CARIBBEAN RESEARCH INSTITUTE

WATER POLLUTION REPORT NO. 10

WATER QUALITY AND ENVIRONMENTAL STATUS OF BENNER BAY-MANGROVE LAGOON, ST. THOMAS

David I. Grigg, Robert P. vanEepoel and Robert W. Brody

(April, 1971)

GOVERNMENT OF THE VIRGIN ISLANDS

DEPARTMENT OF HEALTH, DIVISION OF ENVIRONMENTAL HEALTH

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General Statement and Purpose

Development on the east end of St. Thomas is increasingly geared toward water oriented facilities. The need for boat anchorage and related service facilities on this end of the island is being met in two places -- Red Hook/ Vessup Bay and, to a greater extent, Benner Bay (Figure 1) where, within the past year the number of boats at anchor or piered has more than doubled, due mainly to the opening of a new facility (Antilles Yacht Services). There are presently three bare-boat charter concerns operating out of Benner Bay and plans for their expansion and for additional facilities will result in even higher boat densities and traffic in the future. Construction has begun for the Compass Point Club, a shoreline support facility for "Aquaminiums" -- ownership-lease properties similar to condominiums but involving 46' powered houseboats as the property unit; they are presently operating out of leased space on the channel between Mangrove Lagoon and Benner Bay. Antilles and a second charter sailboat facility, West Indies Yachts, have docks on Benner Bay. Lagoon Fishing Center and Toby Mann Mrine operate the remaining "public" dockage on Benner Bay.

Benner Bay is relatively shallow, maximum depth is about 2.5 meters, and deep draft or deep keeled boats regularly run aground, especially in the narrow passage into the bay between Bovoni and Bird Cays (Figure 2). Several requests have been made by boat owners and area businessmen to dredge and deepen the channel.

Marinas and other good anchorages which are used by large numbers of boats are inevitably sites of extremely poor water quality and an impoverished biota. Motor vessels contribute appreciable quantities of various pollutants to the water, especially when engines are running slowly or at idle as they usually are within the anchorage. Exhaust gases and unburned hydrocarbons are continuously injected into the water at higher than ambient temperatures and pressures. This material dissolves or is finely dispersed in the water and kills living things. In addition to combustion products there is sewage (none of the marinas on the island have pump-off facilities and very few craft have holding tanks, in any case), other refuse and some unavoidable fuel and oil spillage. The significance of these additions to the water can really be appreciated only if other attendant facts are considered. The first is the number, and, more important, the density of boats in most anchorages where their combined effects are concentrated in a relatively small area. The second factor is that places best suited for docking and anchoring are usually least capable of tolerating the ensuing stresses placed upon them.

Quiet, protected waters are often so because of very low currents resulting in poor water exchange or flushing. Pollutants added to such systems are not quickly removed and their concentrations build up to very high levels. These facts must be recognized and taken into account whenever one is assessing the possible impact of boats and boat traffic. This is not to say that marine oriented commerce is undesirable -- without a doubt it is desirable, and necessary, in an island setting -- but its consequences must be recognized and admitted so that its proliferation and development can be kept in proper perspective to other requirements. One of the cardinal guidelines for insular development should be to preserve as many varied natural systems as possible. The tendency to convert natural systems toward the economic end to which they can most easily be converted cannot always be justified when weighed against the rapidly deteriorating quality of man's environment.

During the past few years considerable controversy has centered around a proposal to fill most of the Mangrove Lagoon for construction of a jet airport. Engineering proposals for the airport provide for waterways under the runway designed to maintain the present flow of water from the open sea into the Lagoon. Such flow is essential to the proper circulation and flushing of the Lagoon, but certainly is not the only requirement for its preservation. Conservationists generally agree that, such structures notwithstanding, construction of the jetport would destroy the Lagoon. Physically, it would occupy about two-thirds of the area, leaving only the central shallow turtle grass area and part of one mangrove islet. Additionally, it is anticipated that run-off and siltation and other forms of pollution, during construction and after development of the airport complex and its satellite commercial facilities, will rapidly obliterate these remaining portions of the Lagoon.

The Lagoon area now remains as the only extensive representative of its kind in the U. S. Virgin Islands. Similar areas on St. Croix have already been destroyed in the course of industrial, tourist accommodating and housing developments. While conservationists urge the protection of the St. Thomas site, they are hard put to offer tangible evidence of its value. It presently has no assessable economic value beyond the price of the real estate. Its worth as a natural area and recreation site and its potential for research and aquaculture have been described by conservationists and biologists but have not been translated into terms most people can appreciate, i.e. dollars and cents, or even been publicly acknowledged by local agencies responsible for its disposition.

The purpose of this study was to describe the Benner Bay-Lagoon environment, primarily the water quality. Field work

was conducted from February to July, 1970 by the authors with the assistance of Lyn Slocum (Virgin Islands Ecological Research Station) and several marine technology students from Cape Fear Technical Institute. Other students who assisted in the field and the laboratory were David Morris (Fairleigh Dickenson University) and Laverne Ragster (University of Miami). Eileen Shatrosky, assisted by Sonya Nelthropp of the College of the Virgin Islands, did most of the laboratory analyses and Roosevelt Bryant and Lawrence Lewis of the College of the Virgin Islands prepared the figures. Jackie Thomas of the Caribbean Research Institute and Paula Bailey deserve special thanks for the laborious job of typing the report.

Previous Work

Several previous reports have covered various aspects of the Lagoon biology and hydrography. All have acknowledged the uniqueness and the natural value of the area. In a survey of the biological aspects of water quality in the three Virgin Islands, a Department of Interior, FWPCA, report (1967) includes some data on sediment nutrients in the Lagoon. McNulty, et al, (1968), in the most comprehensive study of the Lagoon to date, divided the area into nine ecological zones, presented data on its hydrography and wildlife and called for several safeguards to be observed for the protection of the area if the airport is constructed. At the request of local government agencies, studies on biological and engineering aspects of the proposed airport were made (Tabb and Michel, 1968; Michel, 1970). These reports contain information on the distribution of the major organisms in the area and on the importance of the existing unique tidal and current regimes to the sustenance of the Lagoon. Michel (1970) presents data on salinity distributions, tidal cycles, and flushing rates of the Lagoon and proposes engineering structures to be incorporated into the proposed runway designs to maintain the critical water flow. Additional hydrographic data are contained in Dammann (1970).

Description of the Study Area

The study was conducted in Benner Bay and Mangrove Lagoon to the west. The area is on the southeast coast of St. Thomas (Figure 1) and is open to the Caribbean Sea on the south. Field work was confined to the area bounded by Patricia and Cas Cays on the south and Coculus Rocks on the east. Sampling stations are shown in Figure 3. Bovoni and Patricia Cays, as well as the low land to the north and west of the Lagoon are alluvial material (Donnelly & Whetten, 1968) deposited by the Turpentine Run gut. This stream is presently the largest surface water producer remaining on St. Thomas. Although it now runs into the Lagoon only after very heavy rains, that portion of it below Mt. Zion, and spots farther southeast, contain water the year round and harbors an interesting but little known faunal assemblage which includes at least two species of shrimp, several species of fish, and an eel. The gut drains the entire Tutu Valley plateau, about four square miles, which lies at about 200 feet elevation and is fed by four tributary branches. Much smaller guts drain the hills around Estate Nulliberg, northwest of the Lagoon and Langmath and Benner on the north and the northeast. The latter drains into a salt pond behind the northeast shore of Benner Bay. The pond has been partially filled as part of the area development already mentioned.

The dominant terrestrial organism in the study area is Rhizophora mangle (red mangrove). The entire shoreline of the Lagoon and of Benner Bay was formerly fringed with red mangrove, but much of the Benner Bay shoreline has been cut and piers and bulkheads constructed. The remaining mangroves along Benner Bay are in a belt usually one plant wide. Extensive growth of mangroves is responsible for the formation of the many cays in the area.

The dominant marine feature of the area is an extensive pasture of turtle grass, Thalassia testudinum, the distribution of which has been mapped by Tabb and Michel (1968) and McNulty, et al, (1968). Its density is sparser as one progresses into Benner Bay where all benthic plant growth disappears below 0.5 meter. Due to the dense boat anchorage, heavy traffic, increased runoff due to land clearing and construction, great shoreline alteration and attendant pollution, water quality in Benner Bay is extremely poor. Although better, the water quality in the northern part of the Lagoon is also reduced. The major part of the Lagoon, however, contains clear water as does the outer portions of Benner Bay and west Jersey Bay.

Other zones in the Lagoon are characterized by various algae, grass and coral assemblages (McNulty, 1968) and contribute to the habitat diversity which makes Mangrove Lagoon possibly the most complex and varied natural system in the islands. Not as obvious, but just as important to this ecosystem, is the reef on the south, dominated by Acropora palmata (elkhorn coral) which has been shown to be vitally important to the Lagoon ecology (Tabb and Michel, 1968; McNulty, 1968; Michel, 1970) by virtue of its effect on the local water circulation. The present distribution of bottom types is shown in Figure 16.

Benner Bay and the Lagoon are well protected from strong seas by the reef and cays on the south and by the eastern tip of St. Thomas and Great and Little St. James islands to the east and southeast (Figure 1). Water moving into the area northwesterly looses most of its energy where the bottom shallows up rapidly between Rotto and Cas Cays.

Most waves are dissipated after moving across the shallows of south Benner Bay.

The north shore of Benner Bay is heavily developed. Except for marinas along the northeast corner, most buildings are private dwellings. North of the Lagoon in the Bovoni-Nadir area, a fair-sized community is developing. Sewage from this community is treated in a 70,000 gpd. plant (Figure 15) located on the northwest shore of the Lagoon and the effluent drained to the shore.

Long Point is undeveloped, although a small salt pond on its west shore, south of Stalley Bay, has been dredged open to the sea and a small beach area has been created by dredging on the lee side of the southeast point. These modifications are shown on Figure 2. The Cays and Compass Point are also undeveloped, although the latter is soon to be the site of extensive construction for another marina facility. Land clearing, shoreline alteration and extensive filling have already been accomplished.

Presently, most of the Lagoon's north shore is undeveloped. A horse racing track has been proposed for the flat, formerly swampy, area west of the highway and some filling and grading has been accomplished on that project.

RESULTS

The raw data collected in this study is presented in thirteen tables. Table 14 gives some mathematical qualities for the data from two diurnal studies. Table 15 is a summary of the monthly averages of the raw data. Locations of sampling stations are given in Figure 3; the mean depth at each station can be found in Table 4.

Temperature

Temperature measurements were made from February to May and are shown in Table 1 with the calculated monthly averages in Table 15.

Minimum and maximum temperatures were measured at Station 10: 24.0°C and 33.0°C. Temperatures of 24°C were also encountered once each at Stations 6 and 8. The average monthly temperatures for the period of study also exhibits a wider range (4.7°C) at Station 10 than elsewhere. The ranges of the monthly means are shown in Figure 4, and give an indication of the relative thermal stability at various points in the area. The shallow waters along the north shore are not as well mixed and have higher and more variable temperatures.

Temperatures are lower and exhibit less fluctuations in the deeper and more exposed east and south parts of the area where good mixing with open sea water occurs. Average temperatures were lowest and very constant at Stations 1 and 2. The depth at these stations, 6.9 and 10.7 meters, respectively, is, however, considerably greater than that at other sample sites. The shallower more protected parts of the area tend to be more sensitive to variations in air temperature than are the deeper better flushed locations. Thus, during cooler periods and at night, water temperatures in the shallows fall below those at the deeper, exposed stations; while during warmer weather or in the daytime, water temperature in the shallows are higher than those at deeper stations.

Salinity

Salinity varied widely, both spatially and temporally (Table 1). Generally the shallow, more protected reaches of Benner Bay and the Lagoon maintain a higher salinity than do the more mobile waters to the south. However, during May and June, 1970 unusually heavy rains caused considerable flooding throughout the island. In May the study area and its watershed received some eight inches of rain, almost half of it between May 9 and 10. Seven inches of rain fell in June, about four inches from June 14 to 16.

In Benner Bay and especially the Lagoon, salinities were depressed considerably; most notably at Station 10 where a minimum salinity of 4.9 ppt. was recorded on June 19. All stations showed some effects of the run-off and the results are somewhat revealing of water circulation in the area.

Before flooding, the highest salinity levels were at Station 10; average for February and March were 37.5 and 37.8 ppt. During these months the average salinity at individual stations ranged from 36.3 to 37.8 (Stations 11 and 10 respectively); a range of 1.5 ppt. During the same period the range on any given day was from 0.7 ppt. to 1.8 ppt. (mean, 1.2 ppt.). As might be expected, salinity was most regular at Station 1, where the range of daily values was 34.8 to 37.0 ppt. and of monthly averages from February to June 35.2 to 37.0 ppt.

After flooding, the range increased to as much as 31.0 ppt. when, on June 19, 1970 salinities of 4.9 ppt. and 35.9 ppt. were measured at Stations 10 and 4. Figure 5 shows the effects of flooding in May and June on the average salinity based on eleven sampling stations. The rank of stations in order of increasing salinity reduction was, in May: 1, 3, 6, (2,7) 5, 8, 9, (4, 11) 10. In June the relative rank was the same, with the exception that salinity was least affected at Stations 4 and 11. The relative ranking is as follows (4, 11) 1, 3, 6, (2, 7) 5, (8, 9) 10. The degree of salinity changes at various stations can be appreciated from the ranges of the monthly averages shown in Figure 4 and Table 15.

The spatial distribution of salinity and its reduction and recovery at each station following flooding can be seen in Figure 6. The monthly salinity averages have been rounded to the nearest 0.5 ppt. to facilitate comparisons. By the beginning of July salinity at most stations was still below normal and the range throughout Benner Bay and the Lagoon was still 5 to 6 ppt.

Since Stations 4 and 11 are at the southern end of the Lagoon and since the prevailing predominant water movement is south to north and tends to oppose the southward spread of flood water, these data indicated that very large amounts of fresh water from Turpentine Run may reach as far south as Patricia Cay. This may be aided if flooding occurs during calm seas or very low tides at which times wave indiced transport from south to north through the Lagoon is at a minimum. (McNulty, et al, 1968; Michel, 1970).

Dissolved Oxygen

In general, waters throughout the area are well-oxygenated (Table 2). Daytime levels below 5.0 mg./L were measured only at Station 10. Mean oxygen content for the study period was highest at Stations 3 and 4. This is perhaps not surprising since both are located in lush growths of Thalassia and other algae and, in addition, have superb water clarity and good circulation due to their positions near the periphery of the study area. The highest and the lowest levels of D.O. encountered were measured on March 21; 8.2 mg./L at Station 2 and 4, and 4.6 mg./L at Station 10 (Table 9). Dissolved oxygen levels seemed to be unaffected by flood run-off following the May rainstorms. The data (Table 2) does not indicate any correlative changes. Monthly averages for each station are given in Table 15.

pH

The pH at all stations was usually between 8.2 and 8.4. Of all the measurements made the lowest was 7.8 taken early on the morning of April 21 at Station 10. It will be shown later, during analysis of the diurnal studies, that nighttime pH values can fall below 8.0. However, the lowest midday value was 8.0. Like other variables measured, pH was more changeable at shallower or more polluted spots. The range of values measured was 8.2 - 8.4 at all stations except Stations 6 - 10. At Stations 6 and 8 the range was from 8.1 to 8.4; at Station 9, 8.1 to 8.5 and at Station 10, 8.0 to 8.4.

Water Clarity

Water clarity is the single most variable water quality indicator in the Benner Bay-Lagoon area. Basically, all of Benner Bay, and to a lesser extent the channels from Benner Bay west to the Lagoon and southeast to Jersey Bay, have poor water clarity and color. In these areas the bottom is typically not visible. Secchi depth is as little as 0.25 meters, the water contains dispersed fine particulate matter. and the color is brown, greyish brown or greenish brown. Quantitative data for water clarity and color are in Tables 4, 5, 6, 7 and 14.

The bottom is never visible at Stations 6, 7, 8 and 9 in Benner Bay even though the depth at all these points is less than 2.5 meters. In contrast, the bottom could always be seen at Stations 3 and 5 and it was (except following mud-laden flood run-off) always visible at Stations 1, 4, 10 and 11 (Figure 4).

Following flooding on May 9th to 10th, Secchi depths were first reduced at those stations nearest the sites of input: the northern Lagoon and the heavily developed Benner Bay Marine basin. Secchi depth reduction was not noted at Station 11 until five to seven days later and the bottom was again visible here after another three or four days. At Stations 1 and 2 more than a week passed before turbidity reached levels high enough to obscure the bottom. At Stations 3, 4 and 5 turbidity, while increased, was usually not severe enough to obscure the bottom.

The relative transparency of water at various points is shown in Table 5. These data do not indicate optimum or usual water clarity because the area was still suffering some effects of the early May flooding when the measurements were made. In particular, the data from Station 11 greatly underrated the clarity of this water which, under normal conditions, is probably the best in the whole area.

It will be noted that the extinction rates given in Table 5 relate well to the Secchi Depth measured on the same day (Table 4). If one divides the amount of available light (surface light) in Table 5 by the extinction rate at each station, it will be seen that this theoretical limit of visibility approximates very closely the Secchi Depth actually recorded. At Stations 2 and 9 these calculated depths of visibility are greater than the depth to the bottom (which is visible from the surface at these locations), indicating that the water is of a clarity sufficient to allow greater visibility; that is, the Secchi Depths at these stations are limited by the bottom and not by the clarity of the water. This close correlation between Secchi Depths and light transmittance in coastal waters has also been recently reported by Holmes (1970).

The amount of suspended matter (Table 7) in the water varies throughout the study area, as is obvious on visual inspection. Further, those sites which routinely have high turbidity are also most heavily affected during periodic flooding. Of interest is the observation that, following the initial drop in concentration of suspended solids, contributed by flooding on May 9th to 10th, there was a second slighter increase about a week later (Figure 7). This increase is attributed to organic debris from organisms damaged or killed by the suddenly lowered salinity. Beginning on May 18th, when enough mud had cleared from the water to make a noticeable improvement in clarity, large amounts of floating material was noted throughout the Lagoon. Most ot it was recognized as fragments of Thalassia, various filamentous algae, and hydroids which are abundant on the mangrove roots.

On May 11, after the storm, the entire area was heavily silted and visibility was poor everywhere. The plume of muddy water extended as far south as the reef and, at that time, as far east as Bird Cay and out to a line running to the eastern tip of Cas Cay. The area around Station 3, south of Compass Point, was not noticeably affected at that time. The turbidity was highest, of course, in the northern reaches of the Lagoon proper and throughout the channel north of Bovoni Cay. The bottom was visible at Stations 2 and 3 and points southeast and the surf cresting over the reef to the south presented an effective barrier to the further southward spread of the plume. Besides the considerable amounts of mud still in suspension, quite a lot had already settled and was disturbed by the boat's prop. At approximately 4:30 p.m. on May 11, with the tide at or near low slack, there was good flow of very turbid water from at least two points on the north shore, one adjacent to Station 10, the other farther west.

On May 13 little improvement was noted. A traverse from Station 10 to 11 stirred up large amounts of brown mud. By May 18 there was improvement in some areas, most notably at Station 11 and southward, where clean, sandy bottom with open worm holes was visible. Clearing to a lesser extent was noted north of Station 11 with increasing amounts of settled clay and turbidity toward the shore where there was still no evidence of improvement. By May 20, however, the bottom was again visible where it usually was, except still along the north shore of the north shore of the Lagoon.

From October 3 to 11 rainstorms again produced considerable run-off, but the effects this time were confined to Benner Bay and the north shore of the Lagoon.

As far as we can tell the water quality and the bottom biota have not yet returned to normal everywhere. Along the north shore of the Mangrove Lagoon and throughout the channel from Benner Bay into Jersey Bay, turbidity has remained higher than it was before flooding. A distinct brown plume extending from Benner Bay into Jersey Bay well southeast of Cas Cay is visible from the air. The shallows over the grass flats northwest of Cas Cay to Bovoni Cay are not noticeably affected, however. This continued turbidity is believed to be maintained by periodic clay contributions caused by rain showers and, in Benner Bay, aided by boat traffic which keeps silt suspended. Water color also, because of increased turbidity in these quarters, is poor.

Estimates of shallow water color are greatly subject to the character of the bottom. The color estimate may, barring large amounts of suspended matter, be the color of the bottom. The apparent color of the waters in the study area falls into four broad categories:

1. Brown, opaque water of Benner Bay and the north shores of the Mangrove Lagoon (Forel-Ule colors ranging from

XVIII-XXI) contains large amounts of suspended and dissolved materials.

2. Green or bluish-green water is relatively clear, low in suspended matter and transmits light reflected from plant cover on the bottom. In deeper water the blue component is heightened as the longer wave lengths are selectively absorbed by the water, giving colors from bluish green (IV), tending toward blue (I), which is characteristic of clear, deep offshore water.

3. Apparently green water (VI-XII) contains some suspended matter, but it primarily reflects the color of the grass and algal cover of the bottom. The largest portion of the area falls into this range, including the grass beds between Bovoni and Cas Cays and most of the Mangrove Lagoon proper west of Bovoni Cay.

4. Clear, essentially colorless water which is not really embraced by the Forel-Ule scale, is found over clean, current-swept sand in the channels and north of Patricia Cay.

Diurnal Studies

This section presents the results of two twenty-four hour studies of the fluctuations of temperature, salinity, pH, and dissolved oxygen at six sites in Benner Bay and the Lagoon. Measurements and water samples were taken at each station at three hour intervals. Data were also taken periodically on sunlight intensity, air temperature, wind, sea and tide state.

Diurnal fluctuations of water quality parameters in Benner Bay and the Lagoon are the result of physical and biological dynamics which are extremely variable from site to site. Tidal effects on salinity, temperature, etc. vary depending on the site, because of the peculiar combination of wave and tidal forces throughout the area and fluctuations of these parameters follow an unusual spatial sequence dictated by the local bathymetry and shoreline irregularities.

Besides the familiar pumping effect of tidal action on water movement, the state of the tide is also critical to water movement induced by wind and waves offshore of the Lagoon. The offshore currents south of the cays have a westerly set with velocities, varying with the tide, from 2.4 to 28.8 ft./min. (McNulty, 1968; Michel, 1970). McNulty's group found that at slack tides the drift was interupted and either no current was measured or there was a weak easterly current.

North of the reefs, inside the Lagoon, Michel and Tabb (1968) found that water movement was always northerly. Their measurements were made north of Bovoni Cay, between Long Point and Patricia Cay and between Patricia and Cas Cays.

Tidal variation along the southern coast of St. Thomas is of mixed character (both diurnal and semidiurnal) although it is primarily diurnal, i.e. one high and one low per day (McNulty, et al, 1968; Michel, 1970; U. S. Dept. of Commerce, ESSA, 1970). The average tidal range is about 0.8 feet.

McNulty (1968) and Michel (1970) both found that the amount of water entering over the reefs to the south of the Lagoon depends on the height of the tide and is modified by the state of the offshore seas. This circulation, which is generally quite good, tends to increase on the high tide and is enhanced by strong wind and wave activity. According to McNulty, et al, (1968) the general wind and surf induced circulation through the Lagoon is north, northwest into the Lagoon from the reefs which run from Long Point to Cas Cay; water then moves easterly from the Lagoon into Benner Bay via the channel north of Bovoni Cay, and then south, southeast into Jersey Bay. Circulation in the northwestern Lagoon and in the head of Benner Bay is usually somewhat retarded. Our observations support this description.

During times of extremely low tides, however, we have observed the tops of the Acropora reef protruding from the water, exposure of the Porites-Penicillus back-reef flats, and apparent cessation of water movement in the Lagoon. Both McNulty (1968) and Michel (1970) also observed similar periodic loss of circulation. At such times, with calm weather, the southerly movement of Lagoon water is unopposed by the usual wind driven waves from the reefs, and hypersaline or storm water may move south from the northwest Lagoon into the channels around Patricia and Bovoni Cays.

This rather unique interaction of waves and tides and its effects on circulation and flushing of the Lagoon is crucial to the hydrography and ecology of the area. One of the most obvious of these effects is that increased circulation causes the water in Benner Bay and the Lagoon to become more homogenous, generally reflected by a reduction of the usually higher salinities in northeast Benner Bay and northwest Lagoon to levels closer to those of the open sea to the south. This effect is less marked at deeper more exposed stations (2, 4, 11) which normally maintain salinities close to open sea values, and, as a consequence, the range of salinity throughout the area is compressed.

On the other hand, during periods of poor circulation evaporation increases salinity in the more remote areas and distinct spatial heterogeneity develops.

Air and water temperatures were higher in April than in March but at most stations dissolved oxygen reached higher levels in March. In March pH was lower, especially at night, possibly the result of higher metabolic activity associated with the higher water temperatures. Diurnal oxygen curves, although markedly different among stations, were similar at each site on both occasions.

These pictures of the diurnal changes in dissolved oxygen are useful in assessing the health and productivity of an area.

Under purely physical forces, dissolved oxygen in surface waters tends to equilibrate at 100 per cent of saturation. The analysis of diurnal oxygen curves for their fluctuation around the saturation point can be used to assess the metabolic activity of an area and to estimate changes in photosynthesis and respiration and the relative balance between the two. Dissolved oxygen levels beyond saturation indicate net photosynthetic activity while concentrations below saturation reflect relatively greater respiration than photosynthesis and, therefore, a net consumption of oxygen.

Station 2 (Figure 9) was the deepest of the diurnal stations and on both occasions maintained supersaturated oxygen levels well into the night. Dissolved oxygen never fell far below saturation. The surface water here is well mixed, not heavily taxed by the benthos and probably equilibrates to near the saturation point at night more as a result of diffusion across a concentration gradient at the air-sea interface than as a result of respiratory depletion which would be expected to cause a continued fall in the dissolved oxygen curve to levels further below the saturation point than were actually encountered. In fact, the curves show a definite leveling off just at or below the saturation levels.

A similar situation is indicated at Station 11 (Figure 14) where, however, daytime levels do not reach as high and there is a greater depletion at night. The depth here is only one-fifth that at Station 2, the bottom is clear white sand with a rich infauna, but practically no grass or algae.

Oxygen curves from Station 4 (Figure 10) are closest to a simple diurnal pattern and indicate an extremely productive area where photosynthesis rapidly builds up dissolved oxygen during the daytime, where this production ceases and a net respiratory depletion begins in the evening and where nighttime demands continue to reduce dissolved oxygen levels.

Station 4 is characterized by an extremely rich algal-grass community, very good water clarity and almost continuous water movement from the reef northward. In such clear waters over Thalassia beds we have observed thousands of small oxygen bubbles rising to the surface from the grass leaves.

Diurnal oxygen changes at Station 7 (Figure 11) are similar to those at Station 9 and indicate maintenance of nocturnal oxygen concentrations by transport associated with the tides. Oxygen concentrations were least dynamic that is, showed the least degree of change, at Station 9 (Figure 12). Changes in concentration follow gentle slopes and the dissolved oxygen is, except for a few hours during the day, near or below saturation. The maximum concentration attained during the day was the lowest for all stations studied. On the other hand, nighttime minima were not as low as at Station 10, probably because of the greater volume of water and apparently lower benthic biomass at Station 9 (the bottom here is patchy Thalassia, as opposed to a dense cover at Station 10). Oxygen curves at Station 9 are very similar to the salinity curves which may indicate that oxygen changes here are due mainly to transport. This interpretation is supported by the fact that nighttime concentrations, on both occasions, did not fall steadily, but were supported during the flood and high tide (2000-2400 hours). In fact, there is bulge or "knee" in both curves during this period.

The greatest diurnal oxygen consumption is indicated at Station 10 (Figure 13) where dissolved oxygen is far below saturation for all but six hours during the day.. In addition, there is a considerable lag in oxygen buildup in the early morning following very low levels (4.6 mg./L) to which it falls at night. The nighttime depletion of dissolved oxygen is extremely rapid, due most likely to the respiratory demands of the bottom fauna. It should also be remembered that the water is very shallow here (average 0.8m.) and so the volume overlying a given area of bottom and the total amount of oxygen it carried is not great. The result is that the small oxygen reserve produced during daylight is rapidly used up at night. The dominant benthic organism here is dense Thalassia, so that the aereal potential for oxygen production is great and once production commences the concentration raises quickly to high levels (7.8 to 8.0 mg./L). However, because of the shallow water column and the generally higher temperatures and salinity, there is little storage capacity for oxygen and on both occasions levels fell rapidly after about 3 p.m. Recovery from nocturnal low begins only after an early morning lag, but is relatively rapid.

SUMMARY

This study and the available literature reveals that the Benner Bay-Mangrove Lagoon area is one of diversity; diversity not only of habitat types but in the degree of anthropogenic destruction throughout the area. Benner Bay, as a result of concentrated development for marine facilities, is biologically devastated. Water color and clarity are extremely poor because of an extremely high loading of various dissolved and suspended pollutants, including clay, organic matter and hydrocarbons. The visibility is so poor that the bottom cannot be seen anywhere in the Bay even though the maximum depth is only about 2.5 meters. Diurnal oxygen balance indicates an excess of respiration over photosynthesis. In addition, the Bay is well protected and, while perhaps desirable for marina facilities, is incapable of handling the present pollution load because the rate of addition is greater than the rate of removal. It is expected that the Benner Bay environment and water quality will continue to deteriorate, although further changes will, relatively speaking, be of no great import.

Water quality and natural systems are less affected to the west along the northern fringe of the study area and improve rapidly toward the south. There is an obvious plume

of turbid water which extends from a focus in Benner Bay south into Jersey Bay along the navigable channel east of Bird Cay. Environmental stresses on the Lagoon are increasing from expanding development in Nadir and Bovoni and as far away as Tutu which contribute increasing amounts of silt and fresh water during storms. Sewage eutrophication and pollution from the Nadir plant will increase and there are signs that the ability of the receiving water to absorb these wastes is waning. Foam from the plant is frequently piled up along the northwest shore.

In addition, previous studies (Michel and Tabb, 1968; Michel 1970; McNulty, 1970) have shown that this corner of the Lagoon is one of the most poorly flushed reaches of the area. It is, therefore, probably the least suitable to receive sewage effluent. The ability of the system to absorb this waste in the past is testimony to the healthy and productive nature of this environment. However, this ability to assimilate organic and inorganic nutrients is not infinite and with the increasing pressures of other ecological modifications (siltation, fresh water, turbidity), the productivity and assimilation potential of the Lagoon may be declining. At any rate, conditions are presently less normal in this quarter than they are elsewhere in the Lagoon. All of the lagoon, however, still appears highly productive even though siltation on Thalassia, resulting from floods a year ago, still persists.

The southern section of the Lagoon, the reefs and the grass flats northeast of Cas Cay remain superb examples of shallow tropical reef and marine pasture systems. They remain so because of the unique northerly flow of clean water from the open sea, because they are not subject to heavy boat usage and because Long Point and the cays are undeveloped. The data collected in this study indicate this area is one of very high net productivity.

RECOMMENDATIONS

We strongly urge that the local government come to a decision on the use to which the Mangrove Lagoon is to be put. The present course of development in and around the area increases pressures daily on this unique ecosystem. Because of the lack of a stated objective for the area, continuing development and shoreline alteration is destroying this area as a basic production, prime recreational and as a research site. Its value for these purposes is being lost by default.

The uniqueness of this environment on the island, with its presently healthy and varied complex of habitats, provides a site of significant natural value for which estimates of the esthetic and economic worth have not yet been constructed. Its destruction, however, can have decisive and far-reaching effects, many of which cannot be predicted and some of which are likely unimagined.

In recent years detailed productivity studies and value analyses have been accomplished for particular open coastal submerged lands, mangrove swamps, and river swamps, and for the first time a total resource worth has been described for some of the coastal zones of the states of Florida and Georgia. These value estimates range from $300 per acre per year for fish production alone on the coastal submerged lands, to over $3,000 per acre per year total value for the highly productive protected marshes. The present worth of an asset yielding $3,000 per year over a long term at nominal interest ràtes would be listed at a surprising figure in the hundreds of thousands of dollars; thus, if the worth of protected lagoons and marshlands is computed in terms of the 100-year asset value, a net worth in the range of $200,000 to $300,000 per acre would be realized.

The island has several marine facilities and other bays which could be used for additional anchorage. There is no other good representative of the mangrove ecosystem in the Virgin Islands. Zube (1968), in a survey of island resources, said:

> "The beach vegetation, mangrove and rain forest areas are important vegetation types because of their relative scarcity compared to other types. They are also important as natural features which contribute to the diversity of the scenery. There is only one remaining mangrove lagoon of size in the U. S. Virgin Islands. It is located on the southeast shore of St. Thomas. . . Decisions on the allocation of this resource should be withheld until comprehensive scientific investigations have

been completed and its intrinsic natural values have been more clearly delineated."

Housing, horseracing and commercial establishments could be planned in the Bovoni-Nadir area in a manner consistent with the continued healthy existence of the Mangrove Lagoon -- if its preservation were deemed desirable government policy. We cannot justify destruction of the Mangrove Lagoon by over-development deemed necessary to accomplish alternate critical land or water use; and with the possible exception of the proposed jetport, none of the existing or proposed land use schemes is absolutely essential at the site. Whether the jetport is built or not, the Mangrove Lagoon will be lost -- is presently being lost -- by default because the appropriate policies and priorities have not been yet assigned.

If there is a decision to preserve the area in a state close to the natural, then immediate action is needed to develop a management plan to ensure proper protection and preservation. In some instances, remedial action may be necessary. It cannot be too strongly emphasized that the present course of development in the Nadir and Bovoni area is inconsistent with the maintenance of the Mangrove Lagoon in the natural state.

Decisive planning for use of the Lagoon itself is just as important, although less pressing, or the area,too, will be committed to further marina and other shoreline development. Because of its predominantly shallow depth and relatively small water volume, the Lagoon is unsuited for sewage outfall or navigation. If development and pollution pressures continue to increase, the natural cleansing abilities of the system will be overloaded and the Lagoon will succumb and eutrophy to a much less desirable state.

Several recommendations are here offered to serve as a basis for action in Benner Bay and the Lagoon as well as to indicate some of the problems which we feel require attention. These recommendations are built around the following assumptions:

1. The proposed airport will not be built.
2. The Mangrove Lagoon is a valuable resource and should be so treated.
3. Benner Bay has been committed to use as a commercial marina area.
4. Planning for the best use of the territory's resources requires the maintenance of a diversity of ecosystems, particularly those which are unique because of their rarity or because they are representative segments of local resources.

The recommendations build the framework for planning and establishing a Virgin Islands Coastal Zone Preserve which, besides its aesthetic worth, will continue to be of value as a recreation site for fishing, sightseeing and swimming; an educational resource for use as a living laboratory; a research asset which can play a significant part in the development of the Islands' economic future and a nursery for the fishery of the northern Virgin Islands. The suggested boundries of the preserve in minimum area form and references to the recommendations are shown in Figure 15.

In May, 1970, by letter to the Department of Conservation and Cultural Affairs, Caribbean Research Institute recommended designation of the area as a territorial natural preserve, protected by legislation and warden policing. Areal extent recommended was "all of the peninsula west of the lagoon, Patricia Cay, Cas Cay, Bovoni Cay and all of the smaller mangrove islands; all of the enclosed submerged lands and enclosed waters, the grass/sand flats east of Bovoni Cay and north of Cas Cay, and the marine waters and submerged lands offshore to the south to a water depth of ten fathoms."

The area outlined in the 1970 recommendation included more land area on the peninsula west of the Lagoon (the western slopes), but did not include Bird and Rotto Cays. This investigation does not support need for inclusion of the western slopes for adequate protection of the Mangrove Lagoon itself, but does suggest need to isolate the flats east of Bovoni Cay from heavy boat traffic; hence, relocation of the channel into Benner Bay if the traffic to the existing commercial marinas is allowed at the present level. The land on the western slope of the Long Point peninsula should still be considered for inclusion in a Coastal Zone Preserve to be set up in more than minimum area form.

Recommendation I:

Marina development should be confined to Benner Bay and any extension should be east rather than westward. No further development should be allowed on the shoreline north of Bovoni Cay. Additional commercial marine activity should be shifted to the Red Hook area (see Grigg, et al, 1970).

All activity allowed under an area use and development plan must be closely monitored and strictly controlled. Submerged land permits, zoning exceptions and building plans must be complete in detail and exact in scope. All applications need to be reviewed with consideration of possible leechings and discharges and direct disposal of effluents prohibited.

Recommendation II:

No dredging should be allowed outside of Benner Bay; except if channel deepening is allowed in the development plan, it should not be allowed in the present channel west of Bird Cay. Necessary access channel improvement should be made around Compass Point north of Bird and Rotto Cays (as shown in Figure 15).

Recommendation III:

The government should acquire the necessary land on Long Point (or institute restrictive zoning to ensure its use in a compatible manner), to include at least all of the eastern slopes and designate the area generally within the suggested boundries shown on Figure 15 as a Virgin Islands Coastal Zone Preserve.

Well planned, limited access to scenic and recreation points would allow public use of swimming and fishing areas. General motor boat traffic within the preserve should be prohibited or strictly regulated. The area would be made available for educational use by local and visiting students and teachers and could be used for a wide variety of research and development programs.

As such, it could become an outstanding example of multiple resource use, which is particularly suited to small island settings which have limited resources.

Recommendation IV:

The Nadir sewage treatment plant should be made to operate closer to optimal. Eventually, the effluent should be piped to an outfall point which is better situated to provide rapid diffusion and dilution of the effluent.

There is need for buffering the Lagoon from the present effects of the effluent now discharged; thus, construction of a polishing pond for further reduction of the effluent strength is recommended. Additionally, economic feasibility of reuse of the polishing pond effluent should be studied -- as in flushing/irrigation systems in the new housing development constructions.

Recommendation V:

The proposed horse race track should not be placed close to the shore, but should be located far enough west to allow for a green belt between it and the shore to act as an ecological buffer zone. Design proposals for this facility should include features necessary to minimize runoff and other pollution of the Lagoon. Use of a race track-park area here will have to be continually regulated and policed as are the other sections of the preserve.

LITERATURE CITED

Dammann, A. E. 1969. Study of the fisheries potential of the Virgin Islands. Contrib. #1, Virgin Islands Ecological Research Station, College of the Virgin Islands.

Donnelly, T. W. and J. Whetten 1968. Field guides to the geology of St. Thomas, St. John and St. Croix, Virgin Islands, Fifth Caribbean Geol. Conference.

Grigg, D. I., R. P. vanEepoel and R. W. Brody 1970. Water quality and marine environment of Vessup Bay, St. Thomas. Water Pollution Report No. 8, Caribbean Research Institute.

Holmes, R. W. 1970. The Secchi disk in turbid coastal waters. Limnol. and Oceanogr. 15(5):688-694.

McNulty, J. K., W. B. Robertson and B. F. Horton 1968. Departmental study team report and recommendations on proposed new jet airport, St. Thomas, Virgin Islands, U. S. Dept. of Interior.

Michel, J. F. and D. C. Tabb 1968. A study of the biological and coastal engineering aspects of the proposed jet airstrip at Jersey Bay, St. Thomas, U. S. Virgin Islands; Part II, Coastal engineering considerations, Institute of Marine Sci., University of Miami.

Michel, J. F. 1970. A study of the hydrodynamic effects of the proposed airport at Long Beach Point, St. Thomas, Virgin Islands. Univ. of Miami, School of Marine and Atmospheric Sciences. Rpt. to the Virgin Islands Port Authority.

Tabb, D. C. and J. F. Michel 1968. A study of the biological and coastal engineering aspects of the proposed jet airstrip at Jersey Bay, St. Thomas, U. S. Virgin Islands, Part I. Biological considerations. Institute of Marine Sciences, University of Miami.

U. S. Dept. of Commerce, E.S.S.A. 1970. Tide tables. East coast North and South America. U. S. Govt. Printing Office, Washington, D. C.

U. S. Dept. of Interior, F.W.P.C.A. 1967. Biological aspects of marine water quality, St. Thomas, St. Croix and St. John, U. S. Virgin Islands. F.W.P.C.A., Tech. Advisory and Investigations Branch, U. S. Dept. of Interior.

Zube, E. H. 1968. The islands. Selected resources of the U. S. Virgin Islands. U. S. Dept. of Interior.

A P P E N D I X

Figure:

Table:

4. Secchi depth and average water depth

5. Submarine illumination

6. Water color

7. Suspended solids

8. March diurnal temperature and salinity

9. March diurnal dissolved oxygen

10. March diurnal pH

11. April diurnal temperature and salinity

12. April diurnal dissolved oxygen

13. April diurnal pH

14. Means, maxima, minima and ranges of diurnal data

15. Monthly averages for water quality parameters

TABLE I

BENNER BAY - MANGROVE LAGOON
TEMPERATURE (^{o}C) AND SALINITY (PPT.)

DATE	STATION 1		2		3		4		5		6		7		8		9		10		11	
	T	S	T	S	T	S	T	S	T	S	T	S	T	S	T	S	T	S	T	S	T	S
2/12/70	27.1	36.5	27.4	36.9	27.7	36.9	27.9	36.8	28.8	37.0	28.6	37.2	28.5	37.2	28.2	37.2	28.3	36.9	--	--	--	--
2/17/70	26.8	36.8	26.8	37.7	26.9	36.4	28.0	36.6	27.6	38.2	27.5	37.0	27.5	37.0	27.6	37.2	27.2	38.1	--	--	--	--
2/19/70	26.8	36.6	26.9	37.0	27.3	36.6	27.5	36.5	28.1	36.6	27.9	37.1	27.8	37.1	27.9	37.2	27.7	37.5	--	--	--	--
2/24/70	26.5	36.5	26.3	36.5	27.0	36.5	26.4	36.3	27.5	36.8	27.3	36.8	27.0	37.1	27.5	36.8	27.0	36.8	27.5	37.5	26.5	36.3
2/26/70	26.7	--	27.2	--	27.5	--	27.7	--	28.1	--	28.0	--	27.5	--	28.0	--	28.0	--	27.0	--	26.9	--
3/4/70	25.3	37.0	25.0	37.0	25.2	36.5	24.8	36.8	24.4	37.0	24.0	37.5	24.2	37.0	24.0	37.3	24.2	37.2	24.0	37.8	24.4	36.8
3/10/70	27.5	--	28.0	--	29.5	--	28.0	--	28.0	--	29.0	--	30.0	--	29.0	--	29.0	--	28.0	--	28.0	--
5/11/70	27.0	36.6	--	35.7	--	--	28.0	30.1	--	33.2	--	35.8	--	35.5	--	35.7	--	31.6	29.0	10.8	29.0	22.4
5/13/70	27.0	37.0	27.0	36.9	26.5	36.8	26.2	34.8	28.0	35.8	28.0	36.1	28.0	36.2	28.0	36.1	29.5	33.6	31.2	14.0	27.8	27.3
5/15/70	--	37.0	--	36.9	--	37.3	--	32.7	--	35.7	--	37.1	--	36.9	--	36.8	--	34.4	--	13.7	--	31.1
5/18/70	--	36.5	--	36.4	--	36.6	--	36.3	--	36.8	--	36.0	--	36.3	--	36.3	--	36.5	--	32.2	--	34.0
5/20/70	29.4	--	27.5	36.6	28.0	--	29.0	35.5	29.5	35.9	29.5	36.6	29.5	36.8	29.5	--	30.0	35.5	32.0	34.0	30.0	35.8
5/23/70	28.2	36.9	29.4	37.3	29.5	36.9	30.5	37.1	31.1	36.9	30.6	36.9	31.0	37.0	30.5	37.1	31.0	36.2	33.0	33.1	31.2	35.7
5/25/70	27.2	36.8	27.4	36.9	27.4	36.9	27.6	37.2	28.5	36.7	28.4	37.0	29.2	37.4	29.0	37.1	28.3	36.9	29.6	33.4	28.6	36.8
5/29/70	28.7	--	28.1	37.5	29.5	--	28.0	37.4	28.8	37.3	29.0	37.3	29.2	37.4	28.9	37.3	29.2	--	29.2	36.1	28.8	37.3
6/19/70	--	35.5	--	32.4	--	34.9	--	35.9	--	31.0	--	34.7	--	31.9	--	30.1	--	24.8	--	4.9	--	35.6
6/23/70	--	34.8	--	35.0	--	34.6	--	36.3	--	33.6	--	33.4	--	--	--	33.7	--	33.7	--	26.7	--	34.9
6/25/70	--	--	--	--	--	34.7	--	35.2	--	34.6	--	34.4	--	34.6	--	35.1	--	34.1	--	26.3	--	35.4
6/29/70	--	--	--	--	--	35.7	--	35.9	--	35.3	--	35.1	--	34.7	--	35.3	--	34.3	--	30.6	--	35.2
7/1/70	--	--	--	--	--	32.8	--	32.7	--	33.0	--	32.6	--	33.0	--	32.7	--	32.7	--	29.8	--	35.9

TABLE 2

BENNER BAY - MANGROVE LAGOON
DISSOLVED OXYGEN (mg/L) AND % SATURATION

DATE	STATION 1		2		3		4		5		6		7		8		9		10		11	
	D.O.	% Sat.	D.O.	%Sat.	D.O.	%Sat.	D.O.	% Sat.	D.O.	%Sat.	D.O.	%Sat.	D.O.	%Sat.	D.O.	%Sat.	D.O.	%Sat.	D.O.	%Sat.	D.O.	%Sat.
2/12/70	5.2	80	5.4	84	6.3	96	5.4	86	5.6	90	5.5	87	5.7	90	5.6	89	5.5	87	-	-	-	-
2/17/70	6.3	97	7.0	109	7.4	114	7.7	122	6.4	102	6.1	95	5.9	92	5.1	80	6.3	98	-	-	-	-
2/19/70	6.1	94	6.4	99	7.2	111	6.7	105	6.3	100	6.1	97	6.2	98	5.8	92	6.2	98	-	-	-	-
2/24/70	6.6	100	6.5	98	7.3	112	6.4	97	6.7	105	6.7	105	6.8	105	6.4	100	6.7	103	6.4	100	6.6	100
2/26/70	6.6	102	6.9	106	7.8	122	7.4	116	6.5	103	6.3	100	6.3	98	6.1	97	6.6	105	5.8	89	6.2	95
3/04/70	6.5	97	6.6	98	7.1	106	6.8	102	6.7	99	6.7	99	6.8	100	6.2	91	6.8	100	6.3	93	6.4	94
3/10/70	6.5	102	6.2	98	6.5	106	6.3	100	6.4	102	6.2	100	6.3	103	5.8	94	6.5	105	5.6	89	6.2	98
5/11/70	6.4	98	-	-	-	-	7.1	108	-	-	-	-	-	-	-	-	-	-	5.2	75	7.1	104
5/13/70	6.5	100	6.3	97	6.8	103	6.1	92	6.9	108	6.4	100	6.4	100	5.9	92	5.9	95	7.9	116	7.5	11[illegible]
5/20/70	6.1	100	6.1	95	6.7	108	6.0	95	6.0	97	6.1	98	6.0	97	5.9	95	6.0	98	5.3	88	5.9	97
5/23/70	6.3	100	6.3	102	6.5	106	6.2	103	6.4	107	6.5	108	6.4	107	6.3	105	6.2	103	6.5	110	6.2	103
5/25/70	6.3	97	5.9	92	6.4	100	5.9	92	5.8	92	5.8	92	6.1	97	5.6	90	5.3	85	4.9	79	6.1	98
5/29/70	6.2	100	6.1	97	6.2	102	7.5	119	5.6	90	5.4	87	5.0	81	6.1	98	5.7	92	4.9	79	6.0	97

TABLE 3

BENNER BAY - MANGROVE LAGOON

pH

DATE	STATION										
1970	1	2	3	4	5	6	7	8	9	10	11
2/12	8.4	8.4	-	8.4	8.3	8.2	8.2	8.2	8.3	-	-
2/17	8.2	8.2	8.3	8.2	8.2	8.1	8.1	8.0	8.1	-	-
2/19	8.3	8.3	8.4	8.4	8.3	8.2	8.2	8.1	8.3	-	-
2/24	8.3	8.4	8.4	8.4	8.4	8.3	8.4	-	8.4	8.3	8.4
2/26	8.4	8.4	8.4	8.4	8.4	8.4	8.2	8.2	8.3	8.1	8.2
3/04	8.2	8.3	8.3	8.3	8.3	8.3	8.2	8.2	8.3	8.3	8.2
3/10	8.4	8.2	8.4	8.2	8.2	8.3	8.4	8.3	8.2	8.2	8.2
5/13	8.4	8.4	8.4	8.3	8.4	8.3	8.3	8.3	8.2	8.4	8.3
5/15	-	8.2	8.2	8.3	8.2	8.4	8.4	8.2	8.5	8.2	8.3
5/18	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.3	8.4	-	-
5/20	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.2	-
5/23	8.3	8.2	8.3	8.3	-	-	-	-	8.4	8.2	-
5/25	8.3	8.2	8.2	8.2	8.2	8.3	8.2	8.1	8.2	8.0	8.2

TABLE 4

BENNER BAY - MANGROVE LAGOON

SECCHI DEPTH AND AVERAGE WATER DEPTH (METERS)

DATE 1970	STATION 1	2	3	4	5	6	7	8	9	10	11
2/12	B	2.8	B	B	B	1.5	0.8	0.8	1.5	-	-
2/17	B	B	B	B	B	1.3	1.0	-	1.5	-	-
2/19	B	4.8	B	B	B	1.3	1.0	1.0	1.3	-	-
2/24	B	B	B	B	B	1.0	1.0	1.0	1.0	B	B
2/26	B	6.5	B	B	B	1.5	1.3	1.0	1.3	B	B
3/04	B	B	B	B	B	1.3	1.0	1.3	B	B	B
3/10	B	4.5	B	B	B	1.0	1.0	1.3	1.8	B	B
5/13	B	B	B	B	B	1.3	0.8	0.8	B	0.5	1.0
5/15	B	B	B	1.0	B	1.2	1.0	-	1.0	0.5	0.5
5/18	B	B	B	B	B	0.7	0.8	0.6	B	0.4	B
5/20	10.5	5.0	B	B	B	0.8	0.6	0.6	B	0.4	B
5/23	9.3	6.3	B	B	B	0.8	0.5	0.8	1.3	0.3	B
5/25	7.0	5.5	B	B	B	1.3	0.8	0.8	B	0.8	B
5/29	B	2.5	B	B	B	1.0	0.8	1.0	1.5	0.5	B
Average Water Depth	10.7	6.9	1.9	2.0	1.0	1.9	1.5	2.3	1.5	0.8	1.3

B= Visibility to bottom

TABLE 5

BENNER BAY - MANGROVE LAGOON

SUBMARINE ILLUMINATION
Noon, May 13, 1970

STATION	Surface Ft. - Cand.	0.5 METER		1 METER		4 METERS		8 METERS		Extinction Rate Ft. -Cand. per meter
		Ft. - Cand.	Pct. Loss	Ft. - Cand.	Pct. Loss	Ft. - Cand.	Pct. Loss	Ft.- Cand.	Pct. Loss	
2	8,700	-	-	7,900	9	5,200	40	3,300	62	780
4	11,700	-	-	5,700	51	-	-	-	-	6,000
7	9,500	-	-	1,900	80	-	-	-	-	7,600
9	8,700	7,300	16	-	-	-	-	-	-	2,800
10	8,700	1,700	81	-	-	-	-	-	-	14,000
11	8,700	3,300	51	-	-	-	-	-	-	8,800

TABLE 6

BENNER BAY - MANGROVE LAGOON

WATER COLOR (FOREL - ULE)

DATE	STATION										
1970	1	2	3	4	5	6	7	8	9	10	11
2/12	IV	V	VI	VIII	XIV	XIV	XVII	XVII	-	-	-
2/17	IV	VII	VI	VI	XII	XVI	XVI	-	XIV	-	-
2/19	IV	VI	VI	VIII	XIV	XVI	XVII	XVIII	XVI	-	-
2/24	III	VI	VIII	VIII	XV	-	-	XVI	XV	XVII	XII
2/26	IV	VI	VI	VIII	XVII	XIX	XIX	XX	XVIII	XVIII	XV
3/04	IV	V	VI	VIII	XV	XVI	XVI	XVI	XVI	XVII	XII
3/10	IV	VIII	VI	VI	XV	XVII	XVII	XVIII	XVI	XVII	VI
5/11	III	-	-	XVII	-	-	-	-	-	XXI	XVII
5/13	IV	VI	V	XIII	XV	XVI	XVI	XVI	XVIII	XX	XVIII
5/15	IV	IV	V	XV	XIV	XV	XV	XVI	XVIII	XVIII	XVII
5/18	III	V	V	XV	VIII	XIX	XIX	XVIII	XVI	XXI	XVI
5/20	III	VIII	V	XV	XVI	XIX	XVIII	XVIII	XIX	XXI	XVI
5/23	III	VI	V	X	XVI	XVI	XVI	XVII	XVII	XVIII	XIV
5/25	III	VI	IV	X	XVI	XV	XVI	XVIII	XIV	XV	VIII
5/29	III	VI	V	V	XVI	XVIII	XIX	XIX	XIV	XXI	VII

TABLE 7

BENNER BAY - MANGROVE LAGOON

NON-FILTERABLE SUSPENDED SOLIDS (mg./l)

(greater than 0.45 micron)

DATE	STATION										
1970	1	2	3	4	5	6	7	8	9	10	11
5/11	102.6	93.2	-	20.2	68.8	170.0	93.5	31.0	106.0	695.5	26.8
5/13	10.5	13.6	11.7	-	17.4	12.6	21.7	19.1	15.3	57.9	21.4
5/15	22.7	22.9	20.0	25.1	18.4	29.1	22.4	27.3	24.4	31.3	31.9
5/18	-	27.1	43.3	48.6	7.9	36.8	83.3	71.8	71.0	-	39.6
5/20	64.4	14.3	14.2	8.2	16.3	22.9	24.4	77.9	9.7	8.9	12.4
5/23	29.9	22.8	16.5	29.7	22.4	24.4	25.0	30.6	19.5	-	16.6
5/25	21.2	12.9	20.0	20.4	19.5	5.5	25.1	32.8	32.9	26.2	20.3
5/29	-	10.6	-	15.8	14.6	17.7	33.8	-	-	32.8	19.6
6/19	20.9	34.8	27.7	29.5	24.7	31.3	25.6	19.5	17.5	107.2	20.8
6/23	6.5	22.2	23.9	21.3	17.6	26.0	-	19.1	24.4	-	17.8
6/25	-	-	34.5	15.0	20.4	22.5	19.6	15.6	16.2	21.7	13.3
6/29	-	-	2.1	13.4	8.1	28.6	14.3	22.2	-	22.9	8.8
7/01	-	-	21.6	22.9	12.6	22.6	23.5	0.4	25.9	20.9	2.5

TABLE 8

BENNER BAY - MANGROVE LAGOON

DIURNAL STUDY, MARCH 21-22, 1970
Temperature (°C), Salinity (‰)

TIME	STATION 2		4		7		9		10		11	
	T	S	T	S	T	S	T	S	T	S	T	S
0630	26.0	37.6	24.8	37.9	26.0	38.6	25.0	38.1	25.5	38.6	25.0	38.2
0930	26.0	38.3	25.8	37.1	26.0	38.5	26.0	38.3	25.5	38.7	25.0	37.1
1230	26.0	38.3	27.0	37.0	27.0	38.9	26.0	38.3	26.0	41.0	25.7	37.9
1530	26.5	38.3	27.0	37.3	27.0	38.9	27.0	39.1	27.5	39.7	27.0	38.0
1830	26.5	37.9	26.5	37.2	27.0	39.5	26.0	38.1	26.5	39.3	27.0	38.1
2130	26.0	36.6	25.0	36.6	26.0	37.4	26.0	38.3	26.0	37.6	26.0	36.8
0030	26.0	36.5	25.0	36.5	26.0	38.7	26.0	38.5	26.0	40.1	25.5	37.9
0330	26.0	37.9	25.0	37.0	26.0	37.8	26.0	37.2	25.5	38.6	25.0	36.9
0630	25.5	38.0	25.0	38.5	26.0	39.1	26.0	38.3	25.0	38.0	25.0	41.0

TABLE 9

BENNER BAY - MANGROVE LAGOON

DIURNAL STUDY, MARCH 21-22, 1970
Dissolved Oxygen (mg./l) and % Saturation

	STATION											
	2		4		7		9		10		11	
TIME	D.O	%Sat.	D.O.	%Sat.	D.O.	%Sat.	D.O.	%Sat.	D.O.	%Sat.	D.O.	%Sat.
0630	6.3	97	5.3	80	6.1	94	5.6	85	4.7	70	5.4	82
0930	6.3	97	7.0	106	6.5	100	5.9	91	4.6	69	5.6	84
1230	6.3	97	7.9	122	6.8	106	6.7	103	5.5	86	6.1	94
1530	7.8	122	8.1	125	7.5	117	7.3	114	7.8	124	7.6	119
1830	8.2	128	7.8	120	7.8	122	6.8	105	7.1	111	7.4	115
2130	7.5	114	5.9	88	7.1	107	6.7	103	6.5	99	7.3	110
0030	6.7	102	5.7	85	6.9	106	5.8	89	5.4	83	6.5	100
0330	6.5	100	5.5	82	6.3	97	6.1	92	4.7	70	5.4	81
0630	6.5	100	5.7	87	5.5	85	5.7	88	5.4	82	5.5	85

TABLE 10

BENNER BAY - MANGROVE LAGOON

DIURNAL STUDY, MARCH 21-22, 1970
pH

TIME	STATION					
	2	4	7	9	10	11
0630	8.4	8.3	8.2	8.4	8.4	8.4
0930	8.4	8.3	8.2	8.4	8.1	8.2
1230	8.3	8.4	8.2	8.3	8.2	8.2
1530	8.4	8.4	8.4	8.3	8.2	8.2
1830	8.3	8.5	8.2	8.3	8.4	8.4
2130	8.2	8.2	8.1	8.2	8.2	8.2
0030	8.4	8.4	8.2	8.2	8.2	8.4
0330	8.4	8.4	8.2	8.3	8.3	8.4
0630	8.4	8.4	8.4	8.4	8.4	8.4

TABLE 11

BENNER BAY - MANGROVE LAGOON

DIURNAL STUDY, APRIL 20-21, 1970
Temperature (°C), Salinity (‰)

TIME	STATION 2		4		7		9		10		11	
	T	S	T	S	T	S	T	S	T	S	T	S
0600	26.5	37.1	25.5	37.1	29.5	38.4	28.0	38.4	27.0	39.2	7.0	38.8
0900	26.5	36.9	26.5	37.9	28.5	38.6	28.0	38.8	27.0	39.6	27.5	37.1
1200	26.5	38.4	28.0	36.9	28.5	37.9	27.5	38.1	27.5	39.6	27.0	37.3
1500	27.0	37.3	29.0	38.6	29.0	38.9	28.5	39.2	28.0	39.5	28.0	38.8
1800	27.4	36.9	28.0	37.3	28.1	38.6	28.0	37.7	28.0	39.9	28.8	-
2100	27.5	36.9	27.0	37.7	28.3	38.4	27.4	37.9	27.5	39.8	28.5	36.9
2400	26.2	37.1	26.5	36.1	28.0	38.4	27.5	37.5	27.5	39.8	27.5	36.3
0300	27.0	36.5	26.3	36.6	28.0	37.9	27.4	38.4	27.0	39.4	26.5	37.9
0600	26.2	35.5	26.2	36.9	26.0	39.1	27.0	38.6	26.5	39.6	26.0	37.9

TABLE 12

BENNER BAY - MANGROVE LAGOON

DIURNAL STUDY, APRIL 20-21, 1970
Dissolved Oxygen (mg./l) and % Saturation

TIME	STATION											
	2		4		7		9		10		11	
	D.O.	% Sat.	D.O.	%Sat.	D.O.	%Sat.	D.O.	%Sat.	D.O.	%Sat.	D.O.	%Sat.
0600	6.5	99	4.9	73	5.7	92	5.1	81	4.5	70	6.0	94
0900	6.5	97	6.2	94	5.6	88	5.8	92	5.2	81	6.4	102
1200	6.6	102	7.3	116	6.6	103	6.1	97	6.7	106	5.2	80
1500	6.5	100	7.5	119	7.1	114	6.9	111	8.0	127	6.8	108
1800	7.7	117	7.3	116	6.7	106	6.2	98	6.7	108	7.0	113
2100	7.4	112	6.5	102	6.2	98	6.2	97	5.7	92	7.0	113
2400	7.4	112	6.0	91	6.2	98	6.1	97	5.6	90	6.7	105
0300	6.3	97	6.2	93	5.7	90	5.9	92	5.3	83	5.5	86
0600	6.1	92	6.1	92	5.8	89	5.4	84	4.5	70	5.5	85

TABLE 13

BENNER BAY - MANGROVE LAGOON

DIURNAL STUDY, APRIL 20-21, 1970

pH

	STATION					
TIME	2	4	7	9	10	11
0900	8.4	8.3	8.2	8.2	8.1	8.4
1200	8.4	8.5	8.3	8.2	8.4	8.4
1500	8.2	8.2	8.0	8.1	8.2	8.1
1800	8.3	8.4	8.1	8.2	8.1	8.3
2100	8.3	8.3	8.1	8.1	8.1	8.3
2400	8.2	8.0	8.0	8.0	7.9	8.2
0300	8.1	8.0	7.9	7.9	7.9	8.0
0600	8.0	8.0	7.9	7.9	7.8	8.0

TABLE 14
BENNER BAY-MANGROVE LAGOON
MEANS, MINIMA, MAXIMA, AND RANGES OF VARIABLES
MEASURED DURING DIURNAL STUDIES

	Air Temp. °C	Water Temp. °C STATION 2	4	7	9	10	11	Salinity ppt. STATION 2	4	7	9	10	11
3/21-22,	1970												
Min.	22.0	25.5	24.8	26.0	25.0	25.0	25.0	36.5	36.5	37.4	37.2	37.6	36.8
Max.	28.0	26.5	27.0	27.0	27.0	27.5	27.0	38.3	38.5	39.5	39.1	41.0	41.0
Mean	24.1	26.1	25.7	26.3	26.0	25.8	25.7	37.7	37.2	38.6	38.2	39.1	38.0
Range	6.0	1.0	2.2	1.0	2.0	2.5	2.0	1.8	2.0	2.1	1.9	3.4	4.2
4/20-21,	1970												
Min.	24.0	26.2	25.5	28.0	27.0	26.5	26.0	35.5	36.1	37.9	37.5	39.2	36.3
Max.	29.5	27.5	29.0	29.5	28.5	28.0	28.5	38.4	38.6	39.1	39.2	39.9	38.8
Mean	26.4	26.8	27.0	28.2	27.4	27.3	27.5	37.0	37.2	38.5	38.3	39.6	37.9
Range	5.5	1.3	3.5	0.5	1.5	1.5	2.5	2.9	2.5	1.2	1.7	0.7	2.5

		D.O. mg/L STATION 2	4	7	9	10	11	pH STATION 2	4	7	9	10	11
3/21-22,	1970												
Min.		6.3	5.3	5.5	5.6	4.6	5.4	8.2	8.2	8.1	8.2	8.1	8.2
Max.		8.2	8.1	7.8	7.3	7.8	7.6	8.4	8.5	8.4	8.4	8.4	8.4
Mean		6.9	6.5	6.7	6.3	5.7	6.3	8.4	8.4	8.2	8.3	8.3	8.3
Range		1.9	2.8	2.3	1.7	3.2	2.2	0.2	0.3	0.3	0.2	0.3	0.2
4/20-21,	1970												
Min.		6.1	4.9	5.6	5.1	4.5	5.2	8.0	8.0	7.9	7.9	7.8	8.0
Max.		7.7	7.5	7.1	6.9	8.0	7.0	8.4	8.5	8.3	8.2	8.4	8.4
Mean		6.8	6.4	6.2	6.0	5.9	6.2	8.2	8.2	8.1	8.1	8.1	8.2
Range		1.6	2.6	1.5	1.8	3.5	1.8	0.4	0.5	0.4	0.3	0.6	0.4

TABLE 15

BENNER BAY - MANGROVE LAGOON
MONTHLY AVERAGES FOR WATER
QUALITY PARAMETERS

1970	STATION 1	2	3	4	5	6	7	8	9	10	11	
Feb.	26.5	26.9	27.3	27.5	28.1	27.5	27.7	27.8	27.6	27.3	26.7	Temp. °C
March	26.4	26.5	27.4	26.3	26.2	26.5	27.1	26.5	26.6	26.0	26.2	
May	27.9	27.9	28.2	28.2	29.2	29.1	29.4	29.2	29.6	30.7	29.2	
Feb.	36.6	37.0	36.6	36.6	37.2	37.0	37.1	37.1	37.3	37.5	36.3	Salinity ppt.
March	37.0	37.0	36.5	36.8	37.0	37.5	37.0	37.3	37.2	37.8	36.8	
May	36.8	36.8	36.9	35.1	36.0	36.6	36.7	36.6	35.0	25.9	32.6	
June	35.2	33.7	35.0	35.8	33.6	34.4	33.7	33.6	31.7	22.1	35.3	
July	-	-	32.8	32.7	33.0	32.6	33.0	32.7	32.7	29.8	35.9	
Feb.	6.3	6.4	7.2	6.7	6.3	6.1	6.2	5.8	6.3	6.1	6.4	D. O. mg/i
March	6.5	6.4	6.8	6.6	6.6	6.5	6.6	6.0	6.7	6.0	6.3	
May	6.3	6.1	6.5	6.5	6.1	6.0	6.0	6.0	5.8	5.8	6.5	
Feb.	8.3	8.3	8.4	8.4	8.3	8.2	8.2	8.1	8.3	8.2	8.3	pH
March	8.3	8.3	8.4	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.2	
May	8.4	8.3	8.3	8.3	8.3	8.4	8.3	8.3	8.4	8.2	8.3	
Feb.	10.7	5.6	1.9	2.0	1.0	1.3	1.0	0.9	1.3	0.8	1.3	Secchi Depth Meters
March	10.7	5.7	1.9	2.0	1.0	1.2	1.0	1.3	1.7	0.8	1.3	
May	9.9	5.7	1.9	1.9	1.0	1.0	0.8	0.8	1.4	0.5	1.1	
Feb.	IV	VI	VI	VIII	XIV	XVI	XVII	XVIII	XVI	XVIII	XIV	Color (forel-ule)
March	IV	VII	VI	VII	XV	XVII	XVII	XVII	XVI	XVII	XII	
May	IV	VI	V	XIII	XIV	XVII	XVII	XVII	XVII	XIX	XIV	
M[illegible]	41.9	27.2	21.0	24.0	23.2	39.9	41.2	41.5	39.8	142.1	23.6	Suspended Solids mg/l
[illegible]e	13.7	28.5	22.1	19.6	17.7	27.1	19.8	19.1	19.4	50.6	15.2	
[illegible]ly	-	-	21.6	22.9	12.6	22.6	23.5	0.4	25.9	20.9	2.5	

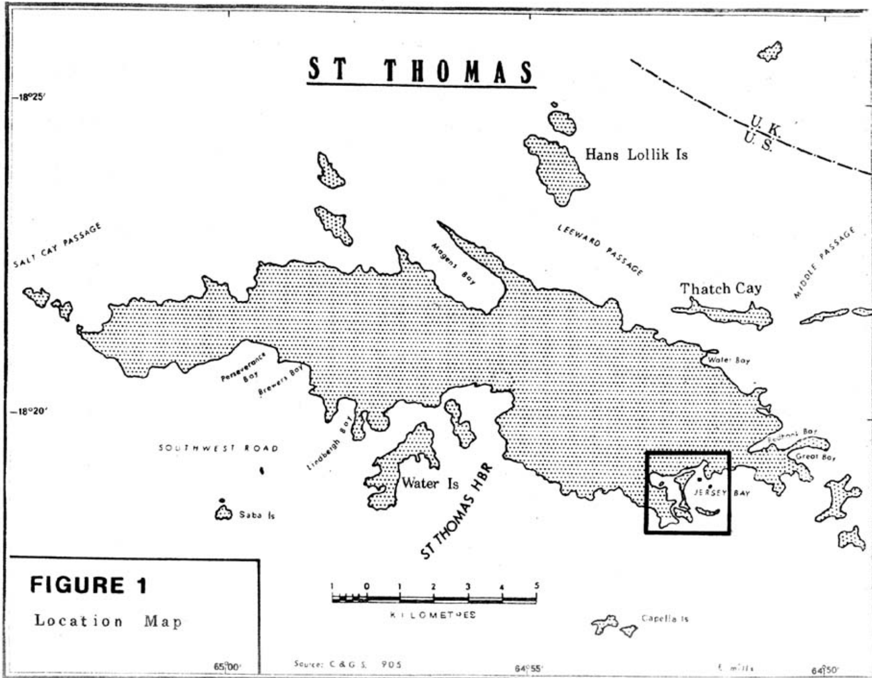

FIGURE 1
Location Map

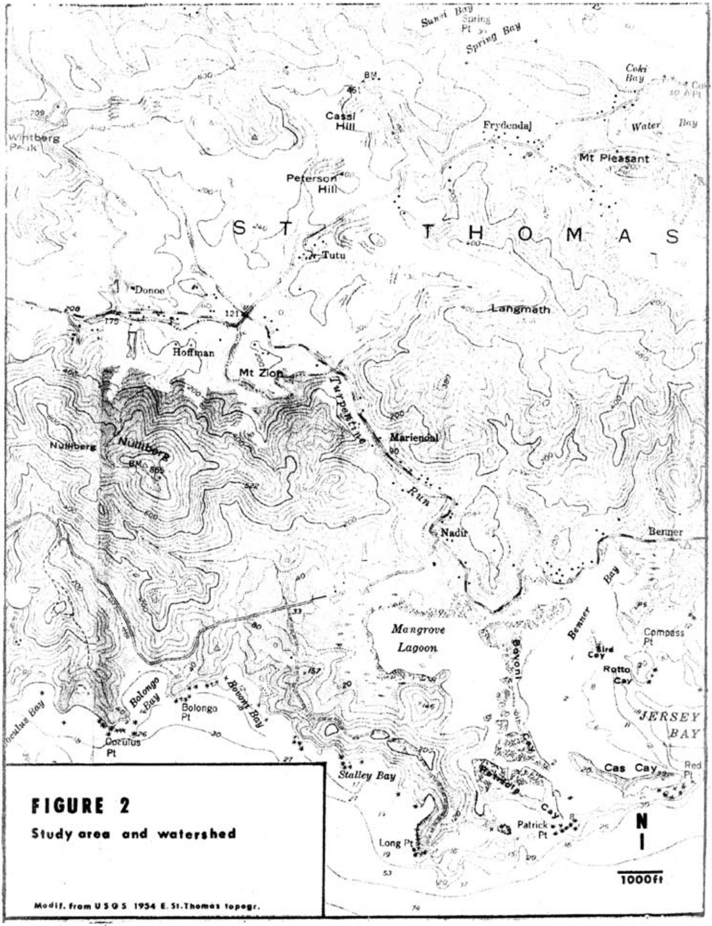

FIGURE 2

Study area and watershed

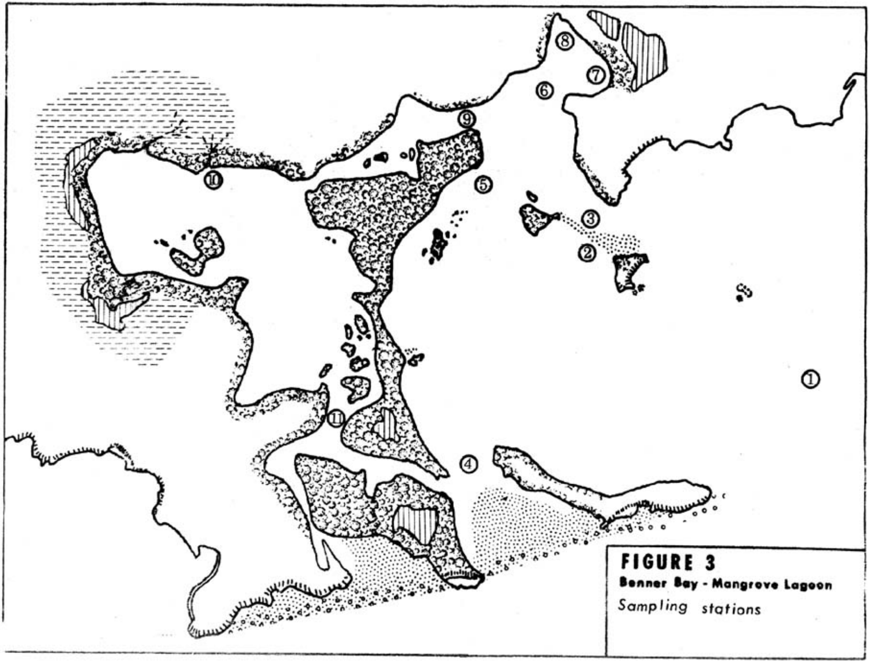

FIGURE 3
Benner Bay - Mangrove Lagoon
Sampling stations

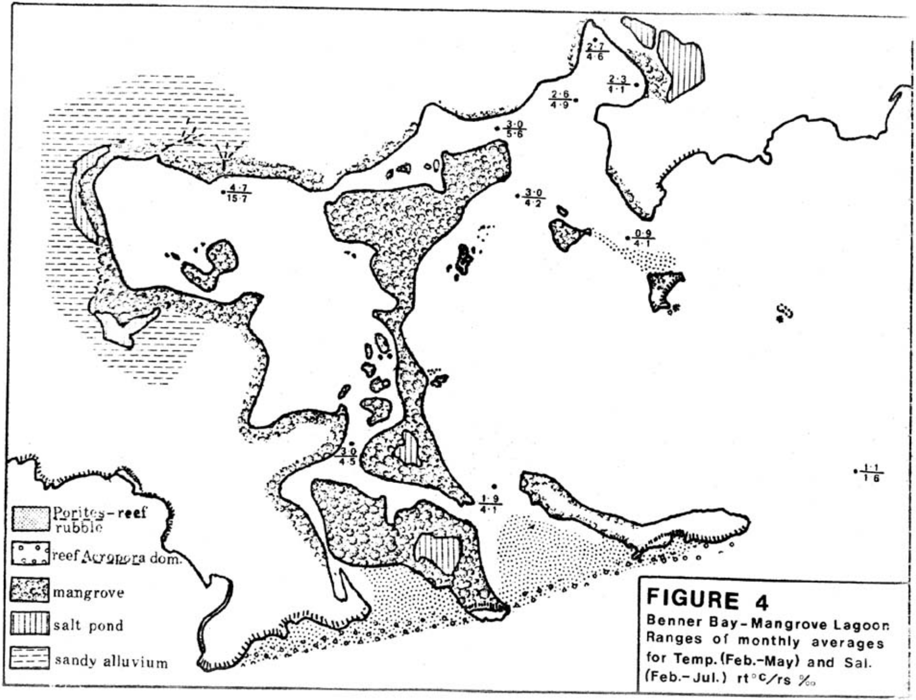

FIGURE 4

Benner Bay-Mangrove Lagoon Ranges of monthly averages for Temp. (Feb.-May) and Sal. (Feb.-Jul.) rt°C/rs ‰

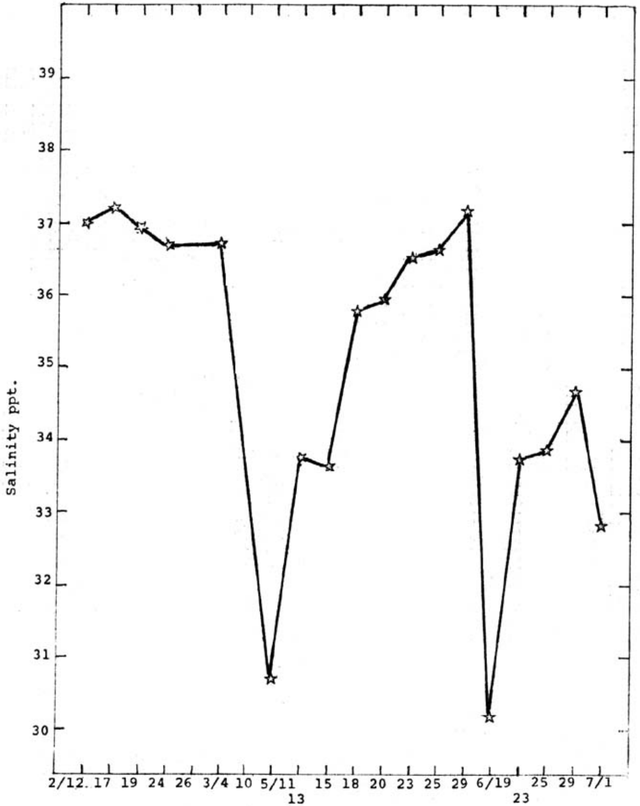

Figure 5. Salinity changes during study period in Benner Bay - Mangrove Lagoon. Average for 11 stations.

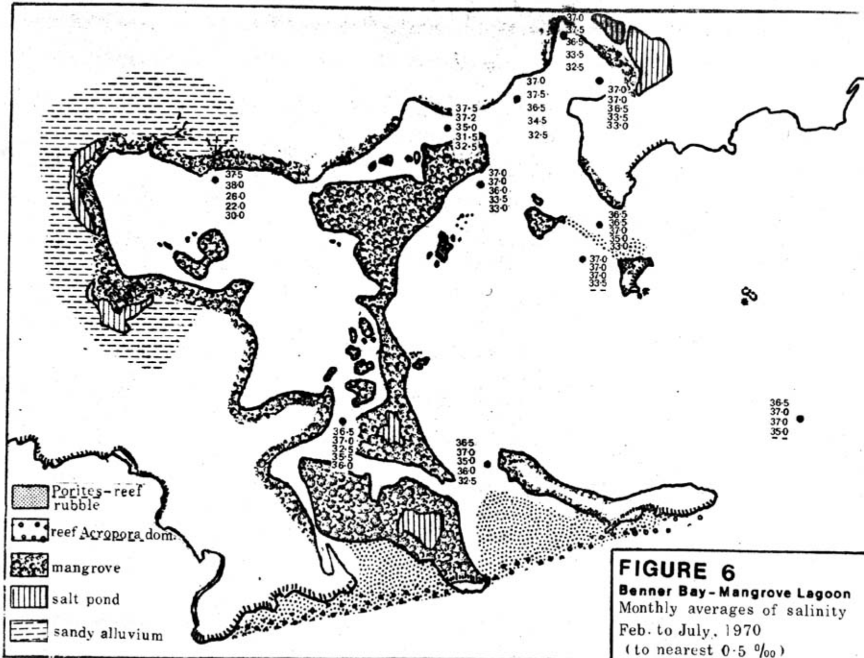

FIGURE 6

Benner Bay – Mangrove Lagoon

Monthly averages of salinity

Feb. to July, 1970

(to nearest 0·5 ‰)

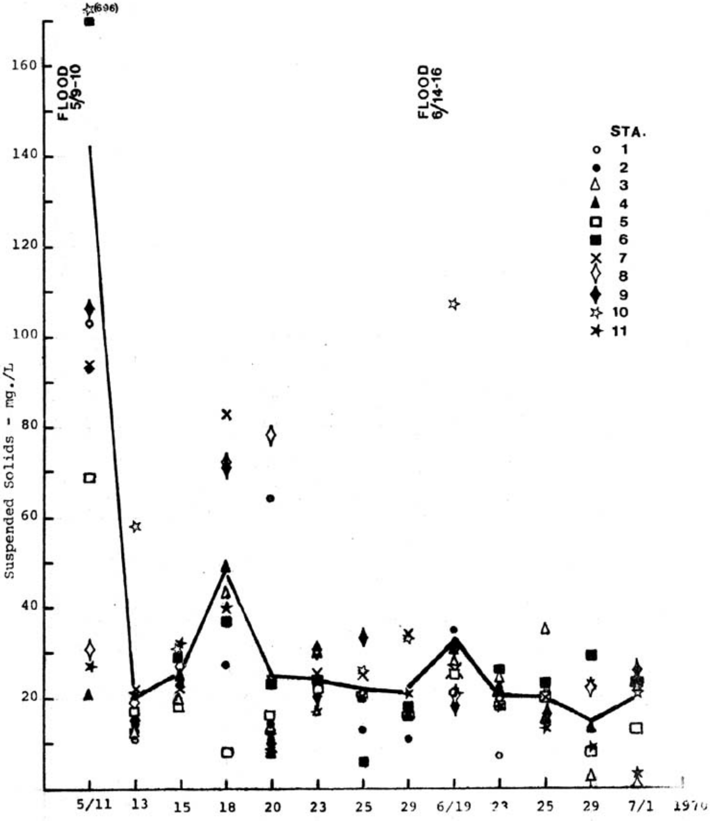

Figure 7. Suspended solids following flooding, Benner Bay - Mangrove Lagoon. Line is plot of average values. Particle size greater than 0.45 micron.

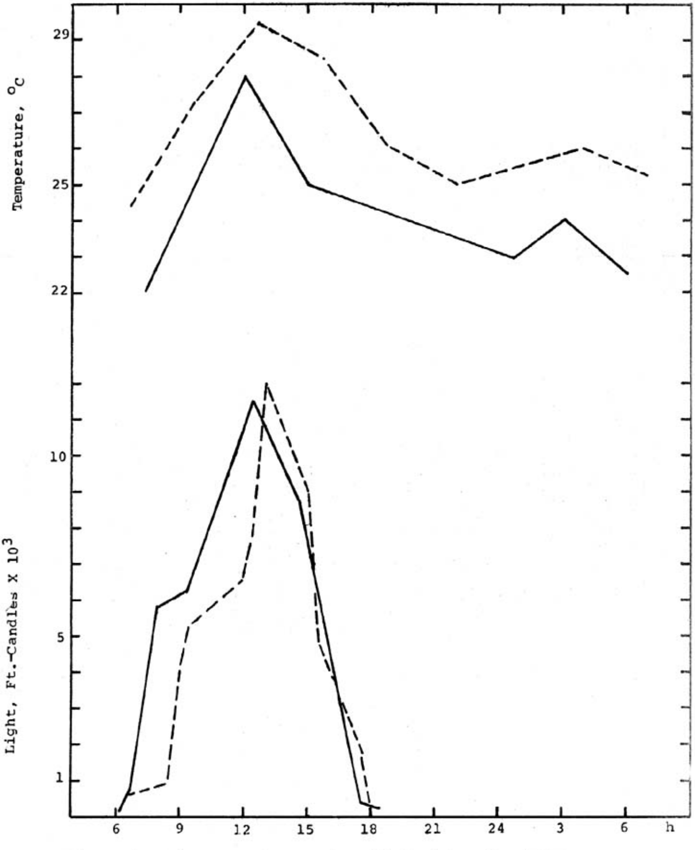

Figure 8. Air temperature and sunlight intensity during diurnal studies. Solid lines March 21-22, broken lines April 20-21, 1970

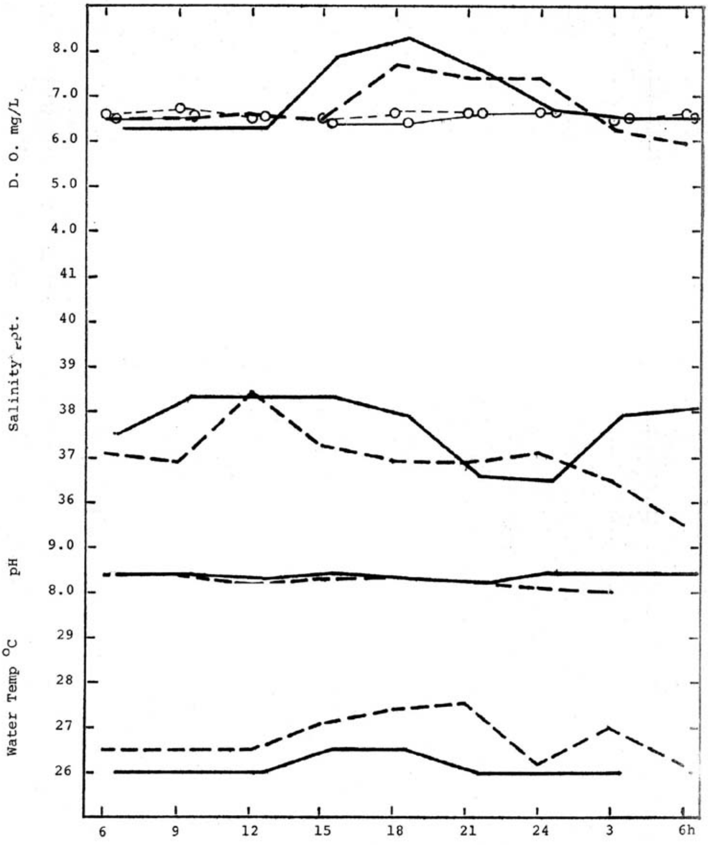

Figure 9. Station 2. Diurnal variables measured at Benner Bay - Mangrove Lagoon. Solid lines March 21-22, 1970, broken lines April 20-21, 1970. ○ indicates D.O saturation points.

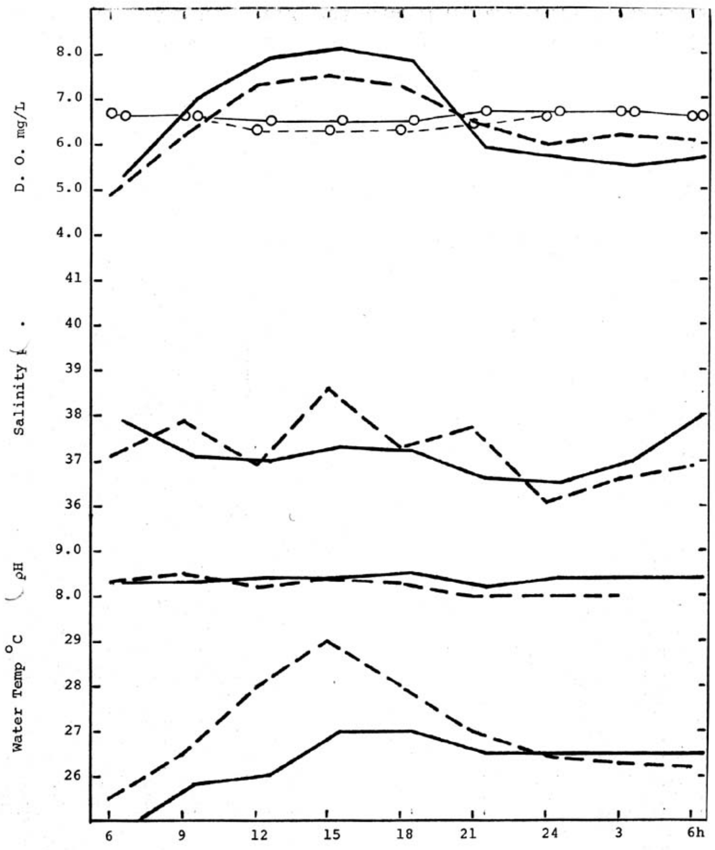

Figure 10. Station 4. Diurnal variables measured at Benner Bay - Mangrove Lagoon. Solid lines March 21-22, 1970, broken lines April 20-21, 1970 O indicates D.0 saturation points.

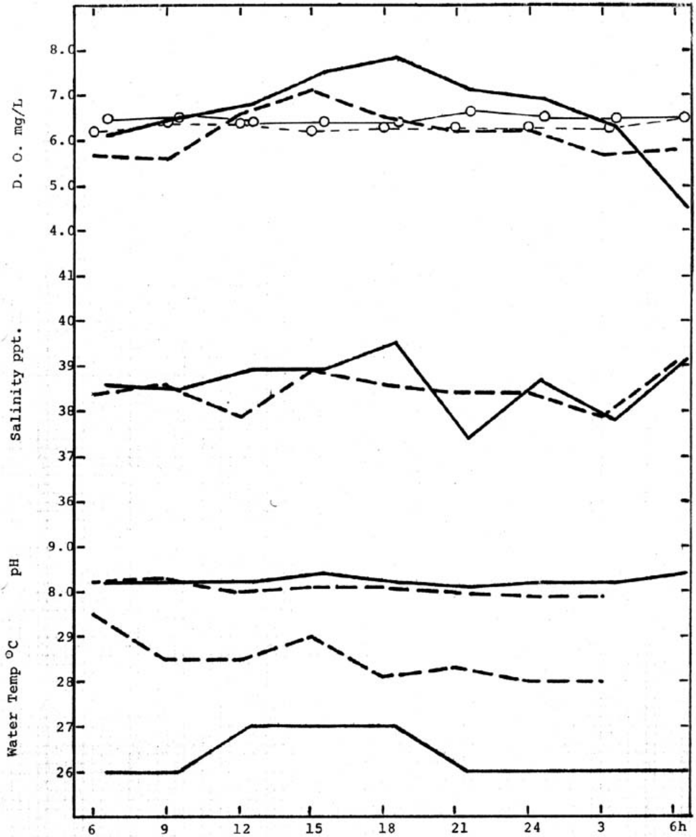

Figure 11. Station 7. Diurnal variables measured at Benner Bay - Mangrove Lagoon. Solid lines March 21-22, 1970, broken lines April 20-21, 1971. O indicates D.0 saturation points.

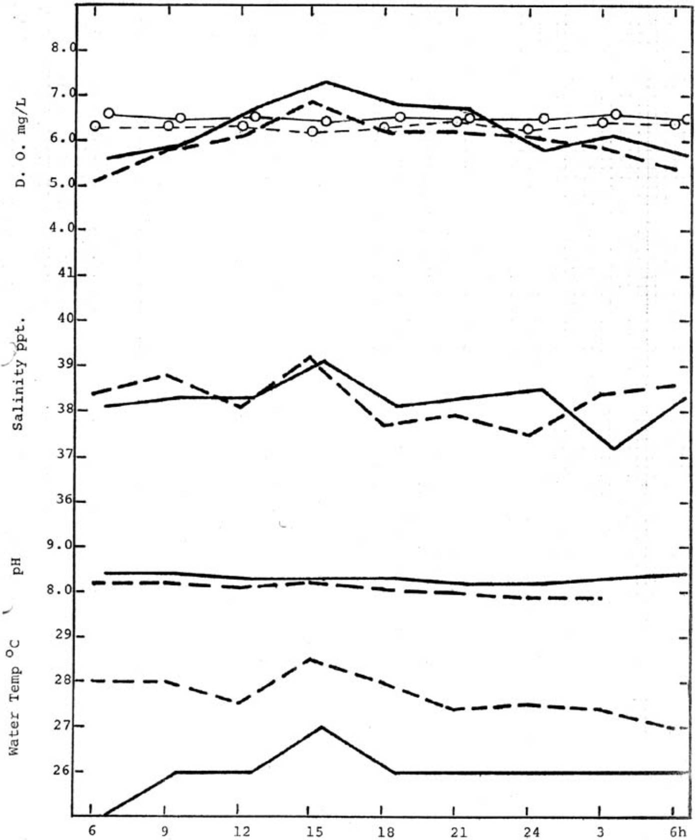

Figure 12. Station 9. Diurnal variables measured at Benner Bay - Mangrove Lagoon. Solid lines March 21-22, 1970, broken lines April 20-21, 1970. O indicates D.O saturation points.

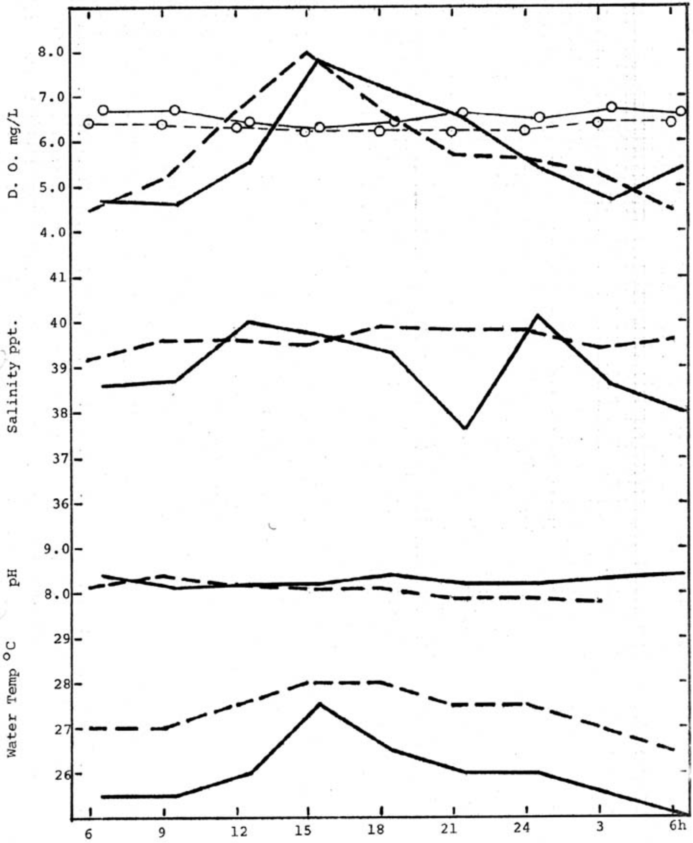

Figure 13. Station 10. Diurnal variables measured at Benner Bay - Mangrove Lagoon. Solid lines March 21-22, 1970, broken lines April 20-21, 1970. O indicates D.O saturation points.

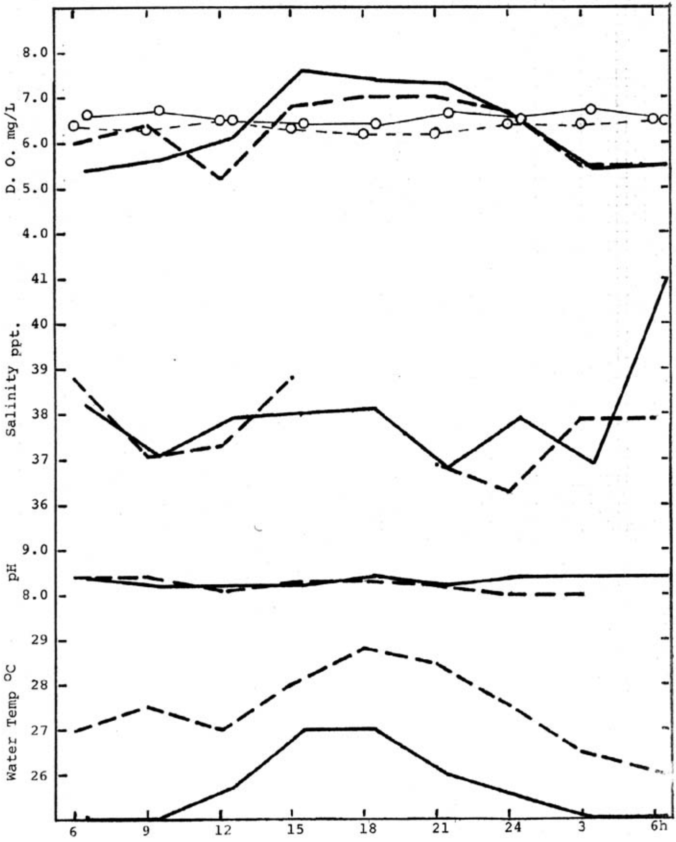

Figure 14. Station 11. Diurnal variables measured at Benner Bay - Mangrove Lagoon. Solid lines March 21-22, 1970, broken lines April 20-21, 1970. O indicates D.O saturation points.

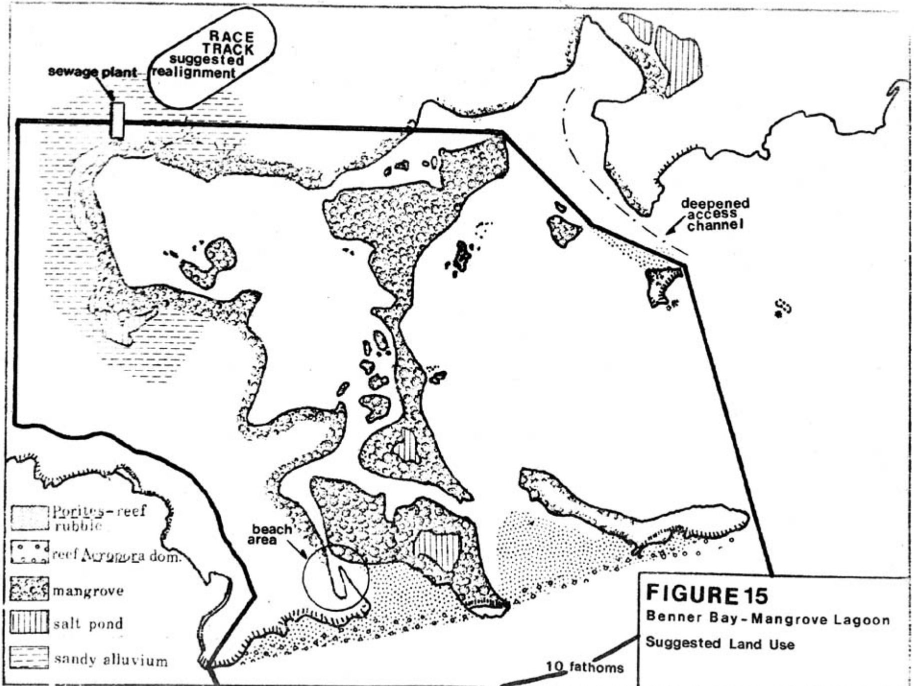

FIGURE 15

Benner Bay - Mangrove Lagoon

Suggested Land Use

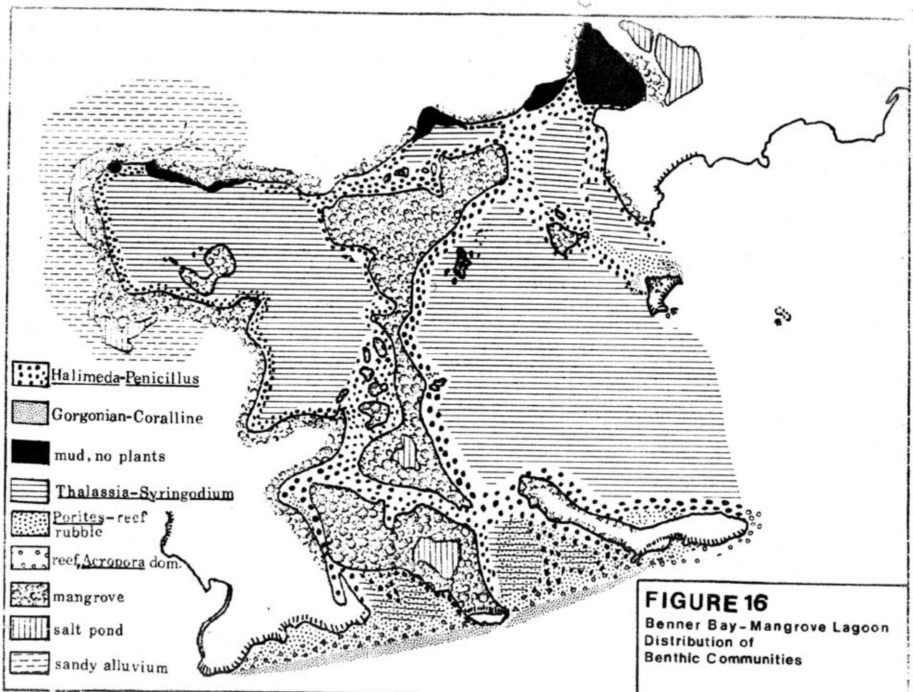

FIGURE 16

Benner Bay - Mangrove Lagoon Distribution of Benthic Communities