ROSENSTIEL SCHOOL OF MARINE AND ATMOSPHERIC SCIENCE
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TECHNICAL REPORT

ST. CROIX: SUPPLEMENT TO A SOURCE BOOK OF OCEANOGRAPHIC PROPERTIES AFFECTING BIOFOULING AND CORROSION OF OTEC PLANTS AT SELECTED SITES

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Drs. Barrie Taylor and Jack Fell, along with numerous other RSMAS scientists, technicians, and graduate students worked closely with some of the present authors on the biofouling and corrosion experiment performed near St. Croix during the summer, 1977. Data generated in that effort has contributed significantly to this report.

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1.0 EXECUTIVE SUMMARY

Although St. Croix has not been designated as an area under serious consideration as a site of an early OTEC facility, there is considerable interest in the location because it is representative oceanographically of the northeastern Caribbean Sea. In addition, it fulfills the basic criteria presently established for an OTEC site (i.e., U.S. possession, depths > 1500 m, $\Delta T \geq 20^{\circ}C$). Data for St. Croix are reported using the same format employed for the Straits of Florida, eastern Gulf of Mexico, Puerto Rico, Hawaii, and Guam in Craig, et al. (1978).

The oceanic area north of St. Croix is well represented in the National Oceanographic Data Center's (NODC) station data files; there is reasonable seasonal coverage of salinity, temperature, oxygen and phosphate. Isolated data sets from the literature are available for currents, total suspended matter and trace metals. A recent OTEC-related experiment conducted north of the island in summer, 1977, by the University of Miami, Tracor Marine, and Battelle Pacific Northwest Laboratories has augmented the data available through standard channels. St. Croix is probably the best characterized, potential OTEC site at the present time. Measurements of temperature, salinity, currents, nutrients, dissolved oxygen, pH, and numerous microbiological characteristics have provided a time-series of data for a 2-1/2 month summer period. Some of the data from that experiment are included in this compilation. In addition, heat transfer, biofouling, and corrosion behavior data from simulated OTEC aluminum heat exchanger tubes were collected.

In this report, data from NODC, the open literature, and the recent St. Croix experiment are presented. The criteria for data selection included quality of the measurements, seasonal coverage, and location.

A principle conclusion of this work is that reliable characterization of an OTEC site, in terms of biofouling and corrosion, requires measurements of relevant variables at a frequency similar to that utilized in the RSMAS/OTEC, St. Croix experiment. The variability of each property should be determined for periods as short as the tidal cycle and as long as yearly to fully estimate their impact on OTEC heat exchanger performance.

2.0 INTRODUCTION

This document is a supplement to an earlier report, "A source book of oceanographic properties affecting biofouling and corrosion of OTEC plants at selected sites," by Craig, et al., 1978. The purpose of both the source book and this supplement is to provide site-specific data to engineers and planners involved with OTEC design for use in defining and predicting 1) the nature and extent of biofouling and organic film formation and 2) the corrosion behavior of heat exchanger surfaces used in seawater service. In addition, the data are assessed to determine their scope and validity. Based upon these reviews, areas where data are lacking are identified. Recommendations are provided to encourage subsequent data collection programs at potential OTEC sites.

Like the source book, this work is primarily an archival search. Most of the data reported herein represent a critically reviewed subset of the existing data base. Much of the work previously conducted in the St. Croix area concerned deep water movement from the Atlantic Ocean, over the Anegada and Jungfern Sills into the Caribbean Sea. To complement data secured through literature and computer searches, selected data gathered during a recent RSMAS/OTEC study north of St. Croix are included. Those experiments, conducted by scientists of the Rosenstiel School of Marine and Atmospheric Sciences, on board a Navy barge operated by Tracor Marine, Inc., have provided physical, chemical, and biological water characterization data down to 1500 m for a site approximately 11.5 km off the north central shore of St. Croix. In addition, biofouling and corrosion data for the performance of simulated aluminum heat exchange tubes were gathered simultaneously. Preliminary results of this experiment are described in Hirshman, et al., 1977. The complete data set of the physical oceanographic program and more detailed analysis and discussion can be found in Lee, Munier and Chiu, 1978. Some of their data sets are included in the present work. Aftring, et al. (1977) have reported the biofouling portion of the experiment; Munier and Craig (1977) give the corrosion results. Additional data, acquired chiefly from the National Oceanographic Data Center, characterize other oceanic areas around the island.

The St. Croix site, as defined in Section 4.0, is upstream of the Puerto Rico site covered in the original source book. Since completion of that work, additional data sets for the Puerto Rico site have become available as an update of the NODC Station Data File. For the sake of completeness, some of these data are included here to further define the western portion of the St. Croix site.

For information regarding site selection, oceanographic property selection, data set discussions and search methods, the reader should consult the original source book by Craig, et al. (1978). Section 7.0 of this report lists possible sources of additional data.

3.0 CONCLUSIONS AND RECOMMENDATIONS

Physical Properties

The summer hydrographic properties of the waters north of St. Croix are unusually well identified from repeated salinity/temperature/depth casts (STD) and hydrocasts made by the University of Miami (Lee, Munier and Chiu, 1978) from mid-July to the end of September, 1977. These data are suitable to resolve fluctuations occurring with tidal to monthly periodicities. However, the other seasons are not well covered temporally or spatially. Hence, the conclusions of Section 3.0, Physical Properties, in Craig, et al. (1978) apply, as well, to St. Croix. It is recommended that the time series stations approach used by Lee, Munier and Chiu (1978), be repeated for the other seasons with the addition of subsurface, moored current meters and expendable bathythermograph (XBT) sections.

Chemical Properties

There are substantial oxygen data reported from the St. Croix site for all times of the year. Values for pH have also been reported, although these are mostly from the summer months (Lee, Munier and Chiu, 1978). However, as noted by Munier and Craig (1977), better precision is required for pH measurements to be useful for the calculation of a saturation index for calcium carbonate or the prediction of corrosion rates of metals in seawater.

There are no trace metal data available specifically from within the St. Croix site, although the study of Betzer (1971) provides a regional characterization of particulate Fe distribution in the Caribbean Sea. No Eh or dissolved CO_2 data were found. Qualitatively, however, the RSMAS/OTEC biofouling and corrosion experiment run off St. Croix during the summer, 1977, has indicated that trace metal, Eh, and dissolved CO_2 quantities were not at levels which significantly influenced either the biofouling or corrosion behavior of simulated aluminum OTEC heat exchanger pipes (Aftring, et al., 1977; Munier and Craig, 1977).

It is recommended that a longer term experiment similar to the RSMAS/OTEC experiment of 1977 be run at St. Croix to determine the annual variability of each property and the impact of their fluctuations on the corrosion behavior of aluminum heat exchanger tubes. At least trace metals and dissolved CO_2, and possibly Eh, should be added to the list of variables measured to determine their background concentrations. As mentioned above, pH should be measured with substantially more precision; $\pm$ .01 pH units are recommended.

Biological Properties

There are virtually no data on the abundance and distribution of trace metals in the St. Croix study area. Betzer's (1971) study of the concentration and distribution of particulate Fe in Caribbean transects and Betzer and Pilson's (1970, 1971) analyses of this element in the vicinity of Puerto Rico appear to be the only information available on metals.

Excellent data sets on the vertical distribution of phosphates and silicates are available from NODC, as shown in the examples given in Tables 3-5, as well as, nitrate, nitrite and ammonia from studies done by RSMAS scientists during summer, 1977 (Tables 8-10). Although no nutrients were measured monthly over a year period, the data on nutrient distribution at St. Croix are the best available for any of the six sites.

Microbiological data from St. Croix are the best for any site studied because of the comprehensive, OTEC-specific work done by Aftring, et al. (1977). Numerous microbial parameters were measured, including bacterial counts, ATP, chlorophyll a, primary productivity, particulate organic carbon and nitrogen, and fungi. Since these variables are not reported from other sites, the extrapolation of St. Croix data to other sites for the prediction of microbial potential may be necessary.

As pointed out in the source book, chlorophyll a was not a variable specified in the search for information on biomass, but it was the only one recorded in three of the study areas. At four stations in the St. Croix area, Hargraves, et al. (1970) measured chlorophyll a at 0, 5, 10, 20, 30, 50, and 100 m. These are averaged values collected over a brief period in January, 1968. Aftring, et al. (1977) also reported chlorophyll a data, both from the mixed layer and in profiles to 600 m.

The recommendations for further investigation are the same as those which conclude Section 3.0, Biological Properties, in the source book (Craig, et al., 1978). It is therefore recommended that (1) potential sites for further evaluation be selected from the five presently under consideration, (2) positions within these sites be selected to serve as station(s) for intensive examination, (3) biological studies be initiated simultaneously and continued on the same schedule in these areas, (4) the stations be sampled monthly, or more frequently if needed, over a period of days in order to record diurnal changes, during one year or more, if needed, and (5) the biological study area be restricted to that part of the water column directly, or indirectly through upwelling or other phenomena, affecting the waters entering the warm water intake. Ideally, the variables to be measured would include:

1) Trace metals

2) NO_3–N and SiO_3

3) ATP

4) bacteria, fungi and other "nannoplankton" (<2 - 20μ)

5) net plankton (>20μ - 2 mm in greatest dimension)

6) macrozooplankton (2 mm - 15 or more cm in greatest dimension).

4.0 ST. CROIX

Site Description

The U.S. Virgin Islands are part of the island chain separating the Caribbean Sea from the Atlantic Ocean (Figure 1). There are three large islands in the group: St. Thomas and St. John, which are within four miles of each other and at the same latitude as Puerto Rico. St. Croix is 40 nautical miles south of St. Thomas/St. John and is wholly within the Caribbean Sea, whereas St. Thomas/St. John border the Atlantic Ocean to the north and the Caribbean to the south.

The Virgin Islands area, particularly the oceanic waters immediately north of St. Croix, is under consideration as a potential OTEC site because it fulfills the following criteria:

1) U.S. possession
2) Tropical location combined with oceanic depths (>1500 m), thus insuring an adequate year-round ΔT ($\geq 20^{\circ}C$)
3) Proximity to user.

For the purposes of this work, we originally limited the site to the area between 17 and 18°N, and 64 and 65°W, which includes, in 10 degree 1008, the two 1/4-degree squares 74–4 and 84–2, as shown in Figure 2. However, in order to better characterize the waters adjacent to the western coast of the island, the site was expanded to include the eastern half of 1-degree square 75. Although this square was searched as part of the Puerto Rico study, a recent update of the NODC file has made available substantial new data applicable to both sites.

Bathymetry

The bathymetry of the study area is shown in Figure 3. The dominant feature is the Virgin Islands Basin, which has a flat floor 4400 m deep. To the north and south, the basin is bounded by sea scarps having apparent slopes of 9 to 43 degrees (Frassetto and Northrop, 1957). The eastern end of the basin is divided into two arms which embrace a 770 m knoll. Both of these arms terminate at sills which separate them from Anegada Passage and the St. Croix Basin. To the west, the Virgin Island Basin is bounded by the Grappler Bank and to the southwest by the Jungfern Passage.

The Anegada and Jungfern Passages are the deepest pathways for deep water renewal between the Atlantic Ocean and the Virgin Island Basin, and the Virgin Island Basin and the Caribbean Sea, respectively. The Anegada Sill is 1915 m deep and is located between Barracuda Bank and Virgin Gorda (Stalcup and Metcalf, 1973). The Jungfern Sill is located just southwest of St. Croix and is shallower than the Anegada Sill (1815 m) (Frassetto and Metcalf, 1957; Stalcup and Metcalf, 1973). Hence, the Jungfern Sill is one of the limiting factors in exchange of deep water between the Atlantic Ocean and the Caribbean Sea.

The island of St. Croix is surrounded by a narrow insular shelf which drops precipitously along the northern shore. The shelf is particularly narrow along the northwest shore, where the break is only 100-200 m from shore. The shelf south of

Figure 1. Bathymetry of the Caribbean Sea showing passages with sill depths greater than 100 m (from Wüst, 1964).

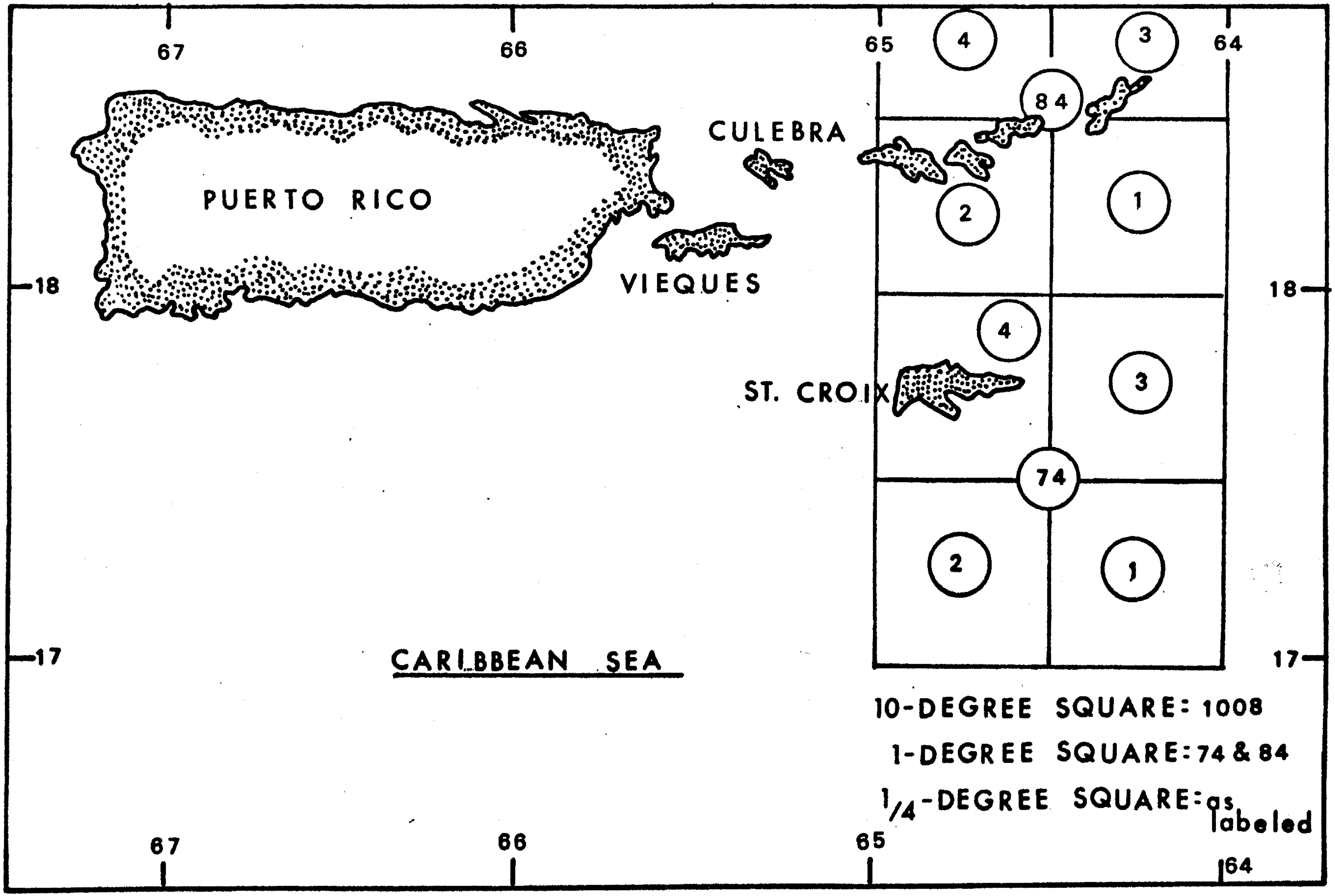


Figure 2: Specific site boundaries for St. Croix. Also indicated are the grid locators used for reporting surface current data (SCUDS).

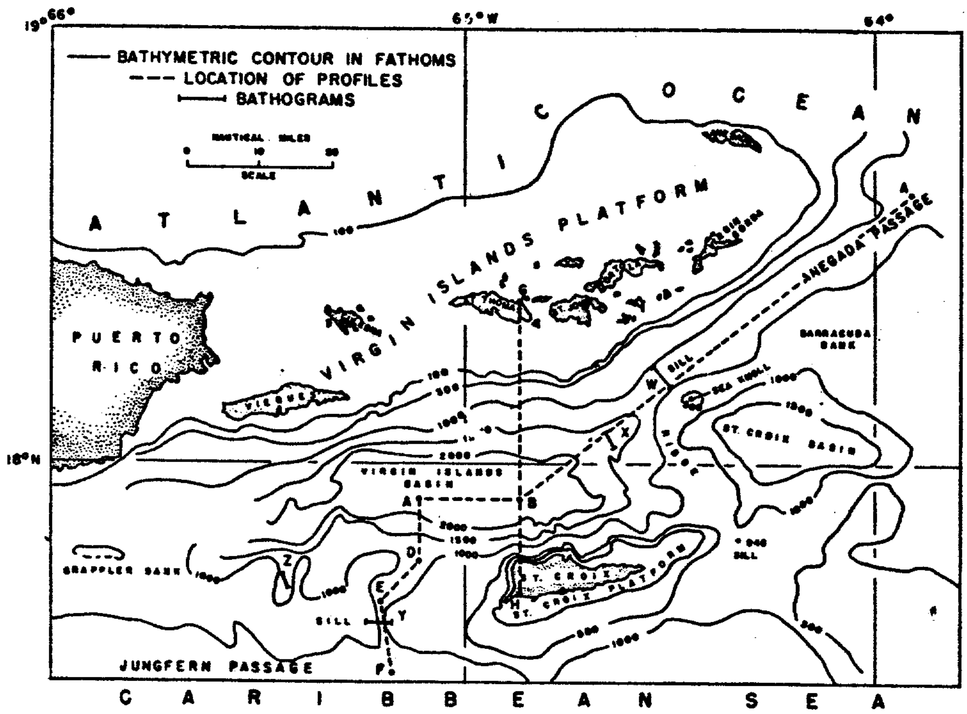


Figure 3: General bathymetry of the U.S. Virgin Islands area (from Frassetto and Northrup, 1957).

St. Thomas and St. John delineates, for all practical purposes, the northern boundary of the study area. It is wider than the St. Croix shelf, averaging approximately 16 km.

Geology

St. Croix is comprised predominately of sedimentary rocks which have been uplifted, folded, and faulted since the late Cretaceous. The oldest sediments are of volcanic origin, probably from the erosion of volcanic rocks located to the north of the island and subsequently deposited on the sea floor via turbidity currents (Caledonia formation). Interbedded with volcanic sands are mudstones, indicating periods of oceanic, fine-grained deposition between turbidity current events.

After the turbidite/mudstone deposition near the end of the Cretaceous, volcanoes to the south and southeast shed volcanic debris northward which was deposited at the present location of St. Croix. These deposits are manifested in the tuffaceous formations seen over much of the northwest portion of St. Croix today.

The emergence of St. Croix as an island took place in the late Oligocene as compressional forces induced uplift, folding, and subsequent faulting. As the land mass emerged, coral reefs occupied the near shore zones accounting for the Kingshill marl and other carbonate, reef-type rocks found predominantly in the central portion of the island.

The Virgin Islands Basin north of St. Croix undoubtedly contains a Cretaceous, deep-water sequence similar to that exposed on St. Croix, overlain by recent sediments. The unconsolidated bottom sediments are principally coarse grained and derived from the erosion of the coral reefs which surround the island (W.D. Bock, pers. comm., 1977).

St. Croix lies near the northern margin of the Caribbean Plate and, hence, is in the vicinity of a relatively active seismic zone. The probability of an earthquake affecting the island, however, is low.

Climate

St. Croix has a marine tropical climate dominated by the easterly trades, which are reasonably steady for at least 10 months of the year. The average, mean air temperature is 26°C with an annual range of only ± 2°C. The remarkably consistent weather is rarely interrupted by fog, high humidity, or thunderstorms. Forty-one years of weather data collected at Christiansted, St. Croix (1875-1916) are summarized in Table 1.

A slight seasonal variation of the trade winds is observed. Speeds are generally highest from mid-summer through winter (15-25 knots) and decrease in the spring and early summer. 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.

Easterly waves occasionally affect the Virgin Islands area. During summer, 1977, two waves passed in the vicinity of St. Croix bringing high winds (40 knots) and heavy rains. These tropical waves form to the north of the intertropical convergence zone in the deep easterly current that flows clockwise around the southern portions of the Azores anticyclone (H.O. Pub. 22, 1963).

Annual rainfall on St. Croix is highly variable and a function of island location. The eastern end of the island is dry, as evidenced by its vegetation, and averages 60 cm of rainfall yearly, whereas the western end averages more than twice that amount. Droughts, however, are not uncommon and can affect the entire island. There is no real rainy season, although late winter and spring are historically the driest months.

There are few data to substantiate the applicability of rainfall data from the island in characterizing the nearby oceanic areas. It is probable, however, that the offshore rainfall pattern resembles that of the dry eastern portion of the island; the mountains of the west end certainly induce the additional rainfall received there.

Hurricanes

Hurricane paths occasionally cross the St. Croix area. The reader is referred to the chart of recent hurricanes which have affected the northeastern Caribbean (Figure 4). The last hurricane to hit St. Croix occurred in 1928. Based on the work of Millas (1965), only five hurricanes struck St. Croix in the entire 18th Century. Millas determined that the mean number of hurricanes which passed through the Caribbean was eight per year, only two of which strike an island. Naturally, the effects of most hurricanes are widely felt, whether or not they strike land. The potential impact of a hurricane at an OTEC site has been discussed previously (see Sections 4.1, 4.2, 4.3 in Craig, et al., 1978) and will not be repeated here.

Currents

The Caribbean Current defines that part of the North Atlantic Gyre which flows westward through the Caribbean Sea. This current is made up of waters from the north and south equatorial regions that enter the Caribbean through passages in the Lesser Antilles. The total volume transport of this flow is estimated at 31×10^6 m^3/sec to the west (Gordon, 1967). The axis of the flow is in the southern portion of the Caribbean. The current exits the Caribbean through the Yucatan Straits, loops through the northeast Gulf of Mexico and finally emerges from the Florida Straits in about the same state as when leaving the Caribbean. Worthington (1971) found that no water colder than 6°C leaves the Caribbean through the Straits of Florida and that circulation of water below this isotherm within the Caribbean must be slight. The average volume transport leaving the Florida Straits is 32×10^6 m^3/sec. The slight increase in transport can be accounted for by weak westward contributions through the northern passages, Anegada and Windward (Gordon, et al., 1967).

Wüst (1964) indicates that surface current flow in the vicinity of St. Croix is generally WNW at rates up to 2 knots for both October and July. These diagrams are reproduced in the Puerto Rico site description of the Source Book and thus are not repeated here (see Craig, et al., 1977, Section 4.3). Gordon, (1967) also found

Summary of Danish Weather Records at Christiansted, St. Croix, 1875–1916*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Mean max. temp. (17 yrs., 1900–16) °F.	80.8	80.8	81.7	82.8	84.9	85.6	85.8	86.2	86.5	85.8	84.2	82.0	83.9
Mean min. temp. (17 yrs.) °F.	72.3	71.8	72.1	73.6	75.6	76.6	77.0	77.5	77.0	76.3	75.2	73.6	74.9
Mean temp. (17 yrs.) °F.	76.6	76.3	76.9	78.2	80.2	81.1	81.4	81.8	81.8	81.0	79.7	77.8	79.3
Mean temp. (28 yrs., 1892–1916) °F.	76.6	76.3	76.8	78.3	79.9	81.0	81.5	82.0	81.7	80.8	79.3	77.5	79.3
Highest temp. (33 yrs., 1882–1915) °F.	86	87	91	91	95	96	94	91	91	91	92	91	96
Lowest temp. (33 yrs.) °F.	65	66	64	67	69	69	70	70	69	69	69	65	64
Relative humidity:													
mean (8 A.M. + 2 P.M. + 9 P.M.) (17 yrs.) %	74	73	72	72	74	76	74	75	77	78	78	77	75
mean (2 P.M.) (4 yrs., 1913–16) %	68	70	65	68	72	69	69	69	70	72	75	72	70
Cloudiness: mean (8 A.M. + 2 P.M. + 9 P.M.) (19 yrs.) tenths of sky	3.7	3.5	3.5	3.7	4.0	4.4	4.3	3.9	4.0	3.9	3.7	3.7	3.9
Rainfall: mean (37 yrs., 1875–1916) inches	2.32	2.05	1.24	2.97	4.39	4.53	3.46	4.26	5.59	5.88	5.89	3.87	46.43
Ave. no. days with rain (37 yrs.)	13	10	7	8	11	11	12	12	12	13	14	13	136
Ave. no. of thunderstorms (19 yrs.)	0.2	0.05	0.05	0.4	2	2	2	3	2	3	1	1	16
Prevailing wind dir. (to nearest 8 points) (4 yrs.)	E	E	E	E	E	E	E	E	E	E	E	E	E

* Reed, W. W. U. S. Mon. Wea. Rev. pp. 133–160. April 1926. Based on Dr. Neumann's records published in the Yearbooks of the Danish Meteorological Institute, Copenhagen, 1875–1916. They were taken in the town proper near sea level, and with standard instruments. The instructions of the Danish Meteorological Institute were followed. There were no observations for 1878–81, and those for 1876, 1877, 1899, and 1916 were not complete for all months.

Table 1: Summary of Danish weather records at Christiansted, St. Croix for the period 1875-1916 (from Stone, 1942).

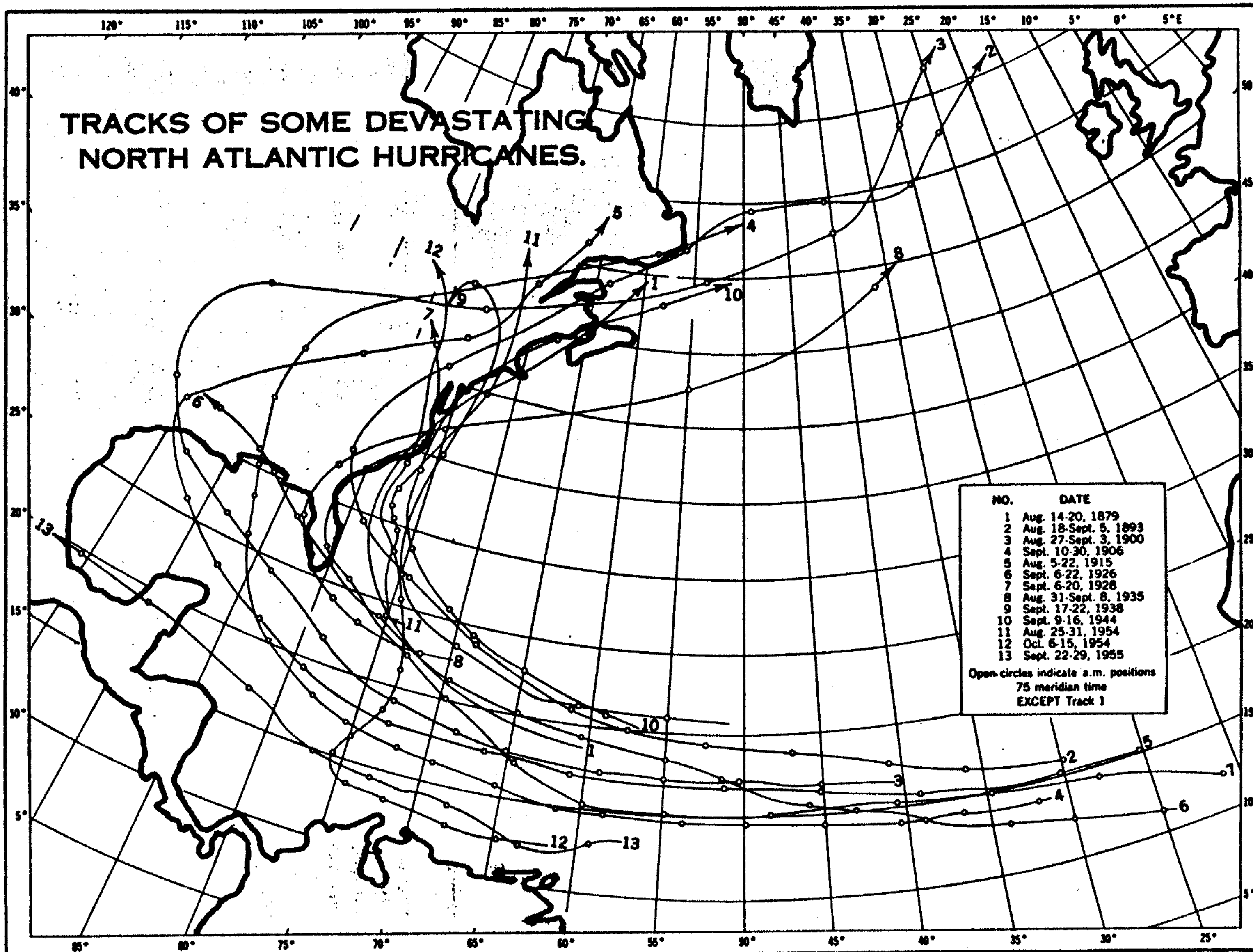


Figure 4: Tracks of some devastating North Atlantic Hurricanes between 1879 and 1955 (from H. O. Pub. 21, Vol. I).

that geostrophic flow (a current resulting from the balance between horizontal pressure gradient and Coriolis forces) down to 850 m near the south shore of St. Croix is to the west at about 6-10 cm/sec. Surface current (SCUDS) data show normal current ranges of 20 to 80 cm/sec spanning all seasons, with NW currents of about 40 cm/sec "average" (Table 2). Occasionally, easterly flows were reported. Drift bottle returns of Metcalf and Stalcup (1974) indicate a general NW flow near the Virgin Islands and Puerto Rico. Bottles released near St. Croix were first stranded on the south shores of Hispaniola, then on the south shore of Puerto Rico and then on Puerto Rico's east shore (on different experiments). Metcalf and Stalcup (1974) related these more northerly returns to a wind shift from ENE to E coupled with the Coriolis force causing a NE wind drift. However, Burns (1977) computed a direction of 10° to the right of the wind for drift currents at the latitude of St. Croix, therefore, an east wind should produce a surface drift toward 260°. The speed of the surface drift should be approximately 3% of the wind speed. Burns (1977) measured the deep currents west of St. Croix with 8 current meters deployed in water depths of 747 to 1064 m. The mean speeds ranged from 5 to 10 cm/sec with extremely variable directions due to the lee effect of St. Croix. The M_2 tidal constituent had speeds of 2-6 cm/sec and accounted for only 10-20% of the total current variability.

Data collected by the University of Miami (Lee, Munier and Chiu, 1978) during the summer, 1977, demonstrate substantial variability of the surface current flow north of St. Croix. Current reversals on time scales of hours to weeks were common, substantiating the contention of Atwood, et al. (1976) that the probability of surface currents from the east or west in the northeastern Caribbean is near 50:50. Typical speeds ranged from 10 to 40 cm/sec.

Water Masses

The water mass stratification north of St. Croix is nearly identical to that described previously for the Puerto Rican site, 100 km downstream. The following discussion is based on recent STD data collected by the University of Miami at a site 11.5 km north of St. Croix during the summer, 1977 (Lee, Munier and Chiu, 1978).

The upper layer is made up of Tropical Surface Water (TSW) to a depth of about 100 m and is characterized by temperatures between 26 and 29°C. Salinities vary between 34 and 36°/oo, depending upon the season and recent meteorological events. The general characteristics of this water mass originate in the tropical rain belt of the equatorial trough. TSW is influenced by freshwater input from the Amazon and Orinoco Rivers and can be significantly modified during transport by mixing and air-sea exchange.

Subtropical Underwater (SUW) lies beneath the TSW in a layer 100 to 200 m thick. It is formed beneath the subtropical Bermuda high, a zone of high evaporation, and low precipitation. Hence, the water mass is characterized by a salinity maximum of 37.2 to 37.3°/oo. The range of salinity is 36.8 to 37.7°/oo. The temperature is 22.3°C at its core and ranges from 20 to 24°C. During summer, 1977, the salinity maximum was seen to decrease in depth from 175 m in July to 150 m in September. There is a steep density gradient at the interface between the surface mixed layer and the Subtropical Underwater.

Beneath SUW is a transition zone of North Atlantic Central Water (NACW), below which Antarctic Intermediate Water (AIW) is found between 600 and 1000 m. The AIW core is at approximately 850 m as indicated by a salinity minimum of 34.9°/oo and a temperature of 6.4°C. Below 1000 m is North Atlantic Deep Water (NADW), which is characterized by temperatures between 5.2 and 4.0°C and salinities near 35.05°/oo.

The Caribbean Sea is strongly stratified in the upper 1200 m, weakly stratified from 1200-2000 m, and homogeneous below 2000 m. Gordon (1967) shows that this stratification is directly related to the sill depths of the Antillean Arc. Most of the Caribbean Sea water enters through the Lesser Antilles passages (sill depths <1200 m). This includes the TSW, SUW, NACW, AIW, and the upper portion of NADW. Deep and bottom water of the Caribbean basins are believed to be renewed through the deeper Anegada and Windward Passages of the Greater Antilles. The deepest passage into the Caribbean Sea leads from the Atlantic into the Virgin Island Basin via the Anegada Passage (sill depth - 1815 m, Stalcup and Metcalf, 1973).

The source of Venezuela Basin deep water is somewhat debatable. Worthington (1966, 1971) argues that the deep water is resident within the basin. Sturges (1965) was of the same opinion, but more recent current meter measurements in the Jungfern Passage (Sturges, 1970) indicate that sporadic inflow surges do occur. Froelich and Atwood (1974) also uses hydrographic data to indicate that deep water renewal is occurring over the Jungfern Sill. There is no disagreement that deep water of the Virgin Island Basin is renewed by NADW through the Anegada Passage.

Tides

The tidal range near St. Croix is generally small. The spring tide range is typically 30-35 cm and markedly diurnal; neap tides have a range of 10-15 cm and are a mixture of both diurnal and semi-diurnal components. A typical tide curve from eastern St. Croix is shown in Figure 5.

Sea and Swell

Sea and swell are from the eastern quadrant the entire year and essentially follow the seasonal variations of the trade winds described above. Average sea and swell conditions for the Virgin Islands are given in Figure 6. Near St. Croix, the seas are generally steep and of short period. Ground swells which accompany northers from the Atlantic do not usually affect St. Croix because it is protected to the north by the other Virgin Islands.

Data Discussion

Station locations of the hydrographic and STD data included in this section are shown in Figure 7. Representative summer and winter profiles are shown in

Figures 8, 9, and 10. Representative monthly profile data are given in Tables 3-13 inclusive. Two sets of total suspended matter data are given in Table 14.

The general characteristics of the waters off St. Croix are virtually the same as previously discussed for the Puerto Rico site because of St. Croix's 100 km upstream location.

Temperature

Temperature data reveal a surface mixed layer that varies in thickness annually from a minimum of about 20 m in summer to a maximum of around 100 m in winter. Surface temperatures vary seasonally about 3°C from 29°C in summer to 26°C in winter. Below the surface mixed layer, temperature decreases rapidly in the thermocline to about 5°C at a depth of 1100 to 1200 m. From that point to the bottom, temperature decreases slowly to a minimum of approximately 3.8°C. Annual temperature variations below 1200 m were less than 1°C from about 4.8 to 3.8°C. A vertical temperature differential (ΔT) of 20°C or greater was always present in the upper 1000 m of the water column.

The depth required to reach a ΔT of 20°C was maximum in the winter at approximately 950 m. During the summer, this distance decreased to a minimum of 630 m in October, due primarily to surface heating.

Salinity

General features of the vertical salinity structure are discussed in the water mass section. Greatest variations in the surface mixed layer, where salinities range from 34.09°/oo to 36.45°/oo (2.36°/oo change) with higher values occurring in the early spring and lower values in the late summer. However, variations of 2°/oo were measured in the 2-month University of Miami study during the summer, 1977 (Lee, Munier and Chiu, 1978).

Salinities below the mixed layer show smaller variations. A salinity maximum occurs within the layer of Subtropical Underwater (salinity range: 36.5 to 37.3°/oo). A salinity minimum of about 34.8°/oo was found near 700 m in the Antarctic Intermediate Water. Below 1000 m, salinity remains nearly constant at approximately 35°/oo.

Turbidity

Turbidity measurements from within the actual St. Croix site are not available. Total suspended matter (TSM) measurements are reported by Bassin (1975) for an area just downstream (west) of the site. These data (Table 14) are not directly comparable to the Secchi disc, water transparency data reported for the sites covered in the source book. Near surface TSM values are significantly higher than those from greater depths. In general, the area north of St. Croix is typical of clear, open ocean conditions.

Currents

Most reports in the literature indicate that currents north of St. Croix should be in a general westward direction with speeds around 10-50 cm/sec. Current measurements made by the University of Miami at a depth of 10 m below a Tracor barge moored north of the island (Lee, Munier & Chiu, 1978) show that surface currents were toward the east at speeds of approximately 25 cm/sec during the first 2.1 weeks of the study, a 180° reversal from normal. Near surface currents were highly variable in direction during periods of low current speeds. Current direction reversals of 180° from due west were common when current speeds were less than 25 cm/sec. During spring tide conditions, when tidal sea level fluctuations were diurnal, a strong, diurnal tidal current develops with speed amplitudes of about $\pm$25 cm/sec and 180° direction reversals. During a 12-day period in the middle of August, the near surface current increased in speed to range between 25 to 50 cm/sec toward the west with very little directional deviation that was not related to local wind. This abrupt shift in the character of the current was accompanied by a similar rapid increase in salinity of the surface mixed layer suggesting the transient advection past the barge of patches of near surface waters of different salinities. Surface current (SCUDS) data (Table 2) show surface currents toward the WSW ranging from 20 to 80 cm/sec, spanning all seasons with "average" currents toward the NW at about 40 cm/sec.

pH

Information on pH levels in the St. Croix site are not available in the literature or from NODC. The only site-specific data available were gathered during the RSMAS/OTEC experiment of July-September, 1977. Daily measurements were made at the intake depth (~20 m). These pH values range between 8.10 and 8.25 averaging about 8.16 (see Table 8). Monthly pH measurements were made at approximately the 0, 20, 50, 100, 200, 400, 600, 900, 1200 and 1500 m levels. Surface values are highest (i.e. most alkaline). Values gradually decrease with depth reaching about 7.7 at roughly 900 m. Below that level, pH gradually increases to 1500 m (see Tables 8, 10 and Figure 9).

Dissolved CO_2, Eh and Trace Metals

No dissolved CO_2, Eh or trace metal data are available for the site under consideration in this work.

Oxygen

The distribution of dissolved oxygen in the waters north of St. Croix follows typical oceanic conditions. In the upper 100 m, dissolved oxygen concentration is highest, approaching 5.0 ml/l. Dissolved oxygen decreases gradually with depth, reaching a minimum value of about 3.0 ml/l in the 600-800 m depth range. This minimum corresponds to the level of maximum nutrient concentration. Between 800 and 1000 m, dissolved oxygen increases slightly to about 4.0 ml/l, a result of incoming oxygen-rich polar waters. Dissolved oxygen concentrations are not a limiting factor to biological processes in the upper 1500 m.

Nutrients

Nutrient concentrations at St. Croix are comparable to those determined at the nearby Puerto Rico site by Atwood, et al. (1976). Measurements of nitrates, phosphates and silicates made by Aftring et al. (1978) showed that nutrient levels near the surface are low, as in other oceanic areas of the southwestern North Atlantic. Increases in nutrient concentrations with depth are recorded in NODC and RSMAS profiles (Tables 3, 4, 6-10, 13). In the upper 200 m, silicate concentrations range from less than 1 to 2 µg-atoms/l, while less than 1 µg-atoms/l of nitrate is present. Silicate increases to 15-28 µg-atoms/l at 1500 m and nitrate reaches a maximum of nearly 13 µg-atoms/l at approximately 1000 m. Phosphate levels increase from a minimum of approximately 0.02 µg-atoms/l near the surface to a maximum of as much as 2.15 µg-atoms/l at depths of 750-1200 m, below which there is a gradual decrease.

Microbial Cell Counts

The RSMAS study of July-September, 1977, showed that populations of aerobic heterotrophic bacteria, yeasts and filamentous fungi were relatively small, comparable with those of surface waters in tropical open oceans. However, the presence of species of filamentous fungi and possibly some of the yeasts is evidence of terrestrial influence at the site. Other biological features associated with measurements of productivity, e.g. concentrations of ATP and chlorophyll a, were similarly low in level. Representative microbiological data collected during the study are given in Tables 15 and 16. Other variables related to and/or influencing microbial populations, e.g. primary productivity, light penetration, and particulate organic nitrogen and carbon, were measured. The interested reader is referred to the report by Aftring et al. (1978).

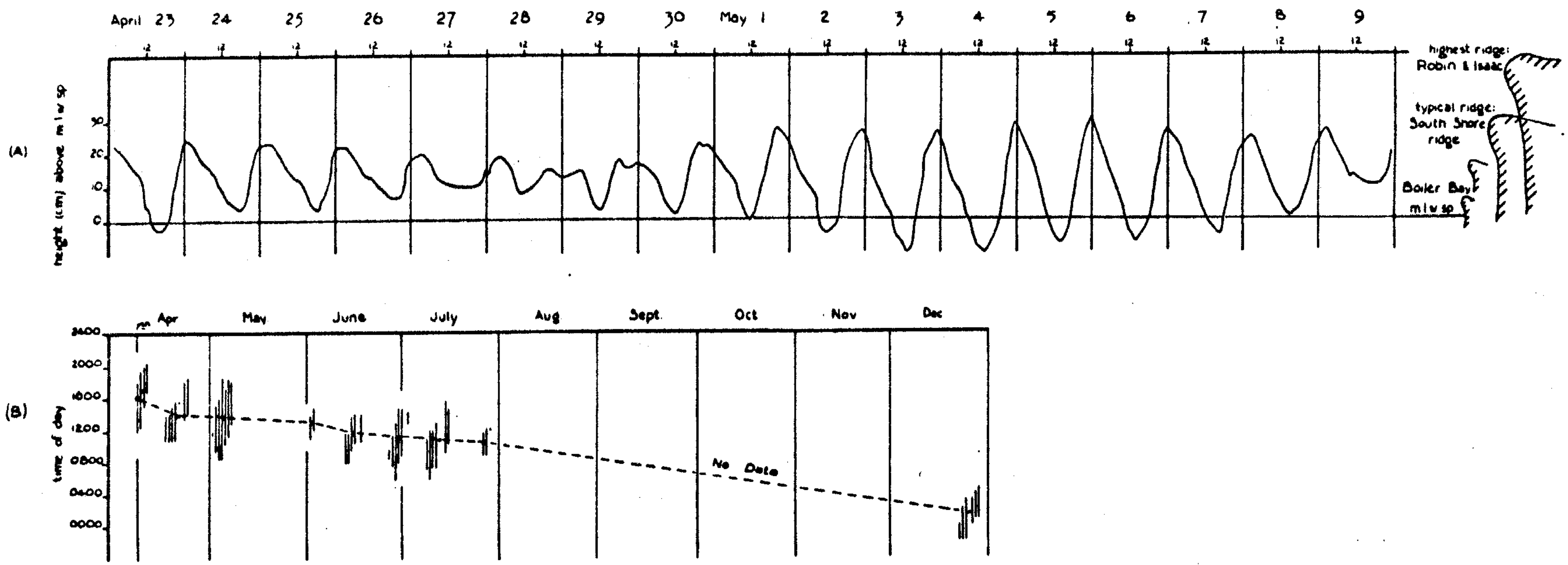
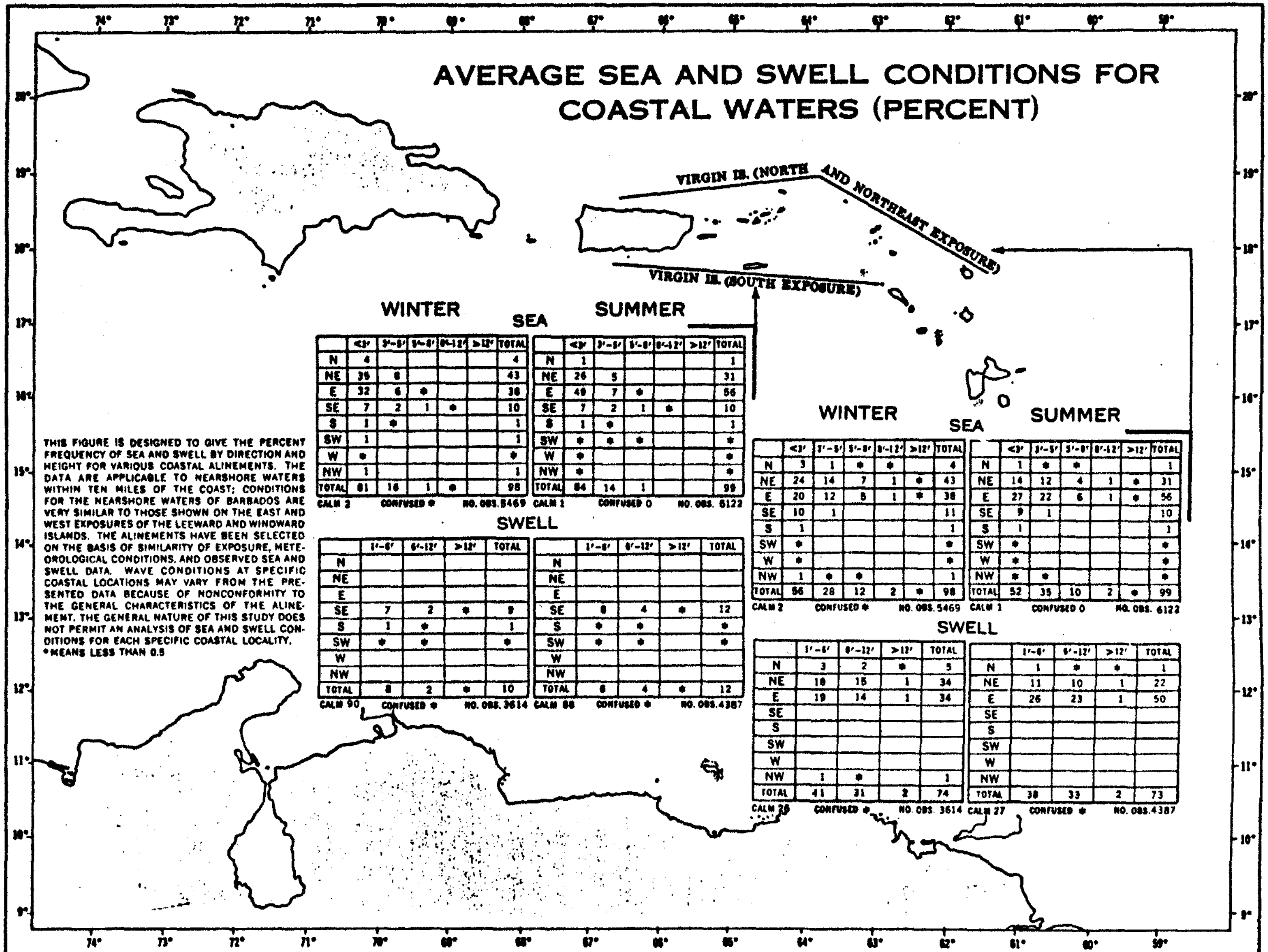


Figure 5: Typical tide patterns on eastern St. Croix. A) Bi-monthly cycle at West Indies Laboratory dock for late April and early May, 1973. Level of mean low water springs based on tides for April to June, 1973. B) Times of occurrence of tide levels at or below mean low water springs. April-December, 1973 (from Adey, 1975).



Virgin Is. (South Exposure) — SEA — WINTER

	<3'	3'-5'	5'-8'	8'-12'	>12'	TOTAL
N	4					4
NE	35	8				43
E	32	6	*			38
SE	7	2	1	*		10
S	1	*				1
SW	1					1
W	*					*
NW	1					1
TOTAL	81	16	1	*		98

CALM 2 CONFUSED * NO. OBS. 5469

SEA — SUMMER

	<3'	3'-5'	5'-8'	8'-12'	>12'	TOTAL
N	1					1
NE	26	5				31
E	49	7	*			56
SE	7	2	1	*		10
S	1	*				1
SW	*	*	*			*
W	*					*
NW	*					*
TOTAL	84	14	1			99

CALM 1 CONFUSED 0 NO. OBS. 6122

SWELL — WINTER

	1'-6'	6'-12'	>12'	TOTAL
N				
NE				
E				
SE	7	2	*	9
S	1	*		1
SW	*	*		*
W				
NW				
TOTAL	8	2	*	10

CALM 90 CONFUSED * NO. OBS. 3614

SWELL — SUMMER

	1'-6'	6'-12'	>12'	TOTAL
N				
NE				
E				
SE	8	4	*	12
S	*	*		*
SW	*	*		*
W				
NW				
TOTAL	8	4	*	12

CALM 88 CONFUSED * NO. OBS. 4387

Virgin Is. (North and Northeast Exposure) — SEA — WINTER

	<3'	3'-5'	5'-8'	8'-12'	>12'	TOTAL
N	3	1	*	*		4
NE	24	14	7	1	*	43
E	20	12	5	1	*	38
SE	10	1				11
S	1					1
SW	*					*
W	*					*
NW	1	*	*			1
TOTAL	56	28	12	2	*	98

CALM 2 CONFUSED * NO. OBS. 5469

SEA — SUMMER

	<3'	3'-5'	5'-8'	8'-12'	>12'	TOTAL
N	1	*	*			1
NE	14	12	4	1	*	31
E	27	22	6	1	*	56
SE	9	1				10
S	1					1
SW	*					*
W	*					*
NW	*	*				*
TOTAL	52	35	10	2	*	99

CALM 1 CONFUSED 0 NO. OBS. 6122

SWELL — WINTER

	1'-6'	6'-12'	>12'	TOTAL
N	3	2	*	5
NE	18	15	1	34
E	19	14	1	34
SE				
S				
SW				
W				
NW	1	*		1
TOTAL	41	31	2	74

CALM 26 CONFUSED * NO. OBS. 3614

SWELL — SUMMER

	1'-6'	6'-12'	>12'	TOTAL
N	1	*	*	1
NE	11	10	1	22
E	26	23	1	50
SE				
S				
SW				
W				
NW				
TOTAL	38	33	2	73

CALM 27 CONFUSED * NO. OBS. 4387

Figure 6: Average Sea and swell conditions for coastal waters (per cent). Data are applicable to nearshore waters within 16 kilometers of the coast (from H. O. Pub. 22, Vol. II).

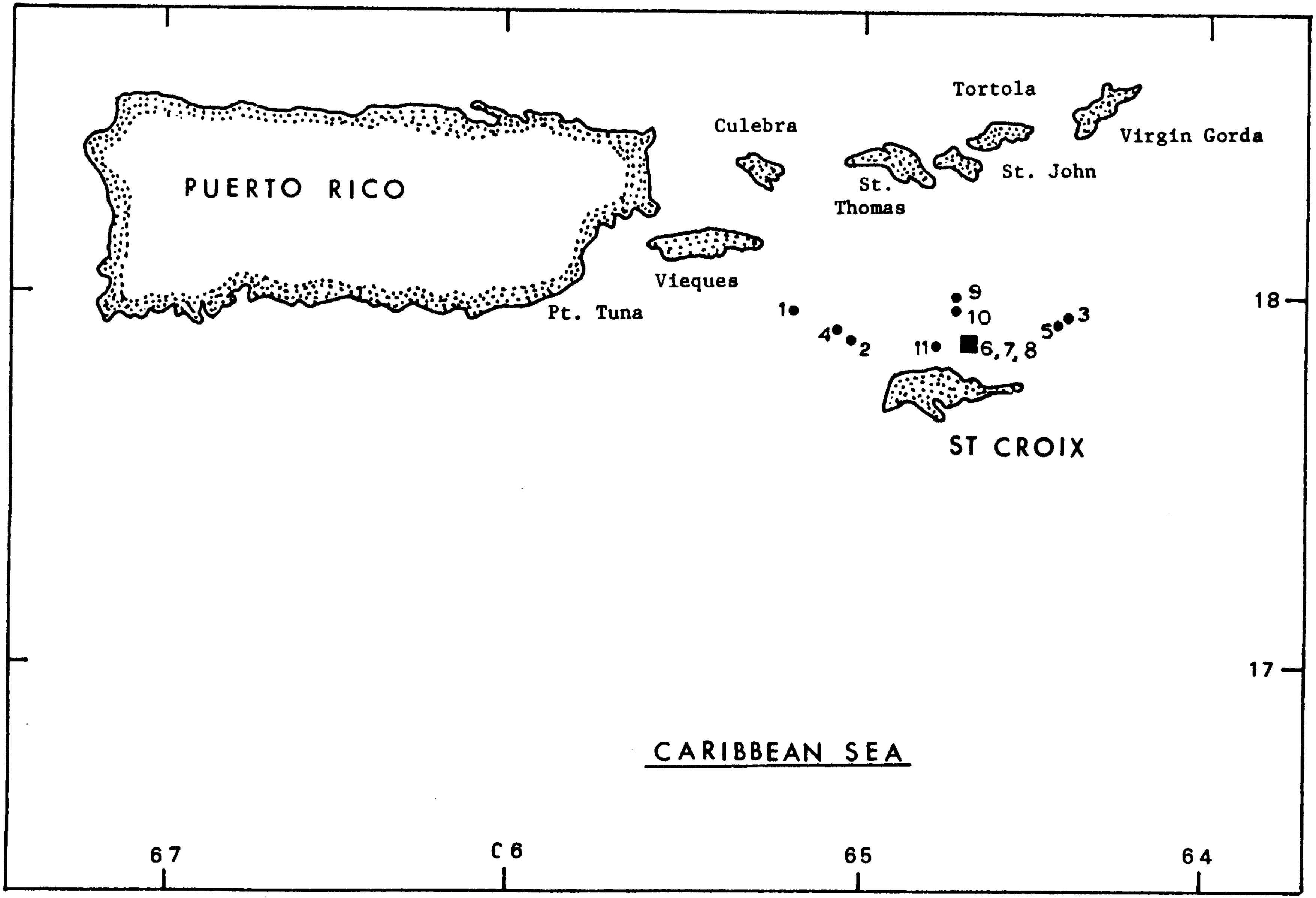


Figure 7: Station locations of data sets for St. Croix Site.

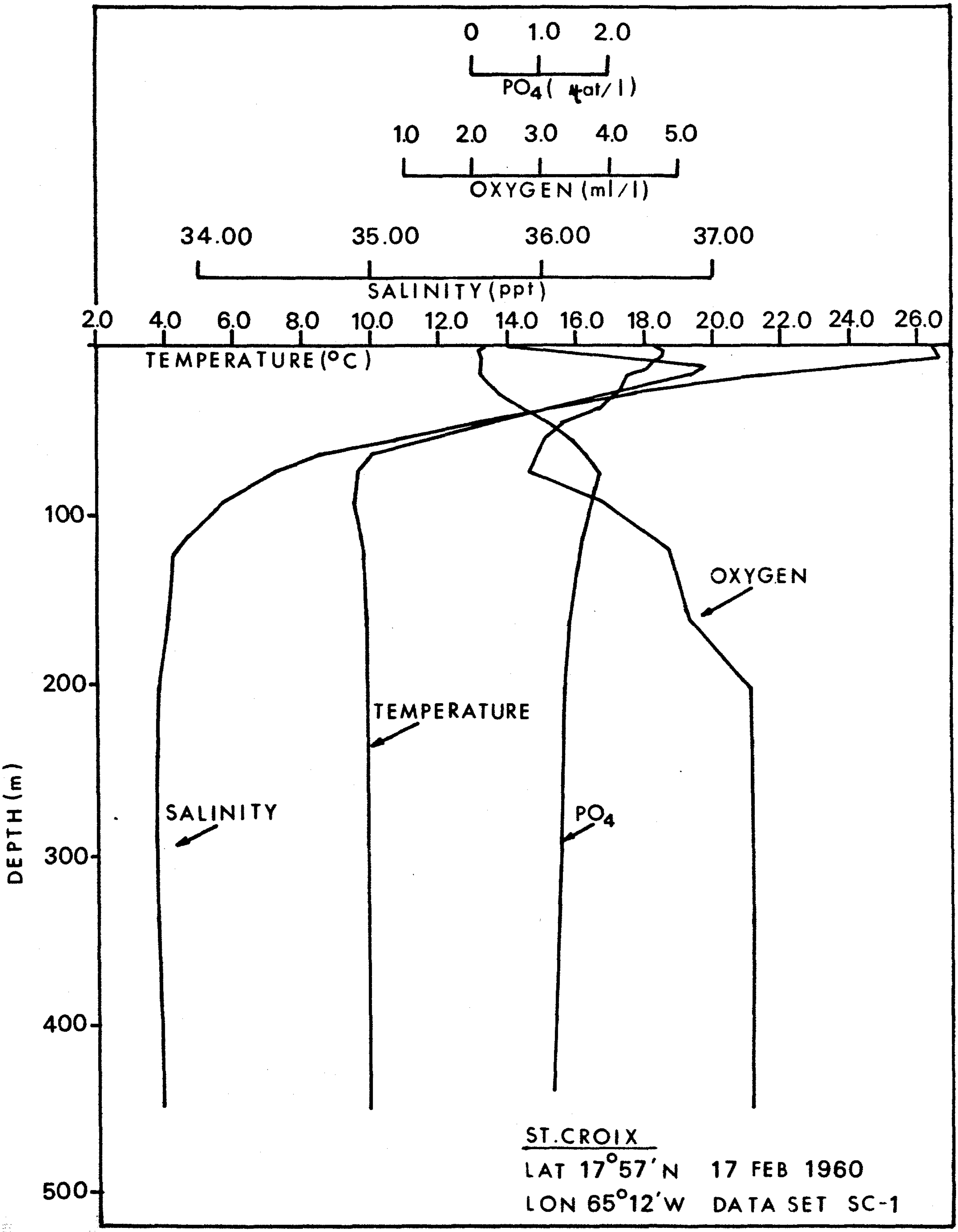


Figure 8: Profiles of temperature, salinity, dissolved oxygen and phosphate for February, 1960, based on NODC Station Data, see data set SC-1.

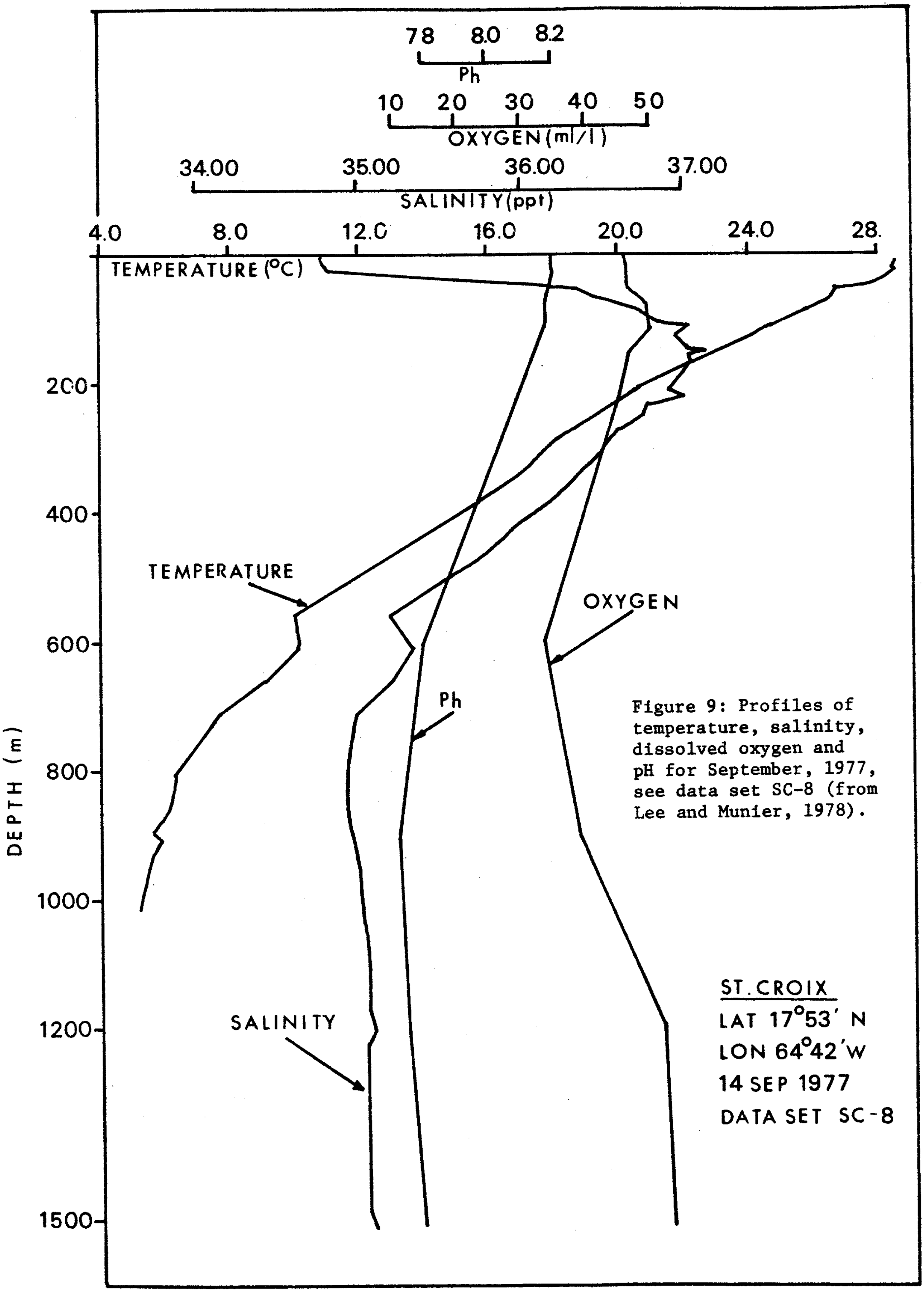


Figure 9: Profiles of temperature, salinity, dissolved oxygen and pH for September, 1977, see data set SC-8 (from Lee and Munier, 1978).

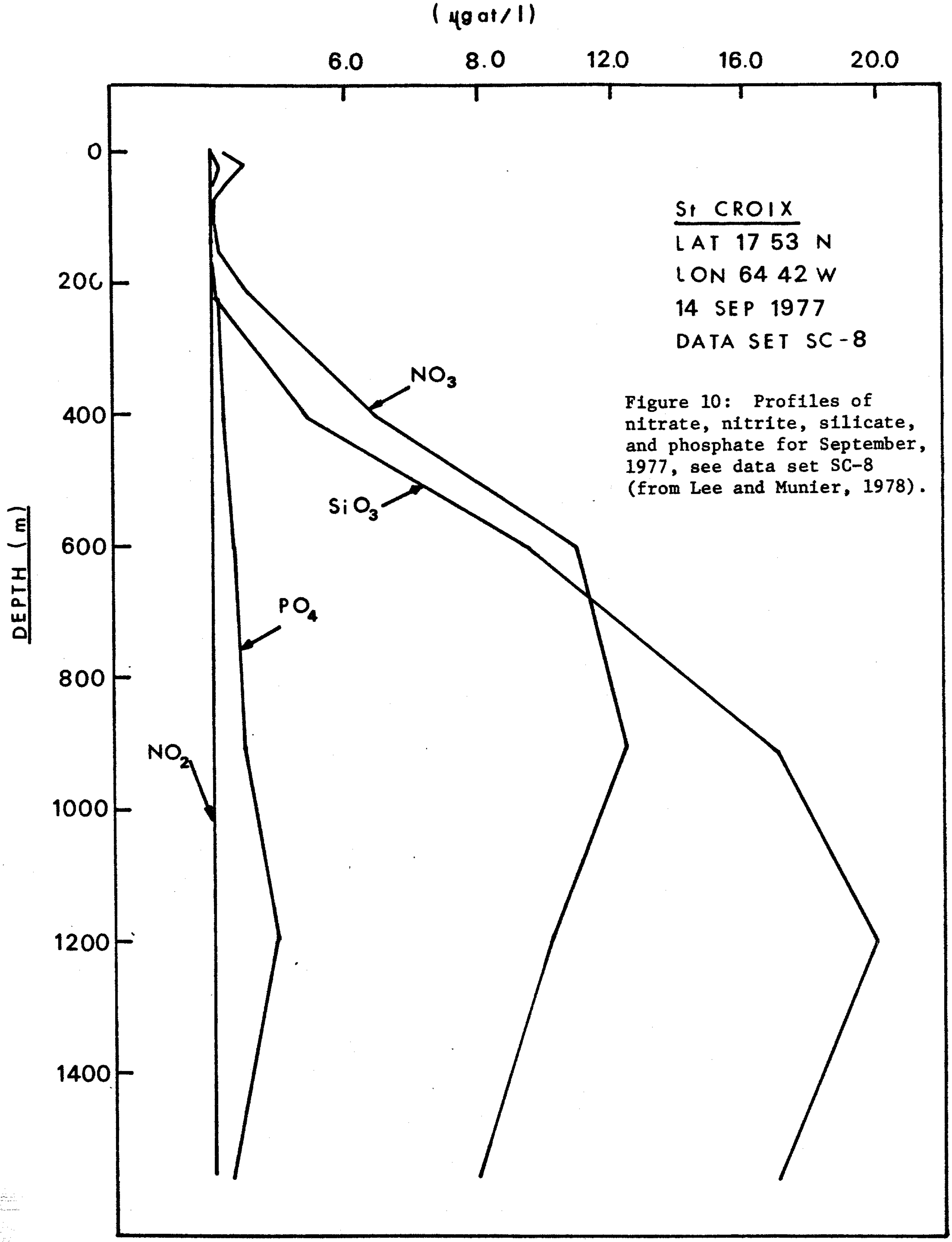


Figure 10: Profiles of nitrate, nitrite, silicate, and phosphate for September, 1977, see data set SC-8 (from Lee and Munier, 1978).

Table 2

SURFACE CURRENT DATA (Ships Drift)

SITE: St. Croix, USVI
10 DEGREE SQUARE: 1008
1 DEGREE SQUARE: 74
1/4 DEGREE SQUARE: 4

Month	Total Observations	Number of Calms	North Comp.	East Comp.	Resultant Direction	Resultant Speed
1	6	0	0.3	-0.4	306	0.5
2	8	1	-0.2	0.0	177	0.2
3	13	1	0.0	-0.3	272	0.3
4	11	1	0.2	-0.2	317	0.3
5	11	0	0.6	-0.5	318	0.8
6	2	0	0.3	-0.1	341	0.3
7	2	0	0.6	-0.0	355	0.7
8	9	0	0.1	-0.2	289	0.2
9	10	0	0.4	-0.2	334	0.5
10	5	0	0.4	0.1	11	0.4
11	9	1	0.1	-0.4	288	0.4
12	4	1	-0.2	-0.1	214	0.2

SITE: St. Croix, USVI
10 DEGREE SQUARE: 1008
1 DEGREE SQUARE: 84
1/4 DEGREE SQUARE: 2

Month	Total Observations	Number of Calms	North Comp.	East Comp.	Resultant Direction	Resultant Speed
1	8	1	0.0	-0.7	271	0.7
2	16	0	0.0	-0.4	277	0.4
3	11	0	0.1	-0.5	281	0.6
4	9	1	-0.0	-0.3	266	0.3
5	10	0	-0.2	-0.5	251	0.5
6	5	2	0.5	-0.4	323	0.7
7	1	0	0.2	-0.2	315	0.3
8	10	1	0.4	-0.4	316	0.6
9	7	1	-0.3	-0.2	211	0.4
10	6	0	-0.1	-0.4	254	0.4
11	10	0	0.2	-0.0	350	0.2
12	2	1	0.7	0.0	360	0.7

Table 3

NODC STATION DATA

SITE: ST. CROIX NUMBER: SC-1 MONTH: FEBRUARY

LATITUDE: 17 57.0 N
LONGITUDE: 65 12.0 W
BOTTOM DEPTH:
DATE: 1960-2-19

DEPTH (M)	TEMP (DEG C)	SALINITY (PPT)	OXYGEN (ML/L)	PHOS (µG-AT/L)	NITRATE (µG-AT/L)	SILICATE (µG-AT/L)	pH
0	26.57	35.721	4.69	.17			
55	26.80	36.167	4.83	.10			
95	25.95	36.732	4.69	.16			
130 T	24.01	36.946	4.59	.11			
185	21.39	36.889	4.28	.13			
280 T	17.70	36.431	4.18	.41			
370	15.27	36.040	3.84	.73			
465 T	12.88	35.657	3.32	1.14			
560	10.74	35.324	3.06	1.48			
655 T	08.50	35.010	2.98	1.66			
750	07.26	34.908	2.85	1.88			
940 T	05.63	34.912	3.91	1.75			
1135	04.68	34.955	4.62	1.59			
1330 T	04.24	34.973	4.89	1.52			
1625 T	04.065	34.982	5.17	1.41			
2020	03.795	34.991	6.06	1.31			
2420 T	03.780	34.987	6.10	1.41			
2915	03.790	34.983	6.10	1.30			
3410 T	03.820	34.978	6.10	1.22			
3910	03.880	34.978	6.06	1.23			
4405 T	03.945	34.981	6.04	1.19			
4430	03.955	34.982	6.05				
4455 T	03.955	34.985	6.17				
4480 T	03.955	34.979	6.12				
4505 T	03.955	34.979	6.08				

Table 4

NODC STATION DATA

SITE: ST. CROIX NUMBER: SC-2 MONTH: MARCH

LATITUDE: 17 54.3 N
LONGITUDE: 65 1.9 W
BOTTOM DEPTH: 4470
DATE: 1972-3-21

DEPTH (M)	TEMP (DEG C)	SALINITY (PPT)	OXYGEN (ML/L)	PHOS (µG-AT/L)	NITRATE (µG-AT/L)	SILICATE (µG-AT/L)	pH
1	26.19	36.097	5.51			2.0	
29	25.38	36.220	5.11			1.0	
49	25.15	36.321	4.87			1.0	
69	25.08	36.394	4.92			1.0	
88	25.08	36.360	4.89			1.0	
108	24.93	36.470	4.85			1.0	
127	24.26	36.963	4.49			1.0	
147 T	22.61	37.000	4.32			1.0	
196	20.14	36.777	4.26			1.0	
245 T	18.66	36.591	3.96			2.0	
294	17.46	36.423	4.05			2.0	
392 T	14.69	35.936	3.53			6.0	
490	12.29	35.552	3.22			10.0	
588 T	09.80	35.183	2.99			16.0	
784 T	07.24	34.929	3.20			20.0	
686	08.34	35.012	3.00			23.0	
981	05.48	34.933	4.10			25.0	
1177 T	04.56	34.953	4.57			28.0	
1544 T	04.15	34.988	5.51			20.0	
1687	03.94	34.988	5.83			12.0	
1735 T	03.91	34.989	5.92			16.0	
1783	03.90	34.990	5.87			16.0	
1830 T	03.88	34.987	5.93			16.0	
1926	03.84	34.985	5.92			16.0	
2402 T	03.82	34.982	5.95			17.0	
2878	03.850	34.982	5.96			17.0	
3353	03.890	34.981	5.95			17.0	
3827	03.925	34.978	5.96			17.0	
4300	03.980	34.978	6.01			17.0	

Table 5

NODC STATION DATA

SITE: ST. CROIX NUMBER: SC-3 MONTH: APRIL

LATITUDE: 17 51.0 N
LONGITUDE: 65 26.0 W
BOTTOM DEPTH: 4114
DATE: 1953-4-12

DEPTH (M)	TEMP (DEG C)	SALINITY (PPT)	OXYGEN (ML/L)	PHOS (μG-AT/L)	NITRATE (μG-AT/L)	SILICATE (μG-AT/L)	pH
0	26.16	36.45	4.71				
10	26.10	36.40	4.68				
20	26.13	36.38	4.73				
30		36.42	4.76				
50	25.32	36.29	4.73				
75	25.18		4.83				
100	24.82	36.36	4.81				
133	23.76	37.14	4.42				
177	21.49	36.91	4.03				
222	19.42	36.42	3.83				
266	18.04	36.78	3.73				
356	15.80	36.20	4.00				
445	13.48	35.82	3.49				
534	10.98	34.88	3.16				
714	07.38	35.43	3.01				
894	05.77	35.08	3.46				
1018	05.48	34.85	3.88				
1276	04.39	34.92	4.71				
1690	03.89	34.97	5.92				
2154		34.96	6.08				
2610	03.76	35.03	6.05				

Table 6

NODC STATION DATA

SITE: ST. CROIX NUMBER: SC-4 MONTH: MAY

LATITUDE: 17 55.5 N
LONGITUDE: 65 5.5 W
BOTTOM DEPTH:
DATE: 1962-5-2

DEPTH (M)	TEMP (DEG C)	SALINITY (PPT)	OXYGEN (ML/L)	PHOS (μG-AT/L)	NITRATE (μG-AT/L)	SILICATE (μG-AT/L)	pH
1	27.33	35.964		.08			
10	26.98	36.014		.09			
25	26.43	36.278		.12			
50	26.05	36.440		.16			
75	25.70	36.608		.08			
99	25.23	36.934		.11			
199	18.92	36.589		.25			
397	12.60	35.535		1.30			
596	08.06	34.879		2.02			
794	06.20	34.818		2.15			
993	05.13	34.924		1.66			
1490		34.969		1.58			
1986	04.06	35.14					

Table 7

NODC STATION DATA

SITE: ST. CROIX NUMBER: SC-5 MONTH: JUNE

LATITUDE: 17 50.6 N
LONGITUDE: 65 19.4 W
BOTTOM DEPTH: 3550
DATE: 1973-6-22

DEPTH (M)	TEMP (DEG C)	SALINITY (PPT)	OXYGEN (ML/L)	PHOS (μG-AT/L)	NITRATE (μG-AT/L)	SILICATE (μG-AT/L)	pH
0	27.80	35.826	4.92	.11			
26	27.31	35.842	4.96	.24			
52	27.98	35.834	4.80	.12			
78	26.66	36.158	4.78	.13			
103	24.34	36.697	4.30	.20			
129	23.10	36.864	4.19	.23			
155	21.97	36.864	3.88	.30			
181	21.19	36.876	4.14	.22			
207	19.91	36.760	4.06	.14			
259 T	17.76	36.461	4.20	.31			
309	16.94	36.345	4.28	.39			
408	14.37	35.905	3.69	.84			
506	10.58	35.236	3.01	1.39			
605 T	09.44	35.103	3.00	1.52			
815	06.41	34.930	3.28	1.71			
1034	04.84	34.926	4.21	1.55			
1253	04.31	35.008	4.96	1.36			
1724 T	02.48	34.96	5.12	1.42			
2272	03.86	35.004	6.02	1.29			

Table 8

RSMAS ST. CROIX DATA

SITE: ST. CROIX NUMBER: SC-6 MONTH: JULY

LATITUDE: 17 52 N
LONGTITUDE: 64 46 W
BOTTOM DEPTH: 3645
DATE: 1977-07-25 1230 HR
REFID: Lee and Munier, Cast #5

DEPTH (M)	TEMP (DEG C)	SALINITY (PPT)	OXYGEN (ML/L)	PHOS (μG-AT/L)	NITRATE (μG-AT/L)	NITRITE (μG-AT/L)	SILICATE (μG-AT/L)	AMMONIA (μG-AT/L)	pH
3.1	28.01	35.440							
18.3	27.90	35.500	4.48	.25	.09	.05	1.00		8.15
23.4	28.06	35.626							
43.7	28.04	35.664							
40		35.645	4.37	.08	.15	0	.20		
63.9	26.98	35.909							
84.2	25.69	36.318							
95.	25.46	36.445	4.14	.10	.90	.10	.30		
104.5	24.98	36.626							
124.8	24.32	36.859							
145.0	23.33	36.994							
165.3	22.52	37.117							
185.6	21.62	37.078							
207.5	21.36	37.103	4.14	.12	.95	.05	0		
226.1	19.62	36.822							
246.4	18.97	36.718							
266.7	17.96	36.532							
287.0	17.58	36.477							
307.2	17.10	36.417							
327.5	16.69	36.347							
347.8	16.24	36.265							
368.1	15.61	36.129							
388.3	14.79	36.005	3.58	.40	5.95	.05	3.00		
408.6	14.38	35.967							
428.9	13.77	35.866							
449.1	13.21	35.763							

RSMAS ST. CROIX DATA

SITE: ST. CROIX NUMBER: SC-6 MONTH: JULY

DEPTH (M)	TEMP (DEG C)	SALINITY (PPT)	OXYGEN (ML/L)	PHOS (µG-AT/L)	NITRATE (µG-AT/L)	NITRITE (µG-AT/L)	SILICATE (µG-AT/L)	AMMONIA (µG-AT/L)	pH
469.4	12.83	35.714							
489.7	11.93	35.546							
510.0	11.39	35.420							
530.2	11.13	35.399							
550.5	10.76	35.157							
570.8	10.27	35.259							
591.1	9.63	35.234							
611.3	9.42	35.193							
633.	9.47	35.172	3.02	.95	12.50	0	12.00		

Table 9

RSMAS ST. CROIX DATA

SITE: ST. CROIX NUMBER: SC-7 MONTH: AUGUST

LATITUDE: 17 52 N
LONGTITUDE: 64 46 W
BOTTOM DEPTH: 3645
DATE: 1977-08-16 1156 HR
REFID: Lee and Munier, Cast #25

DEPTH (M)	TEMP (DEG C)	SALINITY (PPT)	OXYGEN (ML/L)	PHOS (μG-AT/L)	NITRATE (μG-AT/L)	NITRITE (μG-AT/L)	SILICATE (μG-AT/L)	AMMONIA (μG-AT/L)	pH
3.1	27.84	36.221	4.75	.50	.10	0	.4	0.8	8.20
18.3	27.76	36.260	7.52	.18	.08	0	.4	0.6	8.15
23.4	27.91	36.291							
43.7	26.48	36.410							
50.	25.91	36.458	4.95	.30	.05	0	.1	0.6	8.10
63.9	25.87	36.498							
84.2	25.68	36.583							
99.	24.78	36.763	4.95	.10	.02	0	0	0.5	8.17
104.5	24.85	36.730							
124.8	23.79	36.816							
145.0	22.91	36.802							
165.3	22.64	37.019							
185.6	21.81	37.033							
197.	20.82	36.931	4.61	.45	.50	0	0	0.6	8.00
205.9	20.76	36.918							
226.1	20.34	36.904							
246.4	19.38	36.739							
266.7	18.77	36.654							
287.0	18.26	36.592							
307.2	17.69	36.505							
327.5	16.84	36.364							

RSMAS ST. CROIX DATA

SITE: ST. CROIX NUMBER: SC-7 MONTH: AUGUST

DEPTH (M)	TEMP (DEG C)	SALINITY (PPT)	OXYGEN (ML/L)	PHOS (μG-AT/L)	NITRATE (μG-AT/L)	NITRITE (μG-AT/L)	SILICATE (μG-AT/L)	AMMONIA (μG-AT/L)	pH
347.8	16.51	36.315							
368.1	16.09	36.243							
388.3	15.36	36.128							
390.		36.095	4.12	.60	6.95	.05	3.00	0.5	7.88
408.6	14.78	36.025							
459.3	13.87	35.886							
510.0	12.63	35.700							
560.7	11.71	35.545							
581.	10.26	35.285	3.23	.80	7.95	.05	7.00	0.6	7.73
611.3	10.36	35.334							
662.0	9.11	35.205							
712.7	8.19	35.108							
763.4	7.53	35.044							
814.1	6.91	34.998							
834.4	6.63	34.976							
854.6	6.56	34.973							
874.9	6.34	34.968							
885.		34.921	4.27	.95	11.45	.05	14.00	0.6	7.68
895.2	6.29	34.974							
915.5	6.18	34.974							
935.7	6.11	34.976							
956.0	5.98	34.986							
976.3	5.81	34.993							
996.6	5.60	34.997							

RSMAS ST. CROIX DATA

SITE: ST. CROIX NUMBER: SC-7 MONTH: AUGUST

DEPTH (M)	TEMP (DEG C)	SALINITY (PPT)	OXYGEN (ML/L)	PHOS (μG-AT/L)	NITRATE (μG-AT/L)	NITRITE (μG-AT/L)	SILICATE (μG-AT/L)	AMMONIA (μG-AT/L)	pH
1016.8	5.42	35.011							
1067.5	5.02	35.011							
1118.2	4.92	35.011							
1168.9	4.68	35.011							
1188.	4.65	35.029	4.99	.95	10.95	.05	18.50	0.5	7.70
1219.6	4.57	35.011							
1270.3	4.45	35.011							
1321.0	4.36	35.020							
1371.6	4.32	35.021							
1422.3	4.28	35.021							
1473.0	4.25	35.021							
1507.	4.18	35.058	5.18	.93	10.95	.05	19.50	1.1	7.76

Table 10

RSMAS ST. CROIX DATA

SITE: ST. CROIX NUMBER: SC-8 MONTH: SEPTEMBER

LATITUDE: 17 52 N
LONGTITUDE: 64 46 W
BOTTOM DEPTH: 3645
DATE: 1977-09-14 0917 HR
REFID: Lee and Mur.ier, Cast #53

DEPTH (M)	TEMP (DEG C)	SALINITY (PPT)	OXYGEN (ML/L)	PHOS (μG-AT/L)	NITRATE (μG-AT/L)	NITRITE (μG-AT/L)	SILICATE (μG-AT/L)	AMMONIA (μG-AT/L)	pH
3		34.774	4.62	.02	0	0	.40		
8	28.51	34.777							
20	28.43	34.800	4.64	.25	.02	0	1.00		8.20
23.4	28.56	34.803							
43.7	27.81	36.033							
50	26.68	36.344	4.65	0	.03	0	.40	2.2	8.12
63.9	26.56	36.452							
75			4.95	0	.01	0	0	1.0	8.18
84.2	25.84	36.735							
104.5	25.02	36.828							
110	24.66	37.039	5.00	0	.05	0	0	2.4	8.18
124.8	24.22	36.955							
145.0	23.14	37.030							
150.0	22.15	37.202	4.68	.01	.22	0	.01	1.5	8.15
165.3	22.31	37.041							
185.6	21.41	36.990							
205.9	20.59	36.922							
214.5	20.35	37.019	4.53	.12	1.05	.05	.03	0.7	
226.1	19.84	36.794							
246.4	19.42	36.759							
266.7	18.62	36.602							
287.0	18.07	36.538							
307.2	17.71	36.509							
327.5	17.22	36.419							
347.8	16.62	36.324							

RSMAS ST. CROIX DATA

SITE: ST. CROIX NUMBER: SC-8 MONTH: SEPTEMBER

DEPTH (M)	TEMP (DEG C)	SALINITY (PPT)	OXYGEN (ML/L)	PHOS (μG-AT/L)	NITRATE (μG-AT/L)	NITRITE (μG-AT/L)	SILICATE (μG-AT/L)	AMMONIA (μG-AT/L)	pH
368.1	16.16	36.251							
388.3	15.55	36.152							
405.5	14.91	36.055	3.92	.31	4.95	.05	2.80	0.7	7.95
408.6	15.00	36.038							
459.3	13.40	35.804							
510.0	11.73	35.488							
560.7	10.04	35.193							
602.	10.19	35.311	3.33	.70	10.95	.05	9.50	1.1	7.80
611.3	10.13	35.331							
662.	9.12	35.202							
712.7	7.71	34.988							
763.4	6.97	34.943							
814.1	6.37	34.936							
834.4	6.31	34.935							
854.6	6.21	34.935							
874.9	6.02	34.936							
895.2	5.84	34.958							
907.	5.96	34.968	3.91	.95	12.95	.05	17.00	1.3	7.72
915.5	5.83	34.958							
935.7	5.73	34.976							
956.0	5.64	34.991							
976.3	5.48	35.011							
996.6	5.44	35.018							
1016.8	5.27	35.018							
1067.5	5.4	35.040							
1118.2	4.94	35.057							
1168.9	4.79	35.057							
1199.	4.73	35.099	5.18	1.95	10.15	.05	20.00	0.7	7.75
1219.6	4.55	35.050							
1270.3	4.49	35.048							

RSMAS ST. CROIX DATA

SITE: ST. CROIX NUMBER: SC-8 MONTH: SEPTEMBER

DEPTH (M)	TEMP (DEG C)	SALINITY (PPT)	OXYGEN (ML/L)	PHOS (μG-AT/L)	NITRATE (μG-AT/L)	NITRITE (μG-AT/L)	SILICATE (μG-AT/L)	AMMONIA (μG-AT/L)	pH
1321.0	4.42	35.048							
1371.6	4.33	35.048							
1422.3	4.32	35.048							
1473.0	4.25	35.049							
1483.0	4.25	35.049							
1510.	4.17	35.098	5.27	.55	7.95	.05	17.00	0.8	7.80

Table 11

NODC STATION DATA

SITE: ST. CROIX NUMBER: SC-9 MONTH: OCTOBER

LATITUDE: 18 00.0 N
LONGITUDE: 064 44.0 W
BOTTOM DEPTH: 03008
DATE: 1969-10-26 OH
REFID: 31 8425-0001

STD = 'S'
OBS = 'O'

DEPTH (M)		TEMP (DEG C)	SALINITY (PPT)	OXYGEN (ML/L)	PHOS (μG-AT/L)	NITRATE (μG-AT/L)	SILICATE (μG-AT/L)	pH
0000	S	28.92	35.27					
0001	O	28.92	35.270					
0010	S	28.92	35.27					
0012	O	28.92	35.270					
0020	S	28.92	35.40					
0024	O	28.92	35.490					
0030	S	28.93	35.70					
0036	O	28.94	35.860					
0048	O	28.50	36.030					
0050	S	28.37	36.06					
0060	O	27.77	36.190					
0072	O	27.21	36.350					
0075	S	27.01	36.39					
0084	O	26.34	36.530					
0096	O	25.33	36.780					
0100	S	25.06	36.83					
0108	O	24.51	36.910					
0120	O	23.69	36.980					
0125	S	23.31	36.97					
0132	O	22.92	36.960					
0144	O	22.66	36.970					
0150	S	22.61	36.97					
0156	O	22.43	36.970					
0168	O	21.68	36.910					
0180	O	20.75	36.840					
0192	O	20.00	36.770					
0200	S	19.73	36.74					
0204	O	19.57	36.720					
0216	O	18.95	36.620					
0240	O	18.36	36.560					
0250	S	18.13	36.54					
0264	O	17.86	36.510					
0288	O	17.51	36.440					
0300	S	17.45	36.43					
0312	O	17.28	36.420					
0336	O	16.63	36.280					
0360	O	16.05	36.170					
0384	O	15.39	36.040					
0400	S	15.24	36.03					
0408	O	15.10	36.030					
0432	O	14.40	35.880					

NUMBER: SC-9 CONTINUED

DEPTH (M)	TEMP (DEG C)	SALINITY (PPT)	OXYGEN (ML/L)	PHOS (μG-AT/L)	NITRATE (μG-AT/L)	SILICATE (μG-AT/L)	pH
0456 O	13.69	35.740					
0480 O	12.64	35.540					
0500 S	12.00	35.47					
0504 O	11.90	35.460					
0528 O	11.45	35.420					
0552 O	10.71	35.290					
0576 O	10.09	35.230					
0600 S	09.38	35.09					
0600 O	09.38	35.090					
0630 O	08.67	35.000					
0660 O	08.42	35.000					
0690 O	08.04	34.960					
0700 S	07.63	34.91					
0720 O	07.08	34.850					
0750 O	06.97	34.870					
0780 O	06.78	34.840					
0800 S	06.56	34.85					
0810 O	06.46	34.850					
0840 O	06.21	34.850					
0870 O	05.97	34.880					
0900 S	05.75	34.90					
0900 O	05.75	34.900					
0930 O	05.76	34.950					
0960 O	05.66	34.970					
0990 O	05.59	35.000					
1000 S	05.53	35.00					
1020 O	05.44	35.000					
1050 O	05.36	35.010					
1080 O	05.17	35.000					
1100 S	05.15	35.02					
1110 O	05.12	35.020					
1140 O	04.93	35.020					
1170 O	04.85	35.030					
1200 S	04.86	35.03					
1200 O	04.86	35.030					
1230 O	04.81	35.030					
1260 O	04.60	35.000					
1290 O	04.45	34.990					
1300 S	04.45	34.99					
1320 O	04.44	34.990					
1350 O	04.40	34.990					
1380 O	04.36	34.990					
1400 S	04.35	35.00					
1410 O	04.34	35.000					
1440 O	04.33	35.000					
1470 O	04.32	35.000					
1500 S	04.29	35.10					
1500 O	04.29	35.100					

Table 12

NODC STATION DATA

SITE: ST. CROIX　　NUMBER: SC-10　　MONTH: NOVEMBER

LATITUDE: 17 58 N　　STD = 'S'
LONGITUDE: 064 41 W　　OBS = 'O'
BOTTOM DEPTH: 04120
DATE: 1921-11-30 12H
REFID: 26 0008-0065

DEPTH (M)	TEMP (DEG C)	SALINITY (PPT)	OXYGEN (ML/L)	PHOS (µG-AT/L)	NITRATE (µG-AT/L)	SILICATE (µG-AT/L)	pH
0000 S	27.05	34.98	04.51				
0000 O	27.05	34.98	04.51				
0010 S	27.05	34.98	04.51				
0020 S	27.05	34.98	04.51				
0025 O	27.05	34.98	04.51				
0030 S	27.31	35.32	04.55				
0050 S	27.60	36.26	04.64				
0050 O	27.60	36.26	04.64				
0075 S	26.24	36.54	04.62				
0075 O	26.24	36.54	04.62				
0100 S	24.73	36.77	04.46				
0100 O	24.73	36.77	04.46				
0125 S	23.68	36.91	04.24				
0125 O	23.68	36.91	04.24				
0150 S	22.70	36.96	04.10				
0150 O	22.70	36.96	04.10				
0200 S	20.46	36.84	03.76				
0200 O	20.46	36.84	03.76				
0250 S	18.63	36.63	04.05				
0300 S	17.08	36.42	04.13				
0300 O	17.08	36.42	04.13				
0400 S	14.80	35.98	03.68				
0400 O	14.80	35.98	03.68				
0500 S	11.55	35.38	02.88				
0500 O	11.55	35.38	02.88				
0600 S	09.21	35.05	02.77				
0600 O	09.21	35.05	02.77				
0700 S	07.95	34.93	02.82				
0800 S	06.88	34.86	03.00				
0800 O	06.88	34.86	03.00				
0900 S	05.99	34.87	03.39				
1000 S	05.31	34.88	03.74				
1000 O	05.31	34.88	03.74				
1100 S	04.88	34.91	04.04				
1200 S	04.55	34.93	04.33				
1200 O	04.55	34.93	04.33				
1300 S	04.45	34.94	04.67				
1400 S	04.33	34.95	04.96				
1500 S	04.21	34.95	05.19				

NUMBER: SC- 10 CONTINUED

DEPTH (M)	TEMP (DEG C)	SALINITY (PPT)	OXYGEN (ML/L)	PHOS (µG-AT/L)	NITRATE (µG-AT/L)	SILICATE (µG-AT/L)	pH
1500 O	04.21	34.95	05.19				
1750 S	03.83	34.95	05.50				
1800 O	03.79	34.95	05.53				
2000 S	03.72	34.95	05.55				
2000 O	03.72	34.95	05.55				
2500 S	03.72	34.95	05.59				
2500 O	03.72	34.95	05.59				
3000 S	03.78	34.95	05.05				
3000 O	03.78	34.95	05.05				
3500 O	03.82	34.95	05.27				
4000 S	03.89	34.96	04.76				
4000 O	03.89	34.96	04.76				
4030 O	03.88	34.95	05.29				

Table 13

NODC STATION DATA

SITE: ST. CROIX NUMBER: SC-11 MONTH: DECEMBER

LATITUDE: 17 52.0 N
LONGITUDE: 64 49.0 W
BOTTOM DEPTH: 4C30
DATE: 1967-12-1

DEPTH (M)	TEMP (DEG C)	SALINITY (PPT)	OXYGEN (ML/L)	PHOS (µG-AT/L)	NITRATE (µG-AT/L)	SILICATE (µG-AT/L)	pH
0	27.81	34.099	4.72	.21			
20	27.84	34.087	4.67	.24			
40	27.88	34.134	4.70	.22			
60	28.42	35.685	4.84	.22			
70	27.76	36.123	4.70	.23			
80	27.07	36.456	4.75	.23			
90	26.49	36.622	4.91	.22			
100	26.18	36.675	4.56	.27			
120	24.69	36.989	4.47	.27			
150	23.53	37.047	4.39	.29			
199	19.86	36.788	3.77	.56			
498 T	11.256	35.484	3.20	1.60			
996 T	05.39	34.971	4.32	2.00			
1493	04.22	35.016	5.02	1.85			
1988 T	03.83	35.055	6.04	1.53			
2479 T	03.81	35.02	6.16	1.52			
2969 T	03.83	30.56	6.14	1.50			
3458 T	03.89	35.046	6.10	1.58			

Table 14

TOTAL SUSPENDED MATTER CONCENTRATION, SALINITY, TEMPERATURE, AND VOLUME FILTERED AT TABULATED SAMPLE DEPTH FOR TWO STATIONS WEST OF ST. CROIX SITE (FROM BASSIN, 1975)

Depth Meters	Salinity °/oo	Temperature °C	Volume Filtered, liters	TSM, µg/l
Station 7, 17°54.7'N, 65°01.6'W, Bottom Depth 4487 meters				
17	35.139	28.01	25.8	113
1457	34.979	4.28	18.3	26
2457	34.975	3.84	26.3	18
3457	34.971	3.90	27.5	19
3957	34.970	3.94	22.0	34
4257	34.970	3.98	25.8	24
4407	34.969	4.00	24.8	32
4457	34.968	4.01	27.3	23
Station 9, 17°24.0'N, 65°17.8'W, Bottom Depth 3580 meters				
41	35.581	28.50	20.5	170
345	35.969	15.16	22.0	36
1145	34.942	4.70	19.3	39
1965	34.970	4.09	21.3	49
2365	34.973	4.08	18.3	49
2965	34.973	4.12	23.5	31
3365	34.973	4.16	26.5	35
3565	34.971	4.19	23.5	24

Table 15. Extended study of chlorophyll a and ATP in seawater at intake depth (20 m) (Aftring et al., 1977).

Date (Month/Day)	Time (hr)	Chlorophyll a (ng l^{-1})	ATP (ng l^{-1})
7/25	1000	-	31 ± 6 (3)
7/29	1000	124 ± 17 (4)	65 ± 29 (3)
8/3	1600	-	92 ± 18 (4)
8/4	2200	178 ± 8 (4)	101 ± 35 (3)
8/8	1200	-	94 ± 26 (3)
8/15	0900	319 ± 10 (2)	48 ± 11 (3)
8/17	0900	68 ± 2 (3)	-
8/26	0900	104 ± 16 (3)	82 ± 14 (3)
8/29	1500	68 ± 4 (3)	-
9/1	2300	99 ± 4 (3)	95 ± 13 (3)
9/2	1000	208 ± 16 (3)	-
9/9	0900	160 ± 3 (3)	98 ± 6 (3)
9/12	1100	67 ± 4 (3)	97 ± 11 (3)
9/15	2300	131 ± 14 (3)	97 ± 11 (3)
9/23	0600	273 ± 17 (3)	77 ± 27 (3)

Results are means ± one standard deviation with the number of samples in parenthesis

Table 16. Extended study of populations of aerobic heterotrophic bacteria in seawater at intake depth (20 m) (Aftring et al., 1977)

Date (Month/Day)	Time (hr)	Bacteria (cells l^{-1})
7/29	1000	5100
8/4	2200	3500
8/15	0900	3000
8/16	2300	3600
8/26	0900	5100
9/1	2300	1700
9/9	0900	4000
9/23	0600	4000

Results are means of triplicate plates.

5.0 ANNOTATED BIBLIOGRAPHY

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6.0 REFERENCE SUMMARY CHART

REFERENCE SUMMARY CHART AUTHOR	PUBLICATION DATE	MISCELLANEOUS	T TEMPERAT.	S SALINITY	SC SURFACE CURRENTS	CP CURRENT PROFILES	TU TURBIDITY	PH pH	DO DISSOLVED OXYGEN	DCO DISSOLVED CO_2	EH EH	TM TRACE METALS	N NUTRIENTS	MCC MICROBIAL cell counts
ADEY	1975	X												
ADEY AND BURKE	1976	X												
AFTRING et al	1977		X	X				X	X				X	X
ATWOOD, DUNCAN, STALCUP AND BARCELONA	1976		X	X	X	X			X				X	
BAAR, HAMM, HAINES CHU, AND ROELS	1973	X												
BASSIN	1975						X							
BEERS, STEVEN AND LEWIS	1968	X												
BETZER	1971											X		
BOCK	1974		X	X								X		

REFERENCE SUMMARY CHART AUTHOR	PUBLICATION DATE	MISCELLANEOUS	T TEMPERAT.	S SALINITY	SC SURFACE CURRENTS	CP CURRENT PROFILES	TU TURBIDITY	PH pH	DO DISSOLVED OXYGEN	DCO DISSOLVED CO_2	EH EH	TM TRACE METALS	N NUTRIENTS	MCC MICROBIAL cell counts
BURKHOLDER, BRODY, AND DAMMANN	1972	X												
BRUCKS	1971				X									
CRAIG, LEE, MICHEL, HESS, MUNIER AND PERLMUTTER	1978													
CUMMINGS, PARKER, AND ATWOOD	1977		X	X									X	
FRASSETTO AND NORTHRUP	1957	X												
FROELICH AND ATWOOD	1974			X									X	
GENTRY	1971	X												
GERARD AND ROELS	1970													
GORDON	1967			X	X	X								

REFERENCE SUMMARY CHART

AUTHOR	PUBLICATION DATE	MISCELLANEOUS	T TEMPERAT.	S SALINITY	SC SURFACE CURRENTS	CP CURRENT PROFILES	TU TURBIDITY	PH pH	DO DISSOLVED OXYGEN	DCO DISSOLVED CO_2	EH EH	TM TRACE METALS	N NUTRIENTS	MCC MICROBIAL cell counts
HARGRAVES, BRODY, AND BURKHOLDER	1970												X	X
HIRSHMAN, MEIER, MUNIER, AND TAYLOR	1977													X
HOLE	1967	X												
LEE AND MUNIER	1977		X	X	X	X		X	X				X	
METCALF AND STALCUP	1974				X									
MICHEL AND FOYO	1976		X	X					X				X	
MULTER AND GERHARD	1974	X												
MUNIER AND CRAIG	1977		X	X				X	X					
OTHMER AND ROELS	1973	X											X	

REFERENCE SUMMARY CHART AUTHOR	PUBLICATION DATE	MISCELLANEOUS	T TEMPERAT.	S SALINITY	SC SURFACE CURRENTS	CP CURRENT PROFILES	TU TURBIDITY	PH pH	DO DISSOLVED OXYGEN	DCO DISSOLVED CO_2	EH EH	TM TRACE METALS	N NUTRIENTS	MCC MICROBIAL cell counts
OWRE AND FOYO	19													X
ROELS AND GERHARD	1969													
ROELS, GERHARD, HAINES AND CENTENO	1970													
ROSS AND MANN	1971		X											
STALCUP AND METCALF	1972				X	X								
STALCUP AND METCALF	1973													
STONE	1942	X												
STURGES	1965		X	X										
STURGES	1970		X	X		X								

REFERENCE SUMMARY CHART AUTHOR	PUBLICATION DATE	MISCELLANEOUS	T TEMPERAT.	S SALINITY	SC SURFACE CURRENTS	CP CURRENT PROFILES	TU TURBIDITY	PH pH	DO DISSOLVED OXYGEN	DCO DISSOLVED CO_2	EH EH	TM TRACE METALS	N NUTRIENTS	MCC MICROBIAL cell counts
SUKHOVEY AND METAL' NIKOR	1968	X												
SUNDERLIN, TOBIAS AND ROELS	1974	X												
TOSTESON, ATWOOD, AND TSAI	1976	X												X
TSENTAS AND PERKINS	1976													
U.S. NAVY HYDRO. OFF. H.O. 21	1958	X			X									
U.S. NAVY HYDRO. OFF. H.O. 22	1963	X												
WHETTON	1966	X												
WOOD	1971	X												
WORTHINGTON	1966		X	X										

REFERENCE SUMMARY CHART / AUTHOR	PUBLICATION DATE	MISCELLANEOUS	T TEMPERAT.	S SALINITY	SC SURFACE CURRENTS	CP CURRENT PROFILES	TU TURBIDITY	PH pH	DO DISSOLVED OXYGEN	DCO DISSOLVED CO_2	EH EH	TM TRACE METALS	N NUTRIENTS	MCC MICROBIAL cell counts
WORTHINGTON	1971		X	X										
WUST	1964		X	X	X				X					

7.0 ON-GOING RESEARCH

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Betzer, P.R., Carder, K.L.
Navy Environment: Suspended Sediments in the Atlantic and Caribbean Waters: Their Sources, Movements and Characteristics
State University of Fla. Sys., Marine Science Institute, St. Petersburg, Florida 33701

Brooks, I.H.
Navy Environment: Flow Through the Passages of the Lesser Antilles
Nova University, Physical Oceanographic Lab., 800 N. Ocean Dr., Dania, Florida 33004

Carpenter, E.J.
Nitrogen Cycling in the Euphotic Zones of the Caribbean and Southern Sargasso Seas
State University of New York, Graduate School, Stony Brook, New York 11790

Fanning, K.A.
Dissolved Silica in the Deep Eastern Caribbean Sea
Univ. of South Florida, Marine Science Institute, St. Petersburg, Florida 33701

Knauss, F., Sturges, W.
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Univ. of Rhode Island, Narragansett Marine Laboratory, Administration Bldg., Kingston, Rhode Island 02821

Metcalf, W.G.
Atlantic-Caribbean Water Exchange
Woods Hole Oceanographic Inst., Main St., Woods Hole, Massachusetts 02543

Nowlin, W.D.
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Texas A & M University System, School of Geosciences, Oceanography, College Station, Texas 77843

Yager, R.E., Brooks, I.H., Spillane, M.W.
Studies of the Flow Through the Caribbean Sea
Nova University, Physical Oceanographic Lab., 800 N. Ocean Dr., Dania, Florida 33004