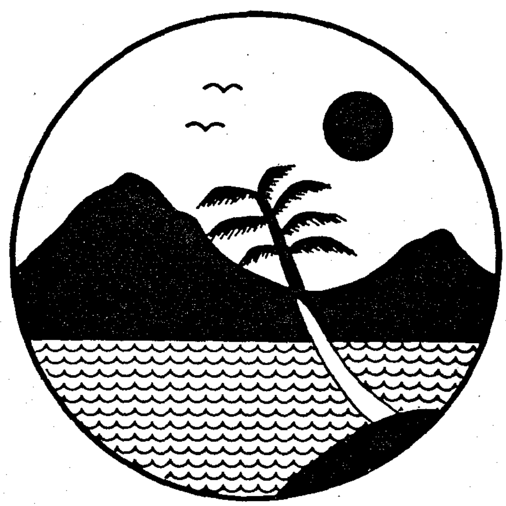
IMPACT OF STORM FLOODING IN THE MANGROVE LAGOON



Final Report

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IMPACT OF STORM FLOODING IN THE MANGROVE LAGOON

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Final Contract Report

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ABSTRACT

The tropical wave of October 5-9, 1977 produced a threefold stress on the Mangrove Lagoon and Benner Bay marked by high rainfall and stream inflow. As flood energy dissipated through the lagoon, it reduced salinity to 9.8 ppt and spread freshened surface water seaward 2 km. The large influx of suspended material and excess nutrients with consequent rapid generation of phytoplankton, raised turbidity three times average levels, and increased phosphorous 15 to 30 times. Flooding switched the salinity structure from a well-mixed to a highly stratified regime. The intense salinity stratification with consequent reduced vertical mixing, led to complete depletion of oxygen in deeper parts of the lagoon. Despite high runoff, sediment loads were surprisingly small. The flood mainly supplied high nutrient loads which over-fertilized the lagoon and stimulated phytoplankton growth within the system. The lagoon recovered from the shock of freshening and oxygen depletion in about 8 days while turbidity and phosphorous content remained high for more than one month. It is concluded that flooding triggered "worst case" conditions for water quality with potential ecological consequences extending for years.

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I. Introduction

Although the Tropical Wave of October 5-9, 1977 was not an unusual storm of hurricane intensity, it produced "worst case" conditions for water quality with potential ecological consequences. The extreme storm runoff introduced more water into the lagoon during a few days of rainfall and runoff than during many months of normal conditions. Where then does the flood-borne water and sediment go? Is it flushed through the lagoon or trapped within the system? And how far seaward did the flooding effects extend? What changes occurred in the water quality and biota? And how long did it take the lagoon to recover? These are among the questions we attempted to answer at the onset of the investigation. Whereas a great many measurements and observations have been made on coastal waters at average conditions of wind, waves and runoff, little is known about the changes that take place when stability breaks down and extraordinary events begin to happen.

The purpose of this study was: (1) to determine the impact of storm runoff on the water quality, sediments and biota of the Mangrove Lagoon; (2) to determine what changes take place in comparison to normal conditions which were recorded in an earlier study (Nichols and Towle, 1977);

(3) to recommend measures that can be taken to minimize the impact of future floods.

2. Methods and Procedures

Water Quality. Stations were located to cover the horizontal gradient of water quality parameters. They include the same stations occupied during former "base" surveys (Nichols and Towle, 1977). Additionally, stations were sited offshore in Jersey Bay to cover the extent of flooding effects as well as in salt ponds, guts and along Turpentine Run, the main stream entering the lagoon (Fig. 1).

Field observations began near peak runoff in Turpentine Run, October 8, 1977. They were concentrated daily in the lagoon between October 9-14 and weekly between October 17 and November, 1977. Altogether, ten areal surveys consisting of 18 to 27 stations each, and one diurnal survey of three stations, were completed. Additionally, seven areal surveys were conducted during and following, the wet season between October 30, 1978 and January 30, 1979.

Instrumentation and laboratory procedures for water sampling and analyses follow those used in the base survey. In brief, water temperature and dissolved oxygen content were measured with an *in situ* probe of a YSI model 54A oxygen meter. The pH was measured on fresh samples with a Beckman model 1009 pH meter. Water samples were returned to the laboratory for analyses of chlorinity and salinity by mercuric

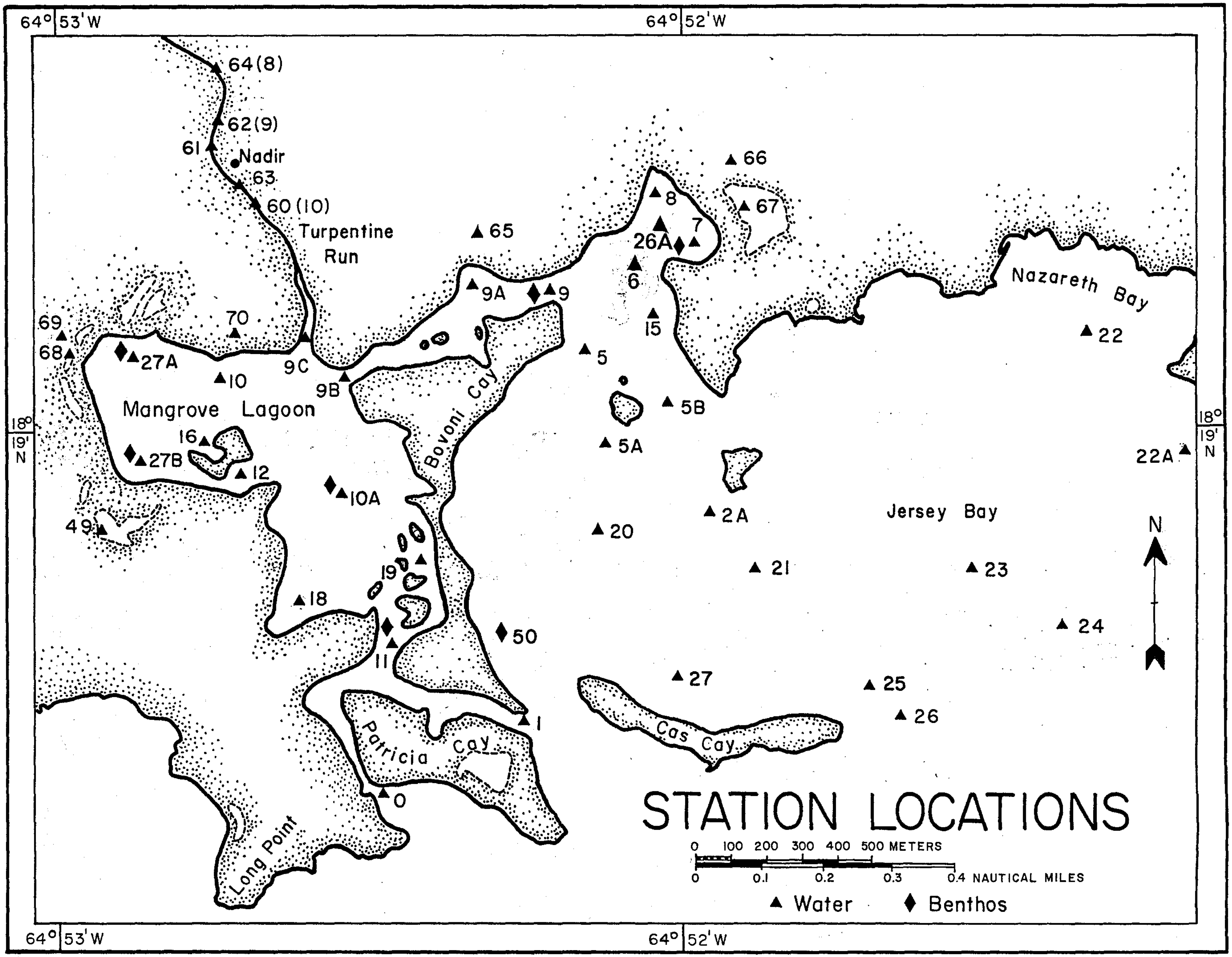

Figure 1. Location of sampling stations for water quality and biotic quadrats.

nitrate titration. Suspended solids were analyzed by gravimetric analyses and Milipore filtration using 0.8μ pore size filters. Dissolved reactive ortho-phosphate and total hydrolyzable phosphate were analyzed by the ammonium molybate and stannous chloride reduction method (U.S. E.P.A., 1976). Laboratory methods for trace metals and organic pollutants in stream water and sediments are given in Appendix 1 of Nichols and Towle (1977). Current velocity was measured with a tethered drogue and stop watch. Aerial observations were conducted October 9, 1977 to trace and photograph the extent of turbid plumes.

Biota. Sampling of the benthic fauna and flora consisted of repetitively sampling 0.25 m^2 quadrats at five stations. The stations were established at the same locations as the former surveys, Figure 1, (Nichols and Towle, 1977). Sampling was performed one week and one month after flooding, October 15 and November 9, 1977 and also after the wet season, February 2 and May 18, 1979. The resulting data, Tables 5 - 9 , together with data of the former surveys (Nichols and Towle, 1977) were analyzed statistically to assess their adequacy and to determine: (1) What distinct community associations can be recognized? (2) What temporal changes occur and what is their significance? (3) Are lagoon biota deteriorating with time? Collection methods and procedural details follow those described for former surveys (Nichols and Towle, 1977).

Statistical analyses consisted of computing: (1) the sample diversity and analysis of variance, and (2) the community diversity with sub-analyses of sample size. The Shannon-Weaver sample diversity statistic H_s was calculated according to the equation:

$$H_s = \sum_{i=1}^{ns} P_i \ln (p_i) \qquad (1)$$

where P_i equals the proportion of the i^{th} species in the collection and ns is the number of species in the collection. The community diversity statistic, H', was calculated after the sample order was randomized, following Pielou (1966) and utilizing the equation:

$$H' = \sum_{i=1}^{nc} \sum_{i=1}^{ns} P_i \ln(p_i) \qquad (2)$$

where nc is the number of quadrats. The units are in nats when natural logarithms are used. The calculation involved creation of a 32 sample by 40 species matrix, calculation of relative species abundance, the Shannon-Weaver calculation for each species, addition of species abundances from sample to sample and recalculation.

3. Storm Stress

The torrential rainfall of the Tropical Wave of October 5-9, 1977 produced 6.83 inches of precipitation over a five day period (U.S. NOAA, 1977), Figure 3A. The storm differed from others on record in that the bulk of the rain-fall, 5.3 inches or 78 percent of the total for the event, occurred within 24 hours, October 8-9. High winds, 25 to 40 mph and high wave action accompanied the passing storm. Total precipitation was relatively uniform over a wide area of the island and it occurred more-or-less simultaneously over the watershed. Consequently, extreme runoff discharged into the lagoon first from nearby streams as Benner Run and hours later from distance streams as Turpentine Run which drains the upper watershed. The event was preceded by 4.3 inches of rainfall during a 16-day period. It was followed by a 3-inch rainfall, November 1, 1977 (Fig. 3).

The flood crest passed down Turpentine Run about 16 hours after the main rainfall began. It topped the animal shelter bridge in Nadir by about 36 inches and inundated the lower flood plain. Wash lines along the channel where the Run enters the lagoon, indicate water levels reached 12 inches (30 cm) above high tide level. In the lower part of Pleasure Boats Run, washlines reached 30 inches above the main bridge. Elsewhere in the lagoon itself, no abnormally high water was reported. Although gaging stations were not in place, it is estimated from historical records at Mt. Zion on Turpentine Run (Jordan and Cosner, 1973) that a total of 165,800 m^3 of water discharged into the lagoon during the main 24-hour rainfall. This amounts to about 86 percent of the lagoon tidal prism, i.e. the amount of water discharged by the tide in a tidal cycle (25 hours). In summary, the storm produced a three-fold stress on the lagoon; first high wind wave stirring, then high inflow from local drainage followed by extreme inflow from the main stream.

4. Lagoon Response

During progress of the flood and for one week thereafter, lagoon water quality changed markedly with time, depth and with distance seaward. Response of the lagoon is revealed by: (1) the seaward extent to which changes occurred, (2) the deviation of measured variables from mean values, and (3) the magnitude and duration of temporal variations. Comparison of changes in the stress and response variables provide a means to trace the dynamic link between inflow from the watershed and the response it caused in the lagoon.

Water Quality

Temperature. Temperature distributions shown in charlets, Figs. 5-8, indicate that flood waters were warmer than offshore water, e.g. by 3.3^{o}C, October 10th. Highest surface water temperature, 31.9^{o}C, was recorded at the mouth of Turpentine Run, October 10th. Flooding created thermal stratification with temperatures decreasing downward 0.4 to 1.5^{o}C per 2 meters of depth. Such a condition, when added to diurnal heating of surface water, tends to retard vertical mixing and buoy up flood water as it passes seaward.

Salinity. Flooding produced a sharp decline in surface salinity with freshening extending seaward 2.0 km to Nazareth Bay and Red Point. Within 32 hours after the main rainfall October 8th, inner lagoon salinity was depressed from 33.5 ppt to a minimum of 9.8 ppt. The distribution of isohalines, which serves as an indicator of water movement, Figure 2, indicates most freshened water was extruded through Bovoni Passage, out Benner Bay entrance, southward past Rotta Cay and eastward toward Nazareth Bay. Thus, reefs to the west around Cas and Patricia Cays were relatively free of freshening. The seaward extent of freshening is delineated by the 33 ppt isohaline which coincides with the seaward edge of brown water observed from the air.

After inflow declined and salinity reached a minimum, October 9th, salinity began to rise at all stations except number 20 where the rise started October 10th. Time variations of salinity (Fig. 3) show salinity recovery was faster in Benner Bay, station 7, than in the inner lagoon, station 27B. Eight days after flooding most waters had regained near-normal salinity for the wet season.

Flooding switched the salinity structure from a homogeneous well-mixed regime to a highly stratified regime. Figure 4 reveals a layer of freshened water overlying a layer of more salty water below mid-depth. Stratification was so intense at station 27B, October 11th, that salinity changed downward 18.3 ppt within 1.6 meters. Since the effects of freshening were detected as far as 2 km offshore in near-surface water, it is assumed that the freshened flood water overode more salty or residual lagoon water rather than pushed it out of the lagoon and into the sea. In this way benthic

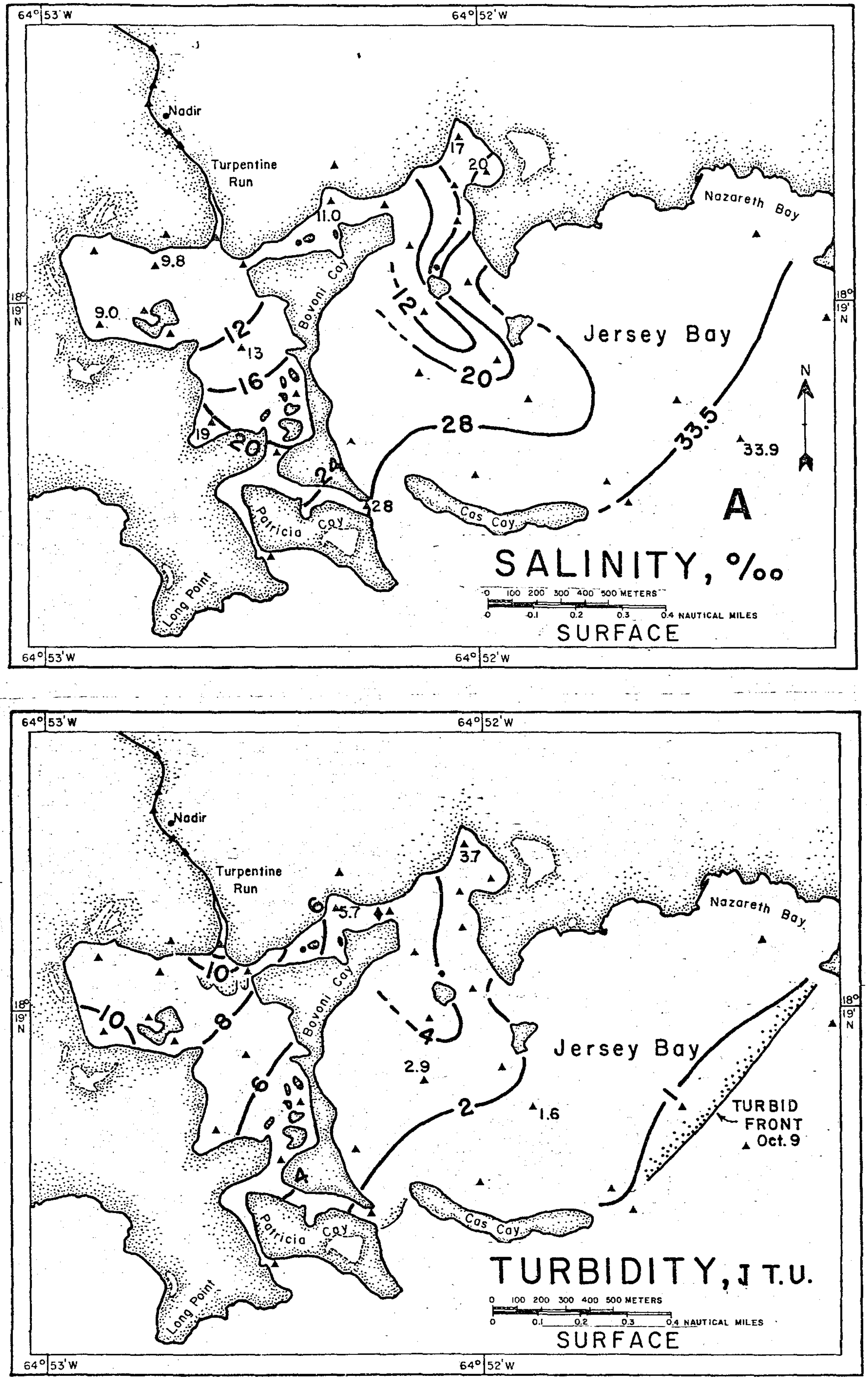

Figure 2. Distribution of water quality parameters near the maximum extrusion of lagoon water, October 9, 1977. A. Salinity, ppt. B. Turbidity, J.T.U. and location of turbid fronts from aerial observations.

WATER QUALITY TRENDS

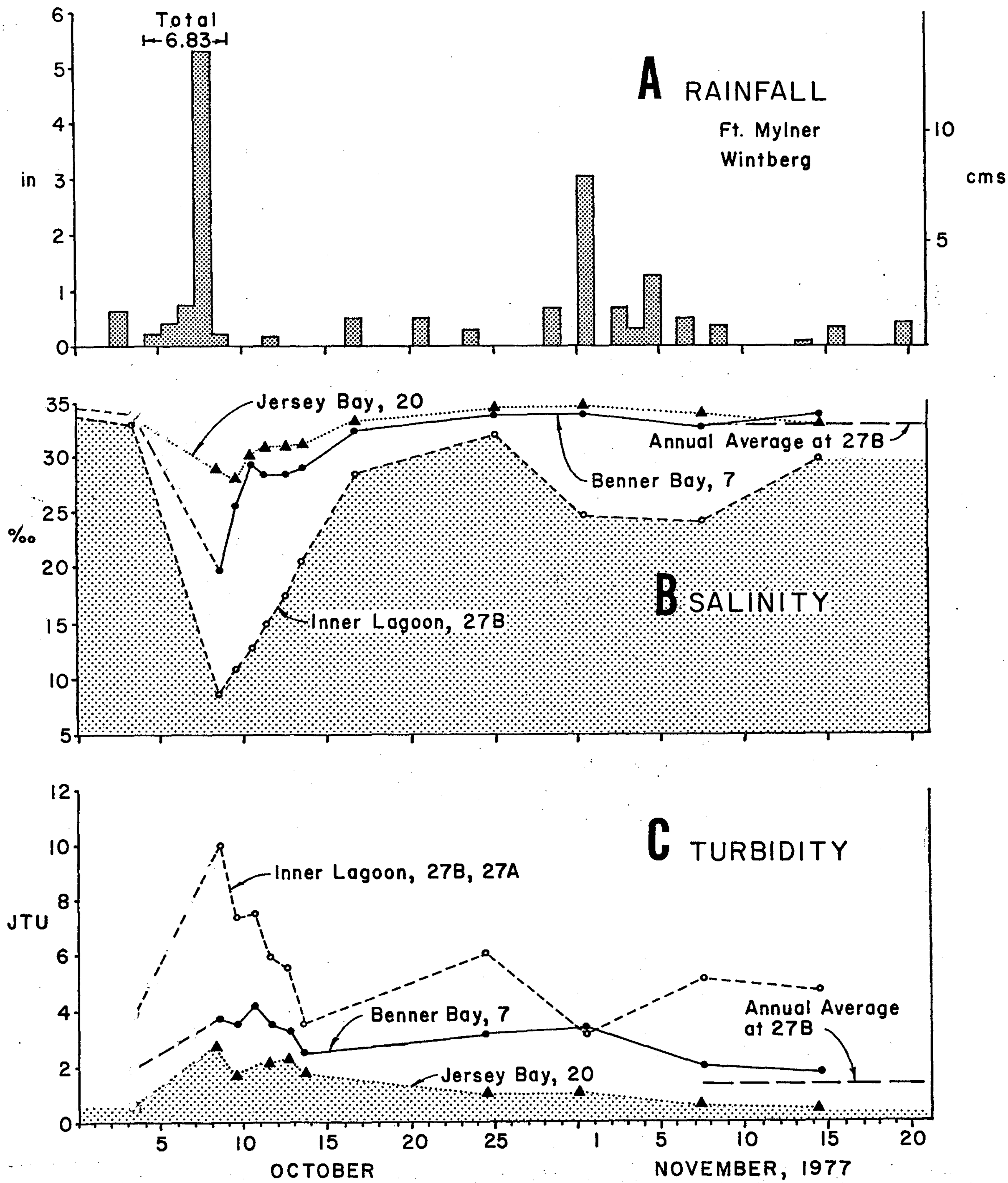

Figure 3. Temporal variations of stress and response parameters between October 1 and November 20, 1977. A. Rainfall at stations in the Turpentine Run watershed. B. Salinity at three lagoon stations. C. Turbidity at three lagoon stations.

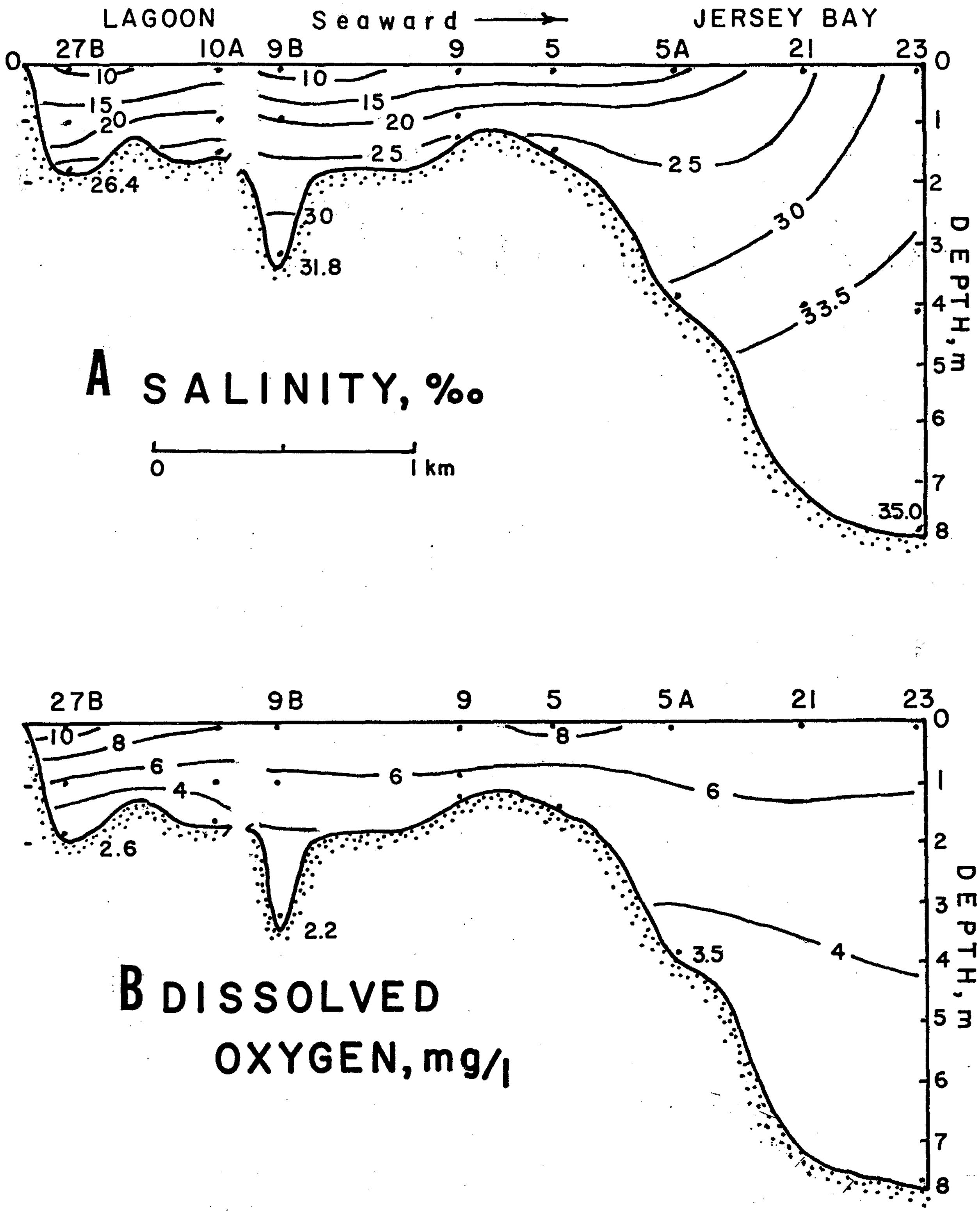

Figure 4. Vertical distribution of water quality parameters seaward from the lagoon head into Jersey Bay. A. Salinity structure, Oct. 9-10, 1977. B. Dissolved Oxygen content, Oct. 10-11, 1977.

fauna in deeper parts of the lagoon, as well as deep reefs off Rotta Cay, were partly buffered from the salinity shock. However, the pool of unmixed salty water retained in the lagoon, and the consequent stratification, were critical to reducing vertical mixing and thus, the depletion of oxygen.

Oxygen. Concentrations of dissolved oxygen content in open near-surface water after flooding, display a broad gradient in the range of 6.8 to 8.3 mg/l (Fig. 5). Locally however, in embayments and backwaters, e.g. stations 7 and 27B, concentrations reached as high as 11.4 and 13.5 mg/l during afternoon hours (Fig. 5). At the same time, near-surface water became supersaturated, 181 to 196 percent. Diurnal ranges October 13 were exceptional; for example at station 27B concentrations ranged from 7.45 mg/l in early morning to 16.45 mg/l in mid-afternoon. Since this condition was associated with high total phosphorous near pollution sources, and with high turbidity produced by abundant phytoplankton, it seems probable the marked oscillations of oxygen content were caused by rapid photosynthetic production of plankton such as the blooms reported by Burkholder et. al. (1972).

In deeper parts of the inner lagoon, oxygen content was markedly reduced after flooding. Complete anoxia occurred at station 27B, during the morning, October 13th while near-anoxia, less than 1.8 mg/l and 20 percent saturation, was measured at stations 7, 27B, 9C and 9B between October 11 and 14th (Fig. 2B). There is little doubt that the depletion of oxygen is created by the intense stratification which deters vertical mixing and allows for rapid consumption of oxygen demanding organic matter in the bed and water. These processes are supported by the high total phosphorous content in near bottom water at stations where oxygen was depleted (Figs. 5, 7). Therefore, it is likely that the lowered oxygen content is created by a combination of: (1) reduced mixing, and (2) an influx of organic matter from varied sources, streams, sewage or production of plankton stimulated by the influx of nutrients. Oxygen depletion places a heavy stress on benthic fauna by reducing vigor and producing mortality.

Phosphorous. Flood water supplied a large amount of phosphorous and nitrogen compounds to the lagoon. Concentrations of total phosphorous in Turpentine Run reached 4738 μg/l while total nitrogen reached 4630 μg/l October 10th (Table 1). Potential sources of nutrient loading were traced by additional samples November 30, 1977 (Table 2), to two treatment plants in the upper drainage basin (Tutu). Moreover, very high concentrations of nutrients were recorded in pond water near the treatment plant at the lagoon head (station 6B, Table 2). Besides these proximate sources, there are substantial amounts of nutrients in bordering mangrove detritus and in organic rich bed sediments (Table 3). It seems likely that storm waves and local flooding also released some nutrients into lagoon water from these sources.

Concentrations of total phosphorous were 15 to 30 times greater in the lagoon than in offshore water of Jersey Bay. Horizontal distributions (Figs. 5, 7, 8) vary systematically with distance seaward from sources in the inner lagoon. There is a corresponding seaward shift in nitrogen-phosphorous ratios from 2.8:1 in the lagoon to 12:1 in Jersey Bay. This indicates an excess of phosphorous was introduced by flooding. Of the total phosphorous in the lagoon more than 80 percent is in organic combination whereas the rest is present as dissolved or inorganic phosphate which has not been assimilated by production. With time the phosphorous gradient flatten; 15 days after flooding concentrations were three times higher in the lagoon than in Jersey Bay. There is no doubt that flooding overfertilized the lagoon with consequent adverse affects in stimulating phytoplankton growth which in turn, produced high turbidity that persisted for months.

Turbidity and Suspended Sediments. Flooding increased turbidity most in the inner lagoon. Values exceeded the annual average three fold (Figs. 2,3). Discolored water spread seaward past Rotta Cay and eastward clouding water off Sprat Beach and Secret Harbor at levels of 1.6 to 1.8 J.T.U. (Figs. 2,5). Microscopic examination of material retained on filters indicates the turbidity is caused by phytoplankton and organic matter. Presumably these constituents were flushed from the lagoon during early stages of flooding. Horizontal with copper (Tables 1,2). Concentrations of these constituents probably come from sewage effluents released into drainage of the Run. Extreme values of copper, more than 100 times offshore water, were recorded from pond water near the lagoon treatment plant, stations 68,69. Additionally, lead and zinc in these ponds were higher than normal.

Bed sediments from Benner Bay, stations 7 and 8, contain higher concentrations of copper and zinc than elsewhere. They are most likely supplied from boat repair facilities but local sewage inputs may also contribute. Lead, zinc, cobalt and oil and grease from pond sediments, station 68, were also much higher than elsewhere. Such concentrations probably reflect sewage releases from the nearby treatment plant.

TABLE 1. Concentration of Trace Metals, Nitrogen and Phosphorous Compounds in Lagoon Water and Inflowing Stream Water, October 8-14, 1977.

Station Number	Sampling Date	NH_3-N mg/l	TKN mg/l	COD mg/l	NO_3-N µgA/l N	NO_2-N µgA/l N	Ortho* PO_4-P µgA/l P	Total* PO_4-P µgA/l P	Cd µg/l	Cu µg/l	Pb µg/l	Zn µg/l
27B	9 Oct. 1977	0.19	0.92	30	93	2.13	5.68	7.99	<0.5	7.2	<5.	1.6
9C	9 Oct. 1977	0.98	2.30	55	220	29.10	35.20	36.80	<0.5	<0.5	<5.	<0.5
7	9 Oct. 1977	0.20	0.69	53	96	1.07	2.08	3.71	3.1	16.0	<5.	6.7
60	9 Oct. 1977	2.00	2.67	42	218	48.30	31.20	33.60	<0.5	5.4	<5.	<0.5
10A	9 Oct. 1977	0.06	0.71	65	92	1.18	2.96	4.97	<0.5	<0.5	<5.	32.0
70	14 Oct. 1977	0.35	1.83	64	43	0.55	1.80	5.63	<0.5	1.8	<5.	17.0
66	10 Oct. 1977	Tr.	Tr.	19	1,360	3.33	6.40	7.35	<0.5	3.6	<5.	<0.5
60	10 Oct. 1977	3.43	4.63	50	190	70.60	50.00	50.40	<0.5	3.6	<5.	1.6
20	12 Oct. 1977	0.02	0.65	26	12	0.33	0.50	1.09	<0.5	1.8	<5.	<0.5
23	12 Oct. 1977	0.02	0.33	26	20	0.10	0.18	0.56	<0.5	<0.5	<5.	<0.5
60	8 Oct. 1977	0.55	2.39	52	310	10.20	21.60	22.80	<0.5	9.0	<5.	5.0
61	8 Oct. 1977	0.08	1.49	52	670	10.50	10.40	11.40	<0.5	5.4	<5.	3.3

TABLE 2. Concentration of Total Nitrogen, Total Phosphorous and Trace Metals in Water Samples from Turpentine Run Nov. 30 1977 and Salt Ponds, 49, 68, 69, Oct. 11, 1977.

Sample Number	TKN mg/l	TP* µgA/l P	Cd µg/l	Cu µg/l	Ni µg/l	Pb µg/l	Zn µg/l
TR1	1.04	6.3					
TR2	0.97	17.0					
TR3	0.77	14.0					
TR4	0.36	3.0					
TR5	39.00	108.0	<0.4	<0.6	<2.0	<3	<1
TR6	8.04	41.3					
TR7	4.12	39.4					
64(8)	4.87	45.6					
62(9)	2.71	36.0	<0.4	11.0	10.0	<3	38
60(10)	0.83	3.5					
69	2.35	7.6	<0.4	110.0	22.0	27	34
68	9.82	31.2	<0.4	160.0	22.0	73	38
49	1.47	5.4					

TABLE 3. Concentration of Trace Metals, Organic Constituents, Nitrogen and Phosphorous Compounds in Sediments and Certain Plants from the Lagoon Area, October 10-14, 1977.

Sample Identification	T.S. %	V.S. %	TKN mg/kg	TP mg/kg	O&G mg/kg	C.O.D. %	Cd µg/g	Co µg/g	Cr µg/g	Cu µg/g	Ni µg/g	Pb µg/g	Zn µg/g
68 (sediment)	40.65	12.00	2,930	425	3,300	8.61	0.23	7.6	12.0	11	3.9	110	108
66	67.53	8.59	1,480	265	300	5.21	0.23	3.9	2.0	16	1.6	51	60
7	42.69	11.90	2,250	280	330	10.90	<0.10	0.4	12.0	120	1.9	22	109
10A (sediment)	33.26	13.02	3,300	198	190	7.59	<0.20	<0.5	9.4	11	4.8	10	14
65	61.11	9.37	2,520	408	790	8.94	0.26	4.4	2.8	21	2.1	47	60
16	32.56	15.18	4,520	306	615	10.50	<0.20	1.4	14.0	26	2.7	12	29
27A	32.11	15.91	5,080	350	1,450	12.30	<0.30	3.9	16.0	55	8.7	22	59
27B	30.13	15.85	3,310	298	420	10.60	<0.70	4.6	16.0	34	8.6	93	47
9A	39.85	12.30	3,180	300	950	9.92	<0.10	6.1	8.9	40	1.3	42	72
G	43.46	8.66	1,520	187	610	4.31	<0.40	1.5	17.0	69	<0.7	27	63
49 60 cm depth	80.16	2.75	145	80	50	0.38	<0.10	0.4	1.7	3	0.55	0.53	2
49 (surface)	68.06	8.02	1,140	160	95	2.98	0.17	4.5	5.3	22	1.8	4	11
67	35.29	17.09	7,550	250	1,190	16.80	<0.10	2.1	3.3	15	1.7	15	2
8	54.87	7.25	1,660	242	570	4.50	<0.30	<0.6	27.0	170	2.4	22	130
68 Leaves, mangrove							<0.10	0.6	<0.5	2	1.1	0.69	3
10							<0.30	<0.6	14.0	15	<0.6	13	21
11	65.36	5.01	560.	103.	75.	1.56	<0.70	2.5	44.0	3	12.0	6	6.9
10A Benthic Plants							<0.10	<0.1	3.3	2	0.94	2	5.9

All sediment values on dry weight basis.

5. Statistical Analyses of Biota

Table 4 summarizes a list of 40 plant species and their relative abundance in the lagoon. These were sampled from 32, 0.25 m^2 quadrats between January 1977 and February 1979. Table 5 lists phytoplankton species and abundance for March 1979.

The sample species diversity values calculated for all samples collected between January 1977 through February 1979, are given in Tables 6-9. The average sample diversity (H_s) is equal to 0.4539 nats. The coefficient of variation (C.V.) i.e. standard deviation divided by the mean and multiplied by 100, is 72 percent between sample sites and 102 percent between various sampling dates. The combined C.V. for all samples is 98 percent (Table 10).

When the H_s values for repetitive samples at different stations were analyzed by the two-way analysis of variance, the variability between H_s values for the stations is significant with F equal to 4.72, $p<0.01$. However, the differences between different sampling dates is not significantly different, i.e. F equals 0.43, p is n.s. This finding indicates that statistically valid time series statements are not possible. When the average values are examined for the different study periods, the diversity is lower during the winter months than at other times.

Using the same technique for analyses of variance in the wet weight of algae samples, Table 11 shows a significant difference in the standing crop of autotrophic plant species at different stations over the sampling period with F equal to 3.85, $p<0.05$. However, the difference between different dates within the stations is not significant; i.e. F equals 1.43, p is n.s.

Results of the community diversity statistics are summarized graphically in Figure 9. The H' statistic increases irregularly with the addition of each sample. However, after the twelvth sample the variations disappear and tend to decay exponentially approaching an asymptotic level in the last few samples. Consequently, the technique was modified to analyze parameters of the Von Bertalanffy growth equation following Walford (1946). In this modification the estimate of H' community diversity for sample i was plotted on the x axis and the estimate for sample i+1 on the Y axis. These two values are equal at the point where the community asymptote occurs. By using a regression equation:

$$H'_{t-1} = 0.23H'_t + 0.93 \qquad (3)$$

H' is significant at the 0.001 percent level where r equals 0.96 and n comprises 17 pairs. Furthermore, the H' value for the autotrophic components in the Mangrove Lagoon was 3.1240 nats. This value is close to that calculated for 1972 ichthyofauna from the lagoon, 2.987 nats, (Olsen, 1978).

High species diversity has long been considered to characterize stable climax communities. On the other hand, Connell (1978) showed that high species diversity arises from a mix of species. This occurs when species are present

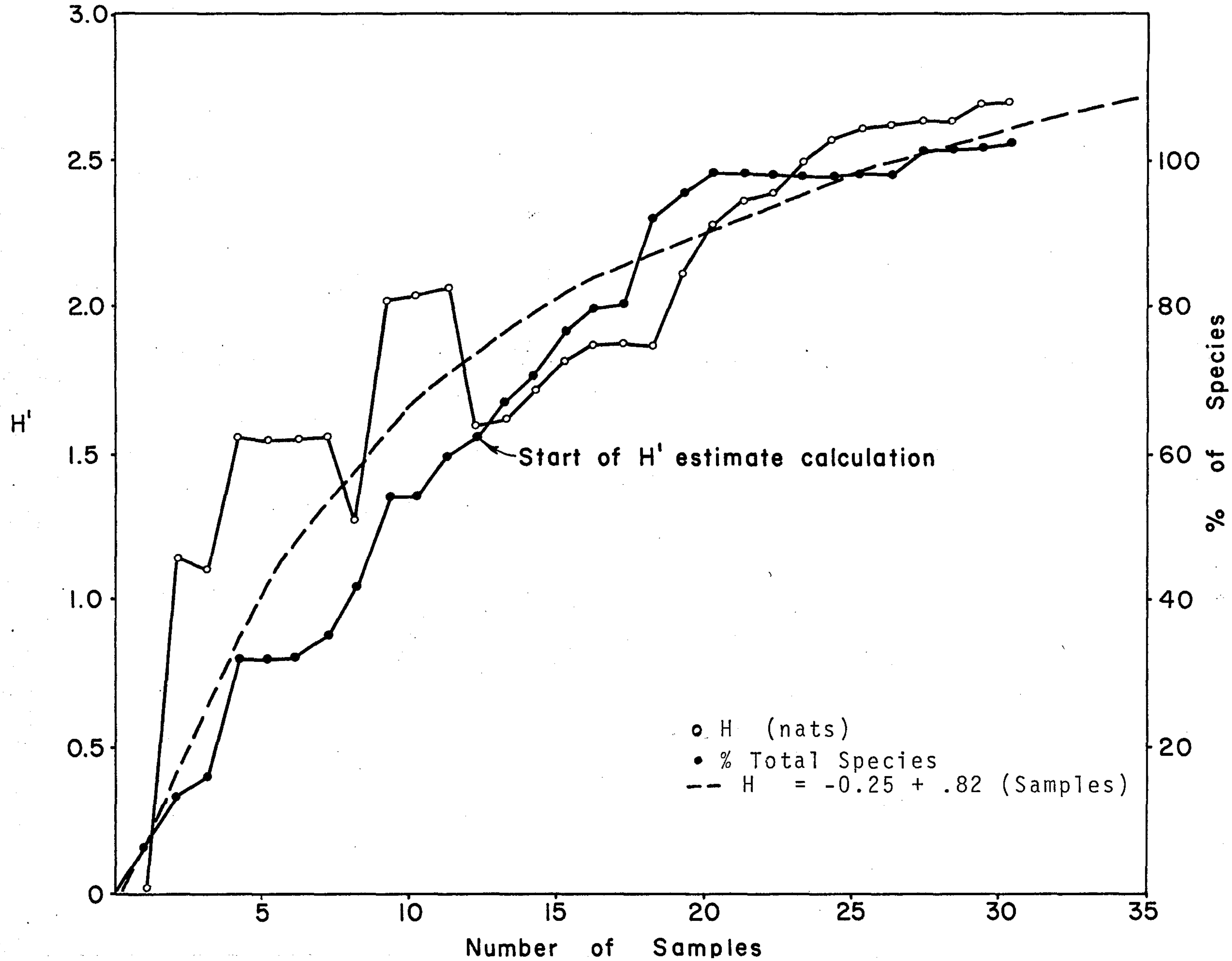

Figure 9. Species diversity H', and cumulative species of benthic plants collected from thirty-two 0.25 m^2 quadrats. The dashed line is a least squares regression predictor from

from various successional stages at the same time and before interspecific competition eliminates species from previous successional stages.

Historical analysis of benthic community patterns surveyed in the Mangrove Lagoon between 1947 and 1977 (Nichols and Towle, 1977, Figures 39-40) indicate a transitional character of community associations. There were greater kinds of species associations in 1977 than in prior surveys. The H' estimate for the present communities is higher than the 95 percent upper confidence limit for the ichthyofaunal community ($2.987 + 0.0215$ nats). Although different statistical treatments were used it appears that a greater portion of the lagoon is undergoing successional changes in 1977 than in 1972.

To determine sample size required to obtain the H' estimate within 95 percent of the actual value, the data were fitted to the equation: $H' \doteq a+b \ln(x)$ (4)

whereby x equals the number of samples. The resulting correlation was significant at the 0.01 percent level (r equals 0.75). The results indicate that to obtain an H' estimate within 95 percent of the asymptotic value previously estimated, and in turn to discriminate between biotic associations, at least 55 samples per association, or over 500 samples per sampling period, are required.

Because of the limited sample size, natural variability, especially variability produced by rapid successional changes, in addition to possible errors introduced through sampling and analyses by different investigators, biological changes between sampling periods of the present data can not be demonstrated by statistical analysis. The sampling variability and the annual variability tend to mask the short-term effects of flooding.

Statistical Analyses of Water Quality

Since benthic communities are often linked to water quality parameters, the long-term variations of these parameters were analyzed to determine spatial and annual differences between stations. The water quality parameters consist of temperature, salinity, dissolved oxygen concentration, pH, turbidity, and fecal coliform bacteria. Data were taken from surface water at three stations, 26(A), 27A, 27B (Figure 1), in the inner and polluted lagoon zones by the Department of Conservation and Cultural Affairs, Division of Natural Resources, between 1972 and 1978. To establish a comparitive baseline, similar monthly monitoring data were analyzed from nine stations occupied between 1976 and 1978 in open coastal bays along the south coast of St. Thomas, Stations 6D, 7A, 7B, 8, 25, 28A, 28B, 29A, and 30. These bays are generally less restricted and more actively flushed than the Mangrove Lagoon.

The parameters change in absolute values as well as in their variability. The absolute differences may create continuing stresses on the organisms while the variability may determine the species occurrence by occasional extreme occurrences. Some stations may have identical

Table 4. Relative abundance of flora from thirty-two 0.25 m^2 quadrats collected in the Mangrove Lagoon between January 1977 and February 1979. Values are percent of total wet weight in grams.

Taxon	Percent of Total Wet Weight
Spermatophyta	
Thalassia testudinum	21.90
Halodule wrightii	1.90
Halophila bailoris	6.30
Syringodium filiforme	1.50
Chlorophyta	
Penicillus capitatus	14.10
Caulerpa sertularioides	8.60
C. cupressoides	3.20
C. webbiana	2.60
C. vickersiae	<0.01
C. ashmeadii	0.90
C. prolifera	2.20
C. fastigata	<0.01
C. racemosa	1.80
C. mexicana	9.00
C. sp.	<0.01
Cladophora howei	5.00
C. sp.	2.80
Halimeda incrassata	3.40
H. monile	3.80
H. opuntia	<0.01
Auranvillea nigricans	0.10
Chaetomorpha sp.	0.10
Udotea flabellum	3.90
U. spinulosa	<0.01
U. sp.	<0.01
Acetabularia crenulata	<0.01
Unident. filament.	2.40
Rhodophyta	
Hypnea musciformes	0.60
Acanthophora spicifera	1.10
Spyridia filamentosa	0.01
Gelidium sp.	<.01
Gracilaria cylindria	<.01
G. sp.	<.01
Unident.	<.01
Unident.	<.01
Unident.	<.01
Phaeophydeae	
Dictyota linearis	0.10
D. indica	2.01
D. divaricata	2.50
Cyanophyceae	
Lyngbya sp.	0.20

Table 5 .Composition and abundance of phytoplankton and microfauna in the Mangrove Lagoon and Benner Bay March 19, 1979. Values are estimated cells per ml.

	STATION				
Taxon	1	5A	7	10A	27B
Crytophyta					
8μ Chroomonas sp.	352	426	827	1396	4292
16μ Chroomonas sp.			52		
5μ Cryptophyte	186	284	1551	776	3671
Bacillariophyta					
Skeletonema costutum		52	6	155	1706
14μ Nitzschia sp.	10		52	103	207
25μ Nitzschia longissima	2	13	52	1	1
60μ Pennate		26		2	1
5μ Cyclotella sp.		26			52
Coscinodiscus lacustris	1		1	4	6
Thalassiosira sp.				1	3
Chaetoceros sp.				5	5
Chlorophyta					
Pyramimonas sp.	83	52	103	103	310
Pyrrophyta					
Katodinium rotundatum	10				155
Peredinium sp.	1			2	92
Gymnodinium sp.			2	1	1
Microflagellates					
3μ flagellate	269	465	1396	1448	1913
3μ biflagellate	103		310	465	
5μ flagellate	10		52		
Total Cells Per ml	1013	1306	4343	4084	11013

Table 6. Composition of ¼ sq. m. quadrats collected in Benner Bay and the Mangrove Lagoon October 15, 1977

Taxon	STATION 7	9	10A	27A	27B
FAUNA, Numbers of individuals, (Minimum number of species)					
Annelida					
Polychaeta	6 (1)	10 (3)	1 (1)	-	-
Oligochaeta	-	3 (1)	-	-	-
Mollusca					
Bivalvia	2 (2)	24 (6)	7 (2)	22 (3)	13 (3)
Total Number of Animals	8 (3)	37 (10)	8 (3)	22 (3)	13 (3)
FLORA, wet weight, gms. (dry weight, gms.)					
Chlorophyta					
Caulerpa vickersiae	0.03 (0.01)	- -	- -		
C. ashmeadii	- -	34.30 (6.70)	- -		
C. cupressoides v. mamillosa	- -	0.68 (0.13)	74.61 (10.63)		
C. cupressoides v. lycopodium	- -	0.04 (0.02)	- -		
C. prolifera f. obvata	- -	- -	82.29 (17.11)		
C. fastigiata	- -	- -	0.05 (0.02)		
Halimeda incrassata	9.70 (2.73)	- -	84.46 (13.90)		
Udotea sp.	- -	- -	4.80 (1.56)		
U. spinulosa	3.30 (1.49)	- -	- -		
Rhipocephalus oblongus	- -	- -	50.27 (15.27)		
Cladophora sp.	- -	- -	36.0 (7.0)		

Table 6.(Continued)

Taxon	STATION 7	9	10A	27A	27B
Rhodophyta					
Acanthophora spicifera	-	0.03	-		
	-	(tr)	-		
Spyridia aculeata	-	0.34	0.04		
	-	(0.02)	(0.01)		
Hypnea sp.	-	0.03	-		
	-	(tr)	-		
Spermatophyta					
Halophila baillonis	0.89	0.01	-		
	(0.12)	(tr)			
TOTAL WEIGHT OF PLANTS	13.92	35.43	330.52	-	-
	(4.35)	(6.87)	(65.50)	-	-
Number of Plant Species	4	7	8	0	0

(tr) means trace

Table 7. Composition of ¼ sq. m. quadrats collected in Benner Bay and the Mangrove Lagoon November 9, 1977

Taxon	STATION 7	9	10A	27A	27B	50
FAUNA, Numbers of individuals, (Minimum number of species)						
Coelenterata						
Anthozoa	0	0	0	0	0	1 (1)
Annelida						
Polychaeta	4 (2)	1 (1)	0	0	0	22 (3)
Oligochaeta	0	6 (1)	0	0	0	0
Mollusca						
Gastropoda	2 (1)	0	0	0	0	19 (4)
Bivalvia	1 (1)	6 (3)	8 (2)	1 (1)	5 (2)	1 (1)
Echinodermata						
Ophiuroidea	0	0	0	0	0	4 (1)
Crustacea						
Paguridae	0	0	0	0	0	2 (1)
Majidae	0	0	0	0	0	4 (1)
Tunicata	0	0	6 (1)	0	0	1 (1)
Total Number of Animals	7 (4)	13 (5)	14 (3)	1 (1)	5 (2)	54 (13)
FLORA, wet weight, gms. (dry weight, gms.)						
Chlorophyta						
Caulerpa spp. (2)	0 -	0 -	<0.01 (tr)	0 -	0 -	0 -
C. cupressoides	0 -	0 -	4.76 (0.68)	0 -	0 -	0 -
Penicillus capitatus	9.11 (2.61)	0 -	15.26 (4.89)	0 -	0 -	0.13 (0.10)
Halimeda incrassata	2.53 (0.73)	0 -	39.82 (10.13)	0 -	0 -	8.41 (4.00)
H. monile	0 -	0 -	0 -	0 -	0 -	22.37 (11.99)
Udotea flabellum	0 -	0 -	5.62 (1.94)	0 -	0 -	0.43 (0.30)

Table 7 .Continued

Taxon	STATION					
	7	9	10A	27A	27B	50
Spermatophyta						
	0.85	<0.01	0	0	0	0
Halophila baillonis	(0.31)	(tr)	-	-	-	- -
Thalassia testudinum	0	0	0	0	0	865.00
	-	-	-	-	-	(232.90)
Total Weight of Plants	12.49	<0.01	65.46	0	0	896.34
	(3.65	(tr)	(17.64)	-	-	(249.29)
Number of Plant Species	3	1	6	0	0	5

(tr) means trace

Table 8. Composition of ¼ sq. m. quadrats collected in Benner Bay and the Mangrove Lagoon February 2, 1979

Taxon	STATION NUMBER						
	7	9	10A	11	27A	27B	50
ANIMALS, Numbers of individuals, (Number of species)							
<u>Mollusca</u>							
Taegulus divisis	1				2	6	
Macoma pseudorama	1					7	
Bulla striata	1	2					
Chione cancellata	1						
Planaxis nucleus	1						
Ringicula semistrata	1						
Crepidula convexa			23				
<u>Ectoprocta</u>			1				
<u>Annelida</u>							
Polychaeta			2 (1)				
Sabellidue			9 (3)	11 (2)			2 (1)

tr means trace

Table 8 .Composition of ¼ sq. m. quadrats collected in Benner Bay and the Mangrove Lagoon February 2, 1979. Wet weight, in grams, is presented with dry weight in parenthesis.

Taxon	STATION NUMBER 7	9	10A	11	27A	27B	50
PLANTS							
<u>Spermatophytes</u>							
Thalassia testudinum							26.61 (4.97)
Halodule wrightii		20.72 (4.52)					0.42 (0.12)
Syringodium filiforme							56.51 (9.20)
Halophila baillonis		0.6 (0.12)					
<u>Chlorophycae</u>							
Penicillis capitatus	4.7 (2.23)		31.06 (9.15)	4.47 (3.31)			10.76 (5.84)
Caulerpa sertularioides							50.16 (9.95)
Cladophora howei		140.91 (28.71)	7.82 (1.54)				0.58 (0.20)
C. sp.			<.01 (tr)				
Halimeda incrassata			136.77 (36.08)	.04 (.03)			7.1 (2.35)
Avranvillea nigricans					3.48 (0.60)		
Chaetomorpha gracilis	<.01 (tr)						
Udotea flabellum		59.27 (21.80)					
<u>Rhodophyceae</u>							
Hypnea musciformes							22.77 (5.52)
Acanthophora spicifera			13.82 (2.14)	4.03 (0.45)			
Gelidium sp.			0.03 (0.02)				
Rhodophycea unident.			<.01 (tr)				
<u>Phaeophyceae</u>							
Dictyota linearis				4.35 0.66			
D. indica							91.06 (22.09)

tr indicates trace

Table 9. Composition of ¼ sq. m. quadrats collected in the Mangrove Lagoon and Benner Bay, May 18, 1979

Taxon	STATION				
	7	9	10A	27A	27B
FAUNA, Numbers of individuals, (Minimum number of species)					
Annelida					
Polychaeta	3(250)	-	2(80)	2(16)	3(13)
Mollusca					
Gastropoda	1(2)	-	1(1)	-	-
Pelecypoda	1(4)	2(9)	2(13)	5(43)	2(45)
FLORA, wet weight, gms. (dry weight, gms.)					
Chlorophyta					
Caulerpa cupressoides	-	-	51.60	-	-
	-	-	(6.36)	-	-
Acetabularia crenulata	-	-	.01	-	-
	-	-	(<.01)	-	-
Halimeda incrassata	-	-	84.78	-	-
	-	-	(27.65)	-	-
Udotea flabellum	-	-	44.73	-	-
	-	-	(16.01)		
Penicillus capitatus	-	-	13.71	-	-
	-	-	(4.45)		
Rhodophyta					
Acanthophora specifera	-	-	33.75	-	-
	-	-	(4.40)	-	-
Gracilaria cylindrica	-	-	0.40	-	-
			(0.35)		
Phaeophyta					
Dictyota divaricata	<0.01	-	-	-	-
	(<0.01)	-	-	-	-
Spermatophyta					
Halophila baillonis	2.80	0.21	-	-	-
	(0.21)	(0.03)	-	-	-
Haludule wrightii	<0.01	39.73	-	-	-
	(<0.01)	(6.40)	-	-	-

Table 10. Sample species diversity $\underline{H}_s$ from 0.25 m^2 quadrats collected from the Mangrove Lagoon, St. Thomas, U.S.V.I., from January 1977 to February 1979.

	COLLECTION DATE							
Station	February 1979	November 1977	October 1977	August 1977	April 1977	January 1977	$\bar{x}$	(C.V.)**
7	0.0133	0.7365	0.7819	0.5385	0.7333	0.5195	0.5538	(52%)
9	0.8648	0.0	0.1749	1.2045	0.7472	0.4947	0.5810	(77%)
10A	0.8566	1.0446	1.6227	0.5078	1.0204	0.2100	0.8770	(56%)
11*	1.1153							
27A	0	0	0	0.2125	0.3622	0.6179	0.1988	(127%)
27B	0	0	0	0.3046	0.0500	0	0.0591	(206%)
50*	1.6144	0.1752					0.8948	(113%)
$\bar{x}$	0.3469	0.3562	0.5159	0.5536	0.5826	0.3684	0.4539	
							Between Sites	(72%)
C.V.	135%	140%	135%	70%	65%	69%	Between Dates	(102%)

*Deleted from Means and Analysis of Variance

All samples combined 0.4934 (98%)

** C.V. is the coefficient of variation

Table 11. Wet weights of algae in grams collected from 0.25 m^2 quadrats in the Mangrove Lagoon, St. Thomas, U.S.V.I. between January 1977 and February 1979.

	COLLECTION DATE							
Station	February 1979	November 1977	October 1977	August 1977	April 1977	January 1977	$\bar{x}$	(C.V.)**
7	4.71	12.49	13.92	155.42	119.42	1.40	51.52	(133%)
9	221.50	.01	34.43	101.31	5.10	56.50	69.81	(119%)
10A	189.52	65.46	330.52	470.31	3.91	342.10	233.64	(77%)
11*	12.89							
27A	3.48	0	0	93.08	5.10	218.80	53.41	(166%)
27B	0	0	0	1.1	0.90	0.60	0.40	(138%)
50*	265.97	896.34						
$\bar{x}$	83.81	18.41	75.77	164.24	26.89	123.88	81.70	
							Between Sites	(126%)
C.V.	(133%)	(152%)	(189%)	(110%)	(179%)	(122%)	Between Dates	(148%)

*Deleted from Means and Analysis of Variance

All samples combined 109.89 (170%)

** C.V. is the coefficient of variation

statistical averages for the same parameter although the individual data may be highly variable and thus place extreme stress on the organisms. As water quality parameters, e.g. temperature, salinity and dissolved oxygen, vary and interact, even without one exceeding normal limits for organisms, they also may produce stress conditions.

The results, presented in Table 12, show marked differences between stations. For example, at station number 26A on Figure 1, from Benner Bay, water temperature is higher than the south coast average and salinity is higher than at other stations. This trend differs however, inasmuch as the values at station 26 (A) are less variable than the lagoon stations, the variability being close to the south coast average. The high temperature and salinity at station 26 (A) is probably responsible in part, for the sub-saturation of dissolved oxygen occuring at this station. Stations 27A and 27B at the lagoon head (Figure 1) have large variations in measured parameters. Fecal coliforms are higher at 27A than elsewhere whereas salinity is lower, a trend that reflects discharge of freshwater and nutrients from the nearby sewage treatment plant. Diversity and standing crops of benthic plants are higher at 27A than at 27B. The low values at station 27B may be either produced by sub-saturation of dissolved oxygen content, or associated with the low plant populations. Station 27B has the greatest variability of fecal coliforms, a trend that may relate to nutrient conditions and the low plant populations found at that site.

Table 12. Comparison of average water quality parameters for three sampling stations in the Mangrove Lagoon with the average for all south coast stations.

	South Coast Average	STATION 26 A	STATION 27A	STATION 27B
Parameter				
Temperature (°C)	27.0	28.3	27.8	27.6
N	231	41	42	37
C.V.	5.2%	6.9%	7.7%	7.4%
Salinity (ppt)	35.7	36.03	35.16	35.66
N	227	37	37	33
C.V.	2.3%	4.4%	11.3%	6.4%
Dissolved Oxygen (mg/l)	6.52	5.75	6.44	6.09
N	232	40	40	35
C.V.	7.1%	10.1%	26.6%	14.4%
% Saturation	100.6%	91.0%	100.5%	94.9%
pH	8.25	8.17	8.16	8.18
N	231	37	37	32
C.V.	1.2%	1.7%	1.6%	1.9%
Turbidity (FTU)	0.59	2.30	3.18	3.38
N	225	39	40	34
C.V.	62.9%	50.4%	79.4%	71.4%
Fecal Coliforms (pr 100 ml)	0.53	14.9	63.6	23.7
N	230	41	42	37
C.V.	621%	161.8%	167.2%	203%
Average C.V. except fecal			48.9%	78.9%
coliforms	15.74	14.7%	25.3%	20.3%

6. Recommendations

Benthic Sampling

1. Future efforts in Virgin Island bays should be statistically designed to account for spatial and temporal variations utilizing foregoing results from the Mangrove Lagoon.

2. Once the design is established it should be followed systematically in identification of species, positioning of sample locations and in laboratory analyses.

3. A chart of benthic community distributions and their boundaries resurveyed from time to time, demonstrates subjectively, the differences in community types and their changes with large environmental stresses.

4. For spatial detail, over 50 samples per community association are required. For long-term temporal changes, four repetitive samplings distributed throughout the year with approximately 15 to 20 stations in all subcommunities, are required.

5. To detect short-term changes, 100 samples per association may be required. Simple wet weight measurements from quadrat sampling may be adequate. However, for more cost-effectiveness water quality changes may be assumed to indicate biotic changes.

Water Quality

1. Monitoring of water quality in Virgin Island bays could be improved by more frequent measurements of salinity, turbidity, phosphorous and dissolved oxygen, following periods of high rainfall.

2. Since flooding produces intense stratification with consequent oxygen depletion in near-bottom water, future measurements of water quality should include detailed vertical profiles from the surface to the bottom.

3. Salinity shocks on the lagoon should be reduced by reducing peak storm flows with flood detention structures in the watershed. A feasible storm-water management plan for Turpentine Run is provided by Black, Crow and Eidsness, CH_2M Hill (1979).

4. The influx of excess nutrients on flood-borne sediment and organic matter should be reduced by controlling sewage effluents at their source, i.e. in overloaded and malfunctioning treatment plants. As suggested by B, C and E - CH_2M Hill (1979), inner canals of the race track could be used as settling basins to reduce sediment as well as nutrients in particulate form.

5. The long-term impact of floods on degrading water quality in the lagoon could be reduced by providing better circulation and drainage between the salt ponds, lagoon and Jersey Bay. A complete list of recommendations for management of the lagoon is provided by Nichols and Towle (1977).

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