire naturelle des Crustacés, comprenant l'anatomie, la physiologie et la classification de ces animaux. Vol. 3, 638 + 32 pp.

Moore, H.B. 1949. The zooplankton of the upper waters of the Bermuda area of the North Atlantic. Bull, Bing. Ocean. Coll., 12(2): 1-97.

Moore, H.B. and D.O. O'Berry. 1957. Plankton of the Florida Current, IV. Factors influencing the vertical distribution of some common copepods. Bull. Mar. Scil Gulf & Carib., 7(4): 297-315.

Moore, H.B. and J.C. Bauer. 1960. An analysis of the relation of the vertical distribution of three copepods to environmental conditions. Bull. Mar. Sci. Gulf & Carib., 10(4): 430-443.

Moore, H.B. and M. Foyo. 1963. A study of the temperature factor in twelve species of oceanic copepods. Bull. Mar. Sci. Gulf & Carib., 13(4): 502-515.

Moore, H.B., H. Owre, E.C. Jones, and T. Dow. 1953. Plankton of the Florida Current. III. The control of the vertical distribution of zooplankton in the daytime by light and temperature. Bull. Mar. Sci. Gulf & Carib., 3(2): 83-95.

Morton, J.E. 1954a. The biology of Limacina retroversa. J. Mar. Biol. Ass. U.K., 33: 297-312.

______. 1954b. The pelagic Mollusca of the Benguela Current. Part I. First survey, R.R.S. "William Scoresby," March 1950 withan account of the reproductive system and sexual succession of Limacina bulimoides. Discovery Rep., 27: 163-200.

Moryakova, V.K. 1968. Composition and distribution of zooplankton in central and eastern parts of the Carivvean Sea. In Investigations of the Central American Seas with Regard to the Material of the Soviet Cuban Marine Expedition: 61-70.

Moryakova, V.K. and A. Campos. 1966. Qualitative and quantitative characteristics of zooplankton of the Cuban bench, In Investigations of the Central American Seas, Ukrainian Soviet Socialist Republic, Academy of Sciences: 128-140.

Motoda, S. 1963. Corycaeus and Farranula (Copepoda, Cyclopoida) in Hawaiian waters. Publ. Seto Mar. Biol. Lab., 11(2): 209-262.

Motoda S. and M. Anraku. 1954. Daily change of vertical distribution of plankton animals near western entrance to the Tsugaru Strait, northern Japan. Bull. Fish., Hokkaido, 5(1): 15-19.

Mulkana, M.S. and T.S. McIlwain. 1973. The seasonal occurrence and abundance of Chaetognatha in Mississippi Sound. Gulf Res. Rep., 4: 264-271.

Munthe, H. 1887. Pteropoder I Upsala Universitets Zoologiska Museum samalde af Kapten C. von Scheele. Bihang till K. Svenska Vetenskaps-Akademiens Handlingar, Band 13, Afd. 4(2): 3-33.

Myers, T.D. 1968. Horizontal and vertical distribution of thecosomatous pteropods off Cape Hatteras. Ph. D. Dissertation. Duke Univ. 224 pp. Univ. Microfilms, Ann Arbor, Mich. (Unpublished).

Nowell-Usticke, G.W. 1959. A check list of the marine shells of St. Croix, U.S. Virgin Island. Lane Press, Burlington, Vermont: 90 pp.

Odum, H.T., P.R. Brukholder and J.A. Rivero. 1960. Measurements of productivity of turtle grass flats, reefs, and the Bahía Fosforescente of southern Puerto Rico. Publ, Inst. Mar. Sc., (In press).

Owre, H.B. 1962. Plankton of the Florida Current. Part VIII. A list of the Copepoda. Bull. Mar. Sci., 12(3): 489-495.

______. 1972. Soame temperatures, salinities, and depths of collection of Eukrohnia bathyantarctica (Chaetognatha) in the Caribbean Sea. Bull. Mar. Sci., 22: 94-9.

______. 1973. A new chaetognatha genus and species with remarks on the taxonomy and distribution of others. Bull Mar. Sci., 23: 948-63.

Owre, H.B. and M. Foyo. 1964a. Report on a collection of Copepoda from the Caribbean Sea. Bull Mar. Sci. Gulf Carib., 142(2): 359-372.

______. 1964b. Plankton of the Florida Current, Part IX. Additions of the list of Copepoda, with descriptions of two rare species. *Bull. Mar. Sci*., 14(2): 342-358.

______. 1967. Copepods of the Florida Current. Fauna Caribbaea, Crustacea, I: Copepoda. *Inst. Mar. Sci., Univ. Miami* (1): 1-137.

______. 1971. Studies on the zooplankton in the Caribbean Sea. *In* UNESCO-FAO Symposium on Investigations and Resources of the CAribbean Sea and Adjacent Regions, Curacao, November 1968. *UNESCO, Paris*, pp. 503-508.

______. 1972. Studies on Caribbean zooplankton. Description of the program and results of the first cruise. *Bull. Mar. Sci*., 22(2): 483-521.

Owre, H.B. and J.K. Low. 1969. Methods of collecting net plankton from a series of known depths through the water column. *Bull. Mar. Sci*., 19(4): 911-921.

Paranjape, M.A. 1968. The egg mass and veligers of *Limacina helicina* Phipps. *Veliger*, 10(4): 322-326.

Park, T.S. 1970. Calanoid copepods from the Caribbena Sea and Gulf of Mexico. 2. New species and new records from plankton samples. *Bull. Mar. Sci*., 20: 472-546.

______. 1974. Calanoid copepods fo the genus *Aetideus* from the Gulf of Mexico. *Fish. Bull*., 72: 15-21.

______. 1975a. Calanoid copepods of the genera *Gaetanus* and *Gaidius* from the Gulf of Mexico. *Bull, Mar. Sci*., 25: 9-34.

______. 1975b. Calanoid copepods of the genera *Actideopsis*, *Pseudaetideus*, and Chiridius from the Gulf of Mexico. *Bull, Mar. Sci*., 25: 272-90.

______. 1975c. A new species of Euchirella and the male of *Euchirella splendens* Vervoort, with notes on *Euchirella truncata* Esterly (Copepoda, Calanoida). Curstaceana, 28: 291-9.

______. 1975c. Calanoid of the Family Eucheatidae for the Gulf of Mexico and Western Caribbean Sea. *Smithson. Contrib. Zool*., 196: 1-26.

Parker, R.H. 1956. Macro-invertebrate assemblages as indicators of sedimentary environments in east Mississippi delta region. *Bull. Amer. Assoc, Petrol. Geol*., 40(2): 295-376.

______. 1960. Ecology and distributional patterns of marine macro-invertebrates, in the northern Gulf of Mexico. *In* Recent Sediments Northwest Gulf of Mexico, 1951-1958. *Amer. Assoc, Petrol. Geol*. : 302-381.

Peck, J.I. 1893. Scientific results of explorations by the U.S. Fish Commission Steamer "Albatross." No. XXVI. Report on the pteropods and heteropods collected during the voyage from Norfolk, Va., to San Francisco, Cal. 1887-'88. *Proc. U.S. Nat. Mus*., 16(943): 451-466.

Pelseneer, P. 1887. Report on the Pteropoda collected by H.M.S. "Challenger" during the years 1873-1876. Part I. The Gymnosomata. Rep. Sci. Res. Voy, H.M.S. "Challenger during the years 1873-1876, Zoology 19(part 58): 1-74.

______. 1888a. Report on the Pteropoda collected by H.M.S. "Challenger" during the years 1873-1876. Part II. The Thecosomata. Rep. Sci. Res. Voy. H.M.S. "Challenger" during the yeras 1873-1876, Zoology 23 (part 65): 1-132.

______. 1888b. Report on the Pteropoda collected by H.M.S. "Challenger" during the years 1873-1876. Part III. Anatomy. Rep. Sci. Res. Voy. H.M.S. "Challenger" during the years 1873-1876,

Perlroth, I. 1971. Distribution of mass in the near surface waters of the Caribbean Sea and Adjacent Regions, Curacao, November 1968. UNESCO, Paris, pp. 147-152.

Pesta, O. 1920. Die Planctonocopepoden der Adria. Zool. Jber., Syst., 43: 471-660.

______. 1928a. Ruderfusser oder Copepoda. I. Calanoida G.O. Sars. Tierwelt Dtsch., Teil 9: 1-68.

______. 1928b. Ruderfusser oder Copepoda. II. Cyclopoida G.O. Sars. Tierwelt Dtsch., Teil 9: 69-136.

______. 1932. Ruderfusser oder Copepoda. III. Harpacticoida G.O. Sars. Tierwelt Dtsch., Teil 24: 1-164.

______. 1934. Ruderfusser oder Copepoda. IV-VII (Monstrilloida, Notoderphyoida, Caligoida, Lernaeoida). Tierwelt Dtsch., Teil 29: 1-68.

Pierce, E.L. 1951. The Chaetognaths of the West Coast of Florida. Biol. Bull., 100(3): 206-228.

______. 1962. Chaetognatha from the Texas coast. Publ. Inst. Mar. Sci. Univ. Tax., 8: 147-52.

Pierce, E.L. and M.L. Wass. 1962. Chaetognatha from the Florida Current and coastal water of the southeastern Atlantic states. Bull. Mar. Sci., 12: 403-31.

Pisek, A. 1924. Verbreitung des Copepoden-Genus Pleuromamma Giesbr. nach Ergebnissen der Plankton-Expedition. Arb. Zool. Inst. Univ. Innsbruck, 1(2): 19-32.

Rang, P.C.A.L. and P. Souleyet. 1852. Histoire naturelle des mollusques ptéropodes. Mongraphie comprenant la description de toutes les especes de ce groupe de mollusques. J.B. Bailliere, Paris: 1-86.

Reed, C.T. 1941. Marine life in Texas waters. Texas Acad, Pub. in Nat. Hist., Non-technical series: 1-88.

Reeve, M.R. 1964. Studies on the seasonal variation of the zooplankton in the marine sub-tropical inshore environment. Bull. Mar. Sci. Gulf & Carib. 14(1): 103-122.

______. 1970. Seasonal changes in the zooplankton of South Biscayne Bay and some problems of assessing the effects on the zooplankton of natural and artificial thermal and other fluctuations. Bull. Mar. Sci. Gulf & Carib. 20(4): 894-921.

Remy, P. 1927. Note sur un copépode de l'eau saumatre du canal de Caen a la mer {Acartia (Acanthacartia) tonsa Dana}. Ann. Biol. Lacustre. 15: 169-186.

Richard, Jules. 1893. Heterochaeta grimaldii, n. sp., calanide nouveau provenant de la troisieme campagne scientifique du yacht l'Hirondelle. Bull. Soc. zool. Fr., 18: 151-152.

Rodríguez, D. G. L. 1965. Distribución de pterópodos en Veracruz, Ver. An. Inst. Biol. Mex., 36(2): 249-251.

Roehr, M. G. and H. B. Moore. 1965. The vertical distribution of some common copepods in the Straits of Florida. Bull. Mar. Sci., 15(3): 565-570.

Roger, C. 1974. Les euphausiaces du Pacifique equatorial et sud tropical. Mem. ORSTOM, 71: 265.

Rose, M. 1929. Copépodes pelagiques particulierement de surface provenant des campagnes scientifiques de S.A.S. le Prince Albert I de Monaco. Result. Camp. sci. Monaco, 78: 1-126.

______. 1933. Copépodes pélagiques. Faune Fr., 26: 1-374.

______. 1942a. Les Scolecithricidae (copépodes pélagiques) de la Baie d'Alger. Ann. Inst. Océanogr. Monaco, 21: 113-170.

______. 1942b. Spinocalanus heterocaudatus Rose, 1937 (Copépode) Bull. Mus. Hist. nat., Paris, 14(5): 315-318.

______. 1957. Manuel de Planctonologie Mediterranéenne, Tome I. Texte. Centre Nacional de la Recherche Scientifique.

Rosendorn, I. 1917. Die Gattung Oithona. Wiss. Ergebn. 'Valdivia,' 1-58.

Rossov, V. V. 1966. On water circulation in the Gulf of Mexico and the Caribbean Sea. Doklady Akad. Nauk UkrSSr, 166(3): 705-708.

Russel, F. S. and J. S. Colman. 1935. The occurrence and seasonal distribution of the Tunicata, Mollusca and Coelenterata (Siphonophora). Great Barrier Reef Exped. 1928-1929 Scient. Rep., 2(7), (The Zooplankton IV): 203-276.

Sars, G. O. 1900. Crustacea. *Sci. Res. Norweg. Pol. Exped.* 1893-1896, 1(5): 1-141.

______. 1901. Copepoda Calanoida. *Crustacea of Norway*, 4: 1-28.

______. 1902. *Ibid*: 29-144.

______. 1903a. *Ibid*: i-xiii + 145-171.

______. 1903b. Copepoda Harpacticoida. *Crustacea of Norway*, 5: 1-28.

______. 1904. *Ibid*: 29-80.

______. 1905a. Liste Préliminaire des Calanoides recueillis pendant les campagnes de S.A.S. le Prince Albert de Monaco, avec diagnoses des genres et des especes nouvelles. (1^{er} partie). *Bull. Inst. océanogr. Monaco*, 26: 1-22.

______. 1905b. *Ibid*., (2^{e} partie). *Bull. Inst. océanogr. Monaco*, 40: 1-24.

______. 1905c. Copepoda Harpacticoida. *Crustacea of Norway*, 5: 81-132.

______. 1906. *Ibid*: 133-196.

______. 1907a. Notes supplémentaires sur les Calanoidés de la Princesse-Alice. *Bull. Inst. Océanogr. Monaco*, 101: 1-27.

______. 1907b. Copepoda Harpacticoida. *Crustacea of Norway*, 5: 197-240.

______. 1908. *Ibid*: 241-276.

______. 1909. *Ibid*: 277-336.

______. 1910. *Ibid*: 337-368.

______. 1911. *Ibid*: i-xiv + 369-449.

______. 1913. Copepoda Cyclopoida. *Crustacea of Norway*, 6: 1-56.

______. 1914. *Ibid*: 57-80.

______. 1915. *Ibid*: 81-140.

______. 1916. Liste systematique des Cyclopoidés, Harpacticoidés et Monstrilloides recueillis pendant les campagnes de S.A.S. le Prince Albert de Monaco, avec descriptions et figures des especes nouvelles. *Bull. Inst. océanogr. Monaco*, 323: 1-15.

______. 1917. Copepoda Cyclopoida. *Crustacea of Norway*, 6: 141-172.

______. 1918. *Ibid*: i-xiii + 173-225.

.1909. *Ibid*: 277-336.

______. 1910. *Ibid*: 337-368.

______. 1911. *Ibid*: i-xiv + 369-449.

______. 1913. Copepoda Cyclopoida. Crustacea of Norway, 6: 1-56.

______. 1914. *Ibid*: 57-80

______. 1915. *Ibid*: 81-140.

______. 1916. Liste systematique des Cyclopoidés, Harpacticoidés et Monstrilloides recueillis pendant les campagnes de S.A.S. le Prince Albert de Monaco, avec descriptions et figures des especes nouvelles. Bull. Inst. océanogr. Monaco, 323: 1-15.

______. 1917. Copepoda Cyclopoida. Crustacea of Norway, 6: 141-172.

______. 1918. *Ibid*: i-xiii + 173-225.

______. 1919. Copepoda Supplement. Crustacea of Norway, 7:1-24.

______. 1920a. *Ibid*: 25-92.

______. 1920b. Calanoidés recueillis pendant les campagnes de S.A.S. le Prince Albert de Monaco. Bull. Inst. océanogr. Monaco, 377: 1-20.

______ . 1919. Copepoda Supplement. Crustacea of Norway, 7: 1-24.

______ . 1920a. Ibid: 25-92.

______ . 1920b. Calanoidés recueillis pendant les campagnes de S.A.S. le Prince Albert de Monaco. Bull. Inst. océanogr. Monaco, 377: 1-20.

______ . 1921a. Copepoda Supplement. Crustacea of Norway, 7: 93-121.

______ . 1921b. Copepoda Monstrilloida & Notodelphyoida. Crustacea of Norway, 8: 1-90.

______ . 1924. Copépodes particultierement bathypélagiques provenant des campagnes scientifiques du Prince Albert 1^{er} de Monaco. Résult. Camp. Sci. Monaco, 69: 1-46 + 127 pls.

______ . 1925. Ibid: (Texte): 1-408.

Schiemenz, P. 1906. Die Pteropoden der Plankton Expedition. Ergebn. Plankton Exped. Humboldtstiftung, 2(F) (b): 1-37.

Schmitt, W. L. 1954. Copepoda. In Gulf of Mexico, its origin, waters and marine life. Fish. Bull., U.S., 55: 439-442.

Schwarz, S. 1960. Zur Crustaceenfauna der Brackwassergebiete Rugens und des Darss, (Acartia tonsa, Caligus lacustris, Microdeutopus gryllotalpa). Hydrobiologia, 16(3): 293-300.

Scott, A. 1909. The Copepoda of the Siboga Expedition. Siboga Exped., 29(1): 1-323.

Sears, M. 1953. Notes on siphonophores. 2. A revision of the Abylinae. Bull. Mus. Como. Zool. Harv. Univ., 109: 1-119.

Sewell, R. B. S. 1913. Notes on the biological work on the R.I.M.S.S. "Investigator" during survey seasons, 1910-11 and 1911-12. J. Asiat. Soc. Beng., 9(8-9): 329-390.

______ . 1924. Fauna of the Chilka Lake. Mem. Indian Mus., 5: 771-851.

______ . 1929. The Copepoda of Indian seas. Calanoida, Mem. Indian Mus. 10: 1-221.

______ . 1932. The Copepoda of Indian seas. Calanoida, Mem. Indian Mus., 10(continued): 223-407.

______ . 1933. Notes on a small collection of Marine Copepoda from the Malay States. Bull. Raffles Mus., 8: 25-31.

______ . 1940. Copepoda, Harpacticoida. Sci. Rep. Murray Exped., 7 (Zool.) (2): 117-382.

______. 1947. The free-swimming planktonic Copepoda. Systematic account. Sci. Rep. Murray Exped., 8 (Zool.) (1): 1-303.

______. 1948. The free-swimming planktonic Copepoda. Geographical distribution, Sci. Rep. Murray Exped., 8 (Zool.) (3): 317-592.

______. 1949. The littoral and semi-parasitic Cyclopoida, the Monstrilloida and Notodelphyoida. Sci. Rep. Murray Exped., 9 (Zool. & Bot.) (2): 17-199.

Simmons, E. G. 1957. An ecological survey of the upper Laguna Madre of Texas. Publ. Inst. Mar. Sci. Univ. Texas, 4: 156-200.

Spoel, S. Van Der. 1962. Aberrant forms fo the genus Clio Linnaeus, 1767, with a review of the genus Proclio Hubendick, 1951. (Gastropoda, Pteropoda). Beaufortia, 9(107): 173-200.

______. 1967. Euthecosomata a group with remarkable developmental stages (Gastropoda, Pteropoda). J. Noorduijn en Zoon, Gorinchem, The Netherlands: 1-375.

______. 1969a. Two new forms of Cavolinia uncinata (Rang, 1829) (Pteropoda, Gastropoda). Beaufortia, 16(220): 185-198.

______. 1969b. The shell of Clio pyramidata L., 1767 forma lanceolata (Lesueur, 1813) and forma convexa (Boas, 1886) (Gastropoda, Pteropoda). Videnskab. Meddr. Dansk. Naturh. Foren., 132: 95-114.

______. 1970a. The pelagic Mollusca from the "Atlantide" and "Galathea" Expeditions collected in the East Atlantic. Atlantide Rep. (11): 99-139.

______. 1970b. Morphometric data on Cavoliniidae, with notes on a new form of Cuvierina columnella (Rang, 1827) (Gastropoda, Pteropoda). Basteria, 34(5-6): 103-151.

______. 1971a. New forms of Diacria quadridentata (de Blainville, 1821), Cavolinia longirostria (de Blainville, 1821) and Cavolinia uncinata (Rang, 1829) from the Red Sea and the East Pacific Ocean (Mollusca, Pteropoda). Beaufortia, 19(243): 1-20.

______. 1971b. Some problems in infraspecific classification of holoplanktonic animals. Zeitschr. Zool. Systematik u. Evolutionsforschung, 9(2): 107-138.

______. 1972. Pteropoda Thecosomata. Cons. Inter. pour L'Explor. de la Mer, Zooplankton sheet 140-142: 1-12.

______. 1973. Growth, reproduction and vertical migration in Clio pyramidata Linne, 1767 forma lanceolata (Lesueur, 1813), with notes on some other Cavoliniidae (Mollusca, Pteropoda). Beaufortia, 21(281): 117-134.

Steeman Nielsen, E. and E. A. Jensen. 1957. Primary oceanic production. The autotrophic production of organic matter in the oceans. Galathea Rep., 1: 49-136.

Steuer, A. 1904. Copepoden der Valdivia Expedition. Zool. Anz., 27: 593-598.

______. 1915. Revision der Gattung Acartia Dana (Dritte vorlaufige Mitteilung uber die Copepoden der Valdivia-Expedition. Zool. Anz., 45(9): 392-397.

______. 1923. Bausteine zu einer Monographie der Copepoden-Gattung Acartia. Arb. zool. Inst. Univ. Innsbruck, 1(5): 89-148.

______. 1926. Copepoda: Cephalophanes G. O. Sars 1907 der Deutschen Tiefsee-Expedition. Wiss Ergebn. Valdivia, 23(4): 179-191.

______. 1932. Copepoda (6): Pleuromamma Giesbr. 1898 der Detuschen Tiefsee-Expedition. Wiss Ergebn. Valdivia, 24(1): 1-119.

______. 1933. Bericht uber der Bearbeitung der Copepodengattung Pleuromamma Giesbr. 1898 der Deutschen Tiefsee-Expedition "Valdivia." Thalassia, 1(2): 1-48.

______. 1935. Die Copepodenfamilie de Macrosetellidae. S. B. Akad. Wiss. Wien, 1(144): 391-399.

Steven, D. M. 1971. Production cycles in tropical waters. In UNESCO-FAO Symposium on Investigations and Resources of the Caribbean Sea and Adjacent Regions, Curacao, November 1968. UNESCO, Paris, pp. 527-529.

Stubbings, H. G. 1938. Pteropoda. John Murray Exped. 1933-1934 Scien. Rep., 5(2): 15-33.

Sturges, W. 1965. Water characteristics of the Caribbean Sea. Jour. Mar. Res., 23(2): 147-162.

Suárez-Caabro, J. A. 1954. Informe preliminar sobre investigaciones en placton de los mares cubanos. Cont. 10, Cent. Inv. Pes. BANFAIC, Habana, 35 pp.

______. 1955. Quetognatos de los mares cubanos. Mem. Soc. Cubana Hist. Nat. Felipe Poey, Univ. Habana, 22(2): 125-180.

______. 1957. Investigaciones sobre el Plancton Marino de Cuba. Dep. Biol. Mar. Univ. Villanueva, Habana, Mongr. 1, 14 pp.

______. 1959. Salinidad, temperatura y plancton de las aguas costeras de la Isla de Pinos. Monogr. Lab. Biol. Mar., Univ. Villanueva, (7): 1-25.

______. 1963a. Bibliografía Seleccionada de Plancton Marino. Inst. Biol. UNAM, México, 25 pp.

______ . 1963b. Plankton and the economic species of the sea. Mexican American Review, p. 33-34.

______ . 1966. Datos hidrográficos, meteorológicos y plantónicos de las aguas costeras de Veracruz, Ver. México. Ann. Inst. Biol., UNAM, 36(1-2): 25-46.

______ . 1967. Conceptos sobre productividad marina. Revista Ciencia, Mexico, 35(5): 149-153.

Suárez-Caabro, J. A. y P. P. Durate-Bello. 1961a. Hidrografía del Golfo de Batabano, I. Temperatura, Salinidad y Oxígeno. Bol. Inst. Cubano Inv. Tec., Habana, Cuba, 6(1): 4-19.

______ . 1961b. Biología pesquera del bonito (Katsuwonus pelamis) y la albacora (Thunnus atlanticus) en Cuba. I. Ser. Estud. Inst. Cub. Invest. Tecnol., 15: 1-151

Suárez-Caabro, J. A. and J. E. Madruga. 1960. The Chaetognaths of the north-eastern coast of Honduras, Central America. Bull. Mar. Sci. Gulf Carib., 10(4): 421-429.

Suárez-Caabro, J. A. y S. Gómez. 1965. Estudio sobre el plancton de la Laguna de Términos, Campeche, México. Bull. Mar. Sci., 15(4): 1072-1120.

Sutcliffe, W. H., Jr. 1948. A list of calanoid copepods from the plankton at Beaufort, N. C. J. Elisha Mitchell sci. Soc., 64: 234-236.

______ . 1949. A new species of calanoid copepod from North Carolina. J. Elisha Mitchell sci. Soc., 65(2): 273-275.

______ . On the diversity of the copepod population in the Sargasso Sea off Bermuda. Ecology, 41(3): 585-587.

Tanaka, O. 1965a. The pelagic copepods of the Izu Region, middle Japan. Systematic account. I. Families Calanidae and Eucalanidae. Publ. Seto mar. biol. Lab., 5(2): 251-272.

______ . 1965b. The pelagic copepods of the Izu Region, middle Japan. Systematic account. II. Families Paracalanidae and Pseudocalanidae. Publ. Seto. mar. biol. Lab., 5(3): 367-406.

______ . 1957a. The pelagic copepods of the Izu Region, middle Japan. Systematic account. III. Family Aetideidae (Part I). Publ. Seto mar. biol. Lab., 6(1): 31-68.

______ . 1957b. The pelagic copepods of the Izu Region, middle Japan. Systematic account. IV. Family Aetideidae (Part 2). Publ. Seto mar. biol. Lab., 6(2): 169-207.

______ . 1957c. On Copepoda of the family Corycaeidae in Japanese waters. J. Fac. Agric. Kyushu Univ., 11(1): 77-101.

———. 1958. The pelagic copepods of the Izu Region, middle Japan. Systematic account. V. Family Euchaetidae. *Publ. Seto mar. biol. Lab.*, 6(3): 327-367.

———. 1960a. Biological results of the Japanese Antarctic Research Expedition. 10. Pelagic Copepoda. Special *Publ. Seto mar. biol. Lab.* 95 pp.

———. 1960b. The pelagic copepods of the Izu Region, middle Japan. Systematic account. VI. Families Phaennidae and Tharybidae. *Publ. Seto mar. biol. Lab.*, 8(1): 85-135.

———. 1961. The pelagic copepods of the Izu Region, middle Japan. Systematic account. VII. Family Scolecithricidae (Part 1). *Publ. Seto mar. biol. Lab.* 9(1): 139-190.

———. 1962. The pelagic copepods of the Izu Region, middle Japan. Systematic account. VIII. Family Scolecithricidae (Part 2). *Publ. Seto mar. biol. Lab.*, 19(1): 35-90.

———. 1963. The pelagic copepods of the Izu Region, middle Japan. Systematic account. IX. Families Centropagidae, Pseudodiaptomidae, Temoridae, Metridiidae and Lucicutiidae. *Publ. Seto mar. biol. Lab.*, 11(1): 7-55.

———. 1964a. The pelagic copepods of the Izu Region, middle Japan. Systematic account. X. Family Heterorhabdidae. *Publ. Seto mar. biol. Lab.*, 12(1): 1-37.

———. 1964b. The pelagic copepods of the Izu Region, middle Japan. Systematic account. XI. Family Augaptilidae. Publ. Seto mar. *biol. Lab.*, 12(1): 39-91.

———. 1964c. The pelagic copepods of the Izu Region, middle Japan. Systematic account. XII. Families Arietellidae, Pseudocyclopidae, Candaciidae and Pontellidae. *Publ. Seto mar. biol. Lab.*, 12(3): 231-271.

———. 1965a. Neritic Copepoda Calanoida from the northwest coast of Kyushu. *Abs., Symp. Crust. Mar. biol. Ass. India*, p. 6.

———. 1965b. Some rare species of Harpacticoida from the Izu Region. *Abs., Symp. Crust. Mar. biol. Ass. India*, p. 6.

———. 1965c. Preliminary report on copepods found in the tide pool in the northwest coast of Kyushu. *Abs., Symp. Crust., Mar. biol. Ass. India*, p. 7.

———. 1960. Pelagic Copepoda. *Biol. Res. Japanese Antarctic Res. Exp.*, (10): 1-95.

Tanaka, T. 1970. Geographical and vertical distribution of Pteropoda and Heteropoda in the western Pacific Ocean. *Proc. of the Second CSK Symposium, Tokyo*, 1970: 299-308.

Taylor, D. and L. Berner, Jr. The Heteropoda (Mollusca: Gastropoda). Contrib. Biol. Gulf Mex., 1: 231- 44.

Tesch, J. J. 1907. The Pteropoda of the Leyden Museum. Notes from the Leyden Museum, 19(18): 181-203.

______. 1910. Pteropoda and Heteropoda (The Percy Sladen Trust Exped. to the Indian Ocean in 1905). 3(10). In Trans. Linn. Soc. London, 14(1-2): 165-189.

______. 1913. Pteropoda. In Das Tierreich. R. Friedlander und Sohn, Berlin, 36: 1-154.

______. 1904. The Thecosomata and Gymnosomata of the Siboga Expedition. Siboga-Expedite, 52: 1-92.

Thiele, J. 1935. Handbuch der systematischen Weichtierkunde. Gustav Fischer, Jena, 1(2): 399-411.

______. 1946. The thecosomatous pteropods. i. The Atlantic. Dana Rep., 5(28): 1-82.

Thompson, I. C. 1888. Copepoda of Madeira and the Canary Islands, with descriptions of new genera and species. J. Linn. Soc. Lond., Zool., 20: 145-156.

______. 1903. Report on the Copepoda obtained by Mr. George Murray, F.R.S., during the cruise of the Oceana in 1898. Ann. Mag. nat. Hist. ser. 7, 12: 1-36.

Thiriot-Quievreaux, C. 1973. Heteropoda. Oceanogr. Mar. Biol. 11: 237- 61.

Tokioka, T. 1955. On some plankton animals collected by the Syunkotu-Maru in May-June 1954. IV. Thecosomatous pteropods. Publ. Seto Mar. Biol. Lab., 5(1): 59-74.

Tokioka, T. y J. A. Suárez-Caabro. 1956. Apendicularias de los mares cubanos. Mem. Soc. Cubana Hist. Nat. Felipe Poey, Univ. Habana, 23:(1): 37-80.

Totton, A. K. 1965. A synopsis of the Siphonophora. London, British Museum (Natural History), 230 pp.

Troost, D. G. and S. Van Der Spoel. 1972. Juveniles of Cavolinia inflexa (Lesueur, 1813) and Cavolinia longirostris (De Blainville, 1821), their discrimination and development (Gastropoda, Pteropoda). Bull. Zool. Mus. Univ. Amsterdam, 2(20): 221-235.

Vayssiere, A. 1915. Mollusques eupteropodes (ptéropodes thécosomes) provenant des campagnes des yachts "Hirondelle" et "Princesse-Alice" (1885-1913). Rés. des Campagnes Scien. accomplies sur son Yacht par Albert I Prince Souverain de Monaco, 47: 1-226.

Vervoort, W. 1946. Biological results of the Snellius Expedition. XV. The bathypelagic Copepoda Calanoida of the Snellius Expedition. I. Families Calanidae, Eucalanidae, Paracalanidae and Pseudocalanidae. Temminckia, 8: 1-181.

______. 1949. Some new and rare Copepoda Calanoida from East Indian seas. Zool. Verh. Leiden, No. 5, 53 pp.

______. 1950a. On the identity of Onchocalanus nudipes C. B. Wilson, 1942. Proc. ned. Akad. Wet., 50(1): 83-92.

______. 1950b. The genus Onchocalanus G. O. Sars, 1905 (Crustacea Copepoda). Zool. Verh., Leiden, No. 10, 35 pp.

______. 1951. Plankton copepods from the Atlantic sector of the Antarctic. Verh. Akad. Wet. Amst., (Tweede Sectie), Dl. 47(4): 1-156.

______. 1952a. Copepoda. Calanoida. Fam. Aetideidae. Key to the Genera and References. Fich. Ident. Zoopl. Cons. Int. Explor. Mer, 41.

______. 1952b. Copepoda. Calanoida. Fam. Aetideidae. Gen. Aetideus, Euaetideus, Aetideopsis. Fich. Ident. Zoopl. Cons. Int. Explor. Mer, 42.

______. 1952c. Copepoda. Calanoida. Fam. Aetideidae. Gen. Gradyidius, Bradyetes, Bryaxis. Fich. Ident. Zoopl. Cons. Int. Explor. Mer, 43.

______. 1952d. Copepoda. Calanoida. Fam. Aetideidae. Gen. Chiridius, Pseudaetideus, Chiridiella. Fich. Ident. Zoopl. Cons. Int. Explor. Mer, 44.

______. 1952e. Copepoda. Calanoida. Fam. Aetideidae. Gen. Gaidius. Fich. Ident. Zoopl. Cons. Int. Explor. Mer, 45.

______. 1952f. Copepoda. Calanoida. Fam. Aetideidae. Gen Gaetanus. Fich. Ident. Zoopl. Cons. Int. Explor. Mer, 46.

______. 1952g. Copepoda. Calanoida. Fam. Aetideidae. Gen. Euchirella. Fich. Ident. Zoopl. Cons. Int. Explor. Mer, 47.

______. 1952h. Copepoda. Calanoida. Fam. Aetideidae. Gen. Pseudochirella. Fich. Ident. Zoopl. Cons. Int. Explor. Mer, 48.

______. 1952i. Copepoda. Calanoida. Fam. Aetideidae. Gen. Chirundina, Undeuchaeta, Pseudeuchaeta. Fich. Ident. Zoopl. Cons. Int. Explor. Mer, 49.

______. 1957. Copepods from Antarctic and Sub-antarctic plankton samples. Rep. B.A.N.Z. antarct. Exped., (B), 3: 1-160. 138 figs.

______. 1962. Report on some Copepoda collected during the Melanesia Expedition of the Osaka Museum of Natural History. *Publ. Seto mar. biol. Lab.*, 10(2): 293-326.

______. 1963. Pelagic Copepoda. Part. 1. Copepoda Calanoida of the families Calanidae up to and including Euchaetidae. *Atlantide Rep.* 7: 77-194.

______. 1964a. Free-living Copepoda from Ifaluk Atoll in the Caroline Islands. *Bull. U.S. nat. Mus.*, 236, 431 pp.

______. 1964b. Notes on two Pacific species of *Centropages* (Copepoda, Calanoida), *C. australiensis* Fairbridge, 1944 and *C. aucklandicus* Kramer, 1895. *Crustaceana* 7 (4): 293-311.

Villalobos-Figueroa, A., J. A. Suárez-Caabro, S. Gómez, G. Lanza, M. Aceves, F. Manrique y J. Cabrera. 1966. The hydrography and productivity of Alavarado Lagoon, Veracruz, México. *Proc. Gulf Carib. Fish. Inst. 19th. Ann. Sess*, p. 75-85.

Vinogradov, M. E. 1968. Vertical distribution of the oceanic zooplankton. *Moscow, Izdatel'stvo Mauka*, 320 pp. (English translation, 1970, 339 pp.)

Wells, F. E., Jr. 1973. Effects of mesh size on estimation of population densities of tropical euthecosomatous pteropods. *Mar. Biol.*, 20: 347-350.

______. 1974. *Styliola sinecosta*, a new species of pteropod (Opisthobranchia: Thecosomata) from Barbados, West Indies. *Veliger*, 16(3): 293-296.

Wheeler, W. M. 1901. The free-swimming copepods of the Woods Hole region. *Bull. U.S. Fish. Comm.*, 19(1899): 157-192.

Wheeler, E. H., Jr. 1970. Atlantic deep-sea calanoid Copepoda. *Smithson Contrib. Zool*. 55: 1-31.

Wickstead, J. H. 1956. A note on some pelagic copepods from the West Indies. *J. Barbados Mus.*, 26(1): 3-28.

______. 1961. A quantitative and qualitative study of some Indo-West Pacific plankton. *Fish. Publ. Lond.*, 16: 1-200.

Wickstead, J. H. 1965. Pelagic copepods as food organisms. *Abs., Symp. Crust., Mar. biol. Ass. India*, pp. 77-78.

Willey, A. 1923. Ecology and the partition of biology. *Trans. Roy. Soc. Canada*, ser. 3, vol. 17, pp. 1-9.

______. 1919. Report on the Copepoda obtained in the Gulf of St. Lawrence & adjacent waters, 1915. *Contr. Canad. Biol.*, 12: 173-220.

______. 1930. Harpacticoid Copepoda from Bermuda. Part I. Ann. Mag. nat. Hist., ser. 10, 6: 81-114.

______. 1935. Harpacticoid Copepoda from Bermuda. Part II. Ann. Mag. nat. Hist., ser. 10, 15: 50-100.

Williams, L. W. 1906. Notes on marine Copepoda of Rhode Island. American Nat., vol. 40, pp. 639-660.

______. 1907. List of the Rhode Island Copepoda, Phyllopoda, and Ostracoda with new species of Copepoda. Ann. Rep. Comm. Inland Fish. Rhode Island, 37, spec. pap. no. 30, pp. 69-79.

Williams, S. E. 1972. The temporal and spatial variation of selected thecosomatous pteropods from the Florida Middle Ground. Master's Thesis, Florida State Univ. 204 pp.

Wilson, C. B. 1924. New North American parasitic copepods, new hosts, and notes on copepod nomenclature. Proc. U.S. nat. Mus., 64(17): 1-22.

______. 1932a. The copepods of the Woods Hole region. Massachusetts. Bull. U.S. nat. Mus., 158: xix + 635 pp.

______. 1932b. The copepod crustaceans of Chesapeake Bay. Proc. U.S. nat. Mus., 80: 1-54.

______. 1936. Plankton of the Bermuda oceanographic expeditions. IV. Notes on Copepoda. Zoologica, 21(7): 89-93.

______. 1942. The copepods of the plankton gathered during the last cruise of the Carnegie. Publ. Carneg. Instn., 536: v + 237 pp.

______. 1950. Copepods gathered by the United States Fisheries steamer 'Alabatross' from 1887 to 1909, chiefly in the Pacific Ocean. Bull. U.S. nat. Mus., 100, 14: 141-441.

Wilson, D. P. 1951. A biological difference between natural sea waters. J. Mar. Biol. Assn. U.K., vol. 30, pp. 1-20, pl. 1-2.

Wilson, D. P. and F. A. J. Armstrong. 1952. Further experiments on biological differences between natural sea waters. Jour. Mar. Biol. Assn. U.K., vol. 32, pp. 335-349.

Wilson, M. S. 1949. A new species of copepod of the genus Corycaeus from the North American coast. Proc. U.S. nat. Mus., 99(3239): 321-326.

______. 1958. A review of the copepod genus Ridgewayia (Calanoida) with descriptions of new species from the Dry Tortugas Florida. Proc. U.S. nat. Mus., 108: 137-179.

With, C. 1915. Copepoda I. Calanoida Amphascandria. Dan. Ingolf-Exped., 3(4): 1-260.

Wolfenden, R. N. 1902. The plankton of the Faroe Channel and Shetlands. Preliminary notes on some Radiolaria and Copepoda. J. Mar. biol. Ass. U.K., 6(3): 344-372.

_______. 1903a. On the copepod subfamily Aetidiinae, with a proposed revision of the classification. Rep. 72nd Meet. brit. Ass. pp. 263-267.

_______. 1903b. Notes on Ceopepoda. In Fowler, G. H. Contribuitons to our knowledge of the plankton of the Faeroe Channel No. 8. Proc. zool. Soc., Lond., 1903 (1): 117-133.

_______. 1904. Notes on the Copepoda of the North Atlantic Sea and the Faroe Channel. J. Mar. biol. Ass. U.K., n.s., 7(1): 110-146.

_______. 1905, 1906a. Plankton studies. Parts I and II. Rebman, Ltd., London. Pp. 1-24 + pls. 1-7; pp. 25-44 + pls. 8-14.

_______. 1906b. Notes on the collection of Copepoda. The fauna and geography of the Maldive and Laccadive Archipelagoes, 2: 989-1040 + pls. 96-100.

_______. 1908. Crustacea. VIII. Copepoda. National Antarctic Expedition 1901-1904, 4 (Zool.): 1-46.

_______. 1911. Die Marinen Copepoden der Deutschen Sudpolar Expedition 1901-1903. Dtsch. Sudpol-Exped. Bd. 12, Zool. 4: 183-380 + 20 pls.

Wood, E., M. J. Youngbluth, P. Yoshioka and M. J. Canoy. 1975. Cabo Mala Pascua Environmental Studies. Puerto Rico Nuclear Center, UPR, Mayaguez, PRNC-188, 95 pp.

Wood, E. J. F. 1954. Dinoflagellates in the Australian region. Aust. Jour. Mar. Freshw. Res., vol. 5, pp. 171-351.

Woodmansee, R. A. 1958. The seasonal distribution of the zooplankton off Chicken Key in Biscayne Bay, Florida. Ecology, 39(2): 247-262.

Wormelle, R. L. 1962. A survey of the standing crop of plankton of the Florida Current. VI. A study of the distribution of the pteropods of the Florida Current. Bull. Mar. Sci. Gulf Caribb., 12(1): 95-136.

Wust, G. 1964. Stratification and circulation in the Antillean-Caribbean Basins. Part One, Spreading and mixing of the water types. Columbia Univ. Press, New York, 201 pp.

Yount, J. L. 1954. The taxonomy of the Salpidae (Tunicata) of the Central Pacific Ocean. Pac. Sci. 8: 276-330.

Zoppi, E. 1961. Distribución vertical del zooplancton en el Golfo y extremo este de la Fosa de Cariaco. Bol. Inst. Oceanogr. Univ. Oriente, 1: 3-31.

_______. 1961. Medusas de la región este de Venezuela. _Bol. Inst. Oceanogr. Univ. Oriente_, 1(1): 1-19.