QH
84.200
Caribbean

V11S

CARIBBEAN RESEARCH INSTITUTE

COLLEGE OF THE VIRGIN ISLANDS

WATER POLLUTION REPORT NO. 3

A STUDY OF THE WATERS, SEDIMENTS AND BIOTA OF CHOCOLATE HOLE, ST. JOHN WITH COMPARISON TO CRUZ BAY, ST. JOHN

Robert W. Brody
David M. Raup
David I. Grigg
Robert P. van Eepoel

January 1970

Digitized by the Internet Archive
in 2012 with funding from
LYRASIS Members and Sloan Foundation

http://archive.org/details/studyofwaterssed00brod

GOVERNMENT OF THE VIRGIN ISLANDS

DEPARTMENT OF HEALTH, DIVISION OF ENVIRONMENTAL HEALTH

WATER POLLUTION REPORT NO. 3

ESTUARINE ENVIRONMENT AT CRUZ BAY, ST. JOHN

PHASE II REPORT

CONTRACTED BY

CARIBBEAN RESEARCH INSTITUTE

COLLEGE OF THE VIRGIN ISLANDS

A STUDY OF THE WATERS, SEDIMENTS AND BIOTA
OF CHOCOLATE HOLE, ST. JOHN
WITH COMPARISON TO CRUZ BAY, ST. JOHN

Robert W. Brody
David M. Raup
David I. Grigg
Robert P. vanEepoel

January 1970

(Second Printing - November 1971)

INTRODUCTION

Chocolate Hole, St. John, U. S. Virgin Islands, was subjected to intensive water quality, benthic biology, and sedimentology sampling effort during the last three months of 1969. Sampling procedures were set up to collect basic information about the local environment with an eye to comparison with an earlier study in Cruz Bay, St. John.#

The same team of investigators* visited the Chocolate Hole area, and this report represents their combined scientific efforts. There are sections presenting the Chocolate Hole data followed by a comparison of the two bays with recommendations. Thanks are due to Mr. Fred Nicholson, Director, Bureau of Public Health Laboratories, Virgin Islands Department of Health, for processing of bacteriology samples, and to the staff of the Caribbean Research Institute for logistic and clerical support.

Brody, R.W., D.I. Grigg, D.M. Raup, and R.P. vanEepoel. "A Report to the Government of the Virgin Islands: Estuarine Environment at Cruz Bay, St. John; A Study of the Effects of Pollutants on the Waters and Sediments of the Bay." 1969.

* Benthic Biology: R. Brody and L. Slocum: Water Chemistry and Bacteriology Sampling: D. Grigg; Geology: D. Raup.

DESCRIPTION AND USE OF THE STUDY AREA

Chocolate Hole has, for the purposes of this study, been limited to include all of the marine waters lying north of a line joining Sam Point and the most southeasterly promontory of Maria Bluff (Figure 1), as shown on U.S.C.G.S. Chart No. 938. There are three salt ponds (one on each of three sides of the bay), two of which are small and not connected to the bay by channels; the third, hereafter referred to as the Pond (Figure 2), covers an area of approximately eleven acres and is connected to the bay by a flowing channel at all stages of the tide.

The Coast and Geodetic Survey Chart does not present an accurate picture of the depth contours of Chocolate Hole, and a chart approximating present depth contours is included (Figure 3). High resolution depth sounding equipment was not available to the scientific staff, and thus this figure represents only a close approximation of the bay's bathymetry.

The ancient contour of the bay probably included within the open width both of the small ponds - one on each side - which are now closed behind narrow strips of coral rubble, and in length the large shallow pond northeast of the present beach at the head of the bay. This pond lies behind a peninsula about 250 feet wide and 300 feet long, and is enclosed except for the narrow, shallow, dogleg creek connecting the northernmost point of the bay to the southwestern tip of the pond. No solid rock formations were encountered in these three water front zones in the course of walkover inspections of the shoreline. The three enclosing strands are

now well established in compacted coral rubble and vegetation, and it is not likely that any of the three would be opened again by natural forces less than catastrophic hurricane seas.

The bay is currently used as a mooring for two small (30') yachts (whose owners do not live aboard) and is an infrequent anchorage for transient vessels. Dr. A. E. Dammann (Director, V. I. Ecological Research Station), whose house is on the bay, reports that the area is infrequently visited on weekends by beach parties or fishermen. There was one commercial fisherman fishing about ten traps on the southwestern point, and infrequent swimmers used the beach at the northern end of Chocolate Hole. Dr. Dammann's house is the sole waterfront property currently occupied; there is one other dwelling now being completed within the study area. A total of six or seven other dwellings lie less immediately adjacent to the bay or the Pond.

It thus is obvious that Chocolate Hole may be considered nearly free of visible effects of marine or terrestrial habitation usage as of the time of the study. There has been some modification of the surrounding hills by bulldozing for home sites and access roads, but in general, the area is densely overgrown with vegetation.

The major recent changes in the marine environment are attributed to storm damage due to heavy sea swells. The passage of Hurricane Bertha (1967) south of St. Croix caused an incoming sea which broke as much as twenty feet above the normal surge zone, piled coral rubble and <u>Thalassia</u> (along with benthic organisms such as echinoderms,

polychaete and annelid worms, and molluscs) in windrows 5 feet deep and 20 feet wide and caused major destruction to the coral communities along the east and west shores (A.E. Dammann, personal communication). This storm and preceding ones probably were responsible for the modification of the bay bottom apparent in the changed depth contours previously cited. The bottom material was pushed to the northeast shore and piled onshore forming a berm which is quite high and steep.

SCIENTIFIC OBJECTIVES AND METHODS OF THE STUDY

The scientific methods and objectives of the Chocolate Hole study are essentially the same as the study undertaken in Cruz Bay. This was done to insure validity in comparisons of the two environments. It must be stated here that no two geographically disparate areas can be considered equivalent, and the Chocolate Hole study does not represent a true "control" on the Cruz Bay project. The obvious differences in exposure to the open ocean and in the surrounding watersheds lead to complex differences in the physical, chemical, geological, and biological parameters which inhibit quantitative comparison of the two bays. It can be assumed that some changes attributable to human use of the environment can be recognized; and it is safe to say that where these changes have occurred in Cruz Bay, there is definite probability that, given similar changes in the habitation of Chocolate Hole, similar changes may occur.

For a complete outline of scientific objectives and methods used the reader should consult the Cruz Bay report. Stations for benthic biology, water chemistry, and bacteriology sampling (as shown in Figures 1 and 2) were chosen to cover both the spatial area of the bay and to include the dominant facies of the biota. The two stations in the Pond were taken to determine some of the relationships between the two areas, especially in terms of proposed development of the Pond as a hotel site.

Dissolved Oxygen (Tables 4 and 5)

The surface water of Chocolate Hole is well aerated and is everywhere loaded to more than 90% of its oxygen-carrying capacity during daylight hours. This represents at least 6.0 mg. of oxygen per liter of water at the prevailing temperatures and salinities. The average D.O. content of water in Pillsbury Sound during this period was 6.31 mg, or 98.5% of saturation. The Pond water carries slightly less oxygen, but nevertheless is well aerated (83% saturation), especially in view of its generally sluggish nature.

Secchi Visibility (Table 6)

Because of the natural clarity of the water, the bottom can be seen at any point in Chocolate Hole and for some distance outside the mouth of the bay. Average depths at working stations are given in Table 6. Only at the mouth of the Pond entrance (Station 7) does the water become, at times, appreciably turbid, especially after heavy rains or storms. In the Pond, most of the bottom cannot be seen because of the large amounts of silt and microscopic algae in the water, although depths are generally less than one meter.

Water Color (Table 7)

Estimates of water color were made at the eight bay stations. Colors range from IV to VII which indicated a clean, clear blue-green water like that commonly seen in other unpolluted local waters.

Color was not estimated in the Pond because the water there does not fall into the range of the comparator scale used. The Pond water has a high load of suspended material; the color is dark, brownish-olive, and seriously restricts light penetration.

Bacteriology (Tables 8-10)

Few insights can be gained from the bacteriological data. The range of values was wide, but most samples were negative or had very low counts. Because the ranges at given stations were so wide, averages do not give a realistic picture of the bacteriologic quality of the water.

SUMMARY OF SEDIMENTOLOGICAL DATA

General Observations:

Four principal sedimentary facies can be distinguished in Chocolate Hole:

(1) Boulder and coral rubble with thin cover of coarse, shelly sand. This facies fringes the shore on the northwest and southeast sides of the bay. Coral development is generally patchy. The only active and continuous reef area is along the central portion of the southeast side of the bay.

(2) Clean, vegetation-free, ripple-marked sand. This facies is found only in a narrow band along the offshore margin of the boulder and coral facies (1, above).

(3) Grass-covered, silty sand. This facies covers most of the central portion of the bay, extending from the mouth all the way to the narrow beach at the head of the bay. It contains a few small pockets of vegetation-free, ripple-marked sand.

(4) Coarse, well-sorted beach sand. The beach in Chocolate Hole is relatively narrow and steep. It appears to be without beachrock although a thorough exploration for beachrock (with drilling or trenching) was beyond the scope of this project.

The distribution of the bottom types just described is shown on the accompanying sediment map (Figure 4).

In composition, the sediments are nearly 100% $CaCO_3$ in the form of broken and abraded coral and other skeletal fragments (including a variety of molluscs, echinoderms, coelenterates, foraminifera, and calcareous algae). There are also minor amounts of rounded volcanic rock fragments. This constituent reaches significant proportions only at the mouth of the narrow channel which separates Chocolate Hole from the Pond to the northeast (Station 7).

Description of Samples

Brief descriptions of eight sediment samples from the bay are given below (the stations are the same as those used for water sampling):

#2. Coarse, poorly sorted, shelly sand; large coral and other shell fragments; rock fragments rare; some fine sand. (Note: Sample was taken 20' east of Station #2 because of the lack of sediment at the station.)

#5. Same as #2.

#7. Same as #2 except for significantly higher frequency of rock fragments.

#18. Medium-grained sand with some silt; Halimeda fragments abundant; bottom well covered with marine grasses.

#20. Same as #18 (vegetation dominated by Thalassia).

#22. Same as #20. but with larger silt fraction.

#26. Same as #2 but coarser and containing no fine sand.

#30. Same as #26.

Evidence of Water Movement:

The sediments and bottom features of Chocolate Hole show ample evidence of frequent high energy water movements. Even in the deeper parts of the bay, the non-vegetated areas show well-developed ripple marking. Hummocking by polychaete worms is rare to absent throughout the bay, even though the organisms are potentially abundant in the bay; this suggests that hummocks are continuously destroyed

by bottom currents and wave-induced water motion. Bottom currents are also indicated by the many accumulations of coarse shell debris (especially bivalve shells).

Several hours of direct observations of the sub-surface currents -- using small floats adjusted to a neutrally buoyant condition -- could reveal no circulatory patterns in the bay. The only motions observed were direct tidal flows into and out of the pond along the axis of the bay, and reversing in-and-out motions driven by sea swell. Water is exchanged between the pond and the bay in a high velocity transit of the shallow, dog-leg channel. Because the channel entrance from the pond is deeper and wider, there is a much lower water velocity at this point and not much of the fine material of the pond bottom is entrained in the water discharges. Water velocity greater than one meter per second has been observed in the narrow, shallow leg of the channel, the section leading to the bay.

Most of the water motion is probably caused by ocean swells entering the bay from the south and southwest, particularly during the summer months. The refraction of the prevailing southeasterly swells (summer and early fall) into Chocolate Hole is well shown on Aero Service Corporation's 1962 aerial photograph of the area (No. 1237 15 407, dated 10/6/62). During the winter months, water exchange in the bay is presumably reduced because of the shift in

prevailing direction of ocean swells.

The Pond

The sediments of the Pond were studied partly through direct observation from the surface (at times of minimal water turbidity) and partly from sediment coring. Five shallow cores were taken and their locations are shown on the accompanying map (Figure 2).

The Pond is floored by an accumulation of organic rich fine silt and clay carried to the Pond by runoff from the land areas to the north and east. The surface material is a soft, H_2S rich ooze which is black except for a buff oxidized surface film (less than 1 mm. thick). The thickness of the ooze varies from a few inches to a foot. The ooze is actively burrowed in places, indicating prolific development of at least one infaunal species. Also, the oxidized surface layer is broken or disturbed in many places by the impact marks of grazing fish.

The sediment beneath the organic ooze is mostly silt and clay but contains occasional sand lenses.

The Pond serves well as a catchment and settling basin for the fine sedimentary debris carried down from the land. In the absence of the Pond, Chocolate Hole could be substantially more turbid than at present, particularly after heavy rains.

SUMMARY OF BIOLOGICAL DATA

Benthic stations were selected to include the major biofacies of Chocolate Hole and thus reflect the general sedimentary facies discussed above.

The areas of living, hard coral growth suggest that active reef development has been limited by the nature of the exposure of Chocolate Hole to southerly seas. The hurricane discussed above (Section 2) caused major destruction to the reef building organisms, and the reef communities are in a stage of apparent recolonization of formerly occupied areas. The active reef growth off the easterly shore is primarily of Siderastrea and Porites with a scattering of other genera. There are small patches of Acropora cervicornis at the base of the reefs and little development of A. palmata or massive colonies of Diploria and Meandrina. The western shore has even less development of scleractinian corals with no true reef development. It is apparent that the high wave energy has limited maximum colony size. The largest colonies are Diploria, and these occur in the lee of large boulders.

The octocorallian corals are more prevalent on the western shore where it is most probable that the flexible axis has permitted their continued existence in the high wave energy zones. The presence of sessile cnidarians is shown in Figure 5. It is notable that the reef-related species are present in a large area of Chocolate

Hole but hardly reach true reef proportions.

The other community of the bay bottom is an area dominated visually by Thalassia, with a substantial component of Cymodocea and calcareous algae. This algal-grass community is at slightly greater density in the area of the outfall of the Pond channel and is nearly uniform in relative distribution among its components throughout the bay. The flora shows little significant variation among the several quadrats which can be attributed to environmental factors except for a slight increase in the abundance of Cymodocea at the deeper stations, probably due to decreased light penetration. Turbidity is so low throughout the study area as to have little discernible effect on the biota. The wet and dry weights of the floral constituents appear as Tables 12a and 12b.

There are noticeable areas of bare sand at the margins of the reef areas (perhaps due to grazing of reef herbivores) and occasional bare patches within dense strands of Thalassia. These patches are probably maintained by water movement but undoubtedly fluctuate in their extent. The rocky intertidal areas of Chocolate Hole are too extensive to permit accurate reporting of the attached algae in this ecozone.

Typical molluscs and annelid worms are present as infaunal species among the Thalassia-covered areas, and a number of conch (Strombus) were noted. There are some populations of whelks (Cittarium) and typical smaller intertidal snails.

The vertebrate populations of the bay were considered too difficult to sample quantitatively within this study. The active reef area just north of Sam Point was subject to an intensive icthyological survey in 1968 by the staff of the Institute's V.I. Ecological Research Station, and their data give an accurate view of the fish fauna. The boulder-strewn areas of the western shore are a secondary site of large fish populations, and a number of large carnivores (barracuda and shark) were seen during the course of the study, especially at night. The presence of a commercial fishing effort suggests that this area is considered productive by local fishermen.

In contrast to Chocolate Hole proper, the Pond is extremely turbid with a strongly reducing sediment and a complete absence of benthic plants. There is a large fish fauna almost definitely tied to a planktonic food chain with numbers of tarpon and mullet who feed on the crustacea. There is at least one major infaunal species tolerant of the reducing sediment; the survey team was unable to obtain samples of the organism, but the burrow shape and general habitat are strongly suggestive of a polychaete worm. The planktonic plants are abundant in the Pond; this flora is dominated by dinoflagellates and diatoms.

SUMMARY OF INFERENCES FROM THE SCIENTIFIC INVESTIGATIONS

Water Quality

The water of Chocolate Hole is of very good quality and comparable to that of other naturally undisturbed local bays. Oxygen content, salinity, temperature and pH indicate a mass of water very similar to that in Pillsbury Sound. This is at least partially because the prevailing swells during the course of study ran into the bay. Because of the absence of sewage, excessive fresh water runoff or other significant sources of pollutants, the level of water quality is maintained on a par with that of the Sound. The color and transparency of the water are also indicative of clean, unpolluted conditions. This is further indicated by the healthy and varied nature of the benthic life in the bay. Even at the deepest points, light penetration is to the bottom, insuring a healthy development of plants and animals.

Because the Pond is a relatively small and very shallow body with restricted communication to the bay, it is quickly affected by changes in the volume of runoff it gets. During periods of heavy rainfall the salinity falls below that of the bay, while during dry periods it can be expected to increase due to evaporation.

Sediments

The Pond bottom is covered with a thick layer of very soft sediment, a good deal of which remains in suspension. Although reducing conditions obtain in the sediment, the Pond water apparently carries enough oxygen to sustain a community which includes a large number of fish and crabs. This is a result of photosynthetic oxygen produced by the planktonic micro-algae and the fact that the water is shallow and acquires a great deal of its oxygen by solution from the air.

Any changes in the surrounding landscape or Pond itself should take into consideration the nature of the Pond, particularly of the bottom sediments, and the effects these could have on the water and marine life of the bay if these sediments are disturbed and escape in large amounts to Chocolate Hole. Catastrophic changes in the Pond alone, even if restricted to this area, could cause a mass kill of the organisms there and produce a foul smelling, stagnant swamp.

The staff of the Institute have investigated the effects of dredging in another bay (Water Bay, St. Thomas), where releases of clays of terrestrial origin (by removal of overlying sands) have caused catastrophic changes to the marine ecosystem with very high turbidity, hence reduced light penetration and reduced

photosynthesis. In addition, the benthic cnidarians, particularly the hard corals, have been smothered by settling particulate material. In the case of Water Bay, the clays were beneath calcareous sands and their presence was not detected in advance, since exploratory cores were not taken. Thus this dredging consequence was not forecast. In Chocolate Hole, especially in the Pond, we are aware of the nature and extent of the sediments and can practically guarantee that expansion of the channel, especially coupled with dredging in the Pond, will produce extremely high turbidity. The small size of the clay particles, coupled with the active water movement induced by incoming waves, can almost certainly mean the destruction of present clear water conditions and the resultant effects on the biota. It is estimated that Water Bay may take many years to clear.

Biological Investigations

Presently the communities of the marine ecosystem of Chocolate Hole represent a flora and fauna typical of undisturbed bays with similar exposure to the open ocean. The effects of Hurricane Bertha (1967) caused similar (or even more extensive) damage to the benthic communities in Hart, Monte, Fish, and Genti Bays on the south side of St. John, to name but a few. The ecosystem has recovered to some extent in all of these areas where human habitation is at a minimum, and regrowth of the plant and animal constituents of the benthic communities can be seen. With time, the

presently sparse reef fauna may regenerate and cause increased productivity of corals, plants and fish. Again, it must be said that dredging in the Pond area may cause near total destruction of the present biota if a channel is opened into Chocolate Hole

The Pond area is rapidly filling with terrestrial debris and would be virtually impossible to clear up. The continued encroachment of the mangroves will ultimately -- hundreds of years -- reduce the size of the area to zero, even if terrestrial runoff could be completely stopped (an impossibility).

Recommendations

Preservation of the obviously high water quality and healthy biota of Chocolate Hole requires that any attempts at developing the Chocolate Hole area be stringently controlled. Sewage disposal systems must conform absolutely to the existing code. Bulldozing and clearing of land should be limited as much as possible. Dredging if authorized, would be with the knowledge of its near certain destructive effects on the entire bay, as enumerated above.

While current water quality standards place Chocolate Hole among Class B waters in 12 V.I.C. Sections 186-3 & 9, the Anti-Degradation clause (12 V.I.C. Section 186-5) definitely prohibits change in the quality of the environment resulting from pollution. We submit that permitting dredging in the Chocolate Hole - Pond

area definitely sets up confrontation with the provisions of this section, as well as with those of Section 186-1 (c) and (d), Minimum Required Conditions.

Present approaches to enumeration of bacteria in local marine waters reflect the standard methodologies of sanitary bacteriologists. No consideration is given to complex nutrient requirements and specific ion tolerances of the variety of heterotrophs necessarily involved in these systems. Given the limited significance of standard indicator groups (coliforms, streptococci) it is suggested that present techniques be supplemented with research on the various relationships of the heterotrophic bacteria with their nutritional requirements, viability in local marine waters, and potential pathogenicity. Specifically it is proposed that a comparison of existing sanitary bacteriological techniques with those culture methods now used routinely in marine microbiological laboratories be undertaken with a view to increasing the validity of local water quality criteria.

COMPARISON STUDIES OF ENVIRONMENTAL QUALITY CRUZ BAY AND CHOCOLATE HOLE

A comparison of the marine waters of Chocolate Hole and Cruz Bay, St. John, is, as noted earlier, a somewhat arbitrary undertaking. So many facets of the ecology of these two areas result directly from their hydrographic situation that the effects of human habitation may be masked, or made more prominent. Nonetheless, there are some obvious differences and some similarities which we will point out.

Because data for the Cruz Bay study were taken in August and September, and in Chocolate Hole between late October and December, there are obvious seasonal differences in current patterns, wind, and their associated changes in temperature, salinity, and conductivity. To minimize this problem, a series of supplementary measurements were made in Cruz Bay concurrent with December measurements in Chocolate Hole. These data appear in Tables 13-22. In an attempt at better understanding the diurnal variations in the physical-chemical parameters, a 24-hour study was made in December with stations taken in Cruz Bay, Pillsbury Sound, and Chocolate Hole.

It is perhaps reasonable to consider those changes attributable to human habitation and usage of the marine waters of Cruz Bay as indicative of potential change in Chocolate Hole. Certainly there is no reason to assume that the apparently "natural" waters of Chocolate

Hole indicate what Cruz Bay may have been like before the influx of human populations. It is most important that these data be taken as base lines for future assessments of man's influence on the environment.

WATER QUALITY COMPARISONS

Water temperature and salinity, in particular, normally change during the four month span of the project. More important, the direction of water movement in the surrounding seas is changed so that the direction of swell energy vectors and the effect on the inshore areas change. The results of this are most marked in Cruz Bay where, owing to the heavy load of pollutants, change is quite obvious in the Creek area. This was apparently the case during much of October, November, and December.

Regardless of season, the differences in physical structures of the two bays greatly affect the movement and quality of their waters. The entrance of Cruz Bay is well protected from the effects of incoming offshore swells (Pillsbury Sound) by the curving point to the north and the reef to the south. The "Creek" is further protected by the Government House Point and the north shore. The bottom of the Bay slopes gently and maximum depths are found only in the main traffic lanes, a relatively small part of the total area of the Bay. Appreciable mass water movement probably only occurs at such times as fairly heavy seas are running from the east or southeast off the Sound.

Water in the Sound, moving predominantly south to north as it was during August and September, seems to contribute little to the movement of Cruz Bay water.

Chocolate Hole, on the other hand, is not so well protected. The shores form almost straight sides, without any curving embayment; there is no protective reef across the mouth; and the bottom contour is much steeper allowing direct fetch to waves. With reduced wave refraction there is higher wave energy entering the bay, and, consequently, increased water exchange.

We have concluded through the course of the study that we cannot apply exact quantification to these water exchange rates. However, these comments can be made: Time for complete water exchange in the Creek area of Cruz Bay can be as long as 10 - 14 days, the time actually observed for reasonable flushing after heavy rains in late June-early July. The average summer - early fall exchange time is probably more in the range of 4 to 7 days. The exchange time probably falls to a 1 to 4 day range in the winter - spring period. By contrast, we believe that water in Chocolate Hole is exchanged daily, perhaps more often in the summer sea and swell pattern, and occasionally less with less favorable vectors.

Temperature

Although water temperature, generally, is lower in winter than in summer, comparison of the supplementary temperature data from

Cruz Bay with data from Chocolate Hole for the same period indicates that the latter is slightly warmer. This is most likely because Cruz Bay receives at least some of the colder water from the Atlantic fringe while, because of its southerly position, Chocolate Hole is less influenced by this water, and more influenced by warmer water moving up from the south.

Salinity

Salinity can be expected to fluctuate more in Cruz Bay than in Chocolate Hole, because of the greater amounts of fresh water (sewage and runoff) dumped into the former (especially into the Creek). Comparison of the data indicated that salinity is uniform throughout Chocolate Hole. No part of this bay is isolated from the rest (as is the Cruz Bay Creek), and circulation is generally better than in Cruz Bay.

During the summer in Cruz Bay salinity in the Creek (33.3 parts per thousand) was lower than in the harbor (33.6 parts per thousand), and both areas were less saline than the open Sound (34.3 parts per thousand). Measurements made in December, however, indicate that salinity in both the Creek and harbor are similar (33.3 and 33.4 parts per thousand, respectively) and further, these are both close to salinity in the open Sound (33.3 parts per thousand). This seasonal change further indicates influx of water from Pillsbury Sound into Cruz Bay during the final months of the study. This accounts for the homo-

geneous nature of the salinity during this period.

pH

The apparent seasonal influence of Pillsbury Sound on Cruz Bay is further indicated by the pH levels. The pH in Chocolate Hole and Cruz Bay Harbor (both summer and fall) were similar to that in the Sound (8.3). However, during August-September, pH in the Creek averaged 8.2., but during December was the same as other areas (8.3).

Dissolved Oxygen

The amount of oxygen in the waters of the two bays is widely different. Chocolate Hole water averages 95% of saturation, whereas that of the Cruz Bay Harbor, about 87% and the Creek, 65-68%. Further, the Cruz Bay levels did not change appreciably between August-September to December; neither did the level in Pillsbury Sound (98%). Oxygen is discussed further in the section on Diurnal Variations.

Depth and Color

The color and transparency of the water in Chocolate Hole is uniformly good, and there is visibility to the bottom everywhere. In Cruz Bay Harbor (the area around the reef, the harbor light, and inside the Bay to the south and east) the color and visibility are generally comparable to that in Chocolate Hole. The Creek water,

however, is of undesirable color and transparency. Definite improvements were noted here in December in the depth to which the Secchi Disk could be seen. The area immediately adjacent to Government House Point and the ferry dock are more turbid than Chocolate Hole, although the reduced depth allows Secchi visibility to the bottom. Temporal changes in the color of Creek water are not apparent, but this test is quite subjective and not extremely discriminating and so may not reflect slight changes in color.

Bacteriology

Fecal coliform and streptococcus counts yielded sketchy data in both areas and while inconclusive, they do indicate a lower density of these organisms in Chocolate Hole than in Cruz Bay.

The range of densities at given stations from week to week and the spread between different stations makes conclusions about bacterial counts very difficult. It is suggested that the fate of these organisms in sea water is unknown and their normal level of occurence, even in unpolluted areas, indicate that they are very insensitive barometers of pollution. Since standard test media do not select for bacteria viable in sea water, we have no real measure of the level of potential toxicity to humans in this system.

Diurnal Variations

Data from the diurnal study appear as Tables 23 and 24 and Figures 6-8. The diurnal oxygen curves (presented as grouped data

for Cruz Bay, the Creek, Pillsbury Sound and Chocolate Hole) do show appreciable changes on a day-night basis, but the probable magnitude of the change is lessened by the obvious tidal change which occurred between 1900 hours and midnight. An increase in D.O. levels such as this during nighttime hours can only indicate influx of fresh oxygenated water into the system; the magnitude of the change is caused by the south-southeast wind which blew all night and the sea swells from the same direction. Under more typical wind and sea conditions, a much reduced increase in D.O. levels might be expected on an incoming tide. The magnitude of the oxygen increase at all stations during peak times of solar energy input indicates photosynthetic production of oxygen. The continual low 0_2 levels in the Creek indicate that oxygen demand in this area is high and, at the innermost station, that 0_2 production offers no net gain in 0_2 over the course of a diurnal day.

Summary Comparison

Because of its enclosed, well-protected nature, and the volume of sewage, fresh water, and fuel pollution it receives, the Cruz Bay Creek has suffered a serious destruction to marine life. A particularly grave loss is that of the photosynthetic plants. The loss of oxygen-producing plants compounds the inability of this ecosystem to destroy wastes and maintain desirable water quality. It appears, however, that seasonal changes in weather and sea conditions can bring some measurable improvement of water quality by increasing somewhat the normally poor turnover rate of the Creek water. However, Cruz Bay water generally, with specific exceptions, is of inferior quality to the

water of Chocolate Hole where, as yet undisturbed by man, a healthy biota thrives in clean water which is regularly renewed by the open sea to the south.

SEDIMENTOLOGICAL COMPARISONS

Most of the differences in bottom sediments between Chocolate Hole and Cruz Bay derive from the fact that Cruz Bay is protected by its location and by its coral reef from the larger waves and swells, whereas Chocolate Hole is more fully exposed to such influences. This explains why ripple marking and shell accumulation are common in Chocolate Hole but virtually absent in Cruz Bay. The lack of polychaete hummocking in Chocolate Hole and its abundance in Cruz Bay probably also stems from the differences in exposure.

In Chocolate Hole, Thalassia and other marine grasses cover the bottom right up to the beach on the northeast shore. Vegetation is thin or absent, however, over much of the near-shore part of Cruz Bay, presumably because of the turbidity caused by boat activity, human habitation, runoff and recent dredging operations in Cruz Bay.

BIOLOGICAL COMPARISONS

As the sections above point out, the major differences in the two bays occur as the result of the effects of human use of the environment. The biological data reflect these differences:

(1) Chocolate Hole proper has a uniform biota of two types: a reef-rock community and an algal-grass community. The variation in species composition between samples of the similar communities in Chocolate Hole is not attributable to changes in the environment beyond natural occurences (e.g. storm swells).

(2) The Pond north of Chocolate Hole acts as a natural sink to trap the majority of particles of terrestrial origin entering the marine environment via runoff and, despite much higher water mass movement and potential "stirring" of particulate matter, there is excellent water clarity and a healthy biota in Chocolate Hole itself.

(3). As a consequence of its "sink" function, the Pond is highly turbid, darkly colored with a reducing H_2S sediment, and with virtually no benthic plant productivity. The color and smell of the Pond waters make it an undesirable recreational area, although it is a perfectly healthy ecosystem with planktonic plants serving the function of primary producer (0_2 producer and initial fixer of carbon), and a food chain based on plankton rather than benthos. The Pond is an area valuable in two ways: It protects Chocolate Hole yet maintains itself. It is a "natural aquaculture system" and, with suitable enrichment, might well produce a higher level of production of protein than a similar sized area of a prettier bay.

(4) The major area of Cruz Bay (the harbor and reef areas) are currently healthy systems with net oxygen production (as opposed to net consumption) based on benthic plants or algal symbionts of the cnidarian animals. Furthermore, it is an excellent harbor for both commercial and recreational usage, and attempts should be made to preserve it. Preservation requires a number of procedures mentioned in the earlier Phase I report. To reiterate:

(a) A strict limitation on any dredging for maintenance of water clarity (hence, continuation of the healthy biota);

(b) Controls on new sewage treatment facilities;

(c) Upgrading of existing pollution-producing sewage treatment units;

(d) Immediate and continued cessation of fuel spills caused by carelessness or habit;

(e) Limitation (and hopefully diversion) of existing terrestrial runoff.

(5) The Creek area of Cruz Bay shows marked pollution and a gradually increasing area of high turbidity. This problem, if unchecked, can cause destruction of benthic plant communities, hence a "debt" in the oxygen balance, and all of the consequential problems of a dirty harbor, reduced recreational desirability, bad smells, tastes, and potential pathogenic health problems. The steps outlined in (4) above should be undertaken if the Creek area is ever to regain desirable water quality characteristics.

SUMMARY AND RECOMMENDATIONS

Cruz Bay

In summary, the picture of Cruz Bay which this project has elucidated is that of a small, relatively undisturbed area with a healthy biota and water of generally high quality. The threat of degradation of existing conditions is present. Indeed, a large portion of the Bay shows the beginnings of change towards a much less ecologically healthy environment.

The flushing cycle of the Bay is very slow, and drainage and raw sewage effluents are not rapidly removed from the Bay. Under exceptional conditions of wind and sea,flushing rates are increased, but these incidents seem to be rare. The potential effects of this situation are demonstrated by existing conditions; the benthic organisms in the Creek area are few and far between, while the northern area of the Bay west of the Creek shows a depleted and unhealthy biota.

At the present time, the primary threat to the natural communities is from a change in the oxygen balance. Increase in the present level of turbidity (hence reduction in solar energy reaching the photosynthetic organisms) may well cause changes in this flora and reduce levels of primary oxygen production, reducing dissolved oxygen levels in the Bay. The continued existence of a healthy community of plants and animals is of primary importance to the maintanance of high water quality in the Bay.

The following specific recommendations are made for the continued healthiness of Cruz Bay:

1. Reduction of the present levels of domestic sewage effluent entering the Bay. This can be accomplished by application of existing criteria for the effluent of septic systems, and the replacement or repair of improper treatment facilities. If possible, a central sewage treatment facility, with proper treatment to eliminate pathogens and effluent introduced into the marine environment at a point where the high levels of nutrients present in the effluent will diffuse rapidly, should be constructed. The current regime of Cruz Bay is such that no such suitable outfall area exists anywhere within the Bay; thus the plant and outfall should be located elsewhere. A reasonable site would be near the seaward edge of Enighed Pond, with a pumped outfall from Moravian Point running out to the west or southwest at least 200 yards.

2. A moratorium on dredging within the Bay. This serves several purposes. Dredging in deep water, either for building sand or increased depth for ship channels, will disturb the benthic flora. This will reduce the existing level of primary production, hence threatening the already tenuous oxygen balance. In addition, dredging may have the secondary effects of:

(a) Increasing suspended material in the water column, thus decreasing light penetration and benthic productivity;

(b) Causing the coral reef to undergo potentially threatening siltation; and

(c) Causing removal of sand on the beaches and reducing their desirability as recreational areas.

3. Limitation of terrestrial runoff. Because of the delicate balance between deteriorations effected by continuing heavy usage and the preservation

of environmental quality amenable to recreation, control of runoff should be considered. At this time, in the harbor proper, this need not be more than recognition of the potential problems and control of land clearings and road constructions.

If the permanent use of the Creek area is established as something other than industrial/commercial harbor operations, further enhancement of Creek water quality would be desirable. Re-establishment of a healthy benthic community would be a substantial aid to this, but may not occur under the stress of intermittent heavy fresh water and silt discharges. Thus, since the natural flushing rate is so low, at least partial diversion of runoff may be needed.

The problem is complicated by the topography of the area. It will be difficult to install a complete gravity discharge since the elevation at natural collection points is in the range of ten to twenty feet. The pipeline lengths to the nearest effective discharge zone, along the north shore of the bay to the point west of the seaplane ramp, would be 1500 to 2000 feet.

Chocolate Hole

The water of Chocolate Hole is of very good quality and comparable to that of other naturally undisturbed local bays. Oxygen content, salinity, temperature and pH indicate a mass of water very similar to that in Pillsbury Sound. This is at least partially because the prevailing swells during the course of study ran into the bay. Because of the absence of sewage, excessive fresh water runoff or other significant sources of pollutants, the level of water quality is maintained on a par with that of the Sound. The color and trans-

parency of the water are also indicative of clean, unpolluted conditions. This is further indicated by the healthy and varied nature of the benthic life in the Bay. Even at the deepest points, light penetration is to the bottom, insuring a healthy development of plants and animals.

Preservation of the obviously high water quality at Chocolate Hole requires strict control of development of the area.

1. Sewage disposal systems must be adequately specified and installed.
2. Unnecessary bulldozing and land clearing must be avoided.
3. Opening of the channel to the large pond behind the bay and/or dredging in the pond would almost certainly have catastrophic effect on the water quality of Chocolate Hole, and the conditions would persist for a number of years.

General

These two recommendations are made for application to the general subject of water quality preservation and pollution abatement:

1. It is recommended that certain changes be made in the Virgin Islands water quality control criteria along the following lines.

Class A. Waters for preservation of natural phenomena

Present criteria require no changes in existing conditions. These conditions are at best poorly known so that changes would be hard to assess, especially at early stages when corrective measures would be most effective. A strong effort should be made to compile water quality data for existing natural preserves, proposed preserves, and other unspoiled areas. These data can then be used as benchmarks to assess changes in these environments as well as estimating the extent of damage in known polluted areas. It is recognized that the gathering of such information would be a long term project

in ecological dynamics.

Class B. Waters for propagation of marine life and for water contact recreation.

The criteria for this class should be strengthened by the consideration of precise limits or maxima on such factors as suspended solids (especially organic), salinity, percent hydrocarbon, and possibly others. All of these factors could be affected by man to the point of limiting the propagation of marine life seriously. Only general mention is made of these in existing water quality control criteria; therefore, unnatural and damaging variations of these factors presumably would not constitute violations of the water quality standards.

The existing criteria for oxygen content should be reassessed. Existing criteria represent an oxygen level which as a diurnal median oxygen content would be acceptable, but measurements are not required to represent such a median. Oxygen levels in marine environments vary in a diurnal cycle. During daylight hours, oxygen is produced by photosynthesis but is utilized by respiration and bacterial and inorganic oxidation processes both in daylight and darkness. Thus, daylight oxygen levels represent the net dissolved oxygen in the water column only during a time when oxygen is actively being produced by photosynthesis. While D. O. levels above the existing minima may be measured at solar mid day, concentrations considerably below that level (perhaps close to zero) may obtain during nighttime hours when respiration of the community, including plants, may equal available oxygen supply. Since water samples are almost always taken during daylight, a false sense of

security is given; a diurnal median D.O. level might well fall well below the defined limit. Research into the primary productivity of marine inshore waters should be undertaken to determine the net amount of oxygen available to the community; this would represent a realistic picture of the oxygen balance in waters such as Cruz Bay where interchange with the surrounding waters of Pillsbury Sound is restricted by the geographic and hydrographic situation.

It is also felt that the requirement regarding fecal coliform density is not stringent enough. The maximum allowable count of 70/100 ml represents a monthly median and does not take into account maximum limits of fluctuation or sampling schedule versus influent schedule. Further, since some swimming areas fall under this designation, it would be advisable from a public health standpoint to base bacteriological criteria on the total number of fecal organisms found. This would include the pathogenic streptococci which are of far greater health concern than the colon bacilli, but which presently are not specifically mentioned in the water quality standards.

Finally, in areas where sewage or other waste outfalls occur in the vicinity of waters designated Class B, specific criteria should be established for rates of mixing or for assimilation (diffusion) gradients into the surrounding water.

Class C. Water for harbors and docking facilities

In this class, specific criteria should also be available for assimilation rates to insure dispersal at a rate which would prevent buildup of large plumes

of polluted water. Within this class also, the allowable fecal bacteria density should be lowered and criteria should be adopted for color, turbidity and odor. It should not be deemed impractical to maintain, even in busy commercial harbors, water which is of inoffensive color and smell, particularly in view of the importance of this natural resource to our economy.

2. It is recommended that the Virgin Islands Department of Health, Division of Environmental Health, initiate a program to locally compare results from standard sanitary bacteriological techniques to those from some of the marine organism culture techniques.

APPENDIX

APPENDIX (continued)

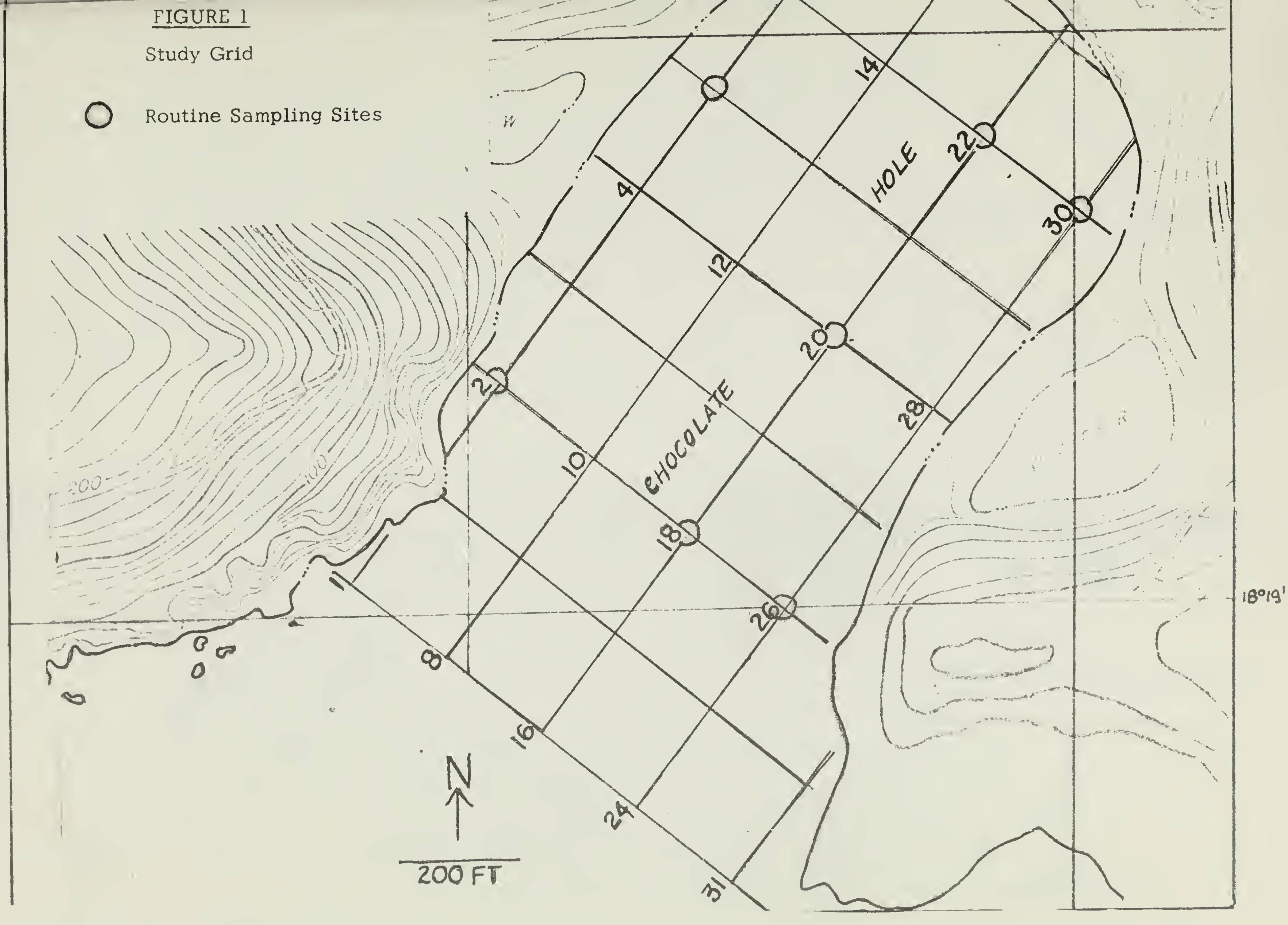
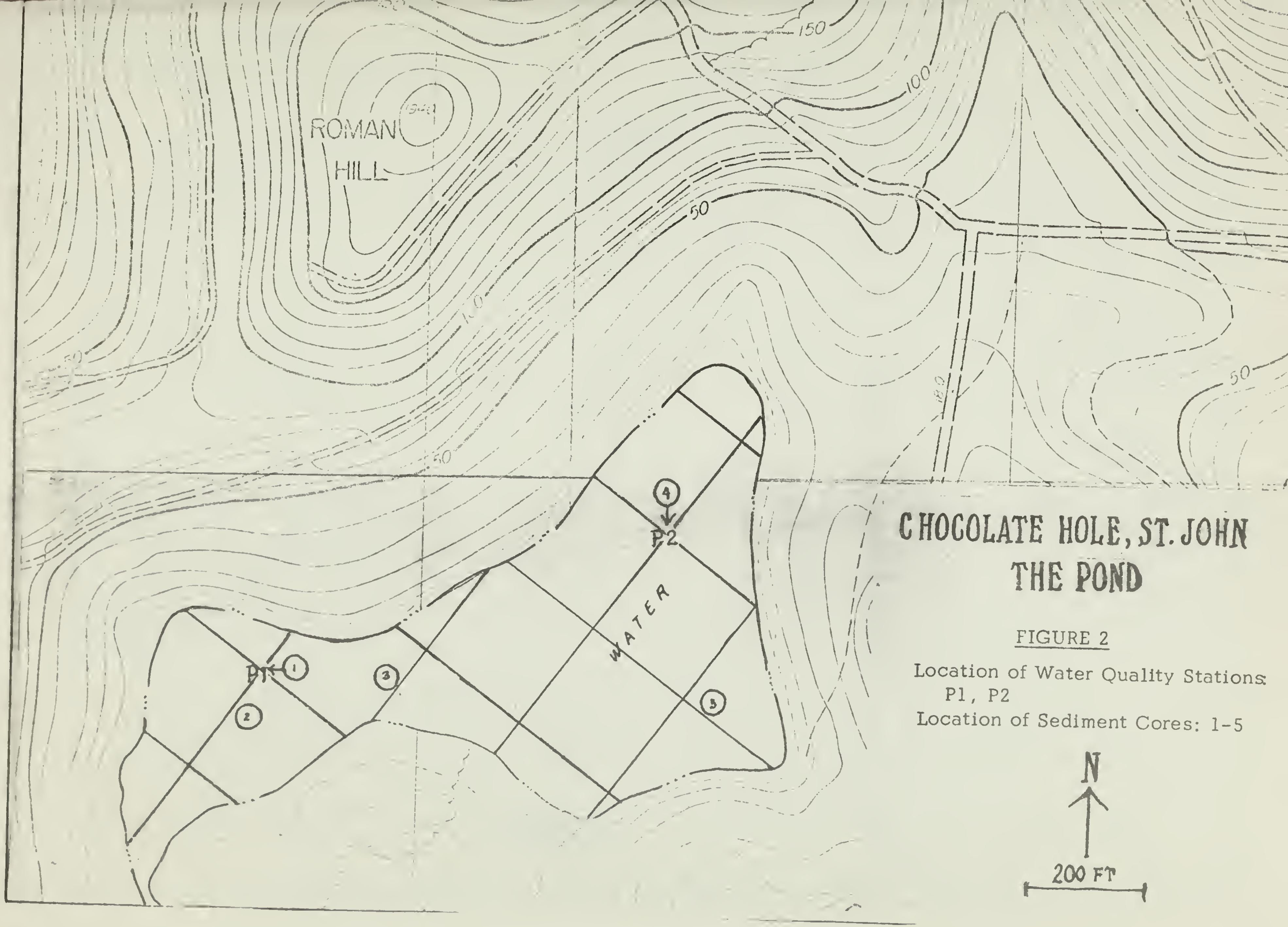


FIGURE 1

Study Grid



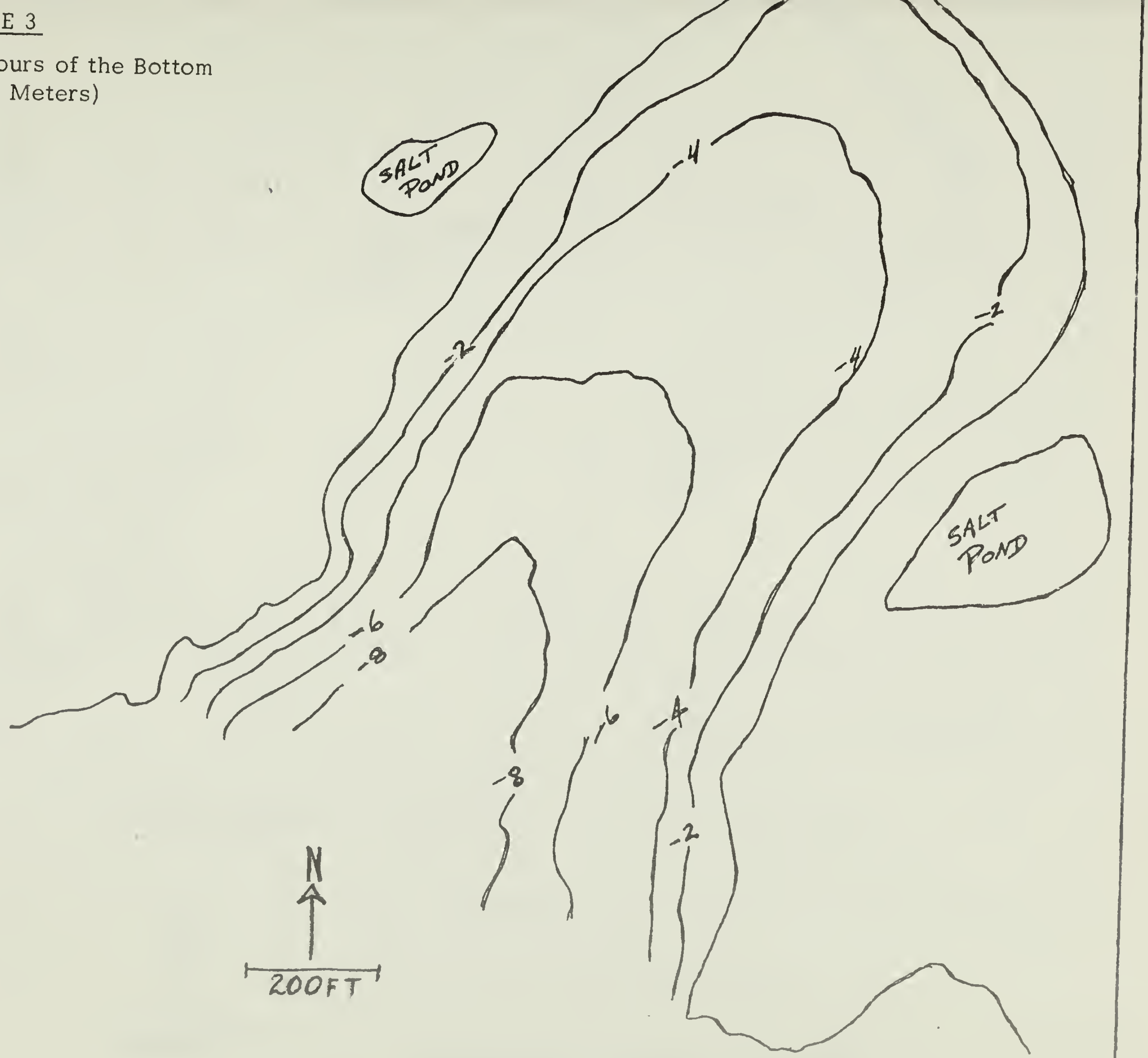
CHOCOLATE HOLE, ST. JOHN
THE POND

FIGURE 2

Location of Water Quality Stations:
P1, P2
Location of Sediment Cores: 1-5

FIGURE 3

Approximate Contours of the Bottom
(Depths in Meters)



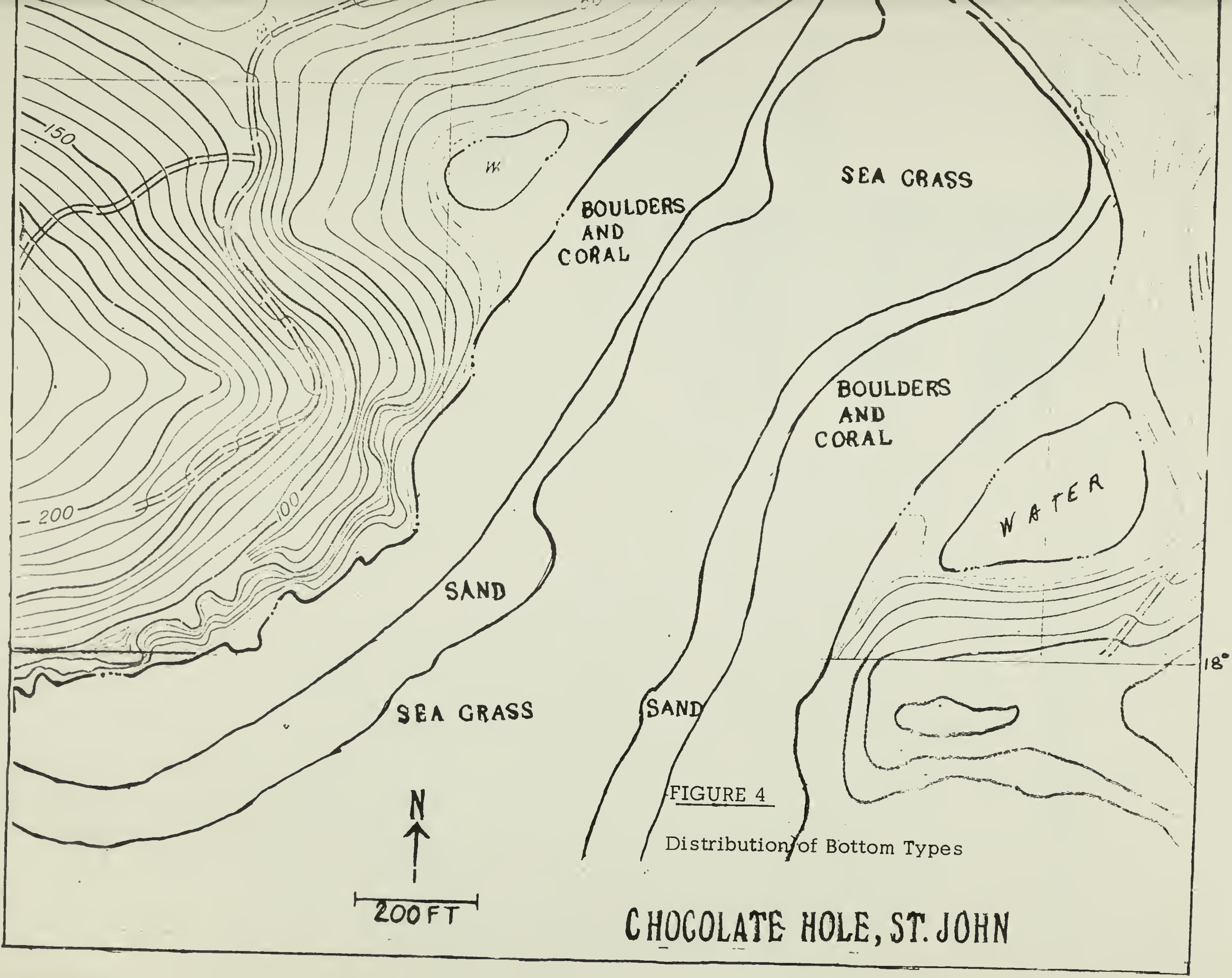


FIGURE 4

Distribution of Bottom Types

Figure 5

Prominent sessile cnidarians in Chocolate Hole

Group	Species	Sta. 2	Sta. 5	Sta. 26	Sta. 29
Madreporaria	*Acropora palmata*	-	-	-	+
	A. Cervicornis	-	-	+	+
	Agaricia agaricites	+	+	-	-
	Diploria labyrinthiformis	+	+	+	-
	Favia sp	+	-	-	-
	Manicina Areolata	+	+	+	-
	Meandrina meandrites	+	+	+	+
	Montastrea annularis	+	+	+	++
	Porites porites	-	+	++	+
Octocorallia	*Eunicea spp* (4)	++	+	-	+
	Gorgonia ventalina	+	+	+	+
	Plexaura spp 2	+	++	+	-
	Pseudplexaura spp(2)	+	+	-	-
	Pseudopterogorgia (2)	+	+	+	+
Milleporina	*Millepora spp* 2	+	++	+	++
Actinaria	*Palythoa spp*	-	-	+	+
	Zoanthus sp	+	-	-	-

- = absent
+ = present
++ = abundant

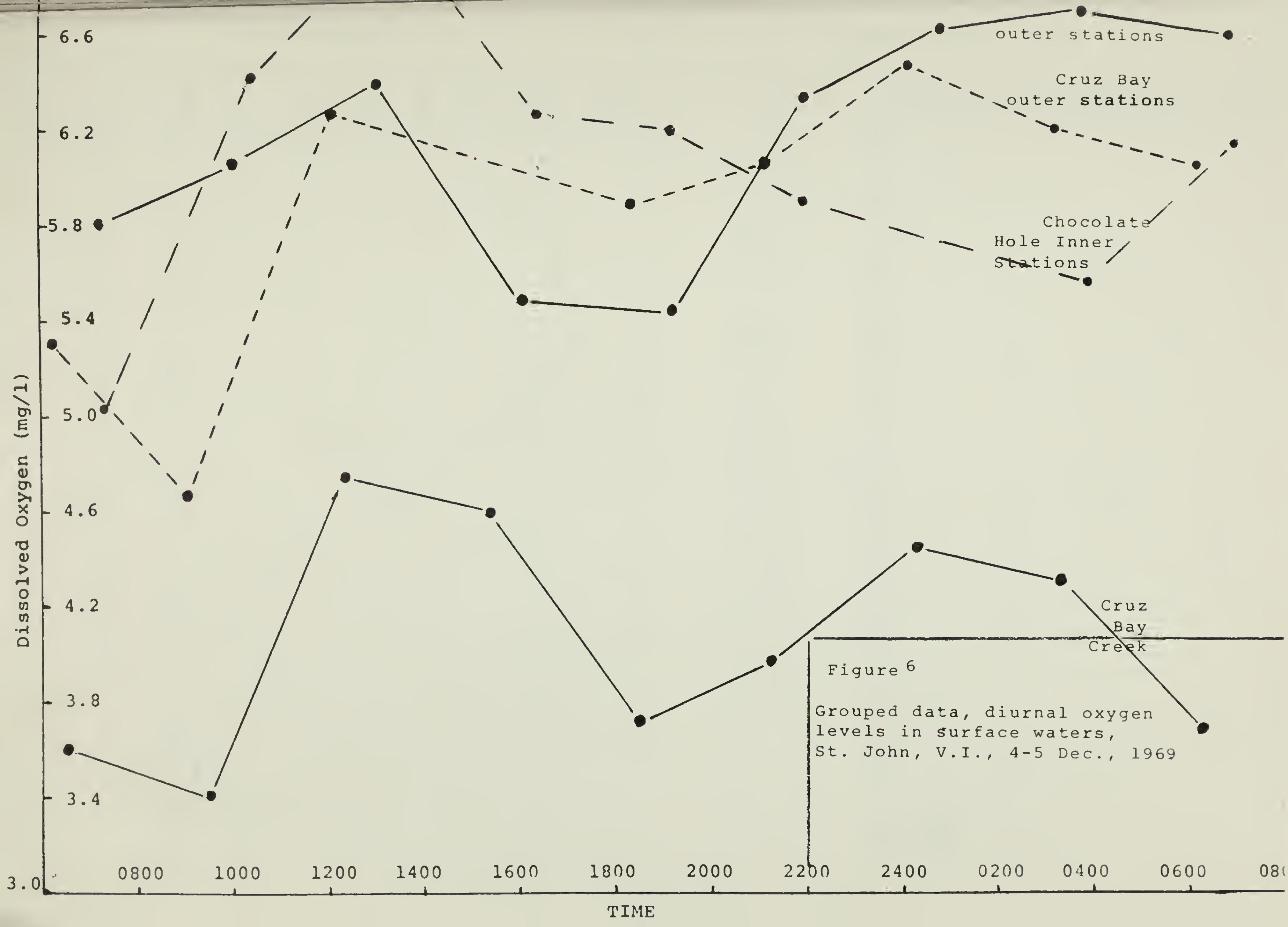


Figure 6

Grouped data, diurnal oxygen levels in surface waters, St. John, V.I., 4-5 Dec., 1969

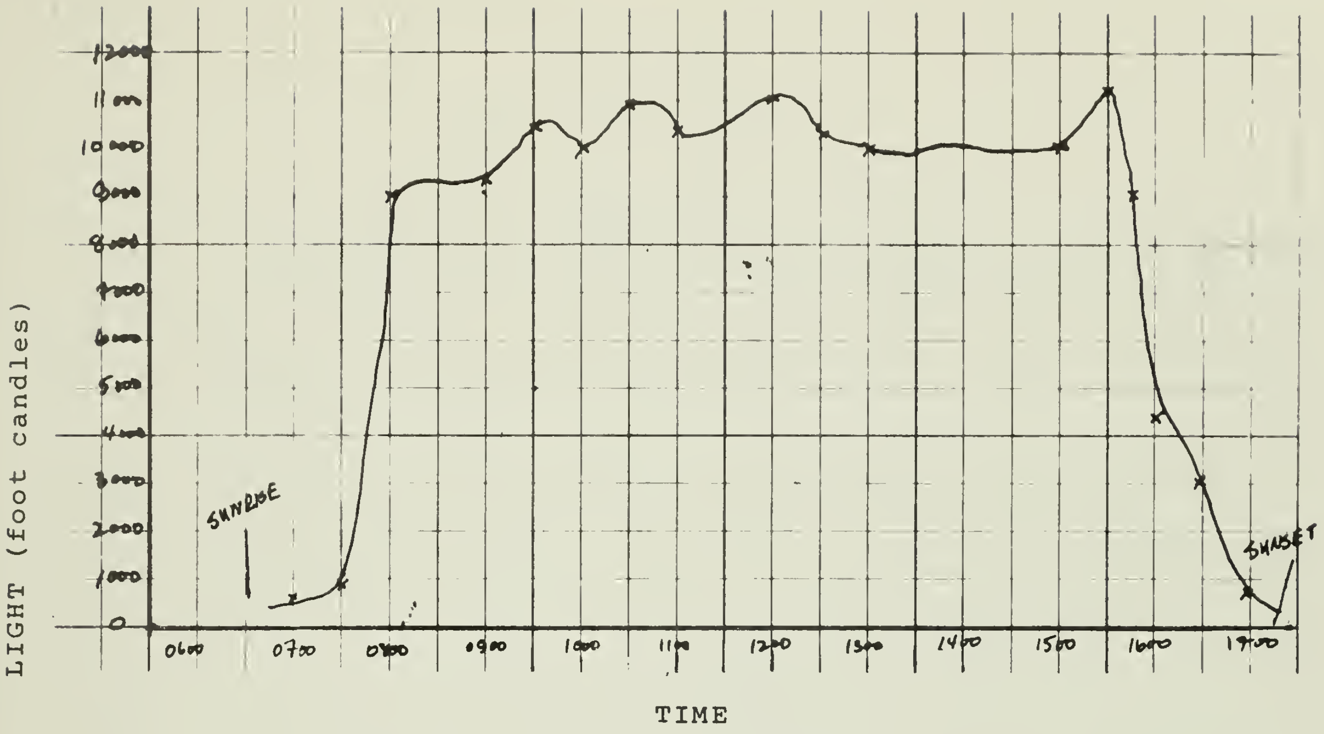


Figure 7. Surface light level during daylight hours, Dec. 4, 1969, St. John, V.I.

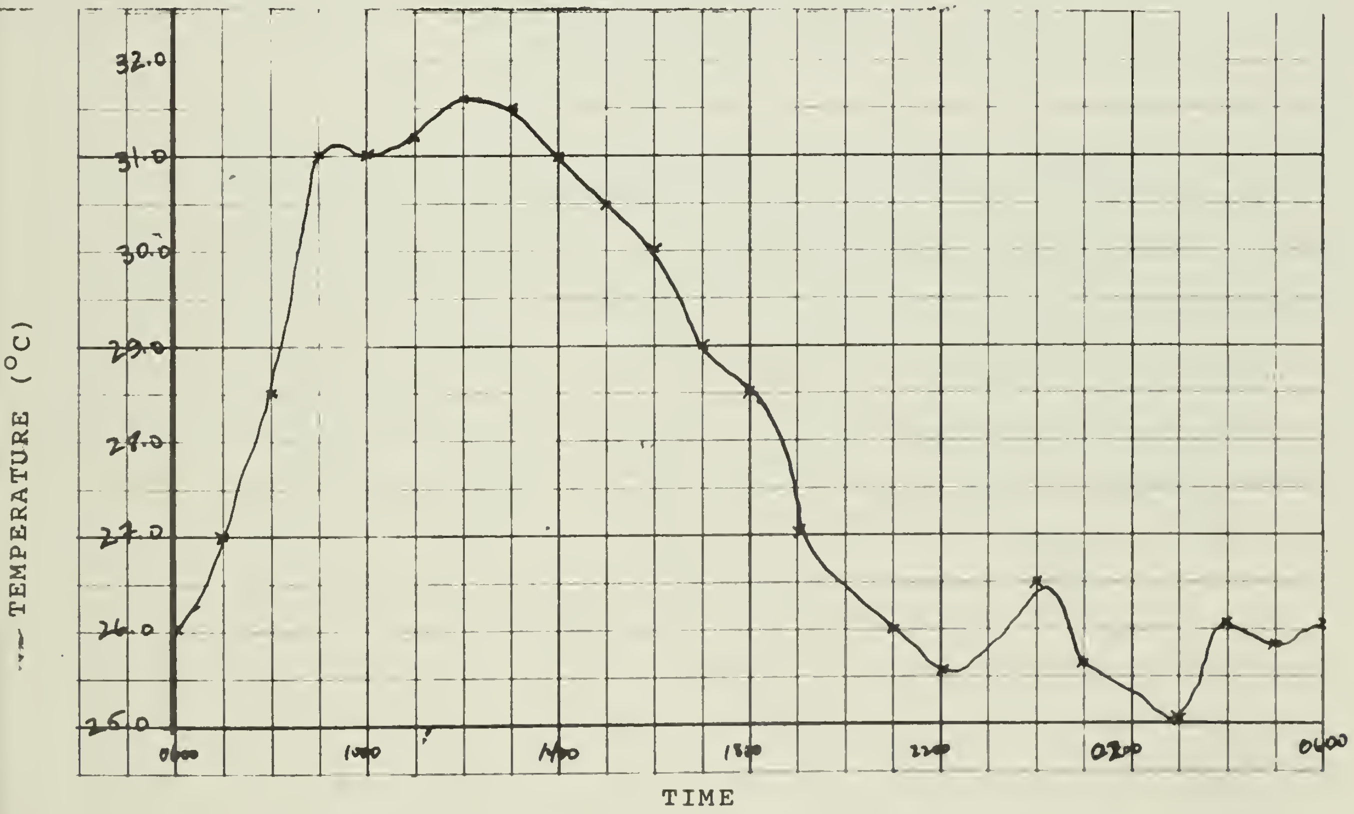


Figure 8. Air temperature in diurnal study area, Dec. 4-5, 1969, St. John, V.I.

Table 1

Chocolate Hole

Water Temperature °C

	Station									
	2	5	7	18	20	22	26	30	p1	p2
Oct. 29	30	29.5	-	30.0	29.6	29.6	30.0	29.4	30.0	30.5
Nov. 5	29.4	29.5	31.0	29.4	29.4	29.5	29.1	29.6	29.6	29.2
Nov. 11	28.6	28.5	28.6	28.9	28.6	28.6	28.6	28.5	29.1	27.6
Nov. 19	28.5	28.3	27.7	28.5	28.5	28.2	28.5	28.1	27.5	27.1
Nov. 26	27.5	27.3	27.6	27.5	27.8	27.5	27.6	27.5	28.4	28.0
Dec. 2	27.6	27.7	27.6	27.3	27.6	27.5	27.4	27.6	-	-
Dec. 10	27.5	27.7	28.1	27.4	27.6	27.7	27.8	27.8	-	-
Dec. 17	27.8	28.0	29.0	27.6	27.9	28.2	28.1	28.0	30.8	30.6
Average	28.4	28.3	28.5	28.3	28.4	28.4	28.4	28.3	29.2	28.8

Table 2

Chocolate Hole

Salinity (PPT)

	Station									
	2	5	7	18	20	22	26	30	p1	p2
Oct. 29	33.5	-	-	33.1	33.5	33.5	33.5	33.5	33.5	-
Nov. 5	32.7	32.9	32.8	32.9	32.9	33.0	33.0	32.9	32.6	32.7
Nov. 11	32.5	32.4	32.4	32.7	32.4	32.5	32.5	32.5	31.4	31.7
Nov. 19	32.8	33.2	32.4	32.8	33.1	33.0	32.8	33.2	31.9	32.1
Nov. 26	33.4	33.5	33.4	33.7	33.6	33.5	33.3	33.2	32.9	33.3
Dec. 2	33.4	33.1	33.1	33.3	33.2	33.1	33.4	33.2	-	-
Dec. 10	33.0	33.1	33.3	33.0	33.0	33.0	33.0	33.2	-	-
Dec. 17	33.1	33.3	33.1	33.3	33.3	33.2	33.2	33.2	34.6	35.1
Average	33.1	33.1	32.9	33.1	33.1	33.1	33.1	33.1	32.8	33.0

Table 3

Chocolate Hole

pH

	Station									
	2	5	7	18	20	22	26	30	p1	p2
Oct. 29	7.8	7.8	-	7.8	7.8	7.8	7.8	7.8	7.2	7.4
Nov. 5	-	8.3	8.4	-	8.3	8.3	8.2	8.3	8.5	8.6
Nov. 11	8.3	8.2	8.3	8.3	8.2	8.3	8.3	8.3	8.2	8.2
Nov. 19	8.4	8.4	8.4	8.4	8.4	8.4	8.3	8.4	7.6	8.2
Nov. 26	8.1	8.3	8.4	8.2	8.3	8.4	8.4	8.4	8.4	8.3
Dec. 2	8.4	8.4	8.4	8.4	8.3	8.4	8.4	8.4	-	-
Dec. 10	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	-	-
Dec. 17	8.4	8.4	8.4	8.3	8.4	8.4	8.4	8.4	8.2	8.6
Average	8.3	8.3	8.4	8.3	8.3	8.3	8.3	8.3	8.0	8.2

Table 4

Chocolate Hole

Dissolved Oxygen (mg/L)

	Station									
	2	5	7	18	20	22	26	30	p1	p2
Oct. 29	4.93	4.45	-	5.51	6.08	6.53	5.95	6.35	2.68	2.75
Nov. 5	5.98	5.33	4.90	5.47	5.52	5.49	5.58	5.41	5.63	5.55
Nov. 11	5.97	6.07	5.97	6.16	6.07	5.68	6.07	6.12	5.44	5.80
Nov. 19	5.99	6.39	6.47	6.06	6.12	6.71	6.38	6.00	6.10	6.63
Nov. 26	6.06	6.67	6.43	6.24	6.14	6.18	6.37	6.53	-	-
Dec. 2	6.48	6.41	6.25	6.55	6.02	6.48	6.52	5.55	-	-
Dec. 10	6.50	6.56	-	6.32	6.25	6.61	6.46	6.52	-	-
Dec. 17	6.49	6.40	6.04	6.54	6.24	6.32	6.36	6.46	5.87	5.84
Average	6.05	6.04	6.01	6.11	6.05	6.25	6.21	6.11	5.14	5.31

Table 5

Chocolate Hole

Dissolved Oxygen (Percent saturation)

	Station									
	2	5	7	18	20	22	26	30	p1	p2
Oct. 29	80.8	71.8	-	88.8	98.0	100	97.5	100	43.9	95.0
Nov. 5	96.4	85.9	81.6	88.2	89.0	88.7	88.5	87.2	90.8	88.0
Nov. 11	93.2	94.8	93.2	97.7	94.8	88.7	94.8	95.6	88.7	87.8
Nov. 19	94.0	99.5	99.5	95.0	95.7	100	100	91.7	93.9	100
Nov. 26	93.3	100	99.0	96.0	95.0	95.1	98.0	100	-	-
Dec. 2	99.7	98.9	96.3	100	92.6	99.7	100	85.5	-	-
Dec. 10	100	100	-	97.0	96.4	100	99.6	100	-	-
Dec. 17	99.5	98.5	95.8	100	96.0	97.6	98.0	98.5	98.3	97.5
Average	94.6	93.6	94.2	95.3	94.7	96.2	97.1	94.8	83.1	83.6
Combined average			95.1%							

Table 6

Chocolate Hole

Depths in Meters by Leadline

	Station									
	2	5	7	18	20	22	26	30	p1	p2
	6.4	3.0		7.3	4.5	3.0	4.5	1.5	0.3	0.6
	5.4	3.1	0.8	7.4	5.0	2.6	3.3	1.8	0.4	0.5
	5.8	3.3		7.2	4.5	2.5	4.3	1.8	0.5	
Average	5.9	3.1	0.8	7.3	4.7	2.7	4.0	1.7	0.4	0.6

Table 7

Chocolate Hole

Water Color (Forel-Ule Numbers)

	Station							
	2	5	7	18	20	22	26	30
Nov. 19	VI	V	-	V	VI	V-VI	V-VI	-
Nov. 26	V	VI	-	V	V	VI	V	IV
Dec. 2	VI	VI	VI-VII	-	VI	VI	-	-
Dec. 10	IV	IV	VII	V	IV	-	V	-
Dec. 17	IV	IV	-	IV	IV	V	IV	-
Average	V	V	VII	V	V	VI	V	IV

Table 8

Chocolate Hole

Fecal Coliform (Cells/100ML)

	Station									
	2	5	7	18	20	22	26	30	p1	p2
Oct. 27	48	24	0	6	0	14	82	302	-	-
Nov. 3	4	2	0	0	0	10	0	70	0	66
Nov. 10	0	0	0	0	0	0	0	0	6	0
Nov. 17	0	0	0	0	0	4	2	2	0	8
Nov. 24	4	0	0	2	0	0	0	0	0	0
Dec. 8	-	0	0	0	2	-	-	0	-	-
Dec. 15	-	0	0	0	0	-	-	0	-	-
Average	11.2	3.7	0	1.1	.1	5.6	16.8	53.4	1.5	18.5

Dash (-) means station not sampled.

Table 9

Chocolate Hole

Fecal Strep (Cells/100ML)

Date	Station									
	2	5	7	18	20	22	26	30	p1	p2
Oct. 27	0	0	0	0	0	0	0	0	0	-
Nov. 3	0	0	0	0	0	0	4	6	2	0
Nov. 10	4	0	0	0	0	0	0	0	0	0
Nov. 17	0	0	0	0	0	0	0	0	0	0
Nov. 24	0	0	0	0	0	0	0	0	2	0
Dec. 8	-	0	0	0	0	-	-	0	-	-
Dec. 15	-	0	0	0	0	-	-	0	-	-
Average	<1	0	0	0	0	0	<1	<1	1	0

(-) indicates station not sampled

Table 10

Chocolate Hole

Average Combined Fecal Organisms (Coliform and Strep Cells/100ML)

	Station									
	2	5	7	18	20	22	26	30	p1	p2
Average	12	3.7	0	1.1	<1	5.6	17.6	54.3	2.5	12.5

Combined Average, All Counts = 11.6 Cells/100ML

Table 11

Pillsbury Sound*

Water Quality

	Temp. °C	Sal. °/oo	pH	D.O. mg/l	D.O. % Sat.	Color
Nov. 5	29.6	33.4	8.4	6.14	99.0	III
Dec. 4	27.4	33.3	8.4	6.33	97.2	III
Dec. 5	28.0	33.1	8.2	6.46	99.4	III
Average	28.3	33.3	8.3	6.31	98.5	III

* Measurements made at points in Sound between Chocolate Hole and Current Hole.

Table 12a

Wet Weights of Benthic Plants From 1/4 Meter Square Quadrats (grams/1/4m^2)

	Calcareous Algae					Non-Calcareous Algae			Marine Grasses	
Station	Halimeda incrassata group	Halimeda monile	Penicillus	Udotea	Valonia	Caulerpa sertularioides	Caulerpa racemosa	Dictyosphaeria	Thalassia testudinum	Cymodocea manatorum
7	330	32	6	tr	tr	10	-	tr	655	38
18	350	65	23	25	14	12	-	tr	248	310
20	72	15	49	18	tr	tr	tr	tr	242	35
22	310	20	30	8	-	tr	-	-	124	112

Table 12b

Dry Weights of Benthic Plants From ¼ Meter Square Quadrats (in grams)

	Calcareous Algae					Non-Calcareous Algae			Marine Grasses	
Station	*Halimeda incrassata group*	*Halimeda monile*	*Penicillus*	*Udotea*	*Valonia*	*Caulerpa sertularioides*	*Caulerpa racemosa*	*Dictyosphaeria*	*Thalassia testudinum*	*Cymodocea manatorum*
7	155	11	2	tr	tr	2	-	tr	135	14
18	198	21	12	18	9	8	-	tr	52	136
20	35	6	24	4	-	tr	tr	tr	52	12
22	158	12	16	6	-	tr	-	-	31	40

Table 13

Cruz Bay

Supplementary Data

Water Temperature ^{o}C

	Station									
	4	14	18	21	23	27	30	34	36	38
Dec. 4	27.5	-	27.4	-	27.5	27.5	-	-	-	27.7
Dec. 10	27.1	26.8	26.8	26.8	26.6	27.0	26.5	26.9	27.0	26.7
Dec. 17	27.0	27.5	26.9	27.3	27.6	27.1	27.3	27.6	27.5	27.5
Average	27.2	27.2	27.0	27.1	27.3	27.2	26.9	27.3	27.3	27.4
Group Average			27.2					27.2		

Table 14

Cruz Bay

Supplementary Data

Salinity - $^{o}/oo$

	Station 4	14	18	21	23	27	30	34	36	38
Dec. 4	33.5	-	33.5	-	33.6	33.4	-	-	-	33.6
Dec. 10	33.2	33.2	33.2	33.2	33.2	33.1	33.2	33.3	33.3	33.4
Dec. 17	33.2	33.3	33.1	33.3	33.2	33.2	33.3	33.3	33.3	33.2
Average	33.3	33.3	33.3	33.3	33.3	33.2	33.3	33.3	33.3	33.4
Group Average			33.4					33.3		

Table 15

Cruz Bay

Supplementary Data

pH

	Station 4	14	18	21	23	27	30	34	36	38
Dec. 4	8.2	-	8.4	-	8.4	8.4	-	-	-	8.3
Dec. 10	8.2	8.4	8.3	8.3	8.4	8.3	8.4	8.2	8.2	8.3
Dec. 17	8.4	8.4	8.4	8.4	8.2	8.4	8.2	8.3	8.3	8.3
Average	8.3	8.4	8.4	8.4	8.3	8.4	8.3	8.3	8.3	8.3
Group Average			8.4					8.3		

Table 16

Cruz Bay

Supplementary Data

Dissolved Oxygen (Mg/L)

	Station									
	4	14	18	21	23	27	30	34	36	38
Dec 4	5.63	-	5.45	-	3.87	5.77	-	-	-	3.71
Dec 10	6.21	6.08	6.14	6.08	5.72	5.86	5.77	2.89	3.96	3.23
Dec 17	6.33	5.63	5.95	5.23	4.64	5.89	4.73	4.80	4.83	4.09
Average	6.06	5.86	5.85	5.66	4.74	5.84	5.25	3.85	4.40	3.68
Group Average			5.67					4.28		

Table 17

Cruz Bay

Supplementary Data

Dissolved Oxygen - % Saturation

	Station									
	4	14	18	21	23	27	30	34	36	38
Dec. 4	86.6	-	83.7	-	59.5	88.8	-	-	-	57.5
Dec. 10	95.0	92.6	93.5	92.6	86.7	89.5	86.4	44.0	60.5	49.1
Dec. 17	96.0	86.0	90.0	79.6	71.3	89.4	72.0	73.4	73.7	62.5
Average	92.8	89.3	89.1	86.1	72.5	89.2	79.2	58.7	67.1	56.4
Group Average				86.5				65.4		

Table 18

Cruz Bay

Supplementary Data

Secchi Depth - Meters[1]

	Station									
	4	14	18	21	23	27	30	34	36	38
Dec. 4	B	-	B	-	B	B	-	-	-	2.0
Dec. 10	B	B	B	B	B	B	2.5	1.4	1.4	2.0
Dec. 17	B	B	B	B	B	3.5	1.8	1.5	B	1.3
Average	B	B	B	B	B	3.5-B (2)	2.2	1.5	1.4-B (3)	1.8
Group Average							1.7			

(1) B indicates visibility to Bottom

(2) Depth to bottom 4.2 Meters

(3) Depth to bottom 1.6 Meters

Table 19

Cruz Bay

Supplementary Data

Water Color (Forel-Ule Numbers)

	Station									
	4	14	18	21	23	27	30	34	36	38
Dec. 4	VI	-	V	-	XV	V	-	-	-	XVII
Dec. 10	V	VI	VI	VI	XII	VI	XVI	XVII	XVI	XIX
Dec. 17	V	VI	VI	VI	XVI	VI	XV	XVIII	XVI	XVI
Average	V	VI	VI	VI	XIV	VI	XV-XVI	XVII-XVIII	XVI	XVII

Table 20

Cruz Bay

Supplementary Data

Fecal Coliform - Cells/100 ML

	Station				
	4	18	23	27	38
Dec. 8	0	14	6	0	2
Dec. 15	0	0	16	0	2
Average	0	7	11	0	2

Table 21

Cruz Bay

Supplementary Data

Fecal Strep - Cells/100 ML

	Station				
	4	18	23	27	38
Dec. 8	0	0	0	0	2
Dec. 15	0	0	0	0	0
Average	0	0	0	0	1

Table 22

Cruz Bay

Supplementary Data

Combined Fecal Strep and Coliform Cells/100 ML

	Station				
	4	18	23	27	38
Dec. 8	0	14	6	0	4
Dec. 15	0	0	16	0	2
Average	0	7	11	0	3

Table 23

Dissolved Oxygen at Diurnal Study Stations
(Mg/L)

Time	CB4	CB18	CB27	CB23	CB37	GCB	CH6	CH23	CH18	CH26
0600	5.36	5.07	5.50	3.47	3.72	5.86	5.41	4.71	5.86	5.70
0900	4.56	4.63	4.63	3.19	3.61	6.14	6.43	6.43	6.00	6.22
1200	7.00	6.27	5.57	5.60	3.90	6.17	7.23	7.07	6.33	6.67
1500	6.33	5.75	6.13	5.64	3.57	5.26	6.53	6.00	5.32	5.89
1800	5.53	6.24	5.89	4.02	3.41	5.44	6.61	5.79	5.41	5.47
2100	6.13	6.49	6.15	4.29	3.64	6.32	5.93	5.87	6.45	6.23
2400	6.43	6.67	6.28	5.07	3.83	6.67	5.76	5.71	6.43	6.73
0300	6.29	6.10	6.21	4.79	3.81	6.70	5.74	5.41	6.77	6.64
0600	6.43	5.64	6.07	3.97	3.41	6.50	6.04	6.19	6.57	6.71

CB = Cruz Bay

GCB = Pillsbury Sound 1 mile off Great Cruz Bay

CH = Chocolate Hole

Study conducted on December 4-5, 1969.

Table 24

Temperature and Salinity at Dirunal Study Stations

(S in °/oo; T in °C)

	CB4		CB18		CB27		CB23		CB37	
Time	T	S°/oo	T	S°/oo	T	S°/oo	T	S°/oo	T	S°/oo
0600	27.4	33.80	27.1	33.80	27.0	33.90	27.5	34.00	25.5	34.00
0900	31.0	33.80	30.0	33.80	27.3	33.70	30.5	33.90	27.9	33.90
1200	28.1	33.50	28.2	33.80	27.9	33.60	28.2	33.80	28.4	33.60
1500	28.2	33.70	28.5	33.70	28.1	33.60	28.3	33.70	28.5	33.90
1800	28.2	33.64	28.7	33.78	28.7	33.74	28.5	33.94	28.7	33.82
2100	28.0	33.66	28.2	33.80	28.7	33.92	28.5	33.82	28.5	33.86
2400	28.0	33.56	28.2	33.80	28.4	33.80	28.5	33.82	28.5	33.83
0300	28.0	33.62	28.2	33.87	28.22	33.88	28.2	33.87	28.2	33.77
0600	27.9	33.90	27.9	33.74	28.10	33.90	28.2	33.88	28.2	33.80

	GCB		CH6		CH23		CH18		CH26	
	T	S°/oo	T	S°/oo	T	S°/oo	T	S°/oo	T	S°/oo
0600	27.2	33.80	28.0	33.60	26.9	33.70	27.2	33.60	27.4	33.60
0900	27.4	33.60	27.4	33.60	27.4	33.60	27.4	33.60	27.4	33.60
1200	27.6	33.50	28.5	33.70	27.8	33.40	28.7	33.50	27.7	33.60
1500	27.5	33.30	28.6	33.80	28.0	33.40	27.5	33.50	27.6	33.60
1800	28.2	33.50	28.2	33.64	28.2	33.55	28.1	33.50	28.1	33.52
2100	27.9	33.56	27.1	33.60	28.1	33.40	28.3	33.82	28.2	33.47
2400	28.1	33.62	27.8	33.65	27.9	33.50	24.9	33.62	28.1	33.62
0300	27.9	33.53	27.4	33.62	27.6	33.45	27.0	33.46	28.1	33.39
0600	27.9	33.63	27.6	33.54	27.9	33.48	27.9	33.47	27.9	33.37