VIRGIN ISLANDS 1976

Coastal Zone Management
Marine Environment

Prepared for:
Virgin Islands Planning Office
Office of the Governor
The Honorable Cyril King, Governor
St. Thomas, U.S. Virgin Islands

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April 8, 1976

Mr. Thomas R. Blake, Director of Planning
V.I. Planning Office, Office of the Governor
Government of the U.S. Virgin Islands

Dear Mr. Blake:

The Virgin Islands constitute a unique island system - a place of value, beauty, and inspiration, possessing a rich history, spectacular marine life, diverse coastlines and a salubrious climate. They also have a promising future as a habitat for resident faunal, floral, and human species, living in a balanced, natural harmony.

There is, however, mounting evidence that the human component of our islands' population has, through oversight, uncontrolled expansion, and ill conceived actions, induced a broad spectrum of stresses that threaten the natural viability of the island system and could destroy what Alexander Pope referred to as "the genius of the place." This process is especially apparent in the coastal zone of the Virgin Islands where competing human interests and dynamic components of natural ecosystems interface and interact.

The present effort to develop a management plan for this critical zone of man-environment inter-relationship offers the promise of minimizing environmental conflict, improving resource allocation decisions, preserving our insular heritage and restoring the intricate balance with natural systems. Our mission was to establish a point of departure in assessing the marine segment of the endangered coastal zone, reviewing what is known, preparing an inventory and classification of component subsystems and defining their inter-relationships. Lastly, we have sought to suggest preliminary guidelines for the planner who bears the ultimate responsibility for devising procedures and making recommendatons to our government on how to improve upon management of the coastal zone.

This has been an exciting, awesome and inspiring project. Thank you for the opportunity to undertake this study. I take great pleasure in submitting this report. We trust you will find it useful in the tasks which lie ahead.

Sincerely yours,

Edward L. Towle

Edward L. Towle, Ph.D.
President

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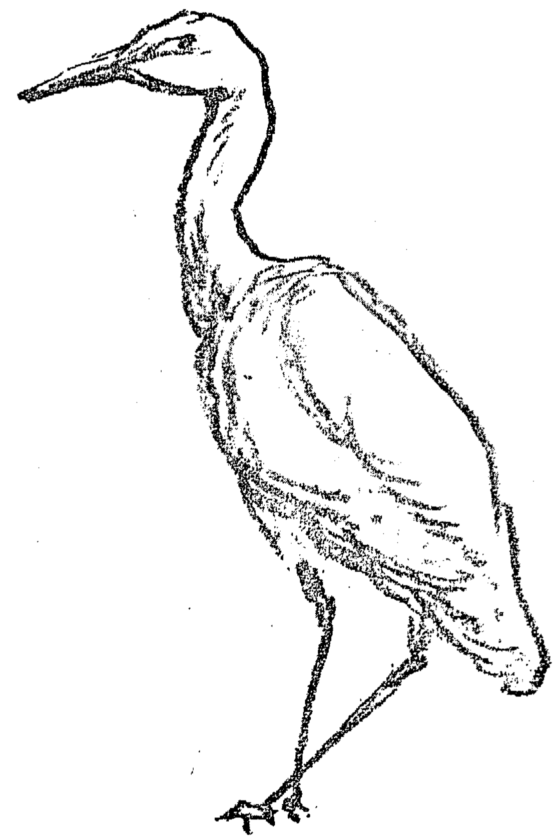

Cattle egret
Egreta

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Introduction

The coastal zone is an area that, far from separating land from sea, brings the two together in a complex interaction of living and physical features. It is an area of constantly active forces that makes it probably the most dynamic portion of the earth's surface. Some of the interplay of forces are constant, even subtle (currents, evaporation, tides, biological processes); while others can be sudden, destructive and catastrophic (hurricanes, earthquakes, drought, flooding). Between these extremes, one finds a continuum of natural processes which are ongoing and interactive, often poorly understood and some, no doubt, yet unknown.

The complexity of processes in the coastal zone is amplified and modified by human activities but continues nevertheless, sometimes shunted or temporarily obstructed as a result of man's activities along inexorable patterns dictated by natural evolutionary systems. Thus, while man has further complicated the kaleidoscope of coastal interactions, he finds it necessary (more so because of his intrusion) to identify and understand the pieces of the pattern and their mechanations. Increasing human modification and exploitation of coastal resources demand an identification and understanding of these resources, their attributes, inter-relationships, constraints and limits. Only from such a starting point can workable plans be developed for maximum multiple-use management of coastal resources.

Some level of resource protection and conservation is imperative, at the very least for self-serving, short-term development related reasons. However, protection and preservation of portions of the environment can also be compatible with other valuable functions including biological productivity, recreation, environmental diversity, aesthetics and cultural preservation. Perhaps the greatest value of preservation is the maintenance of options for further uses. Development and modification of natural resources are frequently destructive in the sense that resource attributes are permanently committed to a particular use and no longer available for alternative uses. Protection not only maintains natural productivity and aesthetic values, but preserves use options for future generations.

The following compilation is intended as a first effort survey of Virgin Islands coastal resources, an interpretive summation of our knowledge of their interactive processes, values and capacities, and our needs for additional information.

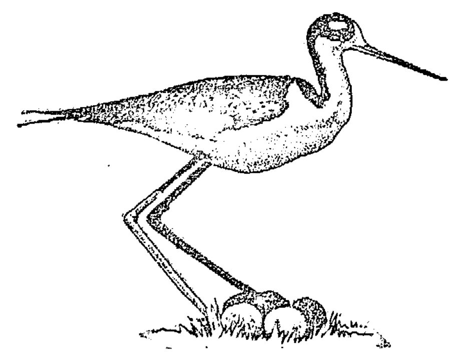
It is important to recognize the necessity for understanding the coastal zone - or any natural system for that matter - as a complex interaction of many pieces, processes and problems. It must be understood also that any modification of a single part or process will cause some response in other parts of the system. Natural systems as a whole maintain their integrity by a process of dynamic equilibrium and must change in response to external stimuli. Sometimes this response is negligible, sometimes catastrophic. Often it is subtle and imperceptible to human scrutiny - assuming an effort at observation is even made.

It is counterproductive, therefore, to approach problems of resource development and exploitation as separate, segmented actions dealing with individual resources or separate development schemes. Ignoring the interdependent aspects of natural systems and the additive and secondary effects of individual resource manipulations is unlikely to promote optimum sustained multiple-use management of these resources.

The information compiled herein is the most comprehensive treatment to date on the marine component of the Virgin Islands coastal environment. It should be noted that a great amount of esoteric detail has not been included, primarily because it is not suited to the scope of a general inventory, review and management document. More important is the fact that a yet greater amount of necessary information is simply not available. We have attempted at several points and in the Recommendations to identify these voids in our knowledge of the Virgin Islands coastal ecosystems and to suggest how some of these lacunae may be filled in.

The final section of the report is an annotated bibliography to the marine component of the Virgin Islands Coastal Zone Management Plan, organized alphabetically by author and publication date. An attempt has been made to distinguish between documents which are of a general or overview nature, those which have particular relevance to local coastal zone management, and those which are technical or specialized.

The key word index refers to appropriate sections of the text and is cross-referenced to provide leads to related information.



Inventory of Natural Resources

Oceanography and Climatology

Tides and Currents

TIDES

Tides are regular cyclical rises and falls of sea level induced by astronomical forces. The gravitational pull of the moon, and to a lesser degree the sun, in effect, create a giant global wave system which produces the earth's tides. Inshore, the tide height and time of occurrence is affected by coastal and bottom geography, but the magnitude of tides generally depends on the relative positions of the earth, moon and sun. Maximum gravitational attraction of the earth's oceans - and therefore maximum tides - occur when the three planets are in a straight line relationship.

Thus, high tides are generated on the sides of the earth nearest to and furthest from the moon and maximum tides (as well as minimum - lowest - tides at tangential points) when the sun and moon are aligned in the same plane with the earth, i.e., at new and full moons. Tides of maximum ranges are called spring tides, when the water level reaches from the higher high water level to the lower low water level. When the planetary positions are such that a given point on the earth experiences only minimal tidal ranges (from lower high water to higher low water), the tides are called neap.

Since the relative positions of the sun, moon and earth change constantly, but cyclically, on a daily and annual basis, the magnitude and locations of tidal maxima and minima also change. Tides are also complicated by such factors as winds, the centrifugal force of the earth and local geography and bathymetry. As a result, the times of high or low water and their heights can vary greatly along a large, complex shoreline.

In the Virgin Islands, tidal ranges are not great, and tidal currents, except in some inshore localities, are not significant. The small islands, lacking complex shoreline physiography, do not restrict changes in water level. The sea flows around the islands relatively unimpeded, resulting in tidal fluctuations of only a few inches to a foot. Further, the steep slopes of the islands rising out of the water means that the intertidal zone - the part of the shoreline regularly covered and uncovered by the tides - is very narrow. We therefore do not have large areas of tidal flats uncovered at low tides as in other places in the world, especially along continental coastal zones.

One of the consequences of this small tidal action is that water exchange in bays due to tidal action is usually very small. For example, it is estimated that 24 to 40 tidal cycles alone would be necessary to exchange all the water in the main part of St. Thomas harbor (Percious, et al, 1972). Fortunately, waves, swells and oceanic currents usually do a good job of flushing most bays. However, these forces are considerably reduced by the time they reach the heads of deep embayments. As a result, circulation may be poor in the inner reaches of some of our larger embayments. The innermost portions of the mangrove lagoon on St. Thomas, of Salt River, St. Croix and of Coral Bay, St. John are like this. To a lesser extent, similar conditions have been observed at the head of Vessup Bay (Redhook), St. Thomas and Cruz Bay Creek, St. John, and probably occurs in other similar locations.

For the planner and decision maker, these conditions are important because it means that pollutants introduced to these calm areas will be very slowly dispersed. For the same reason, such quiet areas are sites of relatively rapid deposition. Sand transported naturally through these bays, as well as silt and debris from the land, tend to settle out in the quieter areas, filling the bottom and eventually extending the shoreline.

Because of different exposures to open ocean water on one side and modified circulation of Caribbean water on the other, the north and south coasts of St. Thomas and St. John experience different tidal activities. On the north, tides are similar to the north coast of Puerto Rico, being semi-diurnal (two cycles of high and low water per 24 hours). The time of tide stages in the Virgin Islands are earlier than in Puerto Rico, however.

On the south coasts of St. Thomas and St. John, and for all of St. Croix, tides are primarily diurnal (only one high and low water per day). The second cycle is reduced to very slight ebbs and floods, and on some days is not measurable at all.

The mean range of local tides is 0.8 - 1.0 feet (0.24 - 0.30 meters). The mean range of spring tide is about 1.3 feet (0.4 meters).

Changes in tidal height with time can be displayed graphically by a marigram, a chart which plots the water level as measured by a tidal gauge. Such marigrams have been constructed for Lameshur Bay, St. John (Dammann, et al, 1969), St. Thomas harbor (Percious, et al, 1972) and Christiansted harbor (Nichols, et al, 1972). The latter two clearly show the vanishing semi-diurnal (second cycle) component of south coast tides (Figures 1 and 2).

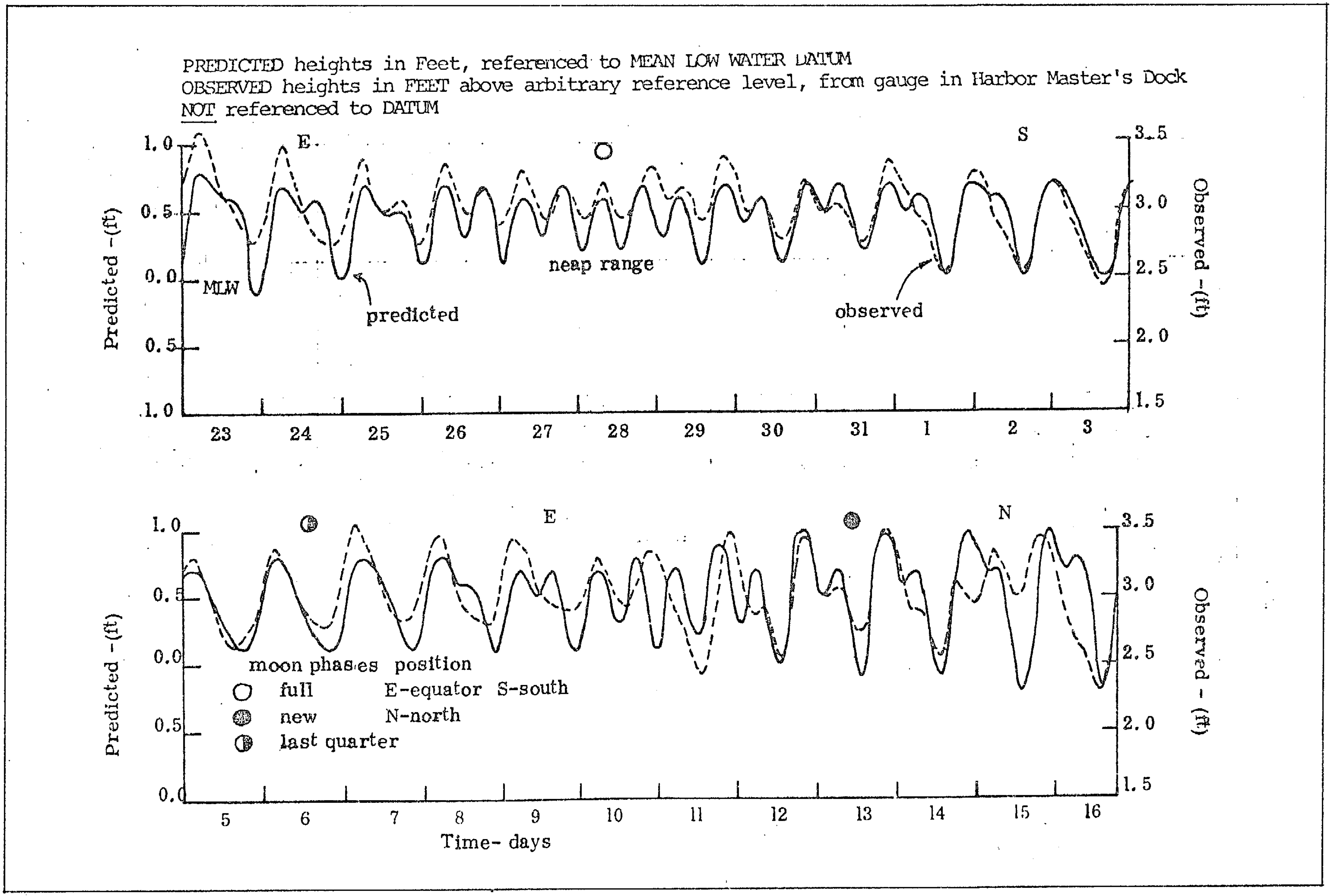


Figure 1. Predicted and observed tidal ranges in St. Thomas harbor, March - April, 1972. From Percious, vanEepoel, and Grigg, 1972.

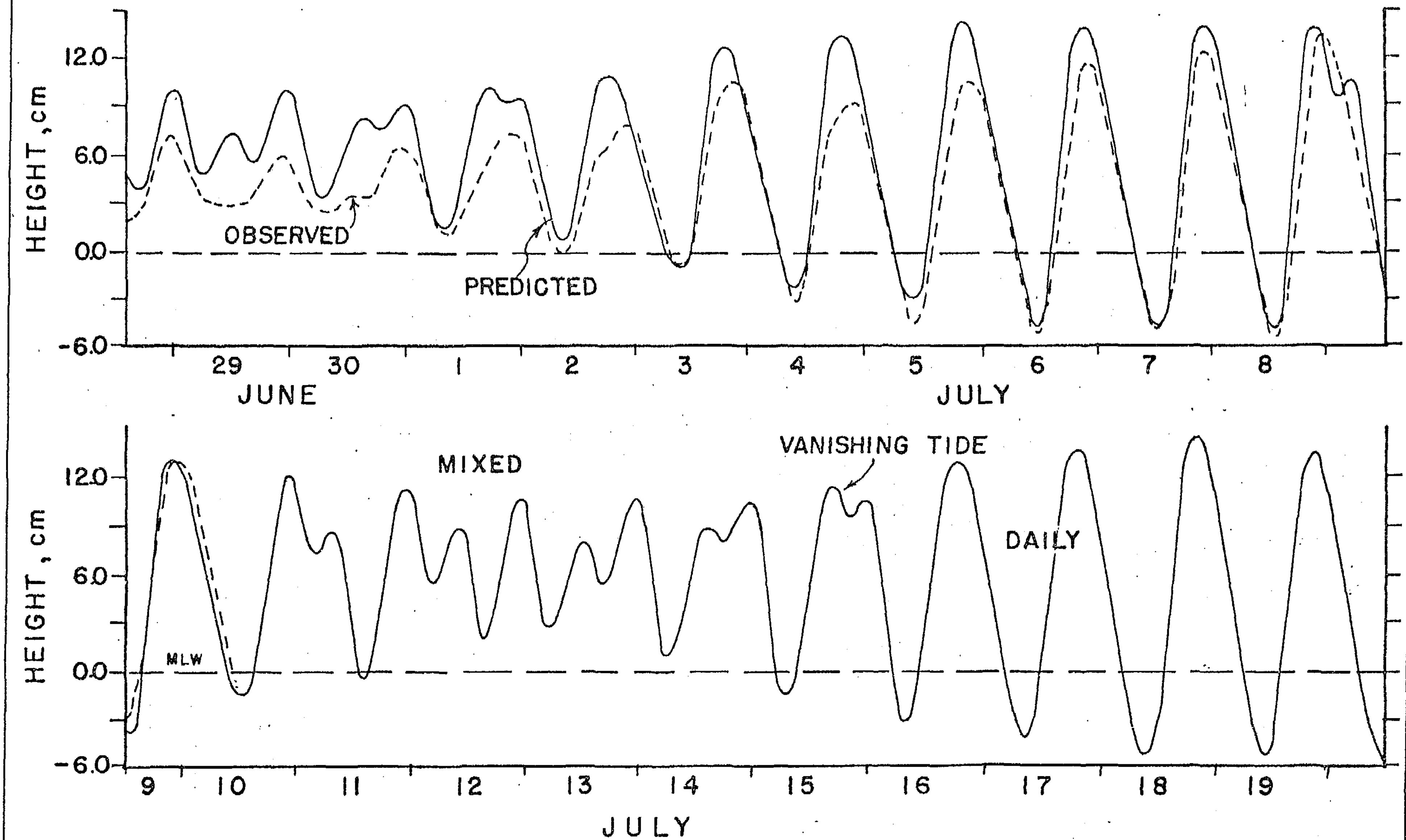


Figure 2. Variations in the character of the tide displayed in time-height curves, from predicted tables and from observed tides in Christiansted harbor, June 29 - July 19, 1971. From Nichols, et al, 1972.

CURRENTS

Currents are defined as horizontal movement of water as a result of any of several driving forces. In actual practice it is often difficult to determine what the causative forces are, and for most purposes it does not matter. Thus, tidal currents are water flow resulting as changes in sea level drive water through channels or embayments. Density currents are generated by differences in dissolved solids (salinity) and/or temperature. Currents are also generated by the rotation of the earth and the resulting wind stress at the surface.

Density and pressure account for the general large-scale currents of the ocean, including the North Equatorial Current which pushes water through the Caribbean Basin (Figure 3) to the west-northwest to eventually join the Gulf Stream.

Ocean water from the Tropical North Atlantic (North Equatorial or Canary Current) enters the Caribbean Basin between the islands of the Lesser Antilles. In most localities, the submarine ridge on which the islands lie is less than 1,000 meters deep, therefore admitting primarily upper water from the Atlantic. This water flows west-northwest past the Lesser and Greater Antilles, entering the Gulf of Mexico and Florida Straits through the Yucatan Channel. Atlantic water from south of the equator also enters the Caribbean between Trinidad and Grenada and eventually joins the north equatorial water in the Yucatan Basin. However, this southern current, with a velocity about twice that of the northern Caribbean current does not impinge directly on the West Indian archipelago.

The major bottom features (ridges and troughs) of the Caribbean, described in the section on Bathymetry, act to restrict movement of deep water through the Caribbean. Movement of the upper layer water is complicated when it flows over the shallow island platforms. For most purposes, these are defined as the submarine shelf from the shoreline to 100 fathoms (183 meters) depth. Here, coral reefs, other bottom irregularities, winds, shoreline configurations and tides act to divert and diverge the prevailing ocean currents.

On the Virgin Islands platform, while the prevailing mass flow of water is still dominated by the west-northwest drift, passage of water between islands and in bays varies depending on location and exposure to the open sea. Generalized flow on the islands' shelves has been plotted by Dammann, et al (1969) and is shown as Figure 4. Because of seasonal changes in wind direction, water is driven across the shelf from the east in the winter and from the southeast in the summer.

In individual bays, unless they have eastern exposures, water movement is controlled primarily by wind and swell.

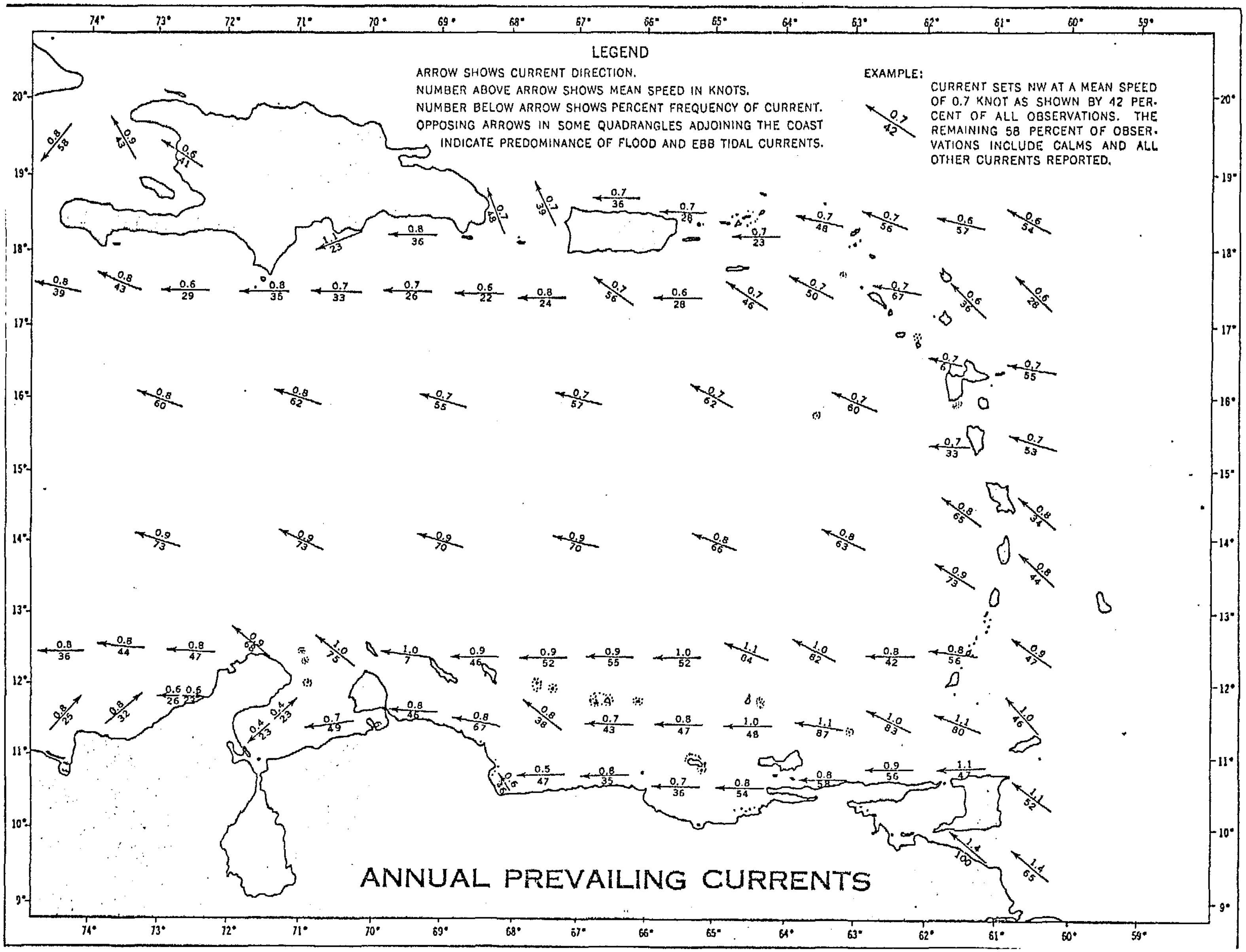


Figure 3. Annual prevailing currents in the Caribbean. From U.S. Naval Oceanographic Office, Sailing Directions, 1963.

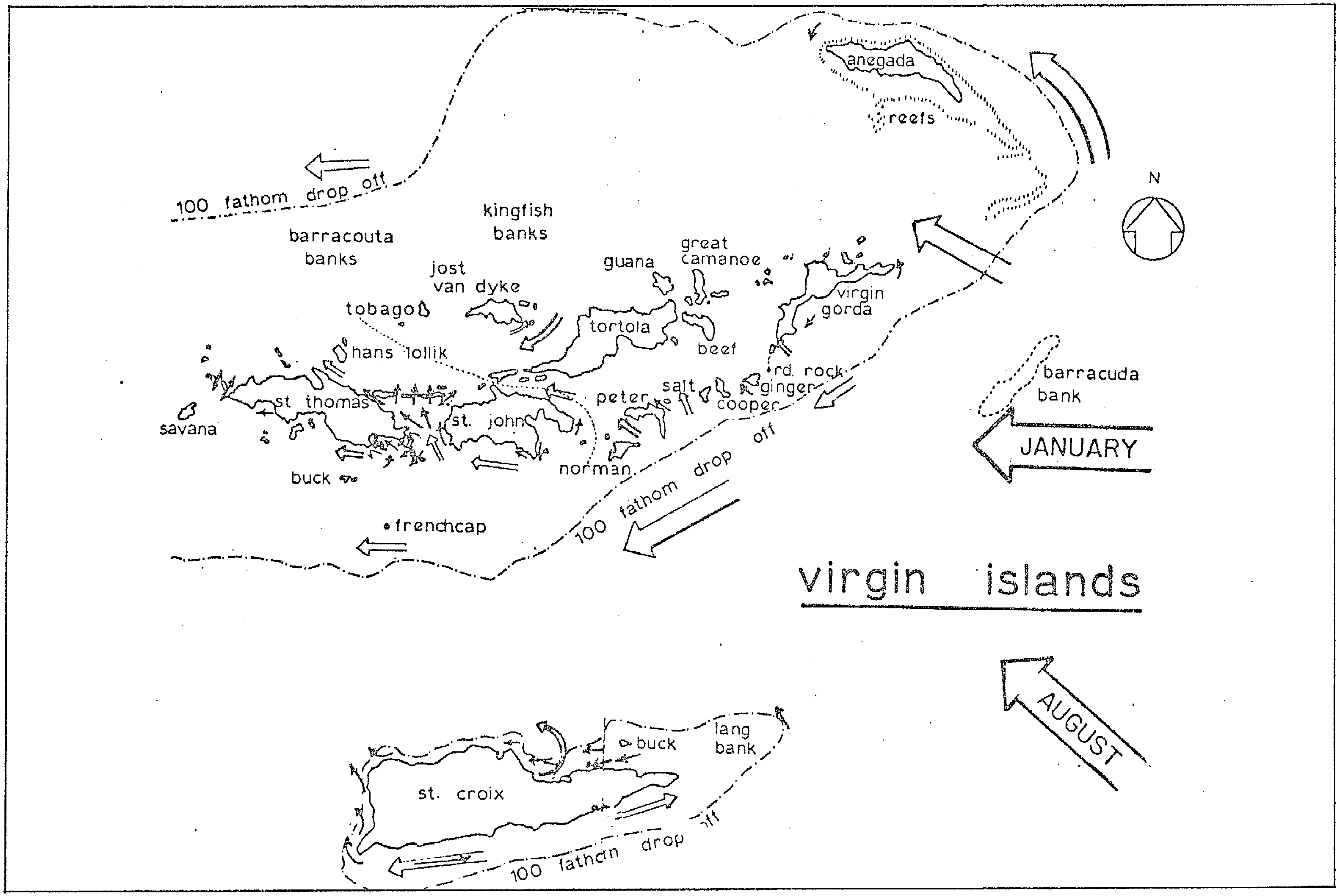
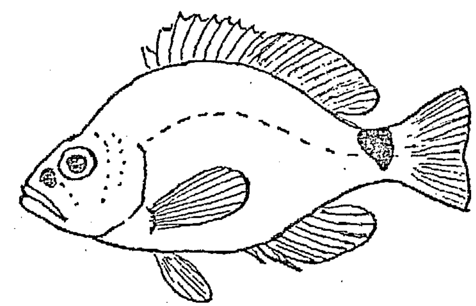


Figure 4. General current patterns on the island platforms. From Dammann, et al, 1969.

If the bay's exposure and shape permits access of offshore current driven water, then often bays on the north exhibit a clockwise movement of bay water, while in those on the south, the circulation is counter clockwise. Many factors interact to determine the direction of water flow in a bay however. Some of these are relative strength of tides, winds, wave, swell, and external currents in addition to the bay's bathymetry, shoreline shape and size. It is therefore not surprising that patterns of water movement in bays, especially the larger more complex ones, change as the relative strength of the various determinants change. For the planner, this is important because it points to the need for site specific studies of currents when these are important for decision making.

Furthermore, such studies should be conducted during a long enough period and under various conditions to determine not only prevailing conditions, but variations that may occur.

Figures 5 through 8 show some available current information for specific bays and point to the variety of circulation patterns which can be encountered locally.



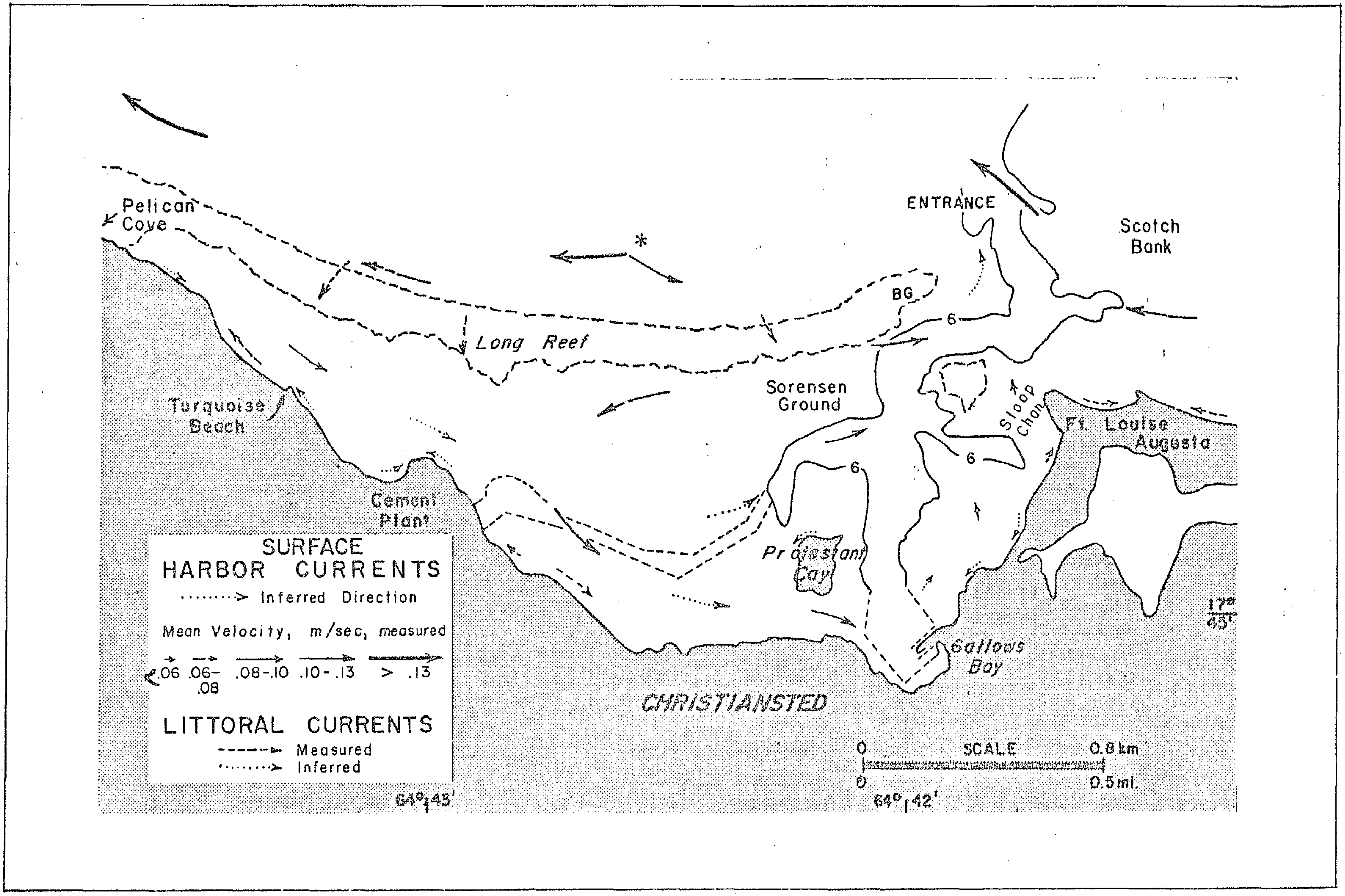


Figure 5. Mean surface current, speed and direction for harbor currents and for littoral currents August 1971. Length and width of arrow indicates speed in meters per second. Harbor currents based on anchor station measurements; littoral currents on dye patch measurements. * indicates two alternating predominate directions. From Nichols, et al, 1972.

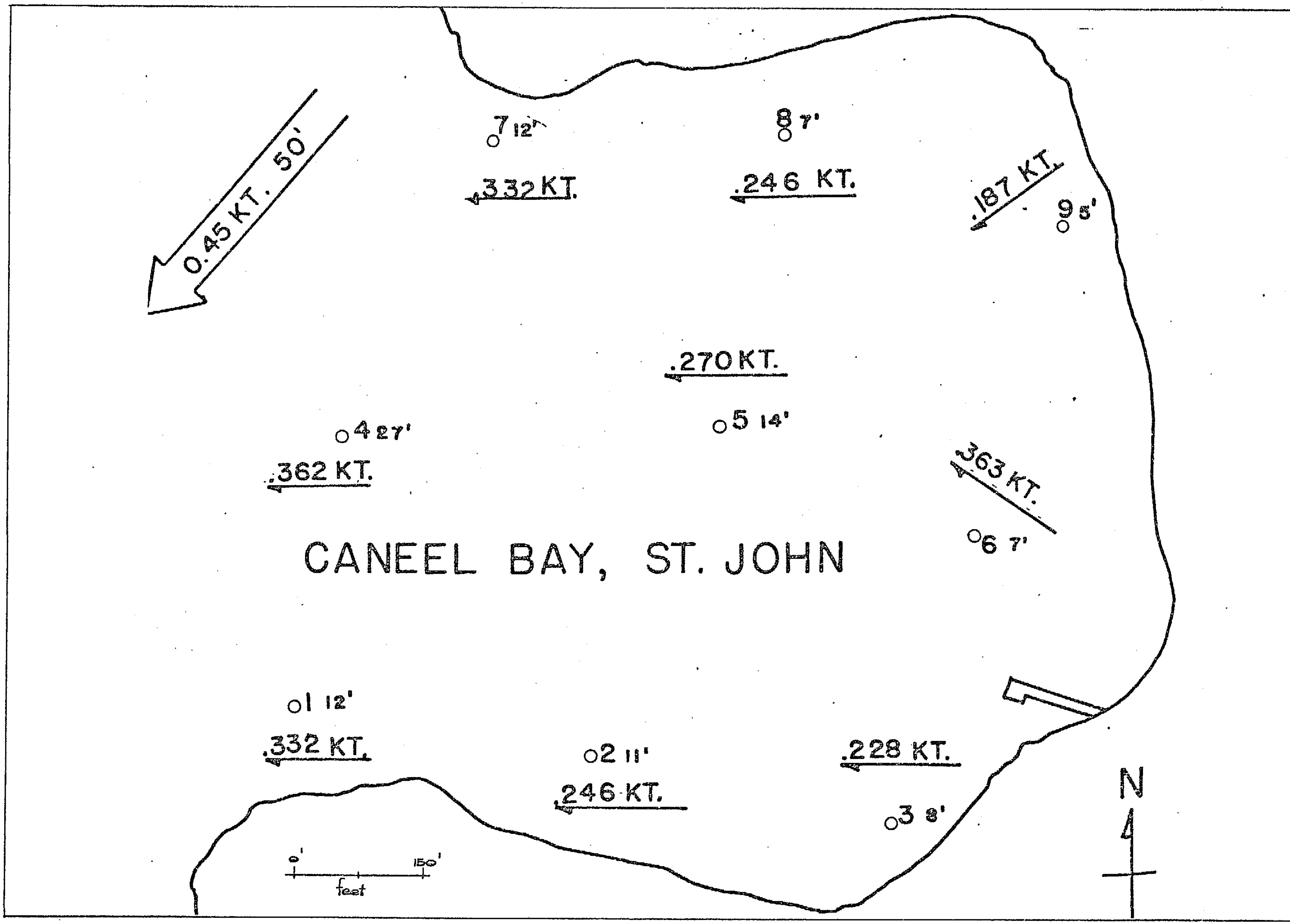


Figure 6. Maximum Bottom Currents Recorded at Ten Points in Caneel Bay, St. John. Recording Depths (feet) shown at each station. From Dammann, et al, 1969.

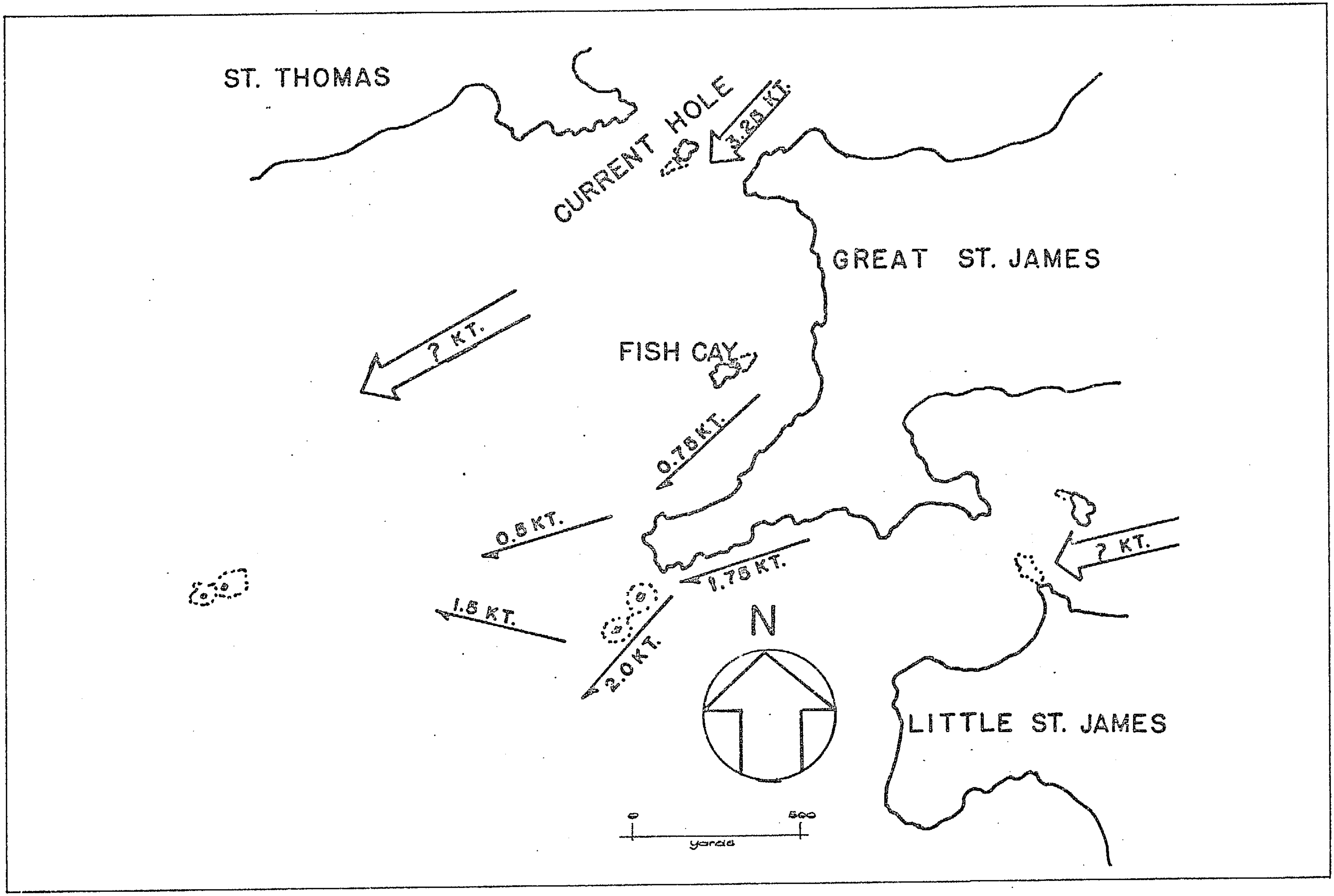


Figure 7. Surface currents near Great St. James Island in August. Determined by dye diffusion. Data from Brody in Dammann, et al, 1969.

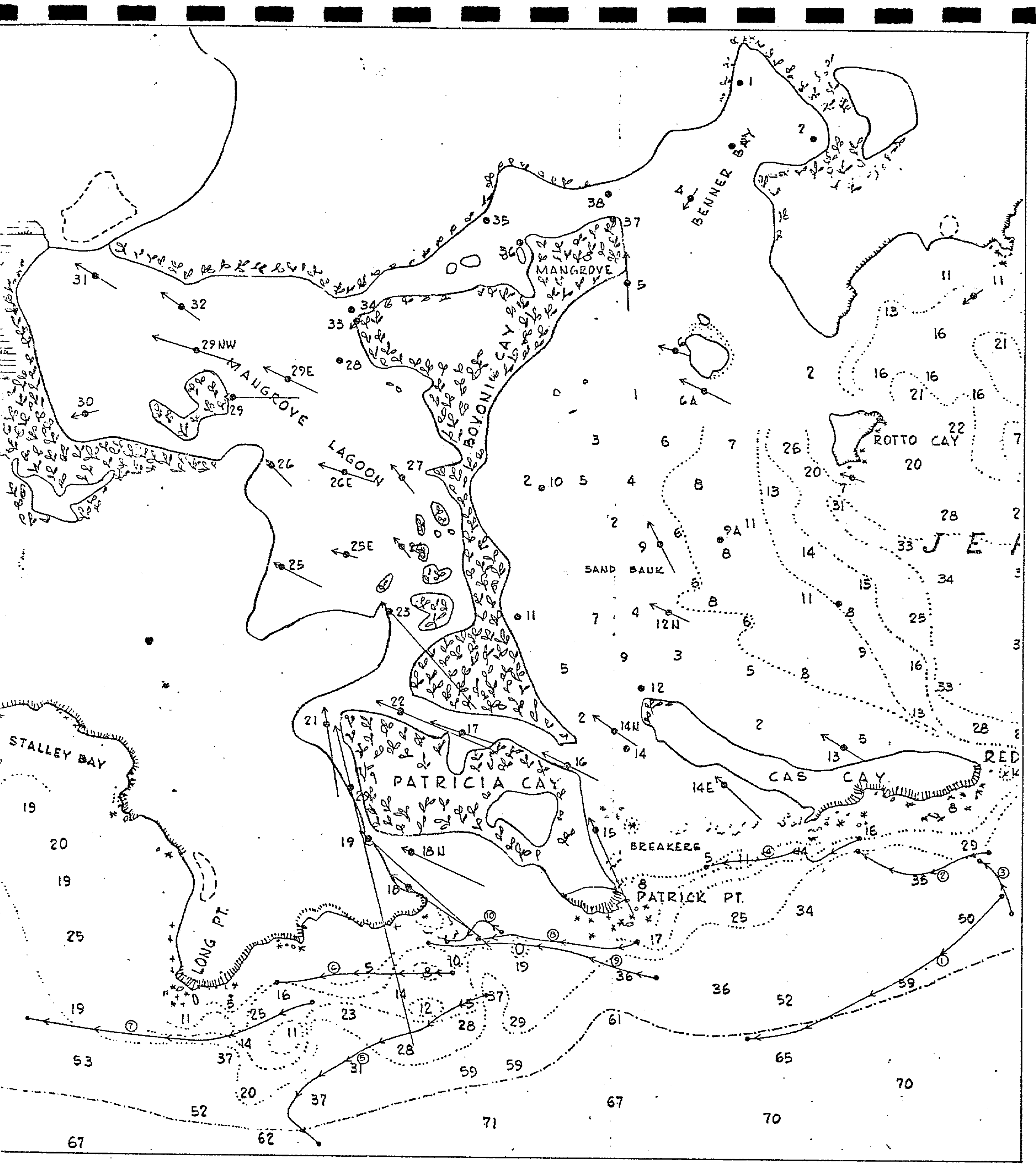


Figure 8. Water movement in Jersey Bay and the Mangrove Lagoon, St. Thomas. From McNulty, Robertson and Horton, 1968.

Waves and Swell

Waves are the main source of energy that move beach sediment and that affect shipping and shoreline structures during storms. Waves differ widely according to their heights, length, period and speed. Their energy depends mainly on height and period.

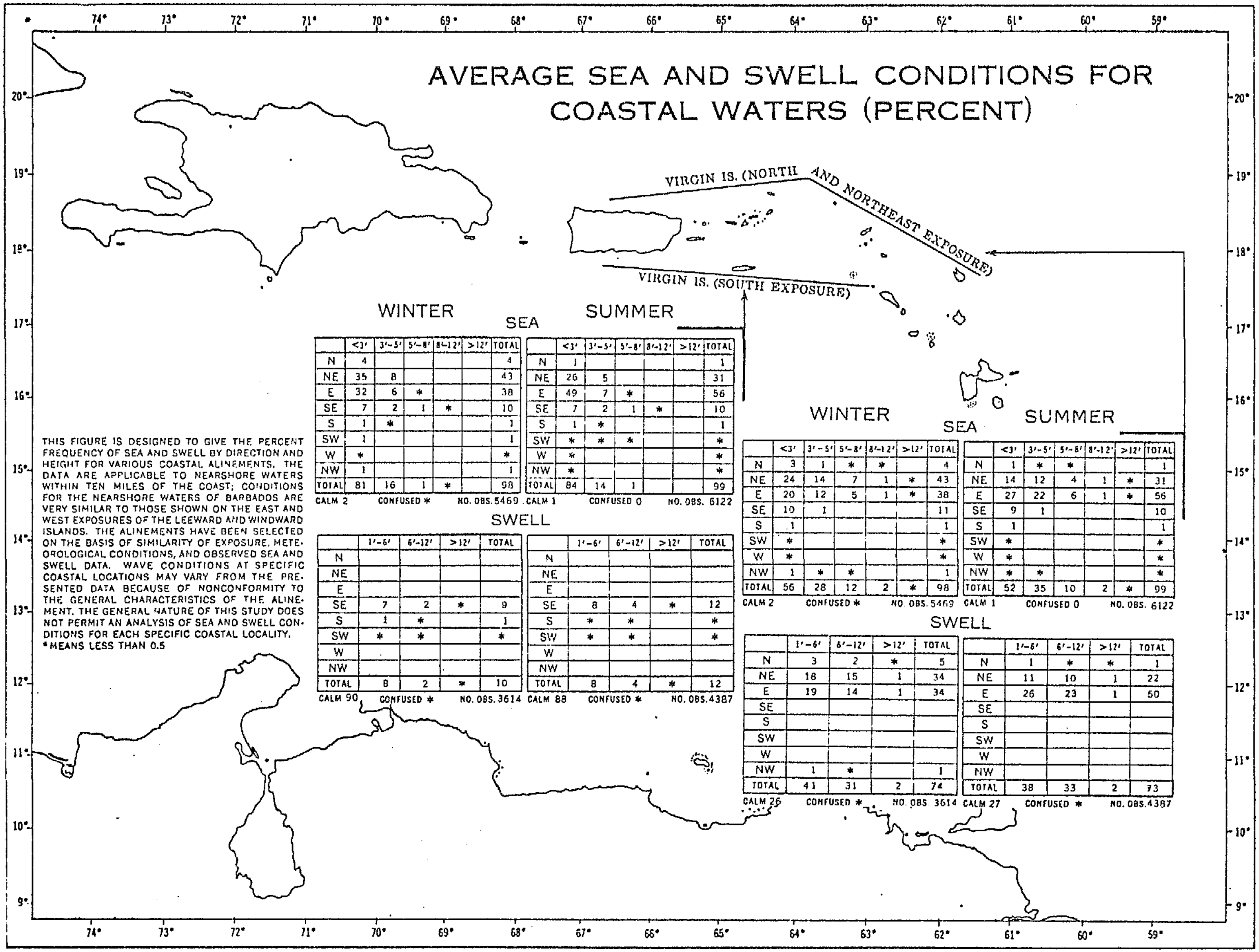
The deepwater wave regime of offshore waters is driven by the northeast trade winds most of the year. On the average, wave heights of one to three feet approach from the east 42 percent of the time throughout the year. For short periods, 0.6 percent of the time, these easterly waves reach 12 feet. Intermediate wave heights and corresponding frequencies of occurrence (Figure 9) are summarized in Deane, et al (1973). In addition to the normal easterly swell that affects the windward coasts of the islands, there are two seasonal modes of wave approach that affect leeward coasts: a southeasterly chop and swell and a northern swell.

The southeasterly swell with waves one to twelve feet high becomes significant in late summer and fall when the trade winds blow from the east or when tropical storms and hurricanes pass the islands at a distance to the south. The east-southeasterly wind and wave regime is associated with the doldrum belt located over the interior of Venezuela and with an intensive high pressure area over Bermuda.

By contrast, during winter when the doldrum belt is located farther south along the equator and the Bermuda High is weak, a long length and long period northern swell develops. Although the swell offshore is only one to five feet high and occurs only four percent of the time, it is significant because it gains heights of ten to twelve feet nearshore. By refracting around the west coasts of the islands, this swell affects leeward coasts for short periods.

Variations in the depth of water and orientation of the coast nearshore greatly modify the height and length of approaching swells. As a result of refraction, wave energy is concentrated on seaward projecting points and, at the same time, it is diffused within the bays. Thus, waves tend to straighten the north coast of St. Croix by erosion of headlands and deposition of sand in the bays. Straightening along the north coast of St. Thomas and St. John is opposed by the variations in resistance to erosion of different rock types. For example, the projecting points on the north side of Magens Bay, St. Thomas, at Mary's Point, St. John and of Thatch and Grass Cays owe their origin to the Tutu rock formation which is more resistant than the Brass limestone.

Commonly, on the north coasts, waves approach the shore from two principal directions. Short period waves and chop approach from the east and north-



Virgin Is. (South Exposure) — SEA — WINTER

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

CALM 2 CONFUSED * NO. OBS. 5469

SEA — SUMMER

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

CALM 1 CONFUSED 0 NO. OBS. 6122

SWELL — WINTER

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

CALM 90 CONFUSED * NO. OBS. 3614

SWELL — SUMMER

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

CALM 88 CONFUSED * NO. OBS. 4387

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

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

CALM 2 CONFUSED * NO. OBS. 5469

SEA — SUMMER

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

CALM 1 CONFUSED 0 NO. OBS. 6122

SWELL — WINTER

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

CALM 26 CONFUSED * NO. OBS. 3614

SWELL — SUMMER

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

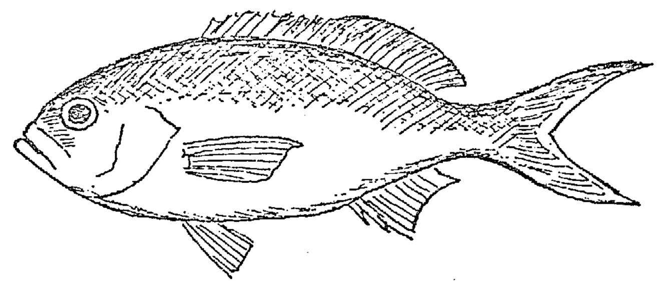
CALM 27 CONFUSED * NO. OBS. 4387

Figure 9. Average sea and swell conditions for Virgin Islands coasts. From U.S. Naval Oceanographic Office, 1963.

east, and, at the same time, long period swells approach from the north. However, in the winter, from November through March, the northern swells are larger than in summer, and they are refracted and redirected more around points and islands. Because of their high angle of approach and large size, such waves create strong longshore currents. Around islands like Dutchcap Cay, St. Thomas and Buck Island, St. Croix, the two wave types produce very complicated patterns of crossing sea and swell which can be observed on aerial photographs.

Along coasts fronted by partly submerged reefs, waves play a significant role in circulating back reef water. As demonstrated in Christiansted harbor (Nichols, vanEepoel, Grigg, et al, 1972), the mass transport of waves breaking over Long Reef drives a harbor-wide circulation (Figure 5) that flushes most of the harbor water through the entrance in about fourteen hours. Consequently, the response of waves to reefs and nearshore bathymetry is significant in reducing pollution and improving water quality.

In many harbors and bays, periodic surging of the water surface, called "seiching" or "surging", has been recorded. Although the seiches are usually less than 15 centimeters high, they create oscillations within a harbor that induce horizontal movements that can drive ships sideways against the dock. Such movements have not been observed in Virgin Islands harbors, but they need to be taken into account when evaluating proposed changes in harbor geometry.



Water Quality

The discussion below has been limited to major parameters most commonly used to describe water quality. While the oceans contain at least traces of almost every chemical element known, obviously the discussion of all of them is impossible and inappropriate to this document. Furthermore, little or nothing is known about the levels of most of the elements in local waters. Oceanographic parameters treated are those commonly used to characterize bodies of water. For most purposes, they reflect the general quality of water and indirectly suggest something about the presence or absence of other broad quality determinants and give inferences about the biota.

Physical and chemical properties are important as they affect the behavior and physiology of the sea's inhabitants from the lowliest to the most complex. Only a relatively small amount of information exists on the biological implications of water quality for tropical organisms. Much of it is general and qualitative. Quantitative data on the effects of specific parameters on specific tropical organisms is particularly scarce. Even such definitive information is not universally and readily transferable to situations outside the closely defined limits of the experimental setting within which it was determined.

Part of the enormous complexity of biological relationship is that there are interacting effect relationships among the many component parameters of the environment. For example, the response of a given organism, including its tolerance, to temperature may vary with salinity. Furthermore, this variable response relationship may be different for different life stages (i.e., egg, larva, juvenile, adult). Levels of turbidity and sedimentation which permit the survival of established coral colonies may not allow settlement of larvae and development of new colonies. Acclimatization also affects an organism's response. For example, an organism accustomed to a relatively high temperature, salinity, turbidity, etc. may often exhibit a higher upper limit of tolerance to said parameter than the same species which is acclimatized to a lower prevailing level of the same parameter. Acclimatization responses are also related to other factors in the organism's environment.

Given such innumerable complex relationships governing the establishment and survival of marine life, it is no wonder that we are, in the main, ignorant of most details of marine ecology. This fact explains why biologists are unable to specify, in fine, cause-effect relationships of observed phenomena and why they are hesitant to make unequivocable predictions about specific effects of particular environmental modifications. Our present knowledge of biological responses to a few variables is simply too inadequate to extend, without reservations, even to the same organism at another time in another setting.

Even naturally occurring environmental components can assume pollution roles when increased beyond normal levels. Thus, thermal pollution can result from heated industrial discharges which raise water temperature beyond the tolerance limit of organisms. Hypersaline effluents or those abnormally high in other natural sea water constituents can likewise be lethal. Sewage, even treated sewage effluents, can add a variety of chemicals which are directly or indirectly antagonistic to marine life. Organic matter removes oxygen from the water directly or in the course of its degradation by microorganisms. Nutrients (nitrogen, phosphorous, silicon), when elevated above their normally low concentration can increase the growth of nuisance species of algae, molds, diatoms, etc. Explosive growth of such forms can smother normal organisms, produce toxins, remove oxygen from the water and may eventually, if conditions persist, change the entire ecosystem.

There is always a normal background amount of suspended matter in the sea and fine particulate matter is constantly settling to the bottom at a slow rate, even in the cleanest water. In some inshore areas, turbidity and siltation may be naturally high, but in both extremes the local biota is composed of species adapted to or tolerant of the prevailing conditions. Chronic increases in turbidity and the rate of siltation will stress and finally extirpate the more sensitive organisms, and their place will be taken by more tolerant ones. However, even the most tolerant organism has a finite ability to endure a given stress. Organisms inhabiting turbid, muddy areas will perhaps survive longer under greater increases of suspended and settleable matter than those inhabiting relatively clear water, but can ultimately be destroyed by chronic, extremely severe conditions.

The effects of pollution are less damaging, in the direct sense, to motile forms than to fixed (sessile) forms. While several environmental modifications (diversity, predator-prey relationships, fishery yield, etc.) may result from the loss of mobile organisms, they can leave an unsuitable area for better surroundings. Fixed forms - plants, corals, sponges, oysters, etc. - must perish if they cannot tolerate the induced stresses. In the larger sense, this loss of sessile organisms has much greater implications than the displacement of mobile ones. Fixed organisms are not simply living components of an environment; they, in large measure, are both physically and biologically the determinant structure of the ecosystem. The corals on a reef - apart from their roles as living members of that diverse community - are the actual physical material of the reef. They provide food, shelter and anchorage for all of the thousands of other species living there. The same is true of sea grass and algae pastures and mangrove forests. If these basic determinant elements of the ecosystem perish, then the rest of the associated biota - even if not directly affected by particular stress factors - will be adversely affected.

The parameters most frequently used to describe basic water quality are temperature, salinity, dissolved oxygen, transparency and sometimes color. For more critical definition of a water body, especially where pollution is present, bacteria, oxygen demand, pH and nutrients ("fertilizers" important for algae growth) are often measured. For assessment of water quality relative to other specific problems, there is an almost unlimited list of other chemical and physical measurements which may be made. Selection of specific ones depends on the information that is needed and on the nature of factors which may be influencing water quality (i.e., the type and source of pollution).

The following discussion treats the more common quality determinants and our knowledge of their natural levels and man-induced variations in local waters.

TEMPERATURE

Most frequently reported in degrees Celcius (or centigrade) in technical literature, water temperature is a function of radiation at the surface. Insolation (exposure to the sun) warms the water; radiation of heat from the surface results in cooling by a loss of "excess" heat (roughly the difference between the water temperature and the night-time air temperature). Water is more heat stable than the land. Thus, while the land surface heats up rapidly under the sun and cools rapidly at night, the sea is able to absorb considerable heat without a resulting large increase in temperature and to hold that heat without rapid loss. The result is that ocean temperatures are much more stable than air or land temperatures and do not show the same wide daily fluctuations.

The larger the volume of the water, the more temperature stable it is. Therefore, shallow headwaters, tidal flats and ponds tend to reach very high temperatures during the day (sometimes 30° C and higher). At night they may cool to air temperature or lower if a stiff breeze promotes evaporation. In contrast, offshore water measured at perhaps one foot below the surface may fluctuate as little as $2\text{-}3^\circ$ C diurnally.

Mixing of the water by waves, swell and current improves temperature stability by reducing localized areas of anomolous temperature and by distributing heat energy more evenly throughout the water mass.

Biologically, temperature is important because every organism has a limited range of temperature within which it can survive. There is usually an even narrower range within which the organism will flourish, exhibit optimum growth and reproduce. Frequently these narrow temperature optima are not the same; organisms may grow faster and reproduce better at different temperatures. Very often optimum temperatures are different for juveniles and adults.

Temperature is also biologically important for several other reasons. Generally, warmer water can hold larger quantities of dissolved salts, but less dissolved gases, including oxygen, than colder water. Organisms, as a rule, tend to be more active as temperature increases within their range of tolerance, although near their upper limits many exhibit behavioral or physiological maneuvers to curtail energy loss and heat exhaustion. The lowered oxygen capacity of very warm water can result in anoxia or death for organisms if they cannot leave the area or reduce their activity and oxygen demand.

Offshore surface water around the edge of the northeast Virgin Islands platform is in the range 27.5 - 27.9° C in August (Dammann, et al, 1969; Figure 10). In January, offshore surface water on the north was measured at 24.0 - 25.5° C, but on the south was reduced only to 25.5 - 27.0° C (Figure 11). This is undoubtedly a result of the southerly encroachment of colder Atlantic water in the winter, while the shallower, warmer Caribbean water to the south is less affected by this seasonal cooling. Inshore temperatures are more variable and generally warmer than offshore. This is perhaps to be expected from the shallower depth and greater variety of water characteristics inshore. Part of the wider temperature range, however, may also be due to the larger number of inshore measurements made. The Virgin Islands Division of Natural Resources Management (formerly Division of Environmental Health) has been making inshore water quality measurements monthly since November, 1972. Their temperature data from bays on St. Thomas show minima of 24.6 - 26.7° C in January-February and maxima of 27.1 - 29.0° C between June-October. Average winter-spring and summer-fall temperatures for the three islands are given in Figures 12-17. During the three years from November, 1972 to September, 1975, a cooling trend is apparent with winter minimum falling from about 26.7° C to 24.6° C and summer maximum falling from 29.0° C to 28.4° C. These data are from clean open-coast bays; areas such as Benner Bay and St. Thomas harbor have been excluded. Data from St. John show the same cooling trend over the past three years.

SALINITY

The saltiness of sea water results from the various minerals dissolved in it. The most abundant is sodium chloride. The relative proportions of the consti-

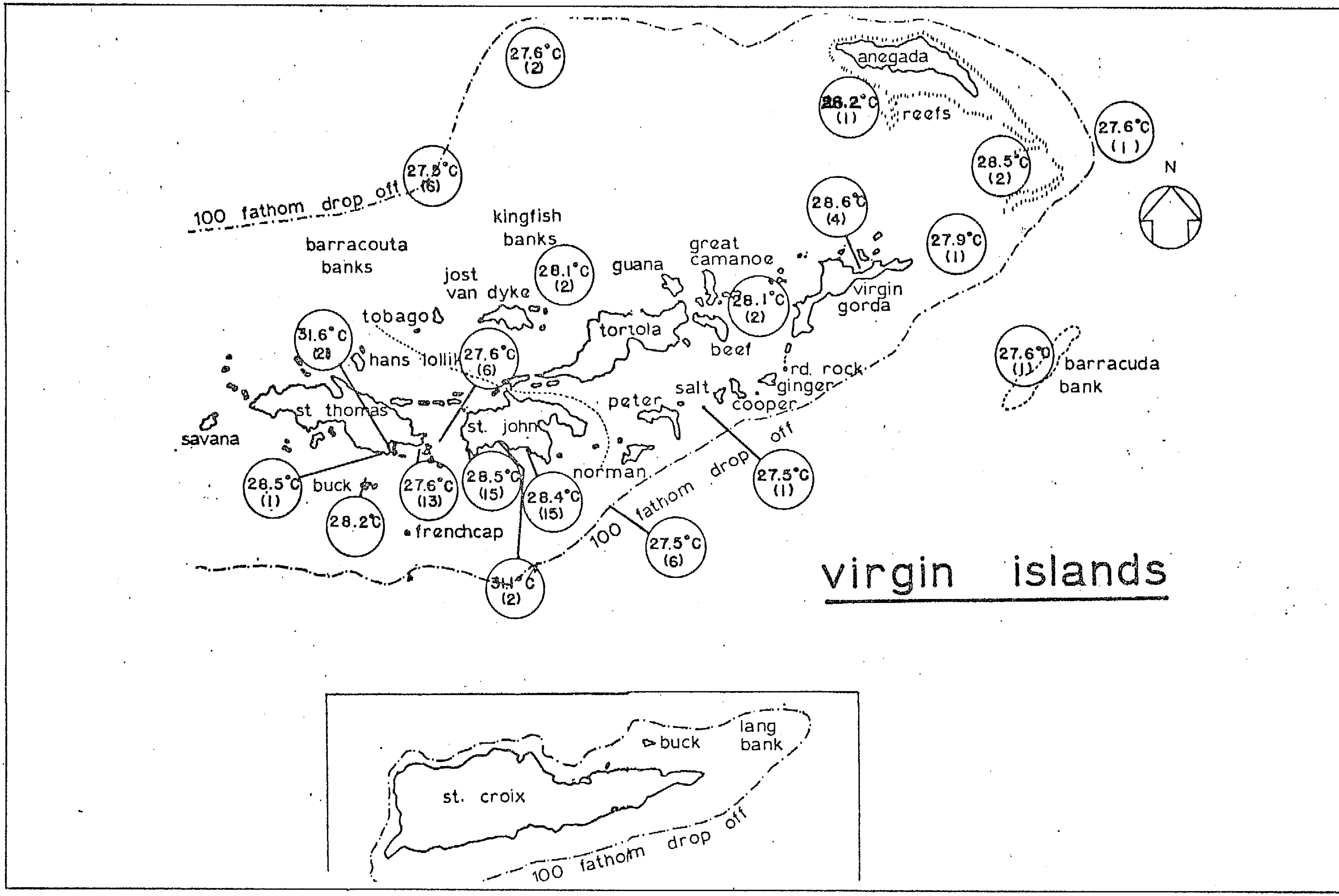


Figure 10. August Surface Temperatures. Temperatures are the average of the number of separate-day samples given in parenthesis. From Dammann, et al, 1969.

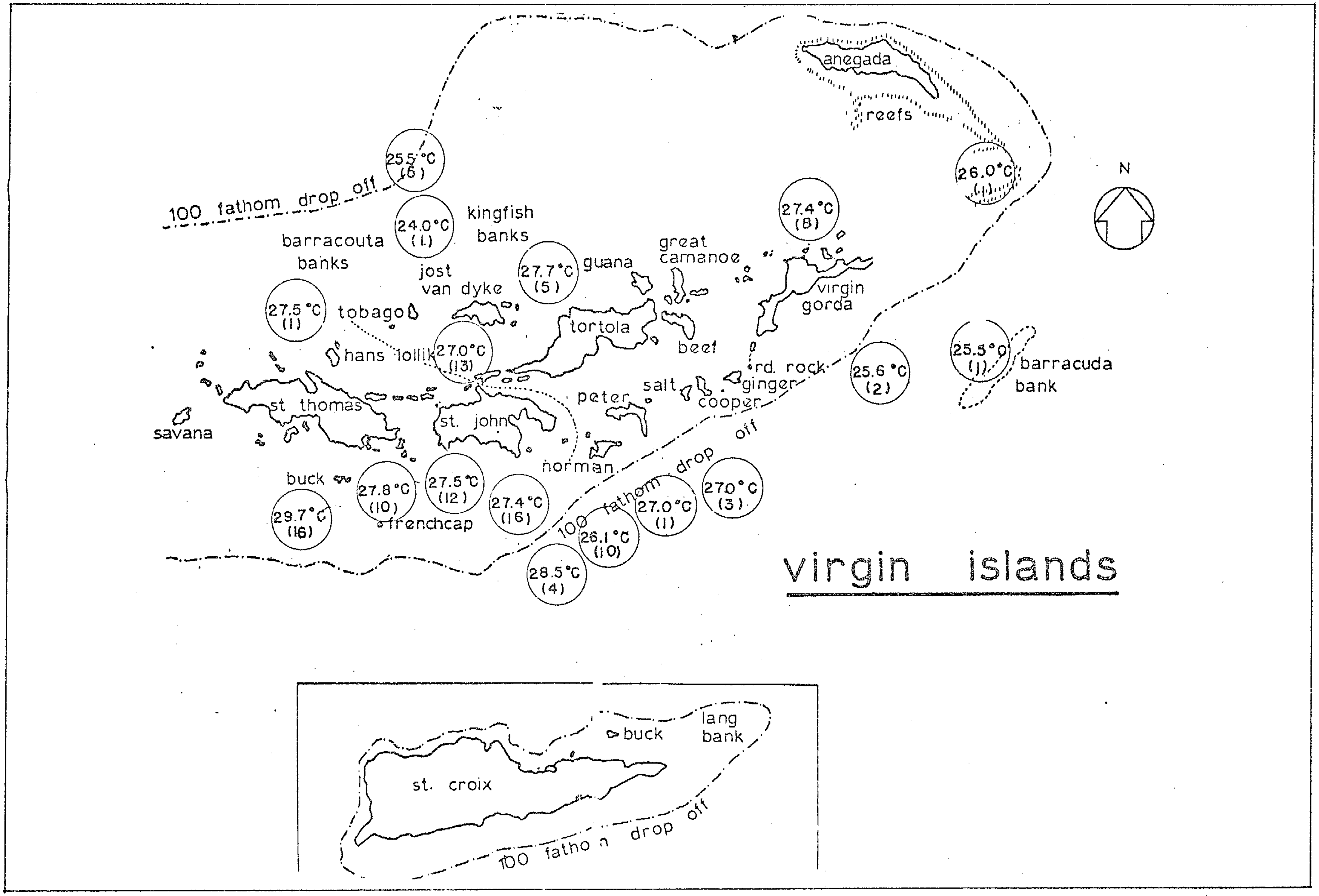


Figure 11. January Surface Temperatures. Temperatures are the average of the number of separate-day samples given in parenthesis. From Dammann, et al, 1969.

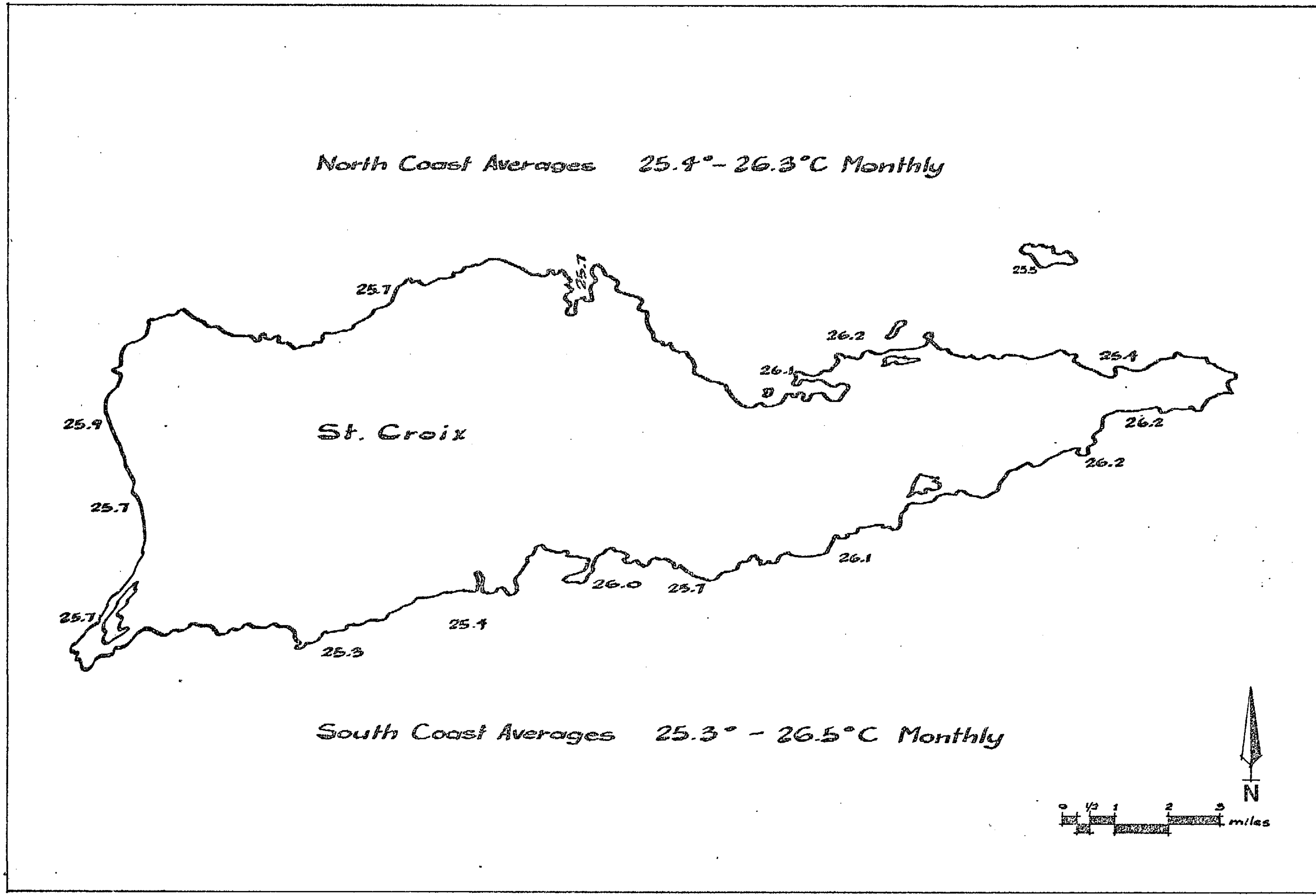


Figure 12. Average Winter-Spring (December-April) inshore water temperatures. Data from the Division of Natural Resources Management, Virgin Islands Department of Conservation and Cultural Affairs.

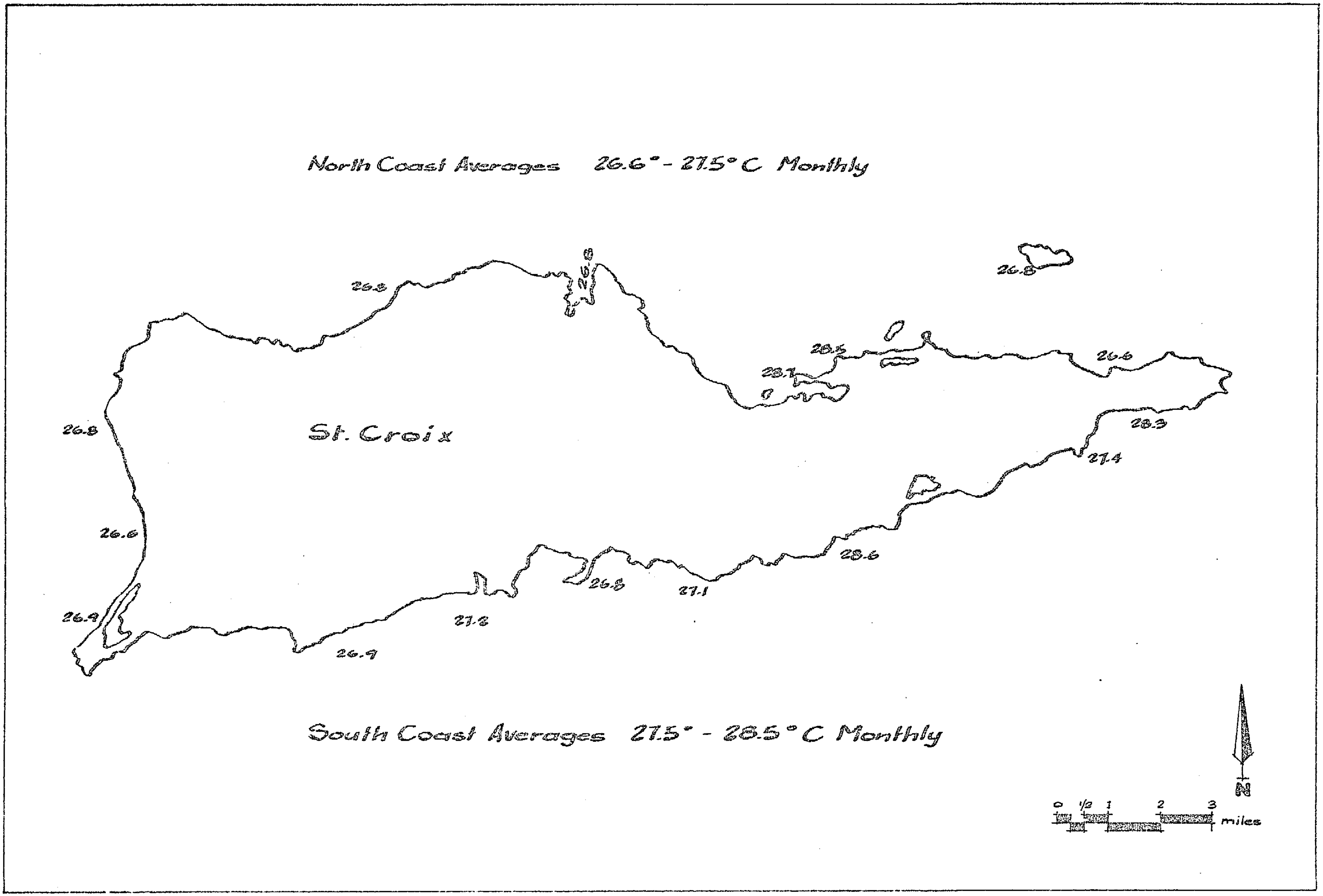


Figure 13. Average Summer-Fall (June-October) inshore water temperatures. Data from the Division of Natural Resources Management, Virgin Islands Department of Conservation and Cultural Affairs.

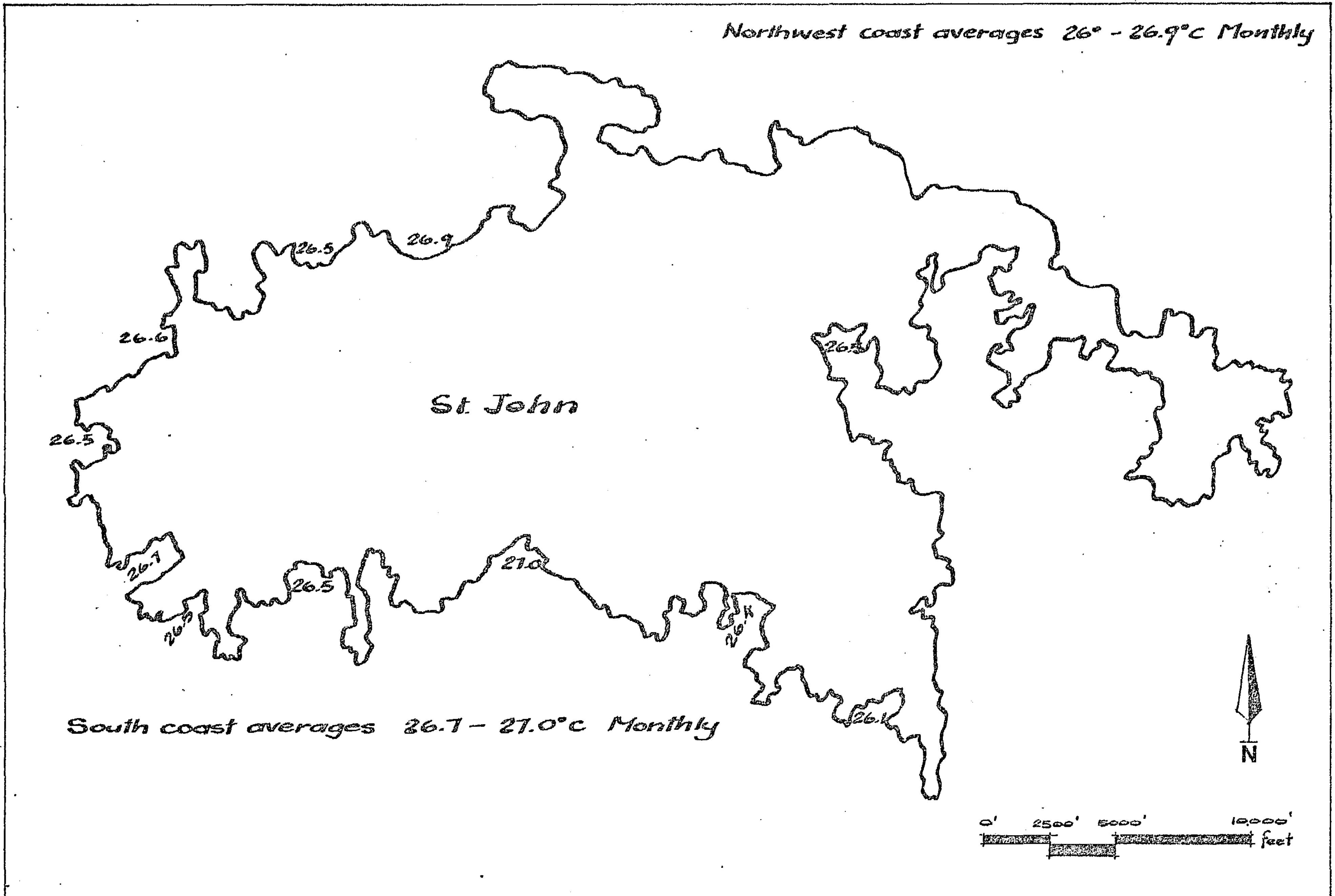


Figure 14. Winter-Spring (December-April) inshore water temperatures around St. John. From data of the Virgin Islands Department of Conservation and Cultural Affairs, 1973-74.

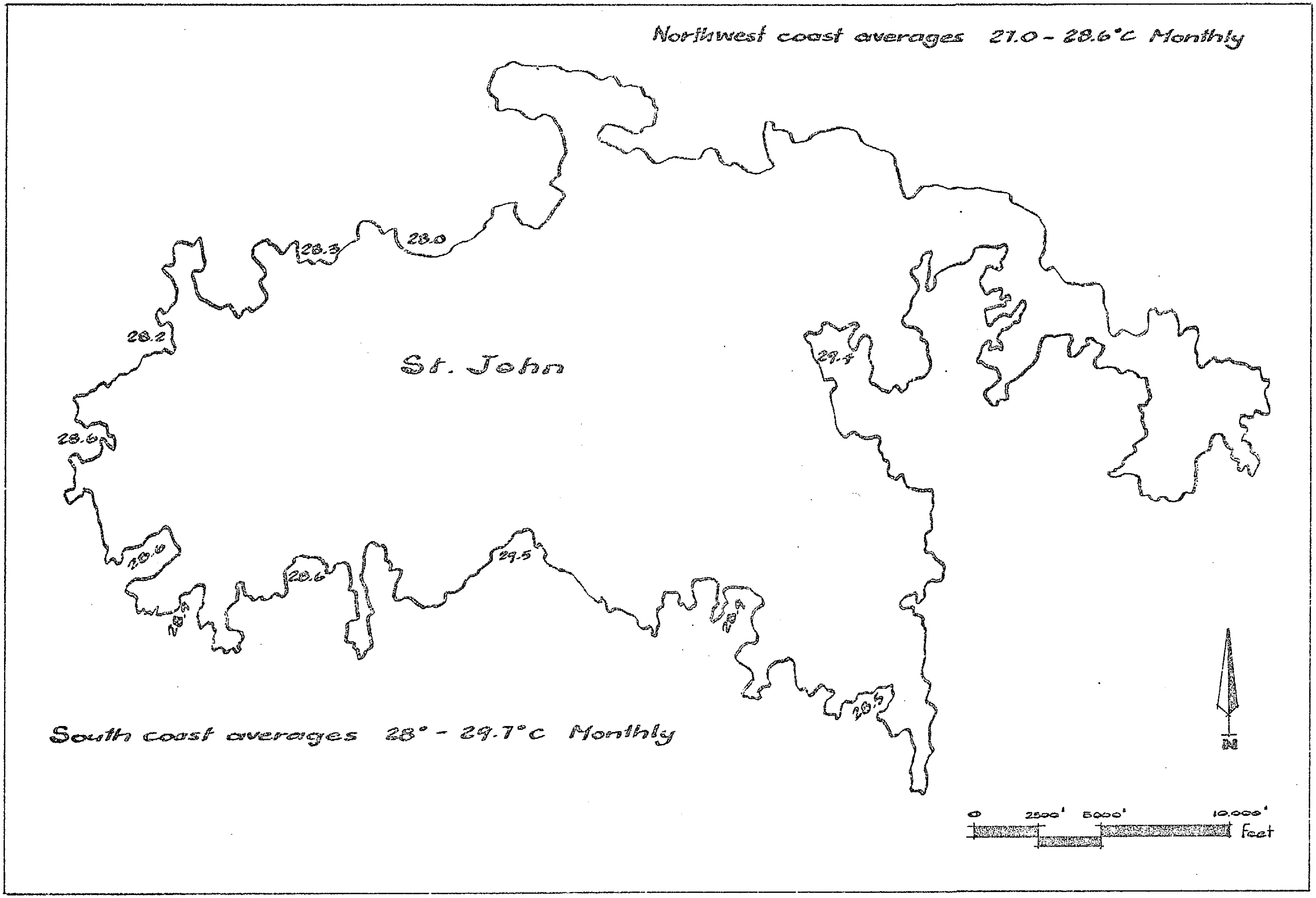


Figure 15. Summer-Fall (June-October) inshore water temperatures around St. John. From data of the Virgin Islands Department of Conservation and Cultural Affairs, 1973-74

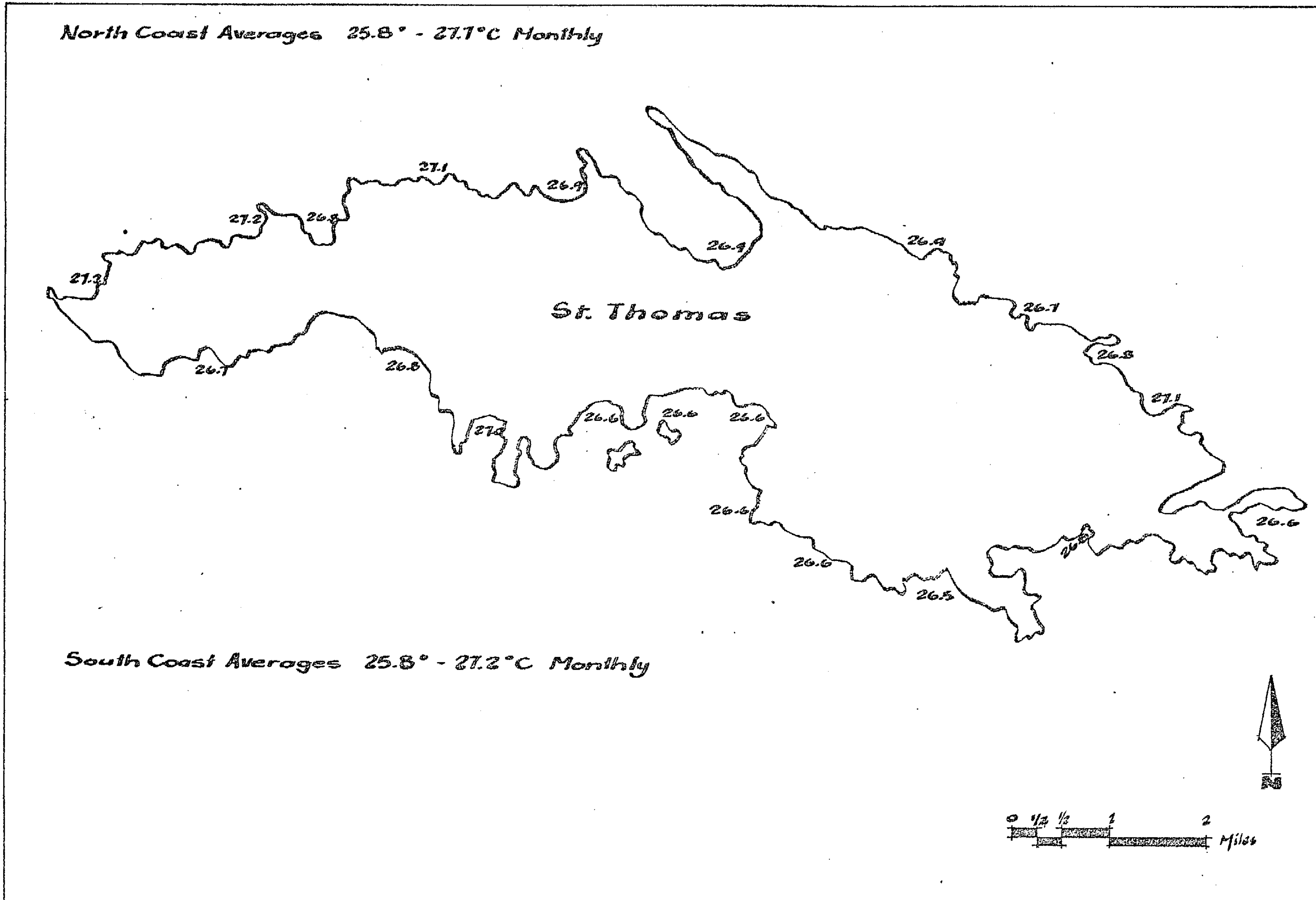


Figure 16. Winter-Spring (December-April) inshore water temperatures around St. Thomas. Data from Virgin Islands Department of Conservation and Cultural Affairs, 1973-74.

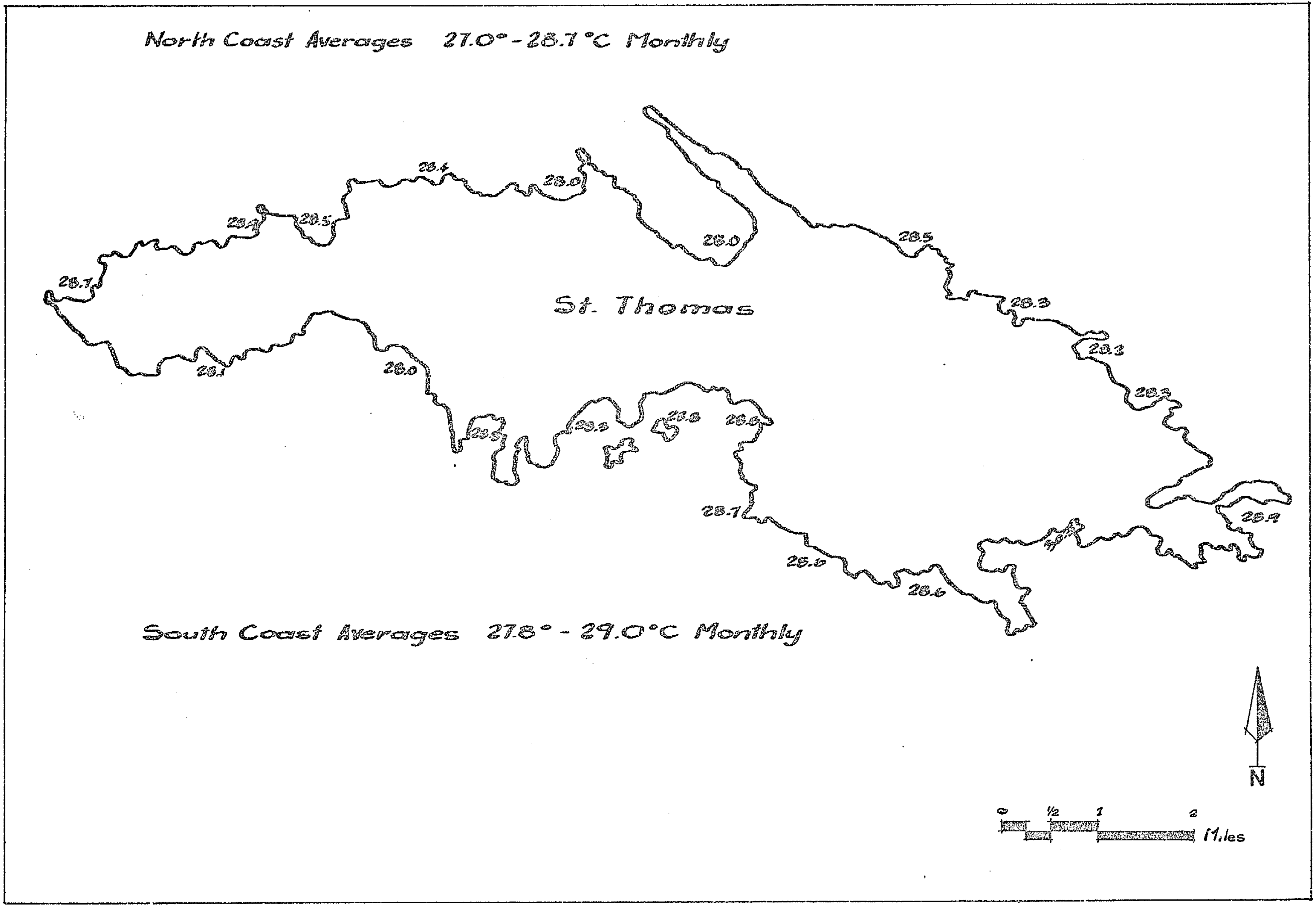


Figure 17. Summer-Fall (June-October) inshore water temperatures around St. Thomas. From data of the Virgin Islands Department of Conservation and Cultural Affairs, 1973-74.

tuents is almost constant regardless of salinity. Significant departures from constant composition ratios occurs as a result of pollution. Table 1 indicates the relative abundance of the 11 major constituents in sea water. In determining salinity, the chloride content is determined and salinity derived from it by an empirical relationship. Salinity can also be derived from measurement of conductivity and temperature.

Table 1. Major element composition of sea water.

Constituents	gm./kg. of water of salinity 35 o/oo
Chloride	19.353
Sodium	10.76
Sulphate	2.712
Magnesium	1.294
Calcium	0.413
Potassium	0.387
Bicarbonate	0.142
Bromide	0.067
Strontium	0.008
Boron	0.004
Fluoride	0.001

Salinity is reported in parts per thousand or grams per litter of salts, more often represented as o/oo. Offshore sea water around the islands has a rather constant salinity of 35..5 to 36.2 o/oo in winter-spring and 34.0 to 35.2 o/oo in summer-fall (Wüst, 1964). Inshore salinity varies from place to place around the islands depending on the relative rates of evaporation, fresh water addition and renewal by offshore water. Inshore salinity can also vary considerably over the year for the same reasons. In protected inshore localities where circulation is poor, evaporation during hot, dry periods can increase salinity to 40 o/oo or more. On the other hand, heavy rains can reduce it to 20 o/oo or less. In fact, for short periods in protected bays, an almost pure fresh water layer or "lens" may lie on top of the sea water. In most localities, however, wind, waves and currents constantly exchange the water for offshore water of relatively "constant" salinity and so dampens salinity fluctuations. Under these conditions, water in most local bays is almost or exactly the same salinity at all depths, shows only small annual variations and, following torrential rain, can recover to pre-flood salinity within a few days after runoff stops.

Oceanographers frequently measure salinity to define bodies of water and identify circulation patterns. The areal distribution of salinity in a bay, for example, can be contoured to produce isohalines - lines of equal salinity. These distributions can reveal sources of water, mixing zones and paths of water flow.

Isohalines constructed for Jersey Bay mangrove lagoon on St. Thomas (McNulty, Robertson and Horton, 1968) show the increasingly higher salinities of the inner areas where poorer circulation and evaporation promote salt concentration (Figure 18).

DISSOLVED OXYGEN

Oxygen, dissolved in the water, is necessary for life support. At the sea surface, oxygen may be absorbed from the air, a process which is aided by surface agitation of waves. The largest part of sea water oxygen, however, is produced by marine plants on the sea bed and floating planktonic algae (phytoplankton). This production is the source of most oxygen in the lower layers of inshore water.

The oxygen holding capacity of sea water is inversely proportional to temperature and salinity. Cold, fresh water can hold more oxygen than warm, salty water. Excess oxygen produced beyond the ability of the sea to dissolve it diffuses into the atmosphere. In fact, marine production accounts for a major proportion of atmospheric oxygen, a factor which contributes to some of the serious concern about the effects of increasing global pollution of the oceans.

Plants produce oxygen as a by-product of photosynthesis, a process which requires light. Therefore, oxygen is not produced at night, but animal requirements for respiration continue. In addition, plants respire (use oxygen) in the dark. Therefore, it is necessary, during sunlight hours, for a net surplus of oxygen to be generated to carry life processes through the night. Diurnal oxygen production cycles have been measured locally at Cruz Bay and Chocolate Hole, St. John (Brody, Grigg, Raup and vanEepoel, 1970), at Vessup Bay (Grigg, vanEepoel, and Brody, 1970), and in Benner Bay - Mangrove Lagoon, St. Thomas (Grigg, vanEepoel and Brody, 1971). Figure 19 reproduces characteristic oxygen curves from a highly productive site in Jersey Bay, St. Thomas on two different days.

Oxygen production begins at about 6 A.M. and the concentration in the water increases rapidly to a peak at 3 P.M., after which it begins to fall and reaches a minimum, below the saturation level, at about 3 A.M. The open-circled points on the graph represent the oxygen saturation capacity of the water based on its temperature and salinity which also vary diurnally, the latter in response to changes in circulation and the volume of offshore water entering the area.

During peak production hours, an observer in the water in such areas can see bubbles of oxygen rising from the sea grasses to the water surface. Under such conditions, the water is supersaturated with oxygen and is passing the excess to the atmosphere.

Oxygen is removed from the water by organisms, including aerobic bacteria feeding on wastes. It is also removed by chemical reaction with waste products and pollutants. Increased amounts of

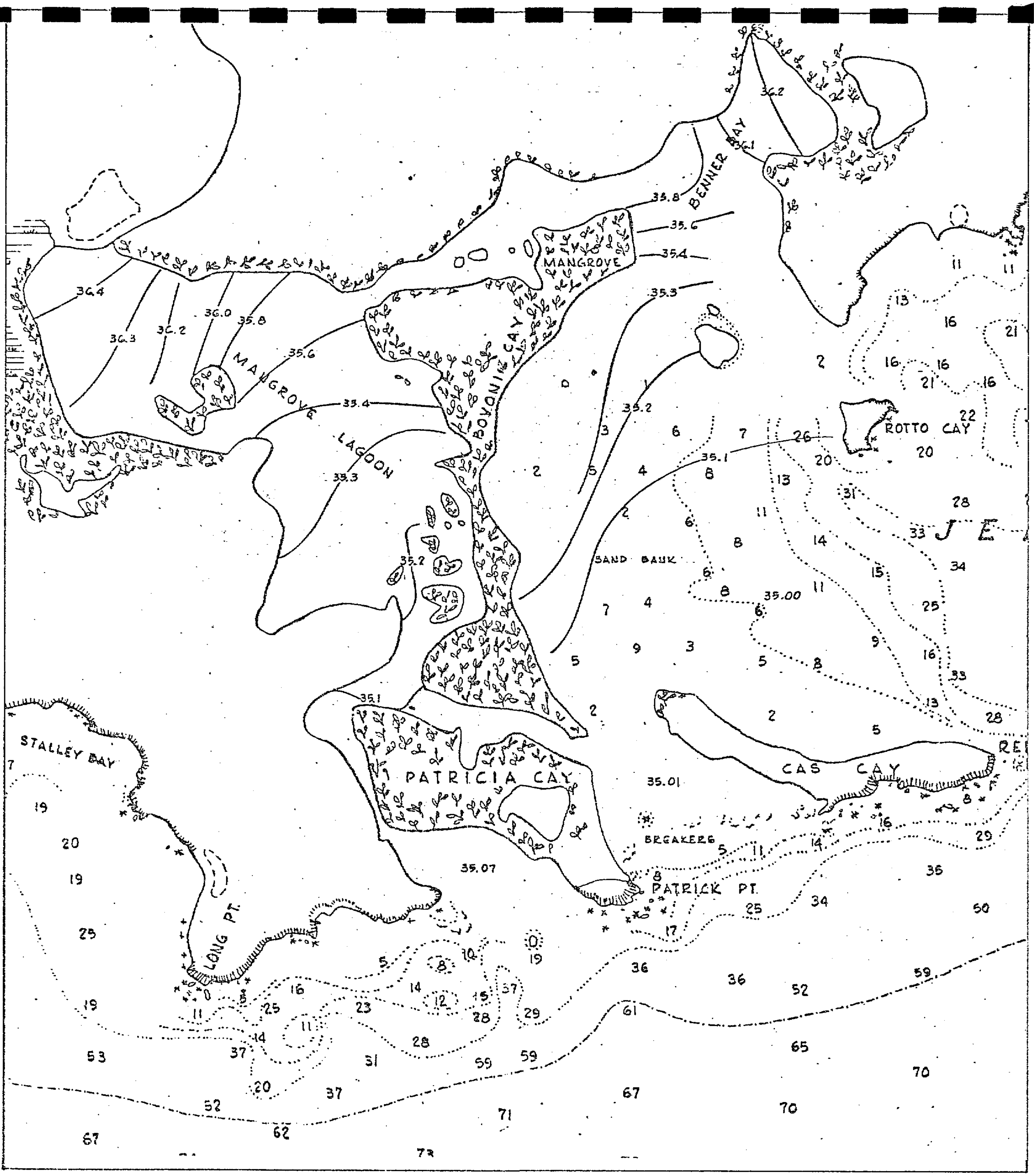


Figure 18. Contours of equal salinities (isohalines) in Jersey Bay and Mangrove Lagoon, St. Thomas. From McNulty, Robertson and Horton, 1968.

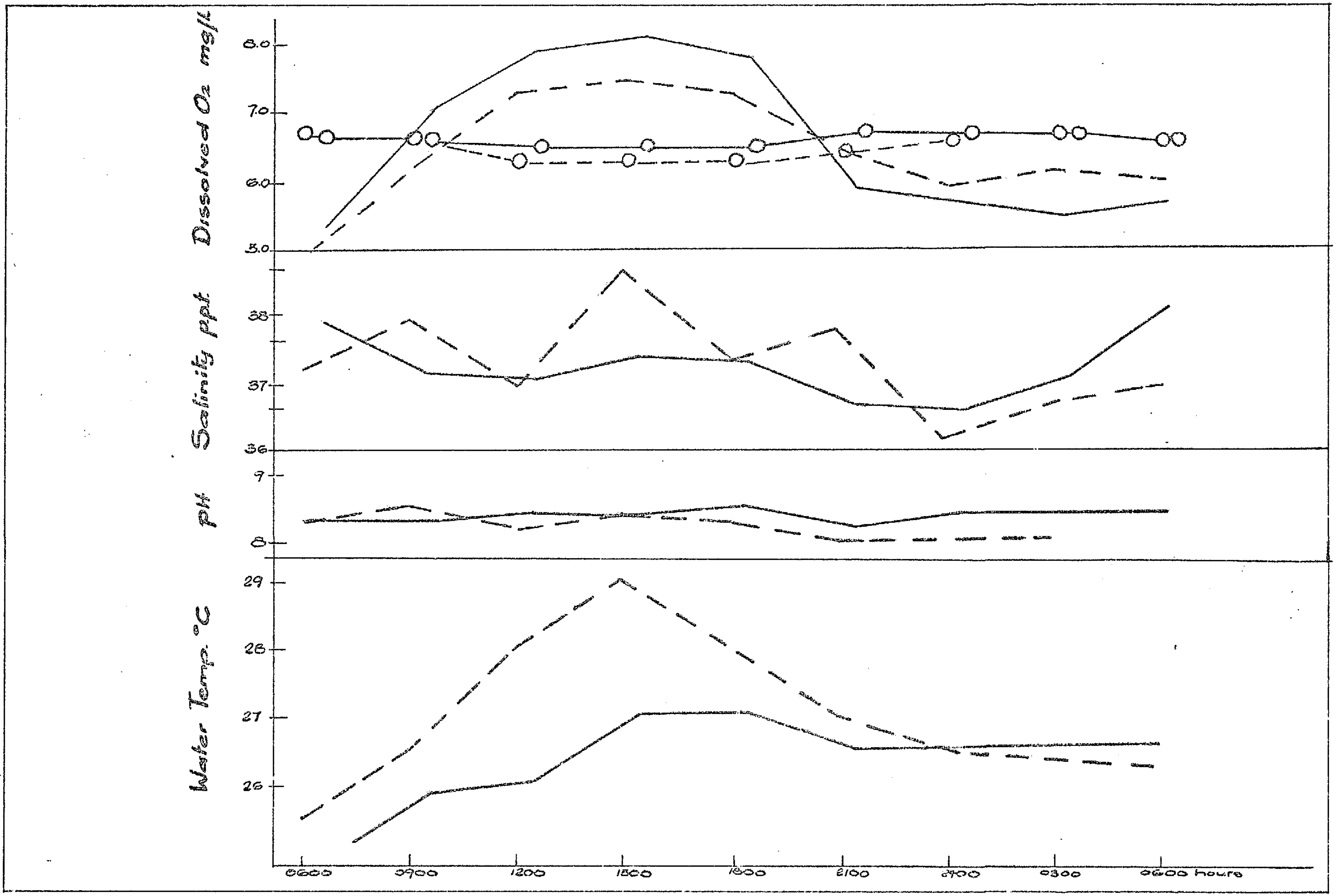


Figure 19. Diurnal variation of disolved oxygen, salinity, pH and temperature measured at one foot depth in south Jersey Bay, St. Thomas. Solid lines March 21-22, 1970; broken lines April 20-21, 1970. Open circles represent dissolved oxygen saturation. Redrawn from Grigg, vanEepoel, and Brody, 1971.

organic pollutants remove more oxygen by chemical reaction and by the life processes of bacteria and other microorganisms which feed on it.

Surface waters around the islands are usually oxygenated at or near saturation during the day. In very productive areas, such as over dense turtle grass beds, supersaturation may occur during mid-day. Because of generally prevailing temperature and salinity, saturation values are about 6.0 - 6.6 milligrams per litre (mg/l). Because of this, annual variations in dissolved oxygen (d.o.) tend to follow annual variations in temperature; salinity varies much less than temperature. At night, especially near the bottom, d.o. may be reduced to 5.0 mg/l or less, depending on local conditions of the sediments, water and biota. Point sources or concentrations of pollutants also depress oxygen concentration, by utilization and can further depress local production by destruction of plant life. However, in areas of good water circulation, these effects may be masked by oxygen transport from other areas. In shallow, polluted inshore parts of the St. Thomas harbor, surface d.o. as low as 4.3 mg/l have on occasion been measured in the past (Percious, vanEepoel, and Grigg, 1972).

<u>TRANSPARENCY</u>

Clarity and transparency of the water is a function of suspended matter. It may be estimated in several ways. The more common are Secchi disk depths, turbidity units, and concentration (weight/volume) of suspended solids. The first two give estimates of light penetration, while the third is difficult to relate to actual clarity except in the extremes because it depends considerably on the size and nature of the suspended particles. Many small particles will cloud the water more than the same weight of larger, but fewer particles. Suspended solids concentrations cannot be related or converted to Secchi depth or turbidity, but under some conditions Secchi depth and turbidity may be quantitatively related.

Secchi disc depth is the depth to which a white or black and white disk can be distinguished when lowered into the water.

Turbidity is a measure of light scattering by suspended particles in a water sample. It is reported in Jackson or Formazin turbidity units, depending on the method of calibrating the measuring instrument. The units are interchangeable.

Suspended solids concentrations are determined by filtering a water sample through a fine membrane, generally with nominal pore sizes of 0.45 micron, drying and weighing to determine the suspended solids concentration in mg/l.

Transparency in most local waters is

excellent. A secchi disk can easily be seen to depths of 30 feet, frequently more, in normal water. This means that in most bays the bottom is visible from the surface, i.e., Secchi depth is 100 percent of the water depth.

Three years of data from the Division of Natural Resources Management reveals that turbidity in undisturbed bays generally is 0.3 - 0.7 Formazin Turbidity Units (F.T.U.).

The St. Thomas harbor, an example of a turbid bay, had Secchi Disk depths only 50-60 percent of the water depth. Since sewage has been removed from the harbor, Secchi depths have increased to 80-90 percent of the water depth. Turbidity in the harbor formerly was as high as 4.5 F.T.U., but since 1973 has fallen to 1.0 - 2.5 F.T.U.

Turbidity of the water is important primarily because it reduces the amount of light reaching plants on the bottom. It is also associated with increased siltation of the bottom because many particles eventually settle out of the water in calm areas. Both effects place stresses on living systems.

WATER COLOR

The apparent color of clear sea water is a result of absorption and reflection of light and of the color of sand or organisms on the bottom. As light penetrates the water, the longer wave lengths (red, yellow) are absorbed rapidly. Shorter, higher energy spectra (violet, blue) penetrate farther and therefore dominate the light that finally reaches the bottom and is reflected. Therefore, deeper water appears to be blue or dark blue, while shallow water is greener. Very shallow water will appear clear or colorless if the bottom is sandy, or green if it is covered with seagrasses and green algae.

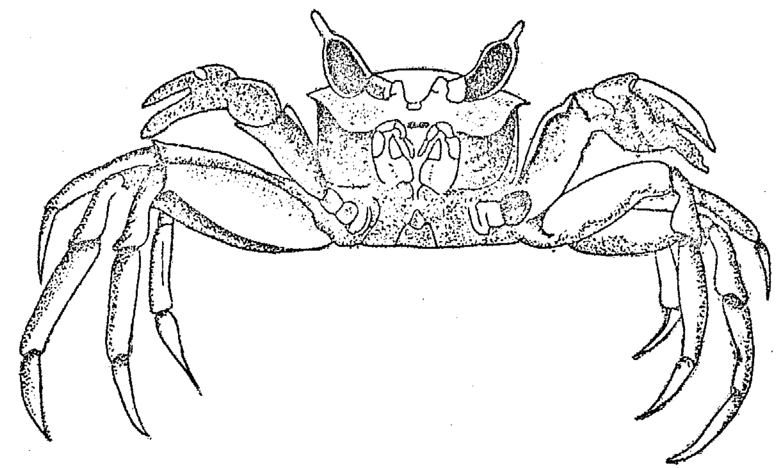
Water color can also be affected by phytoplankton which may be red, green, brown or yellow-green. Turbidity makes the water brown while dissolved materials can produce a variety of colors. Water color may sometimes be of interest in describing local sites or characterizing a particular pollutant, but in most cases color alone is not particularly meaningful.

OTHER QUALITY PARAMETERS

Frequently it is valuable to estimate the density of some type of bacteria in the sea. Since this is most often done to monitor pollution by sewage in coastal waters, one of the common indicator species is usually monitored. *Eschereschia coli*, the most characteristic bacteria in feces of warm-blooded animals, including man, is most often tested for. New methods of analysis are simple and rapid and give results in 16-24 hours. Bacterial density in the water is useful for pinpointing sources of pollution, evaluating public health acceptability and the efficiency of sewage treatment facilities.

Chemical ions such as nitrate, phosphate, silicate and their related compounds are often studied as means of assessing the productivity or eutrophication ("enrichment") of the water. These compounds are highly concentrated in sewage, even treated sewage effluents, and also occur in floodwater from the land. High concentrations of these compounds promote increased growth of plants, partcularly phytoplankton and filamentous types. Rapid growth of these plants, which require or can tolerate high nutrient concentrations, can smother normal clean water forms or produce toxins which are harmful to other organisms.

Organic matter in the water is frequently estimated indirectly by measuring biochemical oxygen demand (B.O.D.) or chemical oxygen demand (C.O.D.). The first is a bioassay which measures the consumption of oxygen by micro-organisms feeding in a water sample under standard conditions, usually for five days. Chemical oxygen demand measures the oxygen uptake of a sample using strong oxidizing agents. Since many substances not easily attacked by bacteria (as in B.O.D. test) are thus oxidized, the C.O.D. value of a given sample is higher than the B.O.D. It is also a more rapid test than B.O.D.



Prevailing Winds

The Virgin Islands lie in the belt of "Easterlies" or "Trade Winds" which traverse the southern part of the "Bermuda High" pressure area. The trade winds approach the islands with great constancy of direction, primarily from the east-northeast and east. The trade winds vary in magnitude and direction as the position of the sun changes seasonally in relation to the earth's surface. Major seasonal changes relate to the normal variations in position and intensity of the "Bermuda High" and "Equatorial Trough." In contrast to the Bermuda High, the Equatorial Trough is a zone of low pressure south of the islands between the sub-tropical high pressure belts in the southern and northern hemispheres (which includes the Bermuda High). Since the wind blows around the low pressure zone as a counterclockwise inflow in the northern hemisphere, the Equatorial Trough directly affects the easterly winds of the islands.

The average percentage frequency of wind speeds for different directions is illustrated in the monthly wind roses of Figures 20 and 21 (U.S. Navy Hydrographic Office, 1963). The annual wind regime can be broadly divided into four seasonal modes: (1) December to February; (2) March to May; (3) June to August; (4) September to November (Brown and Root, 1974). Characteristics of each seasonal mode are discussed below.

December - February. During the winter the trade winds reach a maximum and blow with great regularity from the east-northeast. Wind speeds range eleven to twenty-one knots about sixty percent of the time. Speeds greater than twenty knots occur about twenty-five percent of the time in January. This is a period when the Bermuda High is intensified with only nominal compensating pressure changes in the Equatorial Trough.

The trade winds during this period are interrupted by "Northerners" or "Christmas Winds" which blow more than twenty knots from a northerly direction in gusts from one to three days. Such outbreaks average about thirty each year. They are created by strengthening of high pressure cells over the North American continent, which, in turn, allows weak cold fronts to move southeastward over the entire Caribbean region. These storms are accompanied by intermittent rains, by clouds and low visibility for mariners.

March - May. During the spring, the trade winds are reduced in speed and blow mainly from the east. Winds exceed twenty knots only thirteen percent of the time in April. The change in speed and direction mainly result from a decrease in pressure of the Equatorial Trough.

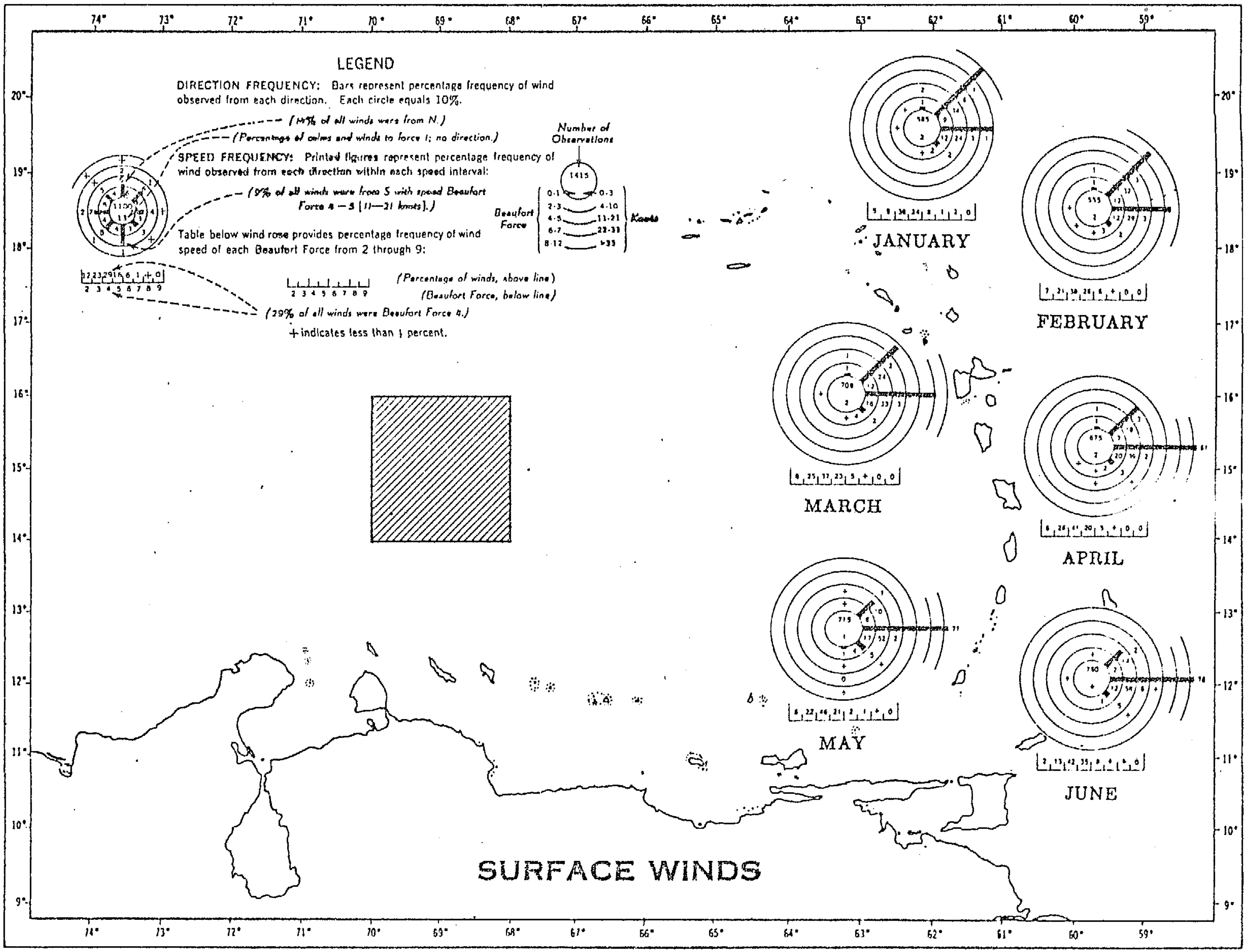


Figure 20. Wind Direction and Speed Frequency, Central Caribbean, January - June. From U.S. Naval Oceanographic Office, 1963.

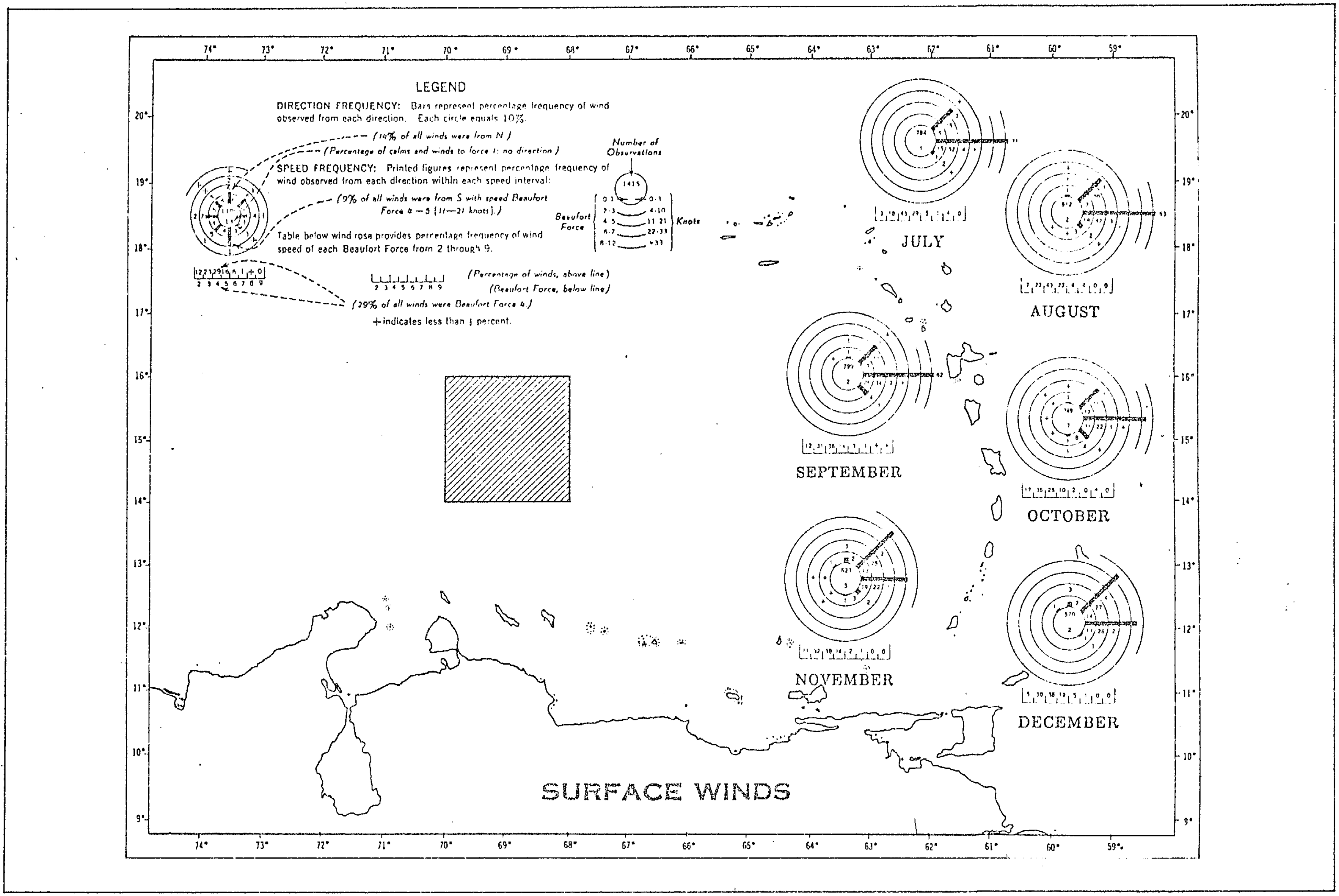
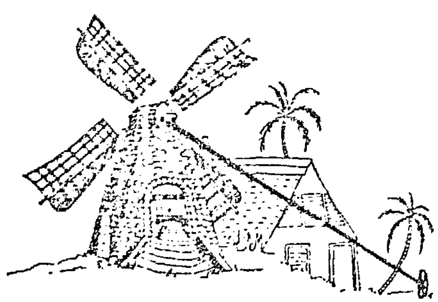


Figure 21. Wind Direction and Speed Frequency, Central Caribbean, July - December. From U.S. Naval Oceanographic Office, 1963.

June - August. Trade winds reach a secondary maximum during this period and blow predominantly from the east to east-southeast. Speeds exceed twenty knots twenty-three percent of the time during July. The trend for increasing winds results from the strengthening of the Bermuda High and a concurrent lowering of pressure in the Equatorial Trough. Trade winds during this period are interrupted by occasional hurricanes.

September - November. During the fall, winds mainly blow from the east or southeast and speeds reach an annual minimum. Only seven percent of the winds exceed twenty knots in October. The low speeds result from a decrease in pressure in the Bermuda High with only a slight compensating pressure decrease in the Equatorial Trough. During this period, especially during late August through mid-October, the normal trade wind regime is often broken down by easterly waves, tropical storms and hurricanes.



Storms and Hurricanes

The major disturbances affecting normal trade wind circulation are caused by the passage of squalls, easterly waves, tropical cyclones and hurricanes.

SQUALLS AND THUNDERSTORMS

The islands are affected by numerous squalls which are often accompanied by thunder and lightening. In the vicinity of land, where the squalls are most frequent, cold air rushes down the mountain sides and moves out over harbors and bays with substantial force. These disturbances are most common in the summer months during periods of sultry weather and light variable winds. Because the squalls last only a few hours, they do not cause a pronounced change in the trade wind speed or direction over large areas.

Thunderstorms are localized wind storms associated with cumulus cloud types that may occur in all months but are most common between June and January.

TROPICAL CYCLONES AND HURRICANES

These storms are of great significance to the wind regime although they occur infrequently. When tropical cyclones sustain wind speeds that exceed 74 miles per hour, they are termed hurricanes. Tropical cyclones form or pass through the eastern Caribbean mainly from August through October. Peak activity is during September (Figure 22). The probability of tropical storms and hurricanes occuring in the islands at dif-

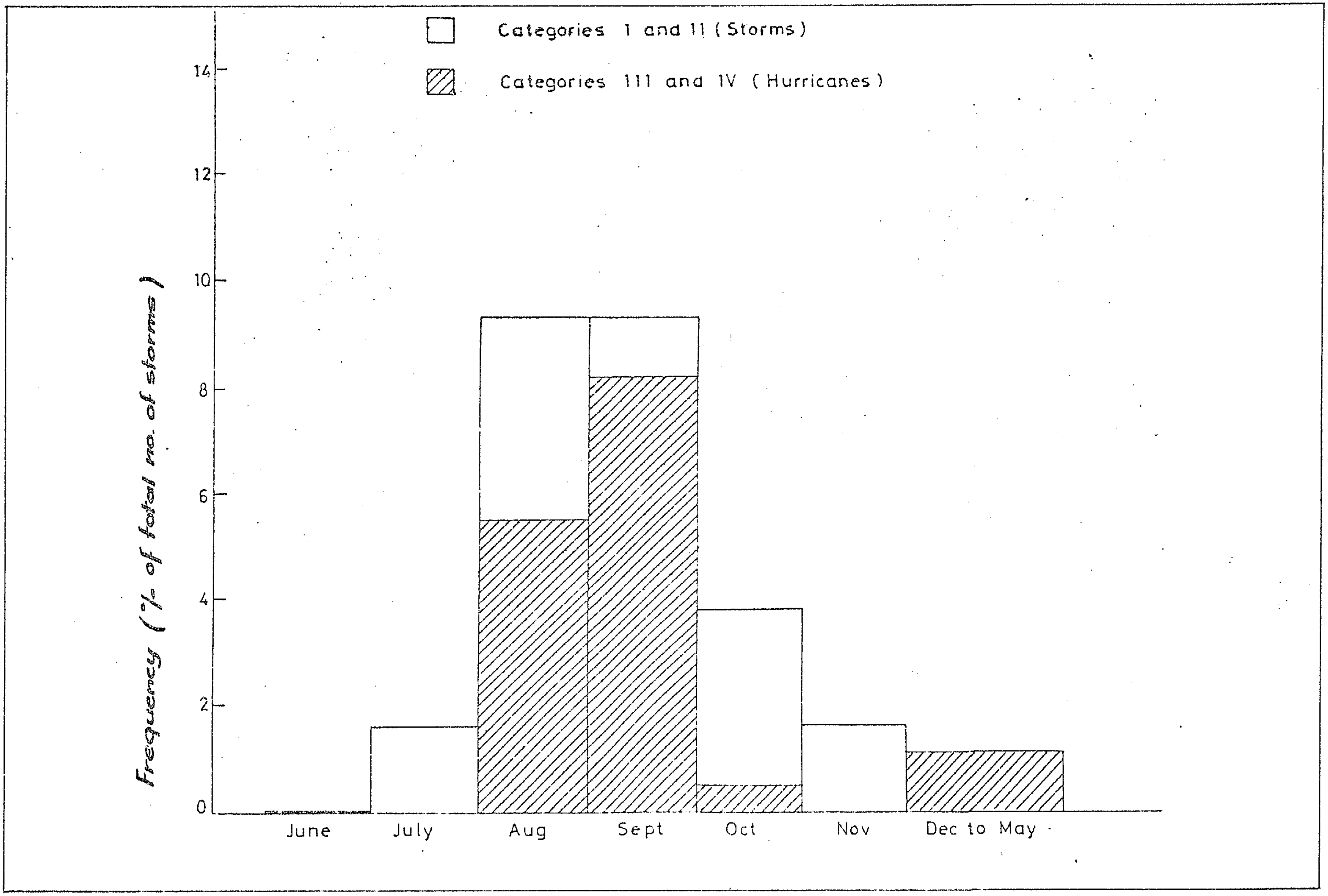


Figure 22. Tropical Cyclone Frequencies: Latitude 15° - 20° N. From Deane, Thom, and Edmunds, 1973.

ferent seasons is given in Table 2 (Brown and Root, 1974). Annually there is an expected probability of one cyclone in sixteen years (Bowden, 1974).

Since 1900, 24 hurricanes have passed within fifty miles of the Virgin Islands (U.S. Army, 1975). Of these, the hurricanes of 1916, 1924, 1928, and 1932 caused the most damage. Hurricane paths that have affected the islands since 1876 are shown in Figure 23.

STORM WAVES AND TIDAL FLOODING

Tidal flooding, created by major hurricanes having a frequency on the average of once in 33 years, raise water levels in St. Thomas from five to twelve feet above normal. A six foot tide height would flood lower parts of Charlotte Amalie for 800 feet landward from the shoreline. A graph prepared by the U.S. Army Crops of Engineers (1975), showing the height of a hypothetical hurricane flood having a frequency of occurrence of once in 100 years, is reproduced as Figure 24. Also presented is the height of the "standard project flood" which is defined as the largest tidal flood that can be reasonably expected to occur as a result of the most critical combination of conditions that are considered characteristic of the region, excluding extremely rare events. Besides flooding, damage to waterfront facilities and erosion of shores by storm waves can be heavy. Moreover, passing hurricanes may create a minus tide of as much as 1.0 feet below mean low water that can temporarily cause grounding of vessels in shoal water and exposure of tidal flats.

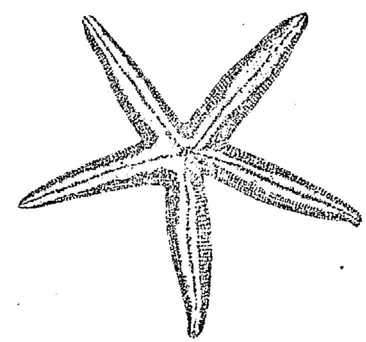


Table 2. Occurrence of tropical storms and hurricanes within 240 nautical miles of St. Croix.

Period of Hurricane Season	Tropical Storms			Hurricanes		
	Average Number Per Year	Average Interval Between Storms, Years	Occurrence Probability On Any Day In Period	Average Number Per Year	Average Interval Between Storms, Years	Occurrence Probability On Any Day In Period
July 6 - Aug 5 (31 Days) (Inactive Early Season)	0.16	6.4	0.50%	0.05	20.4	0.15%
Aug 6 - Sep 30 (56 Days) (Active Mid-Season)	0.70	1.4	1.24%	0.85	1.2	1.52%
Oct 1 - Nov 30 (61 Days) (Inactive Late Season)	0.20	5.1	0.32%	0.13	7.8	0.20%
Entire Season (148 Days)	1.05	0.95	0.70%	1.03	0.97	0.69%

Maximum Number of Hurricanes and Tropical Storms in Any Year: 9, 1933

Minimum Number of Hurricanes and Tropical Storms in Any Year: 0 (occurred in several years)

Source: Brown and Root, 1974.

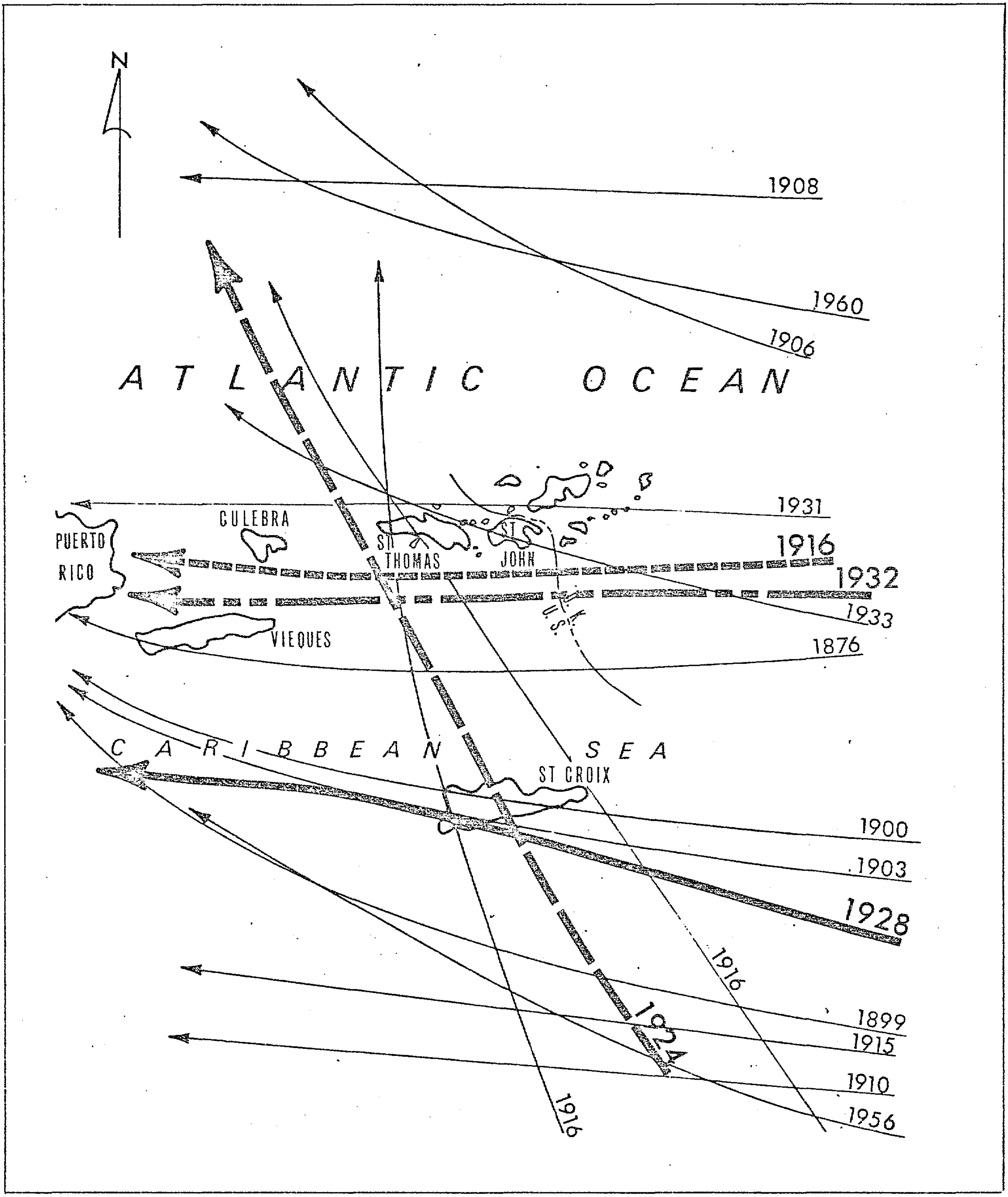


Figure 23. Hurricane paths that have affected the Virgin Islands since 1876. From U.S. Army, 1975.

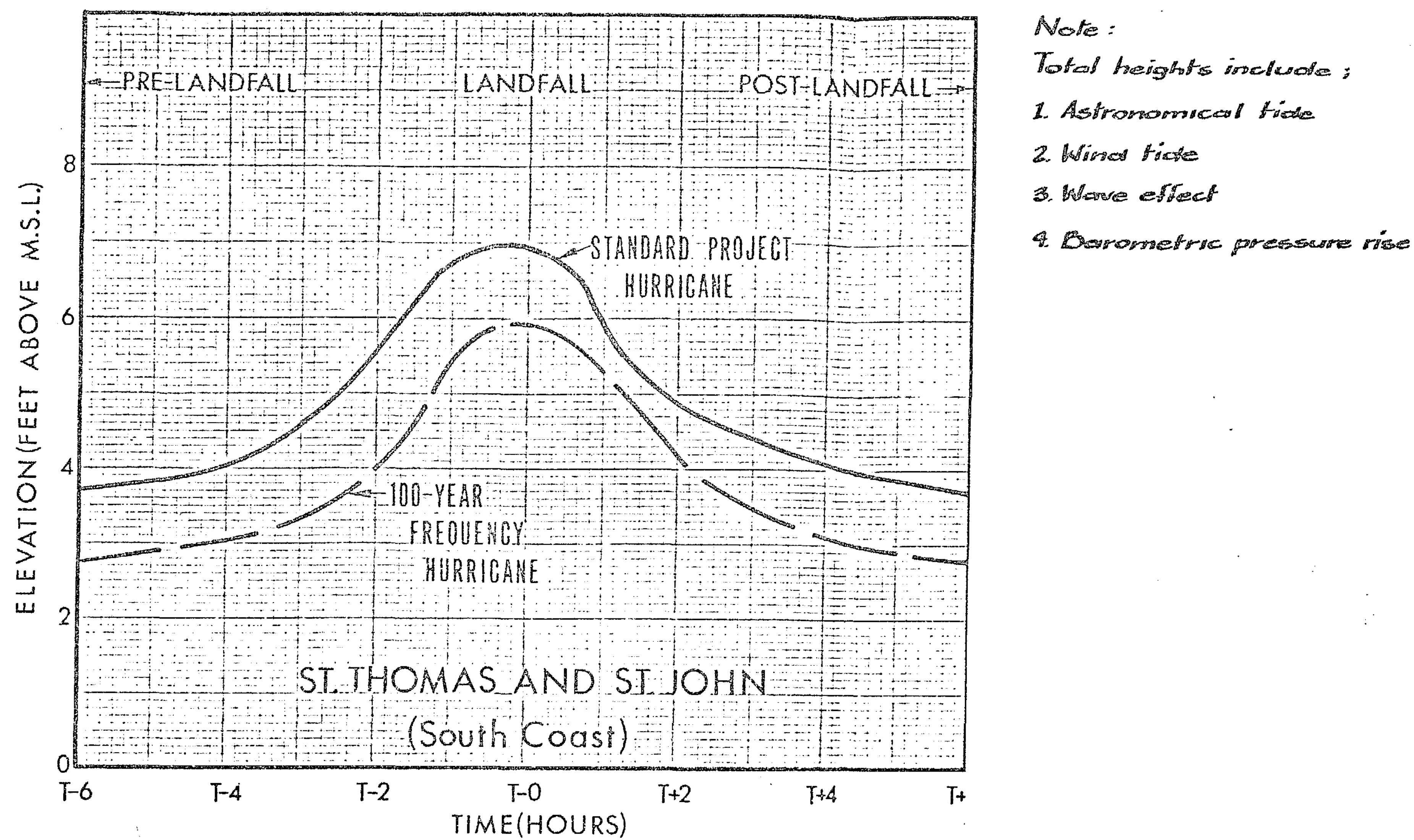


Figure 24. One hundred year frequency and standard project tidal flood stage hydrographs. From U.S. Army, 1975.

Precipitation and Evaporation

Rainfall in the islands is limited and variable. The amount of rain varies monthly, annually, by island and with areas on a given island. Average rainfall data, compiled from several years records at various stations, can be misleading in that it probably poorly represents the available precipitation at a particular area even over a year's time. The U.S. Virgin Islands receive an average of 41 inches of rain per year (Bowden, et al, 1970).

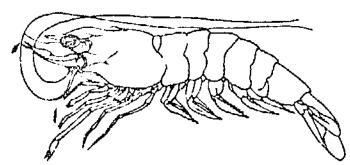
The wettest months are September to December. The dry season is February to July. St. Thomas, including Water Island and Hassel Island, receives about 42 inches. St. John receives about 47 inches. The larger cays probably average between 30-35 inches. A small area of Crown Mountain, St. Thomas averages slightly more than 50 inches. The eastern and southern lowlands of the islands generally are the driest and the central higher elevations wetter. Most of St. Croix receives 35-45 (average about 40) inches of rainfall a year. The northeast hills receive slightly more and Annaly, the wettest area, receives on the average 52 inches a year (Bowden, et al, 1968).

In addition to sparse rainfall, dryness of the islands is heightened by rapid evaporation of surface and soil water by intense solar radiation and constant breezes, most marked on exposed coastal ridges. Soil retention of the sparse rainfall is hampered by the steep slopes which promote rapid runoff instead of infiltration and by the shallowness of most topsoils and their paucity of moisture-holding organic matter. In addition, plants remove moisture from the soil, pumping part of it back to the atmosphere by transpiration.

Rainfall and evaporation are important in the coastal marine environment as they affect salinity, turbidity and other pollutants carried to the sea with stormwater. Most of the light, brief showers which fall are not sufficient to run off the land. This is primarily because the soil is almost always dry and rapidly absorbs these brief showers. During rainy periods when frequent showers may bring soil moisture to saturation, further rainfall runs off the steep slopes to the sea. In flat areas, excess soil water may be able to percolate into the ground before running off. Vegetation, in addition to slope, is also important in determining the speed and extent of runoff. Plants help by interrupting the sheet flow of surface water, reducing its velocity and allowing more time for it to infiltrate the soil. Plants can also absorb and transpire water back into the atmosphere. In addition, their roots help to hold the soil in place. Areas which have been stripped, cut or burned do not offer these advantages, and much less rain is required to promote runoff, which carries soil with it. Local bays receiving drainage from highly developed watersheds (St. Thomas harbor, Christiansted harbor, Benner Bay and Water Bay, St. Thomas) are now subject to discoloration and siltation following good rainfall of an hour or more, while most other drainages do not shed water as readily.

Historically, flooding of the coastal zone was infrequent and probably had negligible consequences for marine organisms. The lack of rivers was fortunate in the sense that coral growth was not hampered by low salinity, turbidity and other terrestrial contaminants which restrict reef growth around larger islands and continental coasts. Without constant or frequent pollution by fresh water, silt and other pollutants, clean-water communities were able to develop almost everywhere around the islands and could recover from the brief impact of periodic torrential rains. Today, fresh water (and a wide variety of transported pollutants) reaches the coastal sea quicker, more frequently, and in greater amounts than in the past. The frequency and severity of these occurrences has begun to be reflected in the condition of the affected environments. In Christiansted and St. Thomas harbors, as well as Benner Bay and Water Bay, and to a lesser degree Cruz Bay, St. John and Stumpy Bay, St. Thomas, turbidity and bottom silt have increased noticeably in the past several years, and areas of coral and marine plants have been reduced. These trends in the environment result from essentially permanent changes in water quality, in part, as a result of frequent rain induced runoff. However, most of these areas are also subject to stress from other sources (i.e., dredging, marinas, boat traffic, sewage).

Rare inundation by fresh water, even without large amounts of other pollutants, can damage or kill most marine organisms. Natural forces usually return normal salinity levels in a matter of days in most localities, and the biota can recover. However, increasing frequency and severity of these episodes will eventually modify the impacted ecosystem.



Geophysical Factors

Bathymetry

The northern Virgin Islands lie on the Puerto Rican Plateau, a submerged plateau defined by the 100 fathom (183 meter) depth curve. This plateau is like a small continental mass surrounded by steep slopes and deep water (Dammann, 1969). The Puerto Rican Trench, with depths to 27,500 feet (9,166 meters) lies to the north, the Virgin Islands Basin with depths reaching 13,500 feet (4,500 meters) lies to the south, and the St. John and Anegada Passages with depths of about 6,000 feet (2,000 meters) lies to the east (Figure 25). The plateau mainly consists of an insular shelf with depths less than 300 feet.

St. Croix lies on a submerged ridge which is separated from the Puerto Rican Plateau by the Virgin Islands Basin. The ridge is broken by the Jungfern Passage to the west and by the St. Croix passage to the east. The sill depths in these passages reportedly control the movement of deep water between the Atlantic Ocean and the Caribbean Sea.

The slopes that border the plateau and ridge and lead down into the adjoining basins or passages are commonly long and relatively straight. Several are more than ten miles long. Locally, there are occasional offsets on the slopes more or less at right angles to the slopes, e.g., off the north coast of St. Croix. Topographic evidence suggests the slopes are of fault origin. They are relatively straight, steep and parallel known major faults on land.

Despite the relatively smooth form of the depth curves in Figure 25, the slope contains many local irregularities on its surface. Relief of the slopes is known mainly from a study (vanEepoel, et al, 1971) to determine the feasibility of laying submarine cables between the islands. Reportedly, the slopes are a region of great relief with thick sedimentary deposits filling the valleys between peaks. The steep slopes and probable existence of a westerly bottom current have contributed to deposition in the valleys. These deposits are believed to consist of turbidities, i.e., deep sea deposits laid down by action of turbidity currents. The records also show evidence of slumping. A detailed description of downslope movement in submarine channels off Cane Bay, St. Croix is given by Multer and Gerhard, 1974.

Bathymetry of the insular shelf is best known from a reconnaissance study of the shelf south of St. Thomas and St. John (Garrison, et al, 1971). This shelf has an average width of 22 miles (14 kilometers), and it slopes about 16 meters per kilometer from the shoreline to 30 meters depth. West of Charlotte Amalie, the profile is smooth and regular (Figure 26). By contrast, profiles to the east are broken by a few hills and

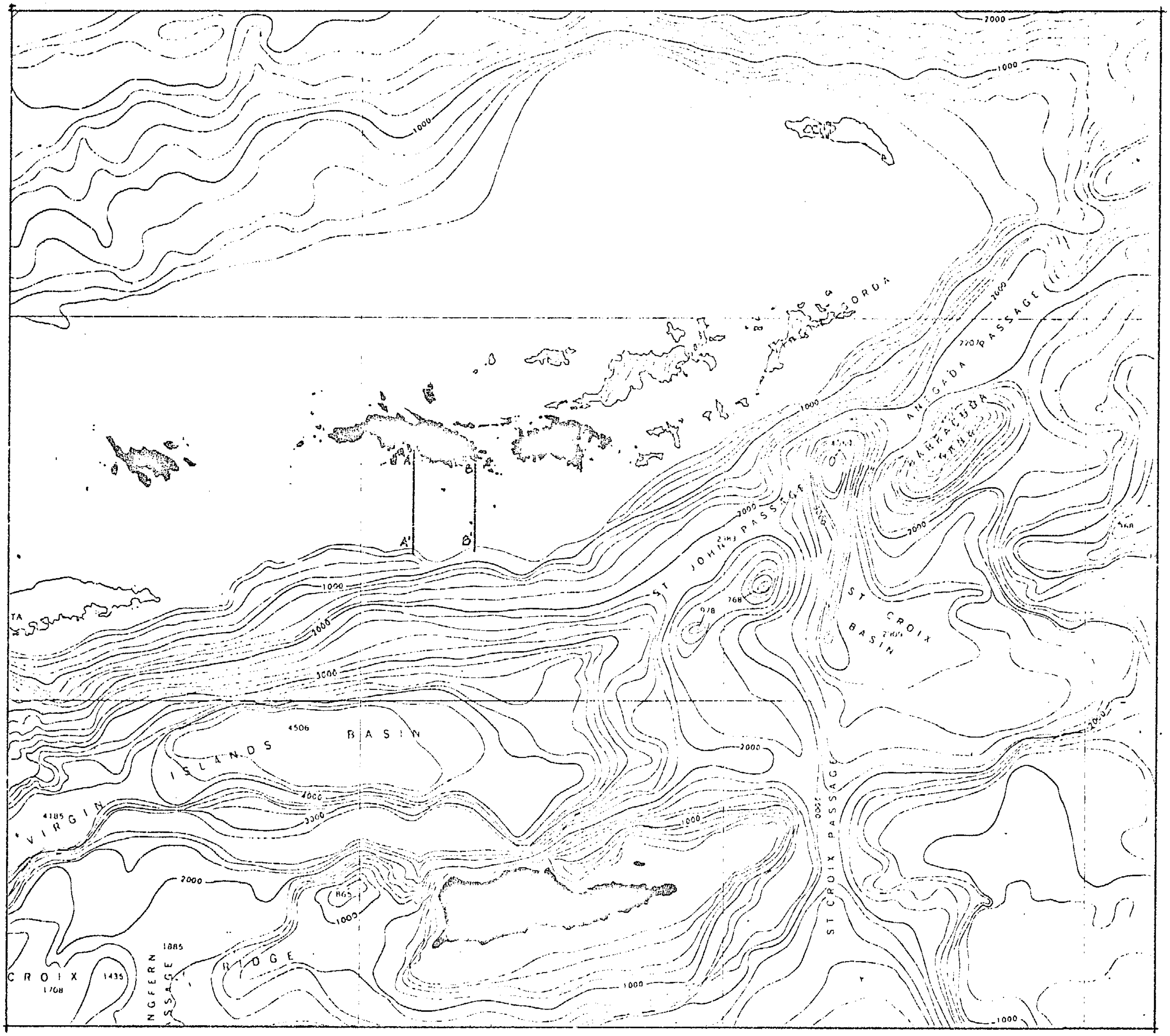


Figure 25. Bathymetry of Virgin Islands basins and plateaus. Depths in meters. From vanEepoel, *et al*, 1971.

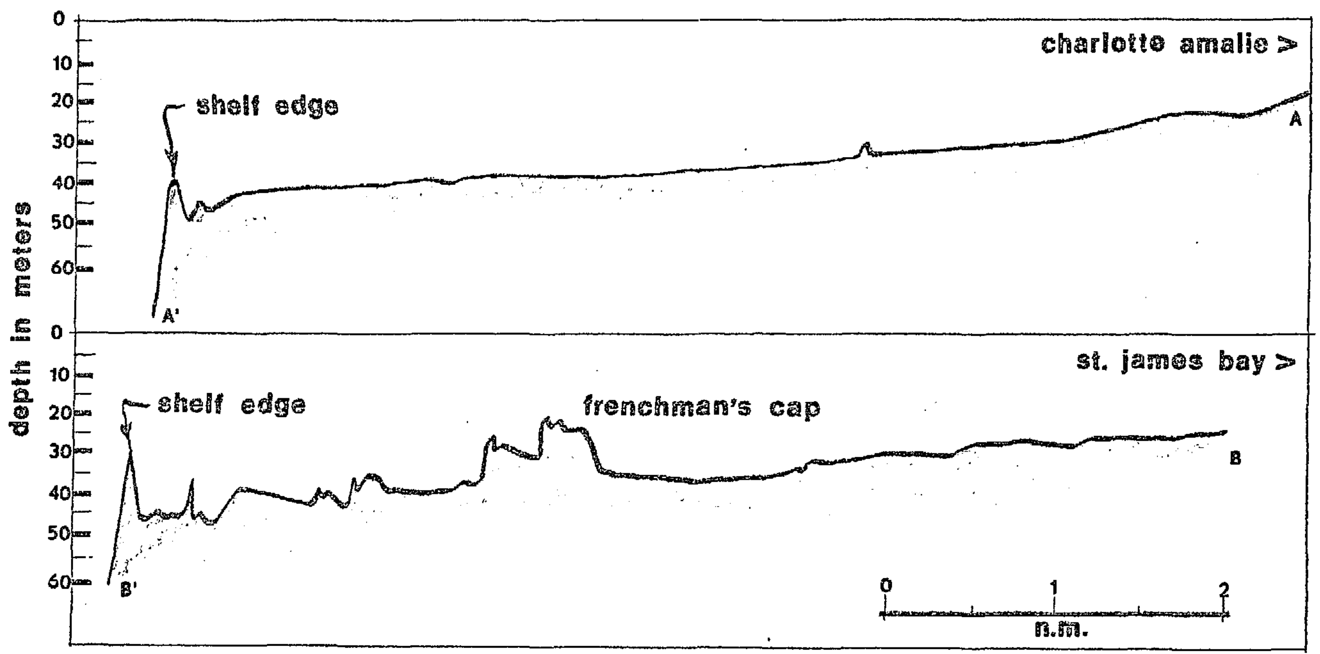


Figure 26. Profiles of bottom topography across the Virgin Islands shelf south of St. Thomas and St. John. From Garrison, et al, 1971. For location, see Figure 25.

ridges that rise about 36 feet (12 meters) above the floor. Most of these features are oriented northeast -southwest and represent fault scarps and partly buried reef masses. Some of the faults are associated with faults mapped on the islands.

Another prominent feature of the shelf profile is the serrated ridges and valleys that run along the edge of the shelf with a relief as great as 90 feet (30 meters). These features represent drowned reef masses believed to be active during Pleistocene low sea levels. Their relief is greatest on the eastern portion of the shelf particularly along segments that are oriented northeast-southwest. This orientation probably allowed optimum exposure to nutrient-bearing currents which were from the southeast essentially as they are today (Garrison, et al, 1971).

Sediments of the shelf surface mainly consist of calcareous sands inshore and carbonate nodules plus coral rubble offshore, below 34 meters. The nodules are less common at shallow depths because wave action tends to break them down into sand. In a few locations, the underlying igneous basement rocks protrude above the shelf surface in the form of small islands or shoals. According to Garrison, et al (1971), blanketing sediments are relatively thin, and thus the subsurface structure "shows through" as lines of low escarpments or reef-capped shoals.

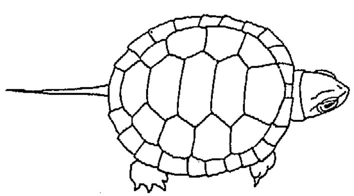
Inner parts of the shelf that surround St. Thomas and St. John exhibit a flat floor or terrace at about the 60 foot depth. On the south coast of St. Thomas, the terrace extends about 0.8 mile offshore, whereas on the north coast and elsewhere, it is narrow, less than 0.3 mile. The relatively flat surface most likely was formed by wave erosion during Pleistocene lower sea levels. Inner parts of the shelf are extensively broken by reef masses or dotted with heads of living coral. Many of these inshore reefs merge with living fringing reefs on island headlands. Consequently, most of the inshore bathymetric curves of minus 30 feet or less tend to follow the shoreline.

Along the south coast of St.Croix, the inner shelf is very shoal, less than 36 feet, and varies from 0.5 mile wide in the east to two miles wide in the west. Reefs form elongate barriers in the eastern part and large patch reefs oriented in lines paralling the coast in the central and western part. Elsewhere, the inner shelf consists of coral sand interspersed with grass beds.

Seismic Activity

Since the Caribbean island arc marks a transition zone between continental and oceanic crustal masses, it is a nearly continuous belt of shallow focus earthquakes. Although seismic activity was more frequent in the vicinity of Hispaniola during 1950-1964, most shallow focus earthquakes in the region are distributed at random throughout the belt. Figure 27 shows the location of earthquake epicenters in the region together with related volcanic and storm surge activity as recorded by the U.S. Naval Oceanographic Office (1963). Earthquakes are generally more frequent in the vicinity of volcanically active islands such as Guadeloupe and Martinique. In the Virgin Islands region, Sykes and Ewing (1965) located the hypo-centers of earthquakes occurring between 1950 and 1964 with a magnitude greater than 3.5 Richter. At this magnitude, which is low to moderate, one earthquake occurs once every three years. Most of these probably occur along the Anegada fault which trends northeast from a position south of Puerto Rico, continues northeast through St. John Passage and Anegada Passage and terminates in the Puerto Rican Tranch.

Large sea waves of extraordinary length, often called tsunamis, have been reported for the area. In deep ocean water they reach 100 miles in length from crest to crest, but their height from trough to crest is only a few feet. When a tsunami enters shoal waters around coasts, the speed decreases but the wave height increases, especially in broad bays. Tsunamis are associated with submarine seismic disturbances, either an earthquake along a fault or an explosion of a volcano. Although most local tsunamis originate in the Caribbean earthquake belt, a few arrive from the mid or eastern Atlantic Ocean. The Lisbon, Portugal earthquake of 1755 created a damaging seismic sea wave throughout the West Indies. Observations are spotty, but small waves seem to occur about every ten or fifteen years (vanEepoel, et al, 1971). A preliminary study of tsunami frequencies by Deane, et al (1973) for the period 1965-1969 indicates a tsunami wave having a maximum two meter wave height will occur once in 75 years.



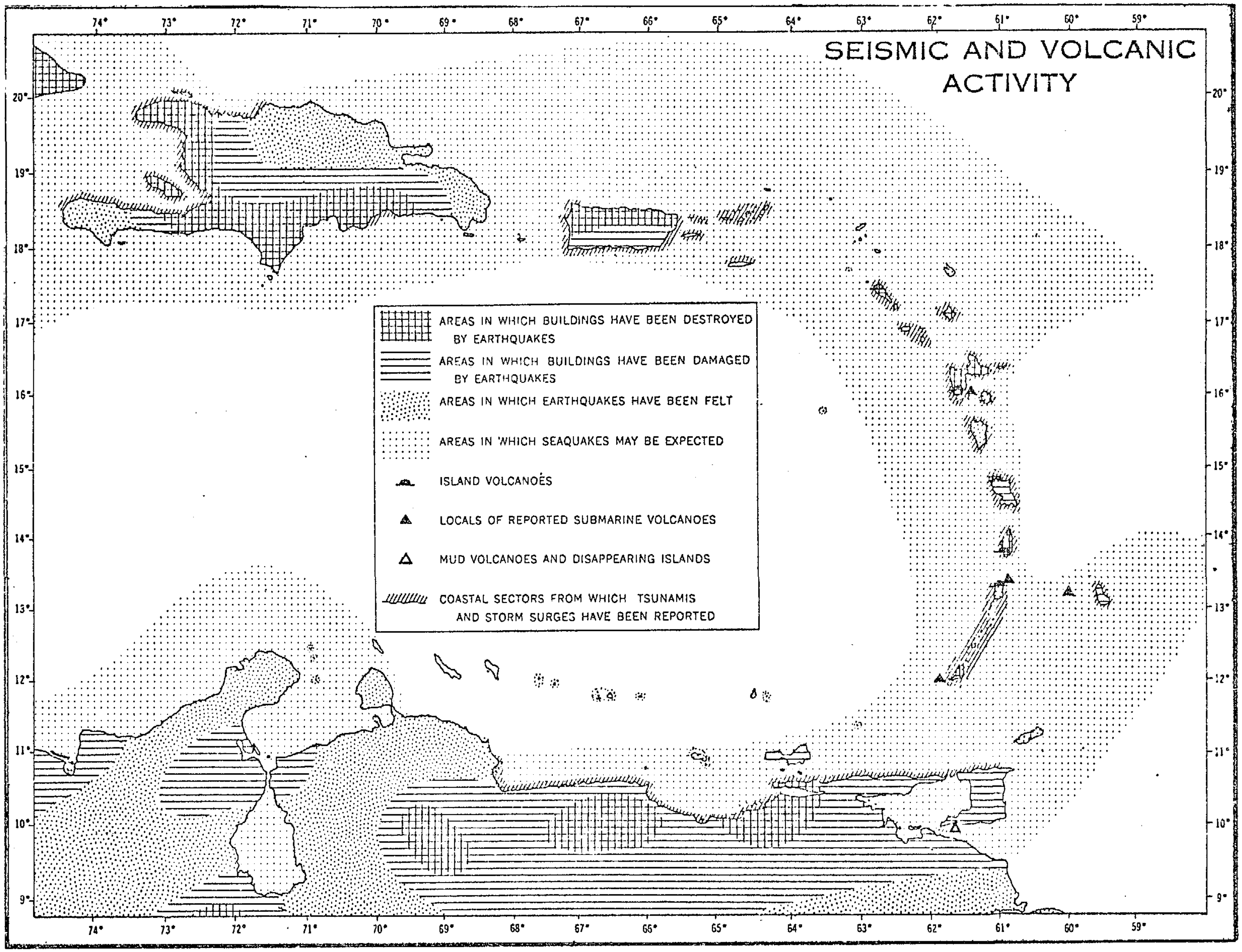


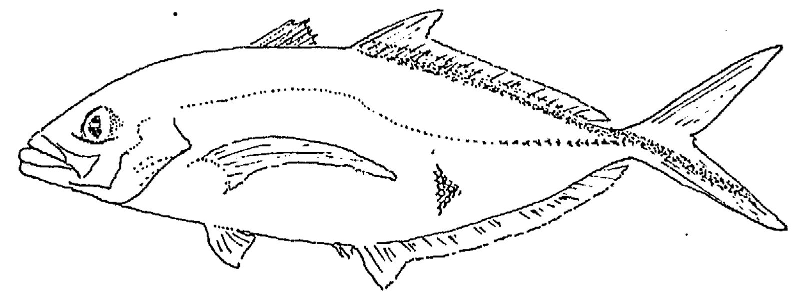
Figure 27. Distribution of Caribbean Seismic and Volcanic Activity. From U.S. Naval Oceanographic Office, 1963.

Marine Ecology

Fisheries

The striking similarity of various studies of fishing in the Virgin Islands going back over forty years emphasizes how fisheries have been relatively static in a period of generally rapid change. The outboard motor, galvanized mesh fish pots, and nylon nets have largely replaced sails, woven wicker pots, and cotton or hemp nets. Diving has acquired greater importance as a fishery method. Catches have climbed gradually in association with improved technology. Fishery resources - particularly, high value semi-sedentary organisms such as conch, whelk, mangrove oyster, etc. - have been reduced to very low densities in accessible areas near population centers.

As the economy and population have burgeoned, the demand for fish and the price per pound have climbed, but the number of fishermen has not changed significantly, except for slight temporary increases during periods of slack in major economic activities (tourism, construction). Personnel from the Virgin Islands Bureau of Fish and Wildlife report such an increase in local fishermen currently. The retarded growth (or decline in some locales) of fishing is part of the general decline of fisheries and agriculture in the West Indies, but specific constraints on fisheries will be treated herein.



Bar Jack or Carang (Caranx ruber)

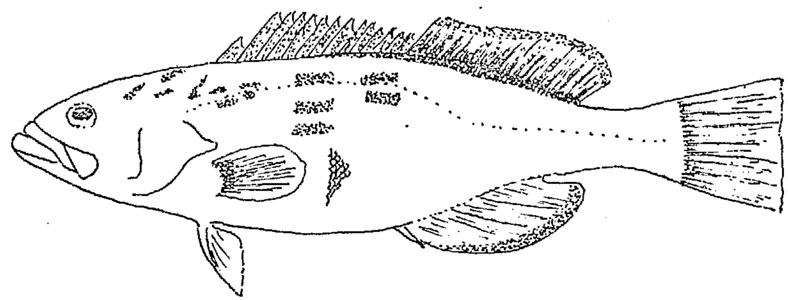
FISHES

The limited pelagic fish resources (billfish, tuna, wahoo, etc.) of the northern Virgin Islands support a sport fishery along the edge of the shelf, but repeated exploratory fishing has made it clear that stocks are not sufficient to support an industrial fishery. The primary commercial resources are demersal fish (and invertebrates) associated with coral reefs and other, usually irregular, "live bottom." A secondary finfish resource is inshore schooling fish, generally jacks, which are traditionally taken with haul seines.

Fish tend to be concentrated around small irregularities at the bottom which provide refuge. Many of the irregularities in the open shelf and its elevated margin are coral reefs produced at lower sea levels during the Pleistocene and now only veneered with living coral or other organisms. Even though primary productivity of these deeper reefs (below 20 fathoms) is lower than shallower reefs, the areas are extensive and currently little exploited. Thus, substantial stocks of fish are present. On deeper reefs, the herbivores (surgeon fish, damsel fish, parrot fish, etc.) which may dominate shallow water trap catches are less common, and catches are more often snappers and groupers which bring a higher price.

Beyond the shelf edge reefs, the bottom drops to 100 fathoms or more before becoming gently sloping again. On the south side of the Virgin Islands plateau, the "drop off" is often a sheer wall from 40 to 100 fathoms, but there are areas, particularly along the northern edge, where the slope is relatively gradual down to 80 fathoms or more. The resources of the shelf edge zone are considerable (primarily several species of red snapper and grouper), but the rough seas and the greater working depths demand a substantial increase in capital investment in gear and boats for effective fishing.

Finfish stocks alone among the living marine resources offer long-term potential for increased yields, primarily by fishing stocks which are now only lightly exploited.



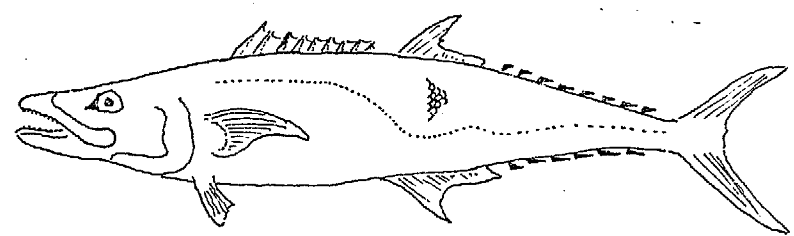
Black Grouper (Mycteroperca bonaci)

OTHER VERTEBRATES

Two other groups make up a small part of the biomass of marine vertebrates on the Virgin Islands shelf - sea turtles and marine mammals. Marine mammals (here whales, dolphins, and porpoises) are not currently regarded as an exploitable resource by Virgin Islanders, but the establishment of a system for reporting sightings or strandings would be of scientific interest. Among these large marine mammals, hump backed whales, pilot whales and bottle-nose dolphins migrate through our waters in the spring.

Sea turtles have been a traditional fishery in the Virgin Islands, and, although relatively few people still fish for them regularly, any turtle encountered incidentally is caught. Islanders still seasonally monitor beaches where turtles are known to nest in order to collect eggs and perhaps capture the nesting female. Unlike lobster or other animals with pelagic larvae, once a sea turtle nesting colony is extirpated, it is probably, in human time frame, gone forever.

Sea turtle species in probable order of abundance in local waters are: hawksbill, green turtle, loggerhead. Despite its relative abundance in the Virgin Islands, the hawksbill turtle is seriously endangered world wide, by a combination of hunting for food and shell. A UNDP-sponsored (United Nations Development Programme) crafts training project in Tortola, British Virgin Islands has contributed to the general resurgence of sales of hawksbill shell artifacts. In the U.S. Virgin Islands, the hawksbill and leatherbacks are completely protected (and the green and loggerhead may be shortly) under the federal Endangered Species Act. Consequently, it is illegal for a tourist to purchase hawksbill products in the British Virgin Islands or elsewhere and import them into the United States. Seizure of endangered species products in U.S. Customs is becoming increasingly likely. The stocks of hawksbill shell being sold in St. Thomas shops were confiscated years ago.



Kingfish (*Scomberomorus cavalla*)

SPINY LOBSTERS

In the Virgin Islands, the spiny lobster fishery is second only to finfish in economic importance. The current fishery is a relatively young one which has developed in response to tourist demand and with improved transportation providing access to more distant markets. Conversations with older Virgin Islands fishermen suggest that spiny lobsters were not formerly relished as food by most of the residents of the English-speaking Caribbean, but, like conch, they were abundant and easily caught and made excellent bait for traps or handline fish.

Currently, lobsters are fished by traps and by divers using wire snares. Relatively small amounts of lobster per haul are caught in traditional fish traps, but specialized lobster traps catch virtually no fish, and there is no clear evidence that they are superior for catching lobsters in this region. For most fishermen, it is a better strategy to set fish traps. A few Virgin Islands fishermen, who have made a substantial investment in large boats and power hauling equipment, have also tried using substantial numbers of lobster pots. Many have eventually rejected them. The average annual catch per boat of lobster by St. Thomas-St. John fishermen using fish traps and fishing 5.8 days/month is reported at 200 pounds (Olsen, 1975) - a yield of 0.17 pound/lobster/trap/haul. Free diving for lobsters requires relatively little capital investment (in addition to a boat) and can provide substantial cash rewards for even weekend efforts. Diving for lobster is the primary employment for only a few Virgin Islanders. For a relatively small sample of boat days (21) distributed over nine months, the mean catch by St. Thomas fishermen diving for lobsters was 44.7 pounds/boat/day (Olsen, 1975).

Lobster landings in the U.S. Virgin Islands in 1967 were 85,900 pounds from U.S. Virgin Islands fishermen and 18,640 pounds worth $15,844 (at $0.75/pound) from British Virgin Islands fishermen (Swingle, et al, 1969). Most local lobster were and are sold whole. If 1967 imports from non-Virgin Islands sources of lobster tail are multiplied to approximate live weight, local lobster made up approximately one-fourth of the total consumed. Thus, a substantial demand exists, but marketing problems, as usual, are serious. In the U.S. Virgin Islands and elsewhere, contractual buying by commercial consumers of lobsters (restaurants, hotels) assures a steady source of supply in the face of fluctuating availability of local product, but this means that the local fisherman, particularly the one who dives for lobster on occasional days-off, has no assured market and may actually lose his catch to spoilage before he can sell it. A substantial (but unknown) proportion of the demand in St. Thomas is now supplied by small-scale entrepreneurs flying lobsters in from nearby islands.

QUEEN CONCH

Aboriginal conch shell mounds on Anegada and elsewhere in the Caribbean attest to a long history of exploitation, but despite its continuing economic importance, relatively little is known about the status of conch populations in the Virgin Islands. Most of our limited knowledge of the biology of the queen conch (Strombus gigas) is contained in a paper by Randall (1964) based on work on St. John. Adult conchs generally occur in areas of low wave energy in beds of sea grass (admixed or sometimes dominated by algae), on open sand, and on rocky pavements veneered with sediment and an algal mat. Adult queen conchs are not frequently encountered below 80 feet, roughly the lower depth limit of sea grasses.

Juvenile conchs generally occur in shallow, relatively quiet water (less than 40 feet deep) on coral rubble, sand or sediment with sparse growths of sea grasses. Juveniles smaller than about three inches are rarely, if ever, found and are presumed to be buried in bottom sediments most of the time. Conchs feed on plant material (primarily soft algae) and organic detritus.

Female conchs deposit large masses of eggs in open sandy areas. These hatch releasing larvae with a pelagic life of about three weeks. Like Virgin Islands lobsters, unless larval adaptations to local water circulation patterns deposit them back more or less where they hatched, conch populations in one area are probably dependent for recruitment on larvae produced in some distant unknown area and more directly on the vagaries of water mass movements. For reasons and in patterns as yet unknown, conchs are migratory and seem to move in groups. High catches may be made one year in areas which yielded increasingly fewer conch for the preceding several years. Therefore, any efforts at monitoring the fishery must be sufficiently prolonged to differentiate low yields from natural causes and those from over exploitation.

Queen conch are collected in the Virgin Islands almost exclusively by diving, generally without compressed air. Where conch populations have been more or less exhausted in free diving range (to 50 feet), a few people have found it profitable to dive for them with compressed air. These deeper areas are less productive, and probably conch growth rates are lower. In the past, they constituted a refuge which by migration probably provided some gradual input into the more heavily exploited inshore waters. Thoroughgoing extraction by SCUBA diving bodes ill for anyone still engaged in low technology, subsistence fishing in the same or adjacent areas.

In 1974 the four major food wholesalers in St. Thomas were importing 35,000 pounds per year from dealers in Florida or Puerto Rico at roughly $0.65 per pound delivered. At that time, little or no local conch appeared to be moving through commercial channels (Stott ms., 1974). Most of the imported conch in 1974 and the local conch in 1967 was used by commercial outlets (restaurants, hotels). There is clearly a strong market for conch, but consistent availability is important for large scale commercial outlets.

The quantitative data are not available, but there are numerous instances in the Caribbean of economically serious local depletion of conch populations (e.g., the Grenadines). There are suggestions of similar trends in the Virgin Islands, with exploitation converging on Anegada, the only island with fairly extensive habitat and remaining stocks of conch.

Intensification of the existing conch fishery should not be contemplated until a serious evaluation of stocks is undertaken. This may require an investment of man days seemingly disproportionate to the commercial value of the fishery, but it should be remembered that conch have some traditional subsistence role. The indirect costs (in imported food purchased, for instance) of eliminating (or at least making inaccessible) the resource for some years are rarely properly tallied up against the small gains in cash income.

WHELKS

The whelk, wilk or West Indian topshell (*Cittarium pica*) is a large marine snail formerly common on exposed rocky shores in the Virgin Islands and elsewhere in the West Indies. It is a traditional food in the Virgin Islands and is the only gastropod, other than the queen conch, of any general economic importance.

The narrow habitat zone occupied by whelk extends from the upper limit of rocks constantly wetted by wave splash to perhaps five feet (generally less) below the surface. The upper limit of whelk distribution probably is controlled by dessication and availability of algae for food, and the lower limit by predation.

Generally, smaller animals occur in the upper tidal zone, and the largest animals (four to five inches basal diameter) occur below the low tide mark in crevices in areas of heavy surge.

Whelks are harvested by walking along rocky shores and picking them from the rock surface or by snorkelling near steep rock shores. The ease and lack of equipment required for gathering whelks partly accounts for their virtual disappearance near populated areas. Whelk larvae are probably at least briefly planktonic, but marking experiments suggest that after juveniles settle out of the plankton, they move only short distances.

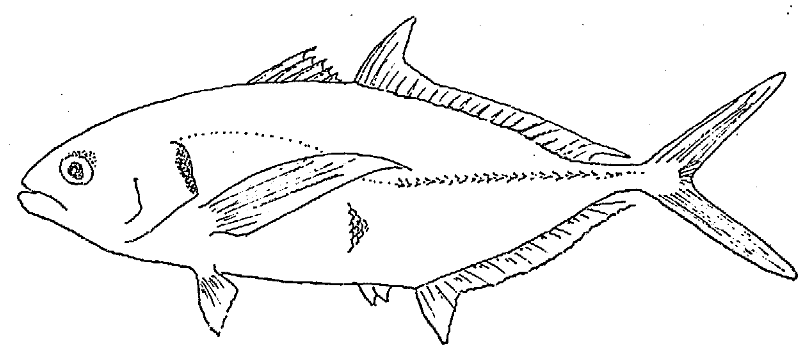
More mobile animals (fish, lobsters, and even conch) may disperse from unexploited areas into those which have been heavily fished and consequently maintain an exploitable population. But in areas depleted of whelk, it will take a number of years for newly recruited juveniles to grow to exploitable size.

The only paper on whelk biology useful to management is by Randall (1964), which includes studies on distribution, diet, size structure, growth and reproduction in a population on the south shore of St. John, U.S. Virgin Islands.

Using boats and/or snorkelling gear to collect in previously unexploited areas (rocky cliffs inaccessible from land or the shores of isolated cays), it is possible to collect commercially significant quantities of whelk.

Swingle, et al (1969) reported that 22,305 pounds of whelk ($8,900 at $0.40 per pound) were sold to commercial outlets in the U.S. Virgin Islands in 1968. No whelk were imported from outside the Virgin Islands. Presently, at least one retailer is importing from other islands. Probably collection for home use is of equal or greater magnitude. In terms of catch per unit effort, each of six U.S. Virgin Islands fishermen reported collecting a mean of 500 pounds/day of whelks for a total of 15 days (Olsen, 1975).

Again, without some stock assessment and monitoring of catch, whelk collecting should be discouraged as a means of diversifying the fishery. The pelagic phase of the life cycle, secretiveness and a preference for rough water on rocky coasts means that some whelks will always be present, if unexploitable, but some decision needs to be made whether whelk are to be viewed as a subsistence or "recreational" resource or one to be exploited commercially. In the event of the development of a regulatory mechanism, any number of arrangements are possible, but the simplest for optimizing yield will probably be a minimum size. If the subsistence aspect is important, a catch limit is also useful.



Blue Runner (*Caranx fusus*)

CIGUATERA FISH POISONING

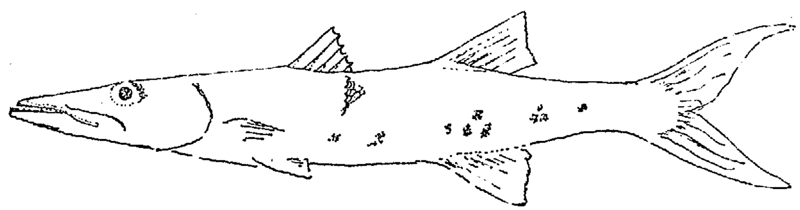
Fish poisoning is a relatively common event in the Virgin Islands and, in addition to the public health problem, constitutes a major impediment to fishery development, particularly in expanding marketing to the tourism sector. In St. Thomas, any mass poisoning resulting from sales of toxic fish to residents temporarily depresses the market for local fish.

The general strategy of fishermen is to avoid certain localities, or particular species in particular localities, which are traditionally known to harbor poisonous fish.

Incidental poisonings of non-residents unfamiliar with ciguatera are relatively common (bare-boat charterers, down-islanders, etc.). Fishermen are also poisoned by taking a chance eating a fish they are unwilling to sell. However, toxic localities are subject to little fishing pressure, and a somewhat unscrupulous fisherman can readily make a good catch and substantial income if he is willing to risk poisoning his customers. As populations rise in the Virgin Islands and community cohesiveness declines, this problem is likely to increase. Any middleman (e.g., a cooperative marketing operation) can fall victim to this unless some system of fisherman accountability is established.

Many potential commercial consumers of local fish in St. Thomas avoid it not only because of high price for unprocessed fish, but because of concern about poisoning their guests. Presumably part of this is reputation and other concerns about liability.

The Island Resources Foundation of St. Thomas maintains an epidemiological register of intoxication incidents, and a laboratory at Bitter End, North Sound, Virgin Gorda in the British Virgin Islands is surveying the distribution of toxic fish and collecting them in order to extract and characterize the toxin. Work is also going on in other parts of the world, but despite considerable effort (Brody, 1972, a summary of ciguatera in the Virgin Islands including lists of toxic species), there is no simple way to determine if a fish is toxic.



Great Barracuda or Barra (*Sphyraena barracuda*)

PRODUCTION AND HARVESTABLE YIELDS

The preceding pastiche of biology, ecology, exploitation history and qualitative recommendations are intended to give a predominantly biological overview of the primary fishery resources of the Virgin Islands shelf which are accessible to current fishing gear and methods. The basic objective of fishery management could be described as obtaining the greatest yield of useable product at the least effort over some extended period of time. It is also desirable that the yield be, if not uniform, at least predictable through time so that large amounts of effort are not wasted at the wrong time looking for resources that are not there.

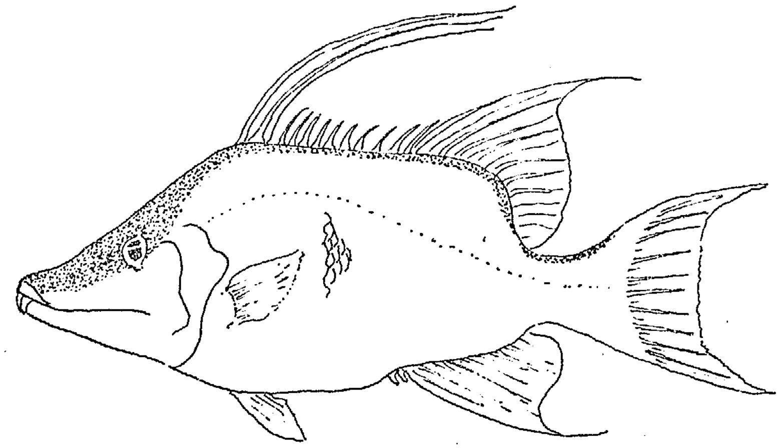
As pointed out in the individual resource discussions, the life histories and primarily the lower reproductive potential of marine mammals and turtles make their management very different from that of most fish and marine invertebrates. This latter group, including virtually all of the species exploited in the Virgin Islands, produce large numbers of planktonic larvae which drift for weeks or months before transforming into something resembling the adult form. In the case of reef associated organisms, they then may establish themselves in some possibly permanent abode on the bottom. The survival of the dispersing planktonic larvae is related to nutrient availability, temperature, and related physical parameters in the waters in which they drift. Thus, the number of new recruits annually to a fish or lobster population is not dependent on local egg production. There are some unexplained activities of tropical fish which make one somewhat uneasy about the completeness of the picture presented by these assertions, but they are, in the main, true.

Though over-exploitation of a fish stock is possible, planktonic larvae and wide distribution make biological extinction of a species by traditional fishing methods extremely unlikely. However, the substantially lower reproductive potential of marine mammals (for many one young/ 2 years) and sea turtles (a few hundred eggs/3-4 years) make it quite possible that continued or expanded harvesting will lead to biological extinction within a region.

Geographic extent of habitat, mobility and/or site fixity of a species also affect the vulnerability for local stock depletion by exploitation. Contrast the restricted habitat and low mobility of whelks with coral reef fish which are relatively rapidly recruited from adjacent areas to occupy desirable habitats from which other fish have been caught.

The growth of most animals asymptomatically approaches an upper limit; thus, growth per unit time decreases. Any fish population is also subject to some mortality, probably through predation and fishing pressure. The mortality is reflected in the size structure of a population (many small fishes versus few large ones). Using basically this information and some assumptions which are reasonably well founded, it is possible to calculate a minimum size limit which will provide a maximum yield. Market preferences and available gear may require modifying the figure somewhat, but it may also turn out that some fisheries are, in a sense, self-regulating, in that fish are caught only at or above the recommended minimum. The issue that then remains is whether the regulatory agency proposes to control the number of fishermen between whom the available catch is distributed or will permit economics to take its course.

In a multi-species fishery, like a coral reef trap fishery, interactions may develop, i.e., if heavy selective fishing removes large predatory species like snapper and grouper, their prey species, including smaller herbivorous species and lobster, may increase in numbers.



Hogfish (Lachnolaimus maximus)

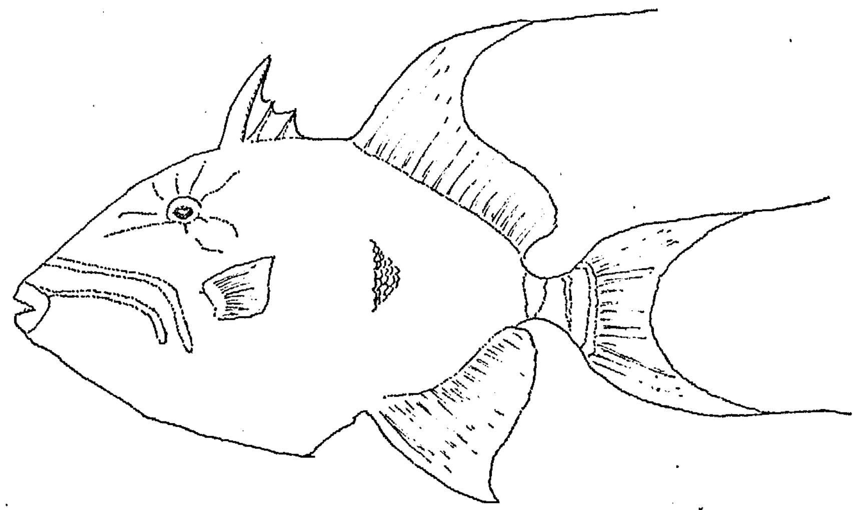
PECULIAR LOCAL RESTRICTIONS

Basic restrictions on the development of large-scale fisheries are imposed by the size of the Virgin Islands Plateau and its geological irregularities. While improvements in technology can no doubt increase the yield of various commercial species, the relatively small plateau areas available for fishing precludes sustained production of vast quantities of most species.

Also, while most of our fishery is associated with reefs, the irregular, hard bottom of most of the Virgin Islands shelf and the concentration of fish in areas of rugged physiographic relief makes trawling impractical and interferes with the use of bottom set-lines, multiple traps on a single ground-line, and stationary nets of various sorts.

The low productivity of the fishery (both in total catch and catch per unit effort) is also a reflection of the naturally low primary productivity (little growth of phytoplankton, the base of oceanic food chains) of Virgin Islands waters. Most primary production inshore is benthic - coral reefs, algae and grass beds - and most fish are caught in these areas. Much of the open shelf of the Virgin Islands is relatively flat but too deep (thus the light is too dim) for sea grasses or vigorous coral reef growth.

Thus, while there is room for improvement in fisheries, local conditions which limit production and harvesting do not allow development of a fishing industry akin to that of continental shelf areas.

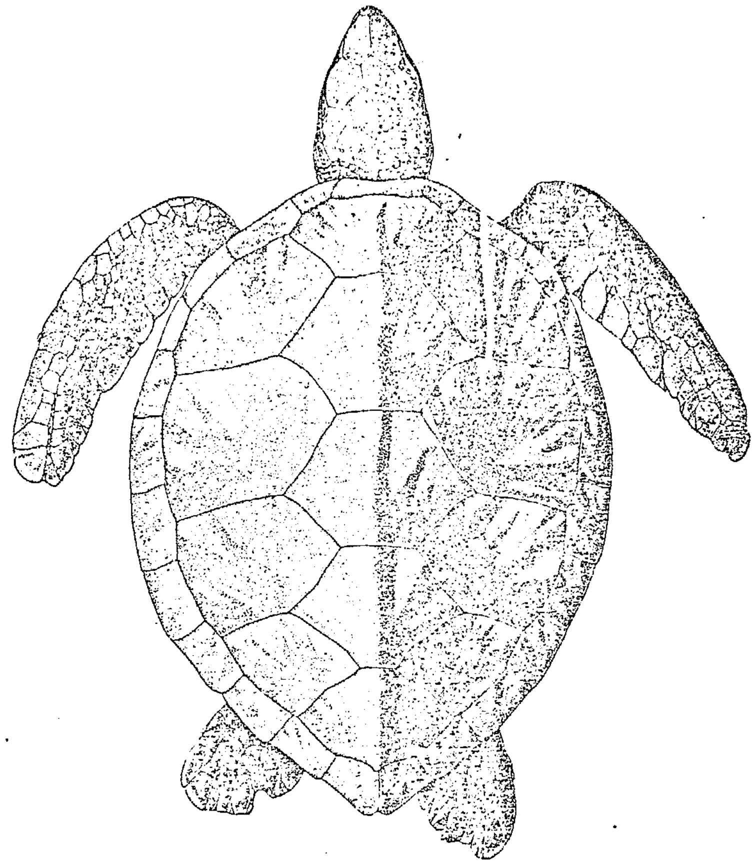


Queen Triggerfish or Old Wife (Balistes vetula)

Other Coastal Wildlife

In addition to strictly marine species, other typical Virgin Islands wildlife are found in coastal areas. Many of our birds depend heavily on mangrove areas and offshore cays as feeding and nesting grounds. The mangroves are apparently the major nesting areas of the vanishing white capped pigeon. Most of the doves which feed and are hunted on St. Thomas nest on the off-shore cays. The common brown pelican - a permanent resident - is in danger of extinction but nests on some of the cays. Other permanent resident sea birds are brown boobies and frigate birds. Laughing gulls, terns, blue-faced boobies and tropic birds come here to nest on the cays. Coastal mangroves provide protective habitats for several other birds and reptiles (lizards and snakes) which are infrequently seen elsewhere. Some offshore cays appear to be the last outposts of rare lizards, skinks, and snakes.

Coastal salt ponds are feeding areas for several kinds of wading birds, especially when they are closed from the sea and the birds do not have to compete with invading fishes for food organisms living in the pond.



Chelonia mydas Green turtle

Coastal and Submarine Habitats

These natural systems, separately and in combination, perform countless valuable functions for man at no cost, drawing energy from the sun. They buffer storm winds and waves, stabilize and protect the shoreline with its expensive man-made infrastructure and facilities, purify water and offer an immense variety of diverse vistas and interesting wildlife and vegetation. The habitats and their associated processes support the safety, health and welfare of every Virgin Islands resident and must be preserved. Different segments of each island contribute in varying degrees to each particular function, and these elements are treated separately.

The following sections describe the major coastal and shallow water marine habitats of the Virgin Islands (to 10 fathoms depth). These include beaches, rocky shores, salt ponds, mangroves, coral reefs, sandy sea beds, grass beds, and the offshore cays. Cays, more than other small oceanic islands including the three larger Virgins, are "coastal" in entirety. Because of their very small size, the entire area of a cay is continually subjected to the influences of oceanic winds and salty air. Also because of their small size, a much higher percentage of their area is bathed by the sea in comparison with larger land masses. Almost all have salt ponds which often occupy a large percentage of their acreage. These factors are strongly determinant of the physiography, hydrology, soil, vegetation and fauna of the cays. Therefore, it is important to include them in the discussion of the coastal zone of the Virgin Islands.

The discussion of each coastal unit procedes from description of characteristic physical and biological processes. Attributes, use options and use limitations are based on these natural characteristics. Figures 28 and 29 present the distribution of each habitat type and highlight other pertinent information.

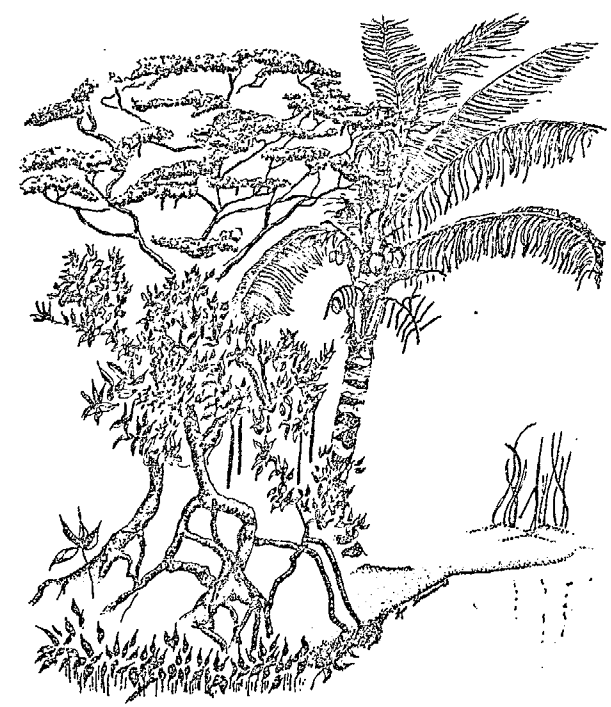
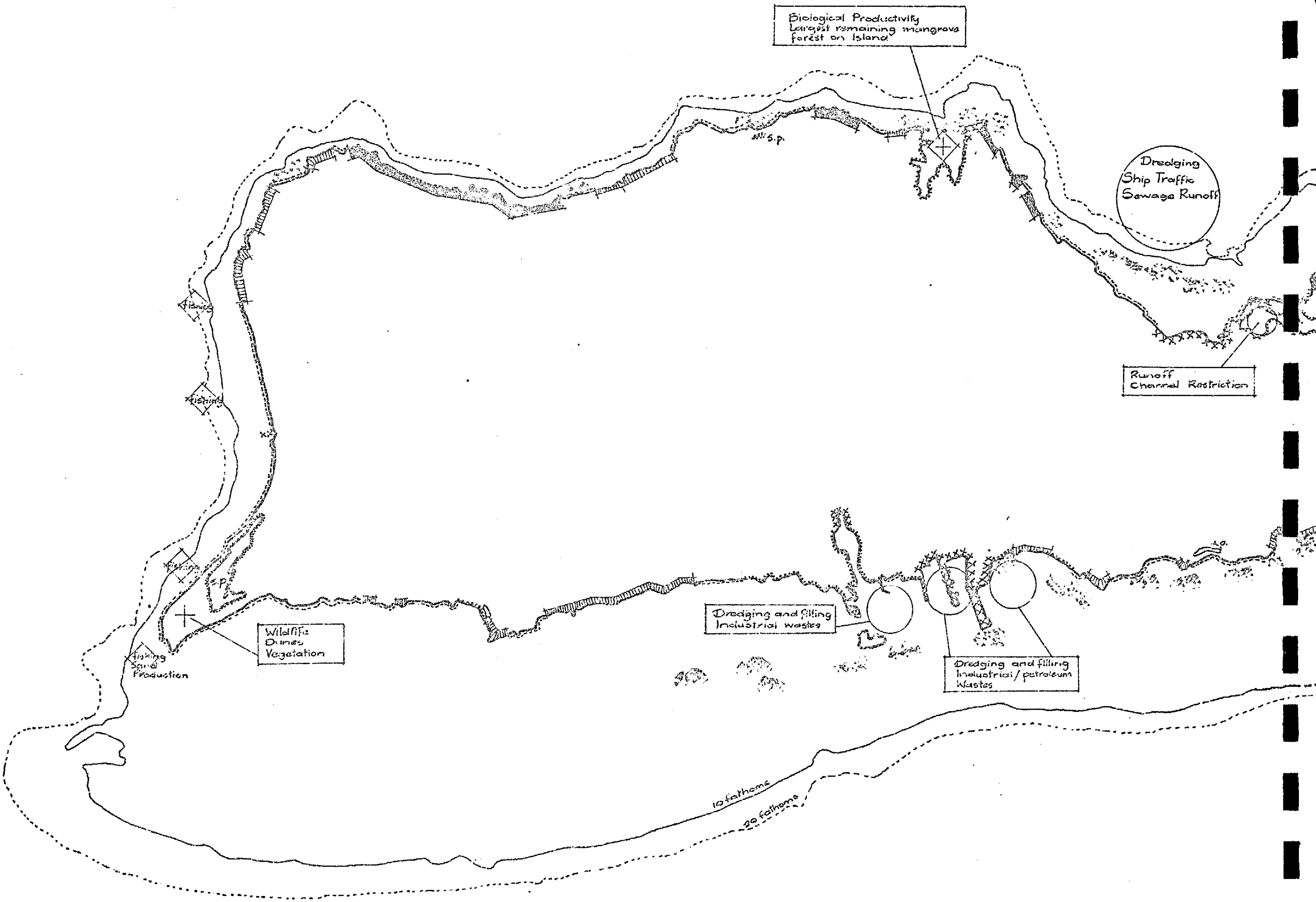


Fig 28 Coastal and Submarine Habitats, St. Croix



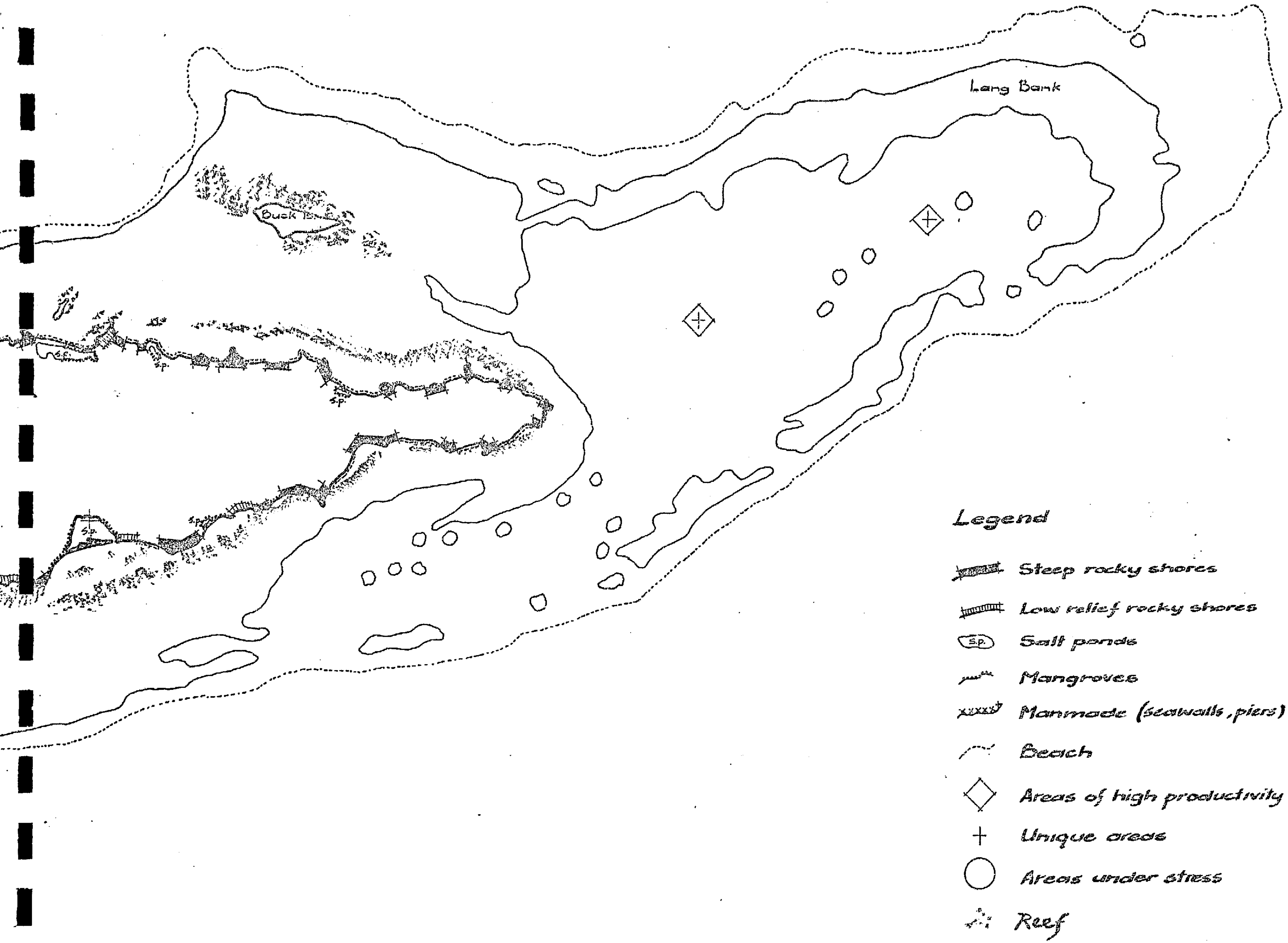
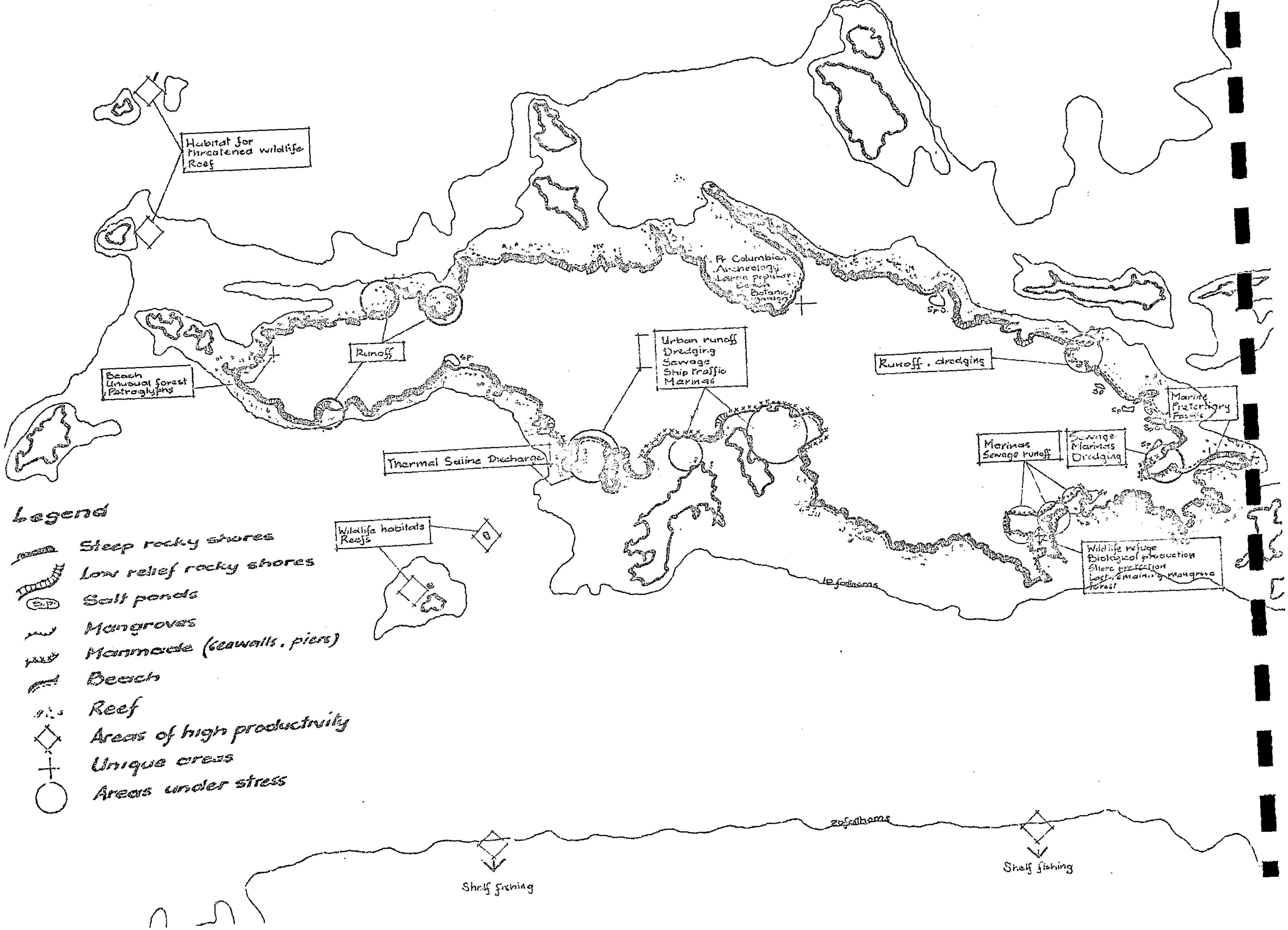
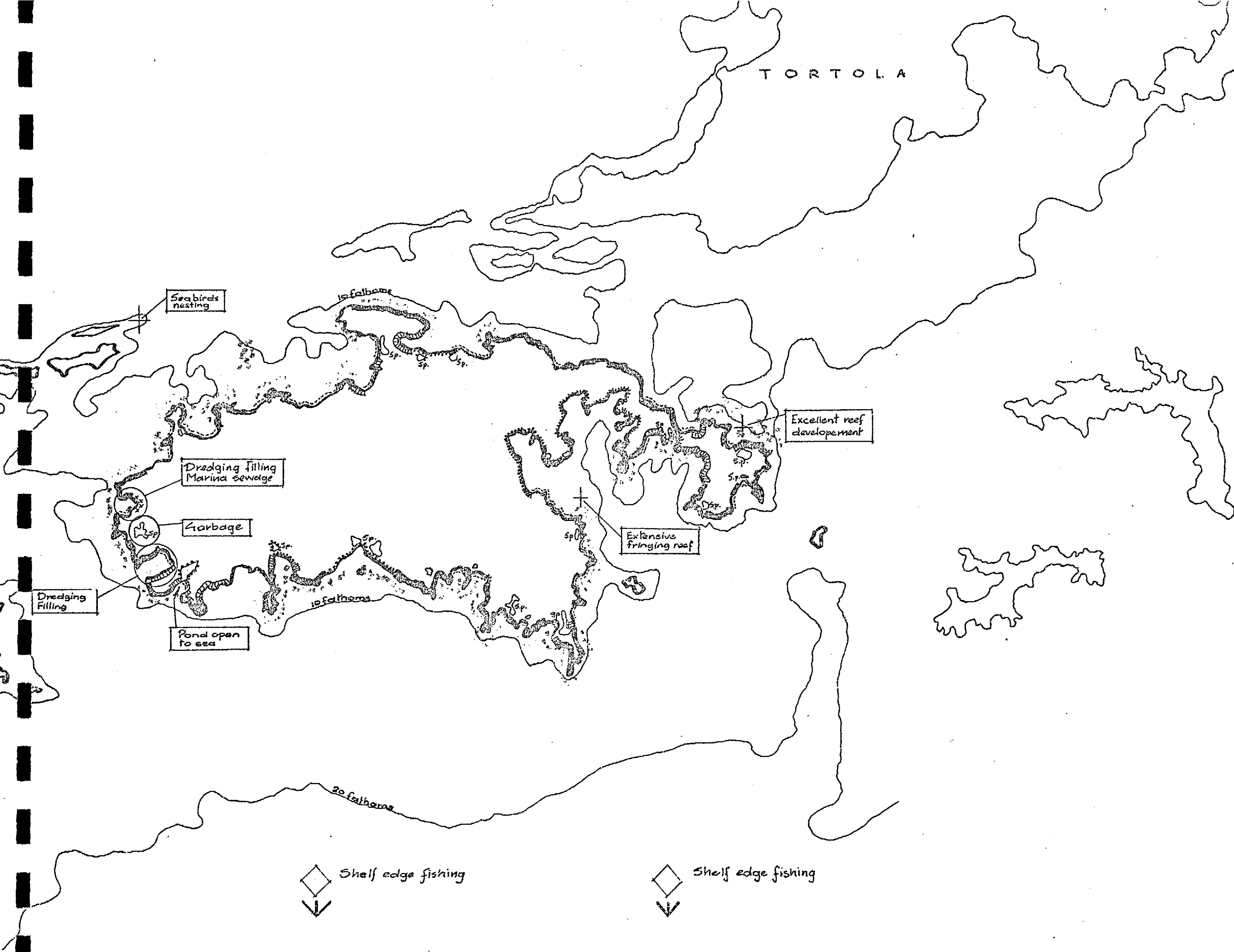
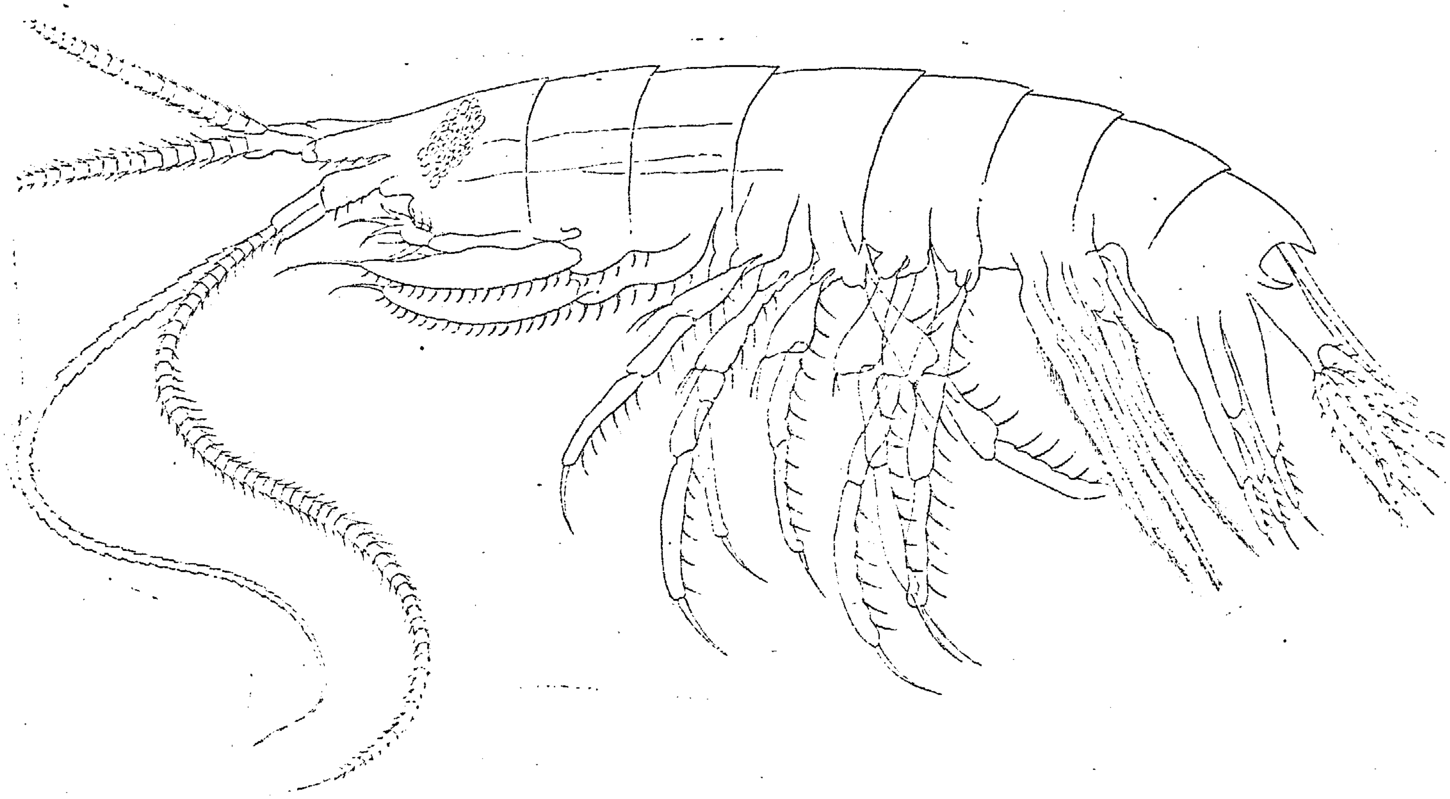

Lang Bank
Buck Is.
S.P.
Legend
Steep rocky shores
Low relief rocky shores
Salt ponds
Mangroves
Manmade (seawalls, piers)
Beach
Areas of high productivity
Unique areas
Areas under stress
Reef

Fig 29 Coastal and Submarine Habitats, St.Thomas and St. John




TORTOLA
Seabirds nesting
10 fathoms
Sp.
Excellent reef developement
Dredging filling Marina sewage
Garbage
Extensive fringing reef
Dredging Filling
Pond open to sea
10 fathoms
20 fathoms
Shelf edge fishing
Shelf edge fishing



BEACHES

Beaches are parts of the shore that are covered with sand, gravel or debris and which are covered and uncovered by the tide. Beach sediments are highly mobile, and thus beaches are constantly changing their form and dimensions.

Beaches are mainly the end product of the interplay of water movements and sediment supplied by cliff erosion or from coral reefs. Beach organisms, however, also contribute to the supply, erosion and consolidation of beach sediments. Beach semiments of the Virgin Islands consist of a variety of materials. They contain within them evidence of their origin, either terrigenous or marine.

SOURCES OF BEACH SEDIMENT

The terrigenous material consists of minerals either eroded from cliffs or eroded from soils that are transported to the shore by streams. The terrigenous components typically consist of quartz and feldspar which are light-colored components, or of rock particles which are dark-colored components. Coarse gravel and boulder material is usually of terrigenous origin, but cobbles often consist of coral debris.

The marine components consist of fragments torn from coral reefs or fragments of shell and algal bits thrown up from the nearshore bottom. They are composed of calcium carbonate which imparts a light color to the sand, commonly white. Coral particles are the main component of island beach sand, but the rate of production of coral sediment supplied to a beach is generally low. Calcareous algal particles as Halimeda and Corallinacaea also contribute to beach sand. Algal sediments are produced faster, but they are exceedingly brittle, readily broken at each joint, and reduced to a fine sand or silt which is easily transported away from a beach. Beach stability, therefore, depends on a supply of sediment either from the land or from the sea which is the main source. Consequently, most beach sands are a mixture of different types of material that varies in size and composition according to its source and rate of supply as well as according to the wave and current processes acting on it.

BEACH PROCESSES IN PROFILE

Most beaches are fashioned into a sloping foreshore and a flattened backshore or berm (Figure 30). The foreshore lies between the low water level and the berm crest, whereas the berm lies between the berm crest and the coastline beyond the reach of ordinary waves. The berm height gives an estimate of the height of storm waves that can be expected. The beach is backed by a cliff or low dune ridge whereas seaward it faces a shallow nearshore bottom fronted by a coral reef. The interplay of waves and currents with different types of beach materials produces distinct profiles. The high energy of wash and backwash acting on windward facing coasts or sides of projecting headlands

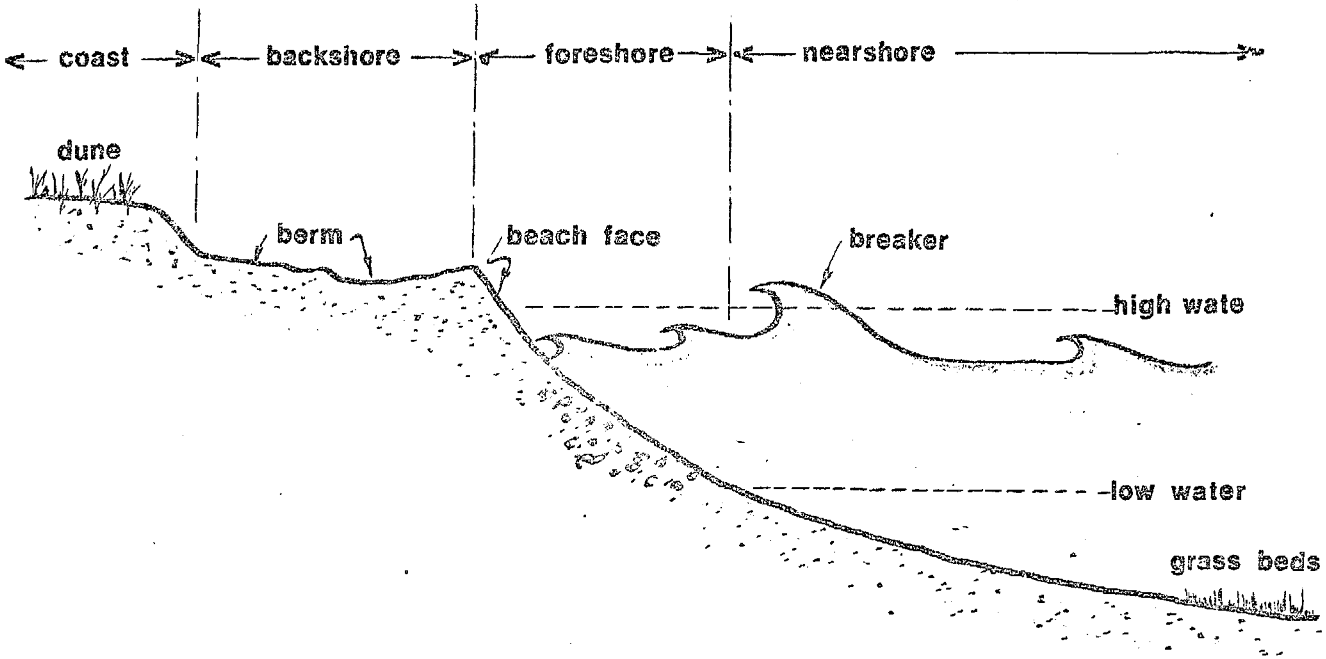


Figure 30. Beach profile showing beach terminology and component parts in relation to high and low water.

produces steep beach foreshores and narrow berms. Sediments, too, respond to the high energy by accumulating as coarse sand, gravel or coral debris. Beachrock is often exposed in lower parts of the profile.

Beach profiles not only change from place to place, but also with time at one place as wave energy changes from season to season. The foreshore is continually adjusting its shape in response to variations in wave height, wave length and direction. Thus, high energy waves of "northerners" acting on a beach will erode the foreshore producing a steep slope and narrow berm (Figure 31). Erosion is also indicated by undermining of trees, exposure of beachrock and a steep beach face (Figure 32). When average waves of less intensity act on the same beach, they tend to deposit sand and build the berm seaward producing a gentle slope. These profile

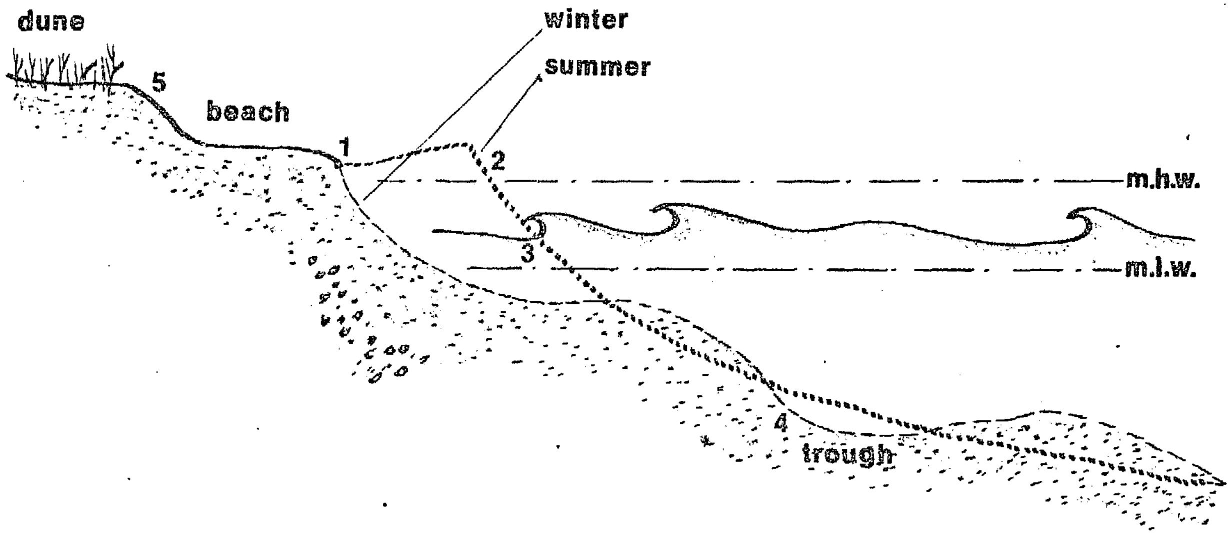


Figure 31. High energy winter profile and moderate energy summer profile (dotted). Modified from Environment Consultants, 1969.

changes reflect the onshore-offshore shuttling or exchange of sand between the beach slope and the inshore. In the process, some of the sediment is lost to deeper water; some is pushed landward across the berm to form dunes or overwash deposits. For another part, the sediment is carried laterally along the beach.

Changes in the beach profile are indicated by the following features. Numbers refer to features in Figure 31.

1. The width of the berm is wider in summer than in winter. Accretion is indicated by several berms.

2. A sharp beach face or scarp indicates beach is undergoing erosion under prevailing waves.

3. The shoreline moves with each wave. Erosion varies with wave height and period. Steepness of the foreshore varies with wave height and permeability and coarseness of the sand.

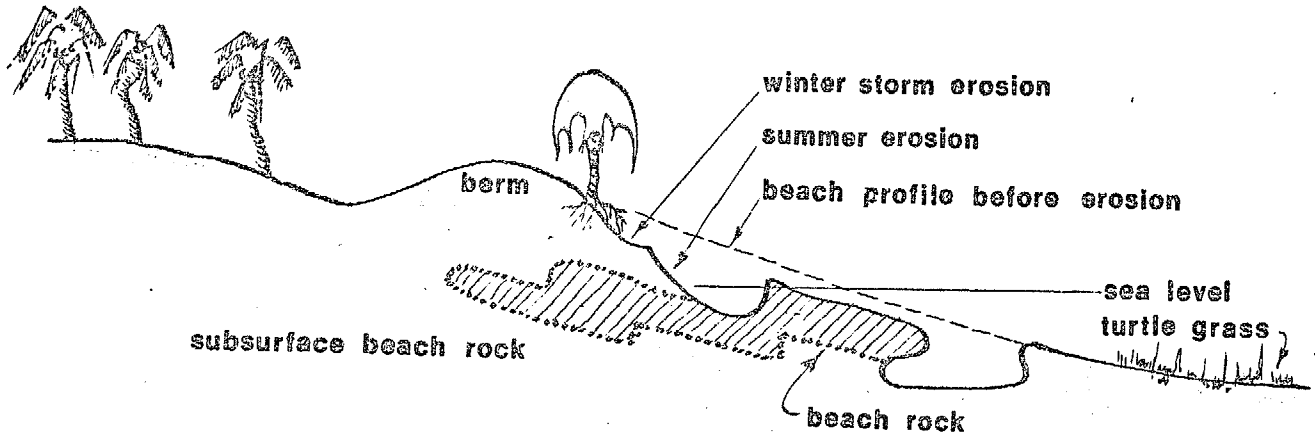


Figure 32. Summer and winter profile in relation to beach rock. Modified from Environment Consultants, 1969.

4. Longshore troughs and bars develop in winter as beach sand moves offshore.

5. Base of dunes is steep when beach undergoes erosion during high storm tides. Trees and banks may be undercut and beach rock exposed in foreshore (Figure 32).

By contrast, the moderate energy of swash and backwash acting on leeward coasts or heads of bays produces gentle beach foreshores and wide berms. Sediments are typically fine-grained carbonate sand.

BEACH PROCESSES IN PLAN

When waves approach the beach from an angle, the water runs up and over the sand at an angle, but then recedes at right angles to the shore. Consequently, sand which is carried by the receding wave is transported downdrift of its origin. Called littoral drift, this transport is a major factor in determining beach width and slope. In the breaker zone, the residual angle of wave approach creates a current along the shore called a littoral or a longshore current. The combined littoral transport is significant in beach stability on relatively straight north and south coasts since these coasts are aligned approximately parallel to the direction of wave approach. As a result of waves approaching the west coast of St. Croix at an angle, particularly during "northerners," sand is continually transported southward by the littoral drift. Thus, the northwestern beaches are narrow and eroding while the southwestern beaches which receive the sand are broad and accreting. Along the south coast a littoral drift directed westward also contributes sand. The combined transport from the north and the east provides an excess amount of sand to the region and thus tend to extend Sandy Point seaward.

Similar lateral movements of sand occur on a single beach as the direction of predominate wave approach changes. For example, at Chenay Bay, which faces northwest on the north coast of St. Croix, swells from the north and northeast drive sand eastward along the beach, whereas local trade wind waves drive sand to the west (Environment Consultants, 1969). During winter "northerners," when swells gain height and become more frequent, this change results in a reversal in the net direction of sand transport: east in winter and west the rest of the year.

The lateral movements of sand result in a change in the width and type of sediment residing on a beach. In general, sediment becomes finer with distance away from a headland, i.e., downstream from its source of supply, and also away from the transporting energy source. Consequently, the beach sediments like those at Botany Bay (Clark, et al, 1964-65) are graded along their length from relatively coarse gravel to coral rubble and finally to sand at the other end. Similarly, beach deposits are relatively narrow and thick on the coarse-grained end and wide and thin on the fine-grained end, i.e., away from the source.

The deeply indented or pocket bays of St. Thomas and St. John display little change in plan. Most changes are onshore and offshore, and many of these beach faces show little seasonal change. Sand transport is largely within the bay itself, and the rates of sand input, transport and loss are more or less in equilibrium. There is little exchange of sediment from bay to bay around the enclosing headland.

Typically, littoral drift and longshore currents along sides of the bays drive the sand inward where it accumulates near the current convergence at the bay head. This is the case for Magens Bay beach (Figure 33) where the convergence is marked by widening of the berm and seaward extension of the shore-

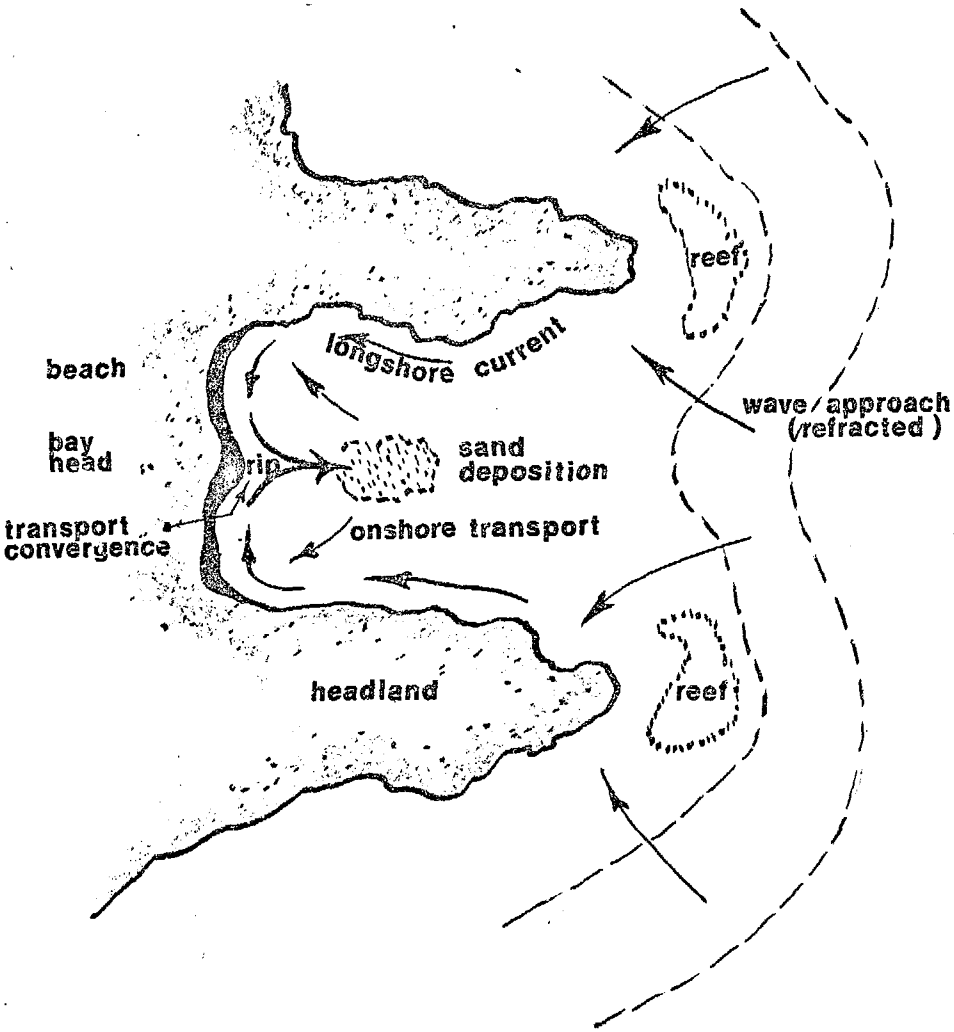


Figure 33. Representation of sand transport in an enclosed bay.

line in central reaches of the beach (Robinson, T., *et al*, 1970). Part of the sand may be carried toward the sea by rip currents directed offshore from the bay head. Another portion of the sand may be driven back ashore by waves acting on the central bay floor. Some bays show a long-term history of accretion at the bay head, particularly where streams contribute sediment to the nearshore zone. By contrast, bays having deep floors, as Cane Bay on the north coast of St. Croix, permanently lose sand from the beach by transport down submarine channels that terminate close to shore (Multer and Gerhard, 1974).

BIOLOGICAL PROCESSES

Although physical processes acting on a beach are the most obvious, organisms are also active in the formation of Virgin Islands beaches. Calcareous algae, coral and invertebrates not only supply most of the sediment to local beaches, but they buffer much wave energy and, in turn, promote accumulation on the beach. Once the sand is deposited, salt-tolerant plants may encroach on the backshore and stabilize the sand. In some places organic debris and grass which inhabits nearshore bottoms is torn loose and deposited on upper parts of the beach. This nearshore grass bed contributes stability to beach sand, acting as a footing to control seaward loss of sand.

Island beaches are not rich in animals, but neither are they sterile. A number of small crabs, clams, worms, and sand dollars live in the sand between the backshore and nearshore zones. Occasional schools of fish fry come close to shore. The offshore grass beds, which may lie in water as shallow as three feet, are rich in plants and animals. Figure 34 relates biological features to the physical zonation of a beach.

BEACH ROCK

Many sand beaches of the Virgin Islands are broken by a ledge of rock that typically runs parallel to the beach and protrudes seaward to the low water line. However, the ledges may be found completely submerged offshore or partly above the high water line or buried within the beach under a thick layer of sand. The rock layer itself is often two to

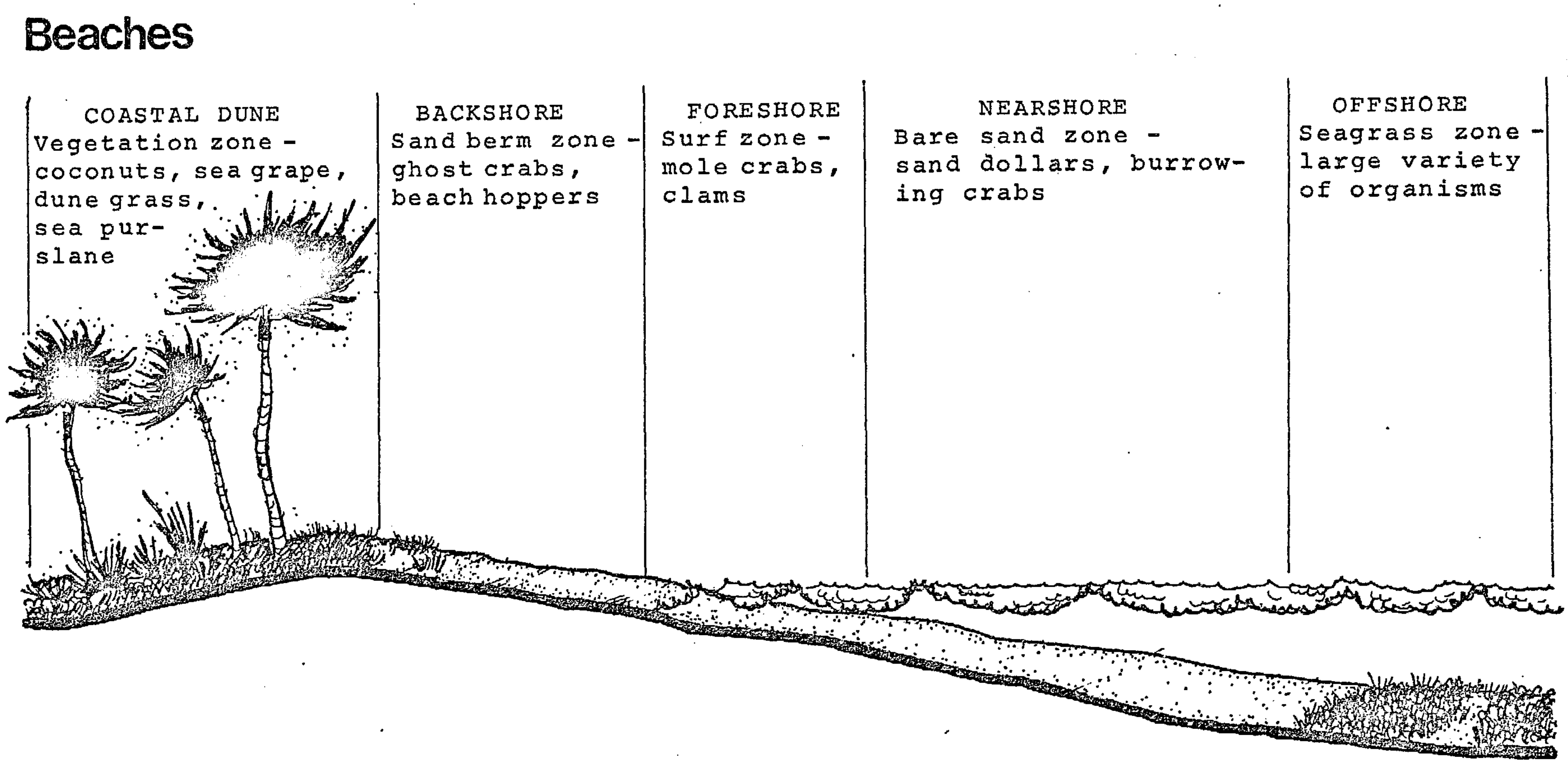


Figure 34. Profile of a beach indicating physical zonation and characteristic organisms.

five feet thick and mainly consists of calcareous sand and shell debris that is held together by carbonate cement. Figure 32 shows the relationship of beach rock to erosion profiles on a beach at Chenay Bay, St. Croix.

The mode of beach rock formation is not fully known, but it is generally believed to be formed in place, below the beach surface, by the natural cementing action of ground water as dissolved calcium carbonate precipitates. In a detailed study of beach rock at Boiler Bay, St. Croix, Moore and Haner (1974) indicated that biological activity contributes to cementation processes. Intermittant exposure in the intertidal zone also may enhance conditions for cementation. Since recent artifacts and debris are occasionally found in the rock, cementation evidently takes place quickly, within a few years. Most beach rock occurs on exposed windward coasts.

GENERALIZATIONS ON STABILITY AND EROSION

Most Virgin Islands beaches are undergoing erosion at varying rates. Erosion rates are generally greatest on exposed windward coasts especially where the rate of sand supply from coral reefs, streams or cliff recession is low. Beaches on windward coasts are generally narrow and less stable than on leeward coasts inasmuch as they are affected by seasonal changes in wave direction and wave height created by "northerners" and passing hurricanes. Beaches along deeply indented bays on St. John and St. Thomas are more stable seasonally than those on open, exposed bays. Depositional beaches, which are relatively wide and often backed by dunes, occur on coasts having coral reefs that protect the beach and supply sand. A few are associated with intermittent stream deltas, a source of supply at some localities. The most rapid accretion occurs around Sandy Point along the southwest end of St. Croix where the beaches receive a dual supply of sand by littoral drifts from west and south coasts.

USES BY MAN

Beaches benefit man directly in five ways: (1) they serve as a buffer zone between land and sea within an ocean island system; (2) they are a source of sand used in concrete aggregate; (3) they are sites for recreation; (4) they serve as terminals for small boat transportation and sites for small boat repair; and (5) some serve as a place to dump wastes or to store sand. Many were also used for nesting by sea turtles in the past, but turtle nesting on Virgin Islands beaches is an extremely rare event now.

As a buffer zone, beaches protect property from wave attack. This use becomes important where shorefront real estate has a high value and where dunes lie close to the beach. Instead of eroding coastal property, the beach has the ability to re-shape itself to the changing physical forces and thus to assimilate wave energy. If sand is temporarily lost offshore, it may be returned later under normal wave conditions. Similarly, if the beach is backed by dunes, sand is often replenished by long-term transfer from the dunes to the beach. Dunes are not only a reservoir of sand but act as a dike that prevents massive flooding of the land by storm tides.

Beach sand has been a traditional source of fine construction aggregate in the Virgin Islands inasmuch as there is no river sand. With rapid growth in construction during the 1960's, mining of sand by both government and private groups led to nearly complete stripping of some beaches. At Boiler Bay and East End Bay, St. Croix, sand was stripped down to the underlying beach rock. As shorefront property values increased and as detrimental effects to recreation and conservation became realized, the Virgin Islands government prohibited mining of beach sand in 1971.

When large quantities of sand are removed from the beach, the natural transport dynamics are affected in several ways: (1) the wave refraction pattern is changed so that sand from both sides of the excavation is moved into the void; (2) sand transported by littoral drift is trapped in the excavation. Therefore, less sand is available for nourishing the beach down coast.

On exposed coasts, removal of large quantities of beach sand results in rapid erosion over the entire beach. The beach slope steepens and the sand becomes coarser. However, on leeward coasts, only a slight local recession of the highwater line is experienced over long periods. A severe swell or hurricane wave attack may cause sudden recession over a wide stretch of beach. The rate of beach recovery from sand mining is reportedly slow, especially where the nearshore bed is excavated and the rate of sand supply to the beach is low as is partly the case for coral sand in Brewers Bay, St. Thomas (Herrick, 1966; Tabb, 1967; Grigg, et al, 1972). Because production of coral beach sand is slow, erosion caused by sand mining is semi-permanent. Offshore sources of sand on the insular shelf provide the best alternative for the longterm needs of an ocean island.

As zones for recreational use, the beaches of the Virgin Islands have exceptional value. They are best used for short-term contact sports, fishing, beach combing, picnicking, camping, horse riding, sunbathing, viewing, and as sites of departure for swimming, surfing, skin diving, small boat launching and SCUBA diving. Recreational uses are described elsewhere in this report.

Although most trans-shipment and boat repair is now accomplished at modern docks and berths, a few beaches in Charlotte Amalie, Christiansted (Nichols, Grigg, vanEepoel, et al, 1972), and outlying areas serve as sites for launching and off-loading small fishing craft. For early islanders, this was the most useful aspect of the beach. Beaches were widely used by lighters and fishing craft as a trans-shipping area in preference to rocky coasts or distant harbors.

Around the urban harbors, beaches have served as sites for waste disposal in an effort to fill and to extend low land. For example, a former bathing beach along Frederiksberg Point, Charlotte Amalie was eliminated prior to 1925 by solid wastes and landfill. A similar case existed along the shore at Truman airport and near Anguilla, St. Croix. Although most disposal is now contained on land, the former fill sites are subject to erosion. Release of former wastes by hurricane presents a potential for pollution of nearshore water.

STRUCTURAL MODIFICATIONS

Engineering structures intended for the beneficial purpose of shore protection often cause deleterious effects when they interfere with natural processes. Effects similar to those caused by sand mining take place when indiscriminate alteration of the beach profile is made by developers. Shore protection structures are of three types: (1) jetties and groins intended to interfere with currents and drift that transport sand; (2) sea walls and bulkheads intended to inhibit direct attack by waves, and (3) beach nourishment by emplacing sand.

By interfering with littoral drift and longshore transport, groins (structures at right angles to the beach) are designed to build up beaches. However, they often cause a shortage of sand on the downstream side of the structure and erosion sets in. A groin only fifty feet long at the Mill Harbor condominium on St. Croix created a wide and high beach but caused severe erosion at neighboring Turquoise Beach. Failure of groins attests to the lack of knowledge concerning the behavior of wave and current processes that they are intended to resist. Groins work best when (1) littoral drift is significant in volume; (2) the material is at least of sand size (between 0.062 and 0.5 millimeter); and (3) when the downstream shore is considered expendable.

By absorbing or reflecting wave energy, sea walls may protect the shore, but they do not prevent the loss of sand on the beach in front of them. In fact, they often accelerate the loss of sand by deflecting wave forces downward onto the beach deposits. At LaGrande Princess, St. Croix, construction of a sea wall in front of the Cruzan Princess condominium not only caused the beach to recede 23 feet within one year, but also caused severe erosion on adjoining property to the east that received much deflected energy from the wall (Environment Consultants, 1969). In short, the structures are often as deleterious as they are beneficial.

ARTIFICIAL BEACHES

When sand is placed on a beach in an attempt to rebuild it artificially, the natural processes continue essentially unhampered. Beach nourishment not only checks erosion but also supplies sand to adjacent beaches. It is economical when large quantities of sand are available and when it does not require long-term management commitment, as do sea walls and groins. Moderately successful beach land fill and nourishment projects have been completed at Protestant [illegible] near Fort Louise Augusta, Christiansted (Nichols, et al, 1972) and at Brewers Bay, St. Thomas (Grigg, et al, 1972). With the sharp rise in beach property values during the late 1960's, there have been attempts to pump offshore sand onto the beaches at several resorts, notably at Grapetree Bay Hotel, St. Croix.

USE IMPACTS

As previously noted, mining of beach sand promotes rapid erosion over an entire beach. Often little sand is left to supply dunes or to buffer the shore against hurricane waves. Dredging of sand has caused moderate damage to reefs in Christiansted harbor (Nichols, et al, 1972), in Brewers Bay (Grigg, et al, 1972), but effects elsewhere are not well known.

Although the best use for beaches seems to be for recreation, even these activities tend to destroy aesthetic and recreational values through littering and pollution. Since backshores are washed only during storm tides, trash and litter often accumulate in this zone. A critical factor for upper backshore dune stability is vegetative cover. Dune buggies, motorcycles and overgrazing by animals can be damaging since exposure of the sand to wind and waves can trigger erosion. Without sanitary facilities on a beach, recreational activities can have a degrading impact on future use. Together with the addition of solid wastes, they present a potential for pollution of shallow ground water supplies and nearshore waters.

Unregulated construction and improperly designed structures present a potential threat to life and property when they fail during storms. Besides accelerating erosion, such structures may result in a recreational hazard as well. Scour holes often develop at the toe of vertical walls and broken masses of concrete and steel rod often protrude from displaced sections. At Cinnamon Bay, St. John, a rock revetment constructed to protect an old Danish warehouse created wave reflections (rather than energy dissipation) that increased scour at the base of the wall and produced sediment plumes extending offshore onto the reefs (Hoffman, et al, 1974). The wall itself was undermined and collapsed.

Artificially nourished beaches display the following impact features: (1) a steep beach foreshore or scarp caused by disequilibrium of the beach profile with nominal wave forces; (2) beach material is often coarse-grained and contains coral debris; (3) lowering of the nearshore profile accompanied by erosion of the deposited sand, and (4) a lag deposit of coarse gravel or coral debris often accumulates in the breaker zone, while fines are released from the nearshore bed or foreshore, cause a turbidity. These effects often extend to nearby marine communities as turbidity reduces light penetration and as the substrate becomes unstable for benthic organisms. Reestablishment of 'pioneer' species in dredge holes and beach fill areas is typically slow (Cronin, et al, 1969; Grigg and vanEepoel, 1971).

Additionally, beaches are increasingly subject to the impact of containerized or accidental discharges of wastes in the open ocean. Floatables found on island beaches include plastics, tar balls, and oil coatings. These typically accumulate on the upper berm and are deleterious to both the biota and aesthetic aspects of the beach environment. Besides long-term accretion of ocean wastes, island beaches are continually threatened by major oil spills from transfer facilities, refining storage and tanker wrecks.

Although nearshore grass beds stabilize the beach by absorbing energy, they present problems for heavily used beach areas. Thick plant growth makes swimming uncomfortable, while heavy deposition of detached grass on the beach produces noxious odors and makes walking and sunbathing uncomfortable. But when grass beds are eliminated nearshore, sands are subject to erosion. Plants comprising the beach litter mainly are Thalassia (turtle grass) and Syringodium (manatee grass).

Beaches are subject to a variety of different impacts from time to time, and these may have cumulative effects over the years. For example, dredging or blasting of coral reefs off a beach often leads to a die-off of the reef. In turn, this reduces the rate of reef-borne sand supply and increases wave attack and erosion on the beach. In areas of high ship and motor boat traffic, boat wakes cause erosion and turbidity of nearshore water. Large-scale reclamation of lowlands disturbs the natural equilibrium of the beaches over wide stretches of coast or throughout a coastal compartment. Along some coasts a small change in coastline geometry or the vitality of mangroves and nearshore grass beds can have a large effect as demonstrated at Estate Whim, St. Croix (Environment Consultants, 1971). Human interference with natural processes is one of the major causes of beach erosion in the Virgin Islands.

EFFECTS OF DREDGING

Channels and ditches dug across beaches to drain and flush back beach lagoons or salt ponds have a history of self-healing closure shortly after they are opened. This is well documented at Altona Lagoon and to some extent at Southgate Pond (Environment Consultants, 1971). At Magens Bay, St. Thomas, torrential rains occasionally overfill the mangrove pond behind the beach causing it to break through the middle of the beach. The resulting canal is reclosed naturally within a few days.

Dredging nearshore beds too close to shore causes sandy beaches and dunes to either erode severely or to slump away into the dredged hole. The beach at Sugar Bay on the south shore of Water Bay, St. Thomas was lost in this way (Grigg and vanEepoel, 1970). Dredging and extensions of the shore-line seaward through landfill in Gordon Bay, St. Thomas harbor allowed wave energy to extend farther land-ward than normal and caused erosion of the nearshore bottom by two or three feet in forty years.

The effects of dredging may be ex-tended to distant beaches via near-shore transport. Serious erosion in Estate Whim, Long Point Bay, St. Croix relates to dredging of the Hess Oil channel five miles to the east (Environment Consultants, 1971). In this case, turbidity generated by dredge spoil caused a reduction in the near-shore grass cover off the beach. Such grass beds normally absorb wave energy, but without them wave energy is entirely expended on the beach. This case illus-trates how beaches may be linked to a sequence of impacts in a chain of causes and effects.

ATTRIBUTES, USE OPTIONS

* Highly desirable recreational areas. Besides swimming, provide easy access to snorkelling, SCUBA diving, sailing, water skiing, etc.

* Generally protected from heavy seas providing safety for recreational uses.

* Plastic nature of sandy shore changes in response to seasonal sea conditions, absorbing wave energy and protecting back shore.

USE LIMITATIONS

* Sand dynamics make beach unstable for structures.

* Structures across beach usually inter-fere with natural sand movement, often having undesirable effects.

* Not suitable for sand mining which usually causes destructive redistri-bution of remaining sand.

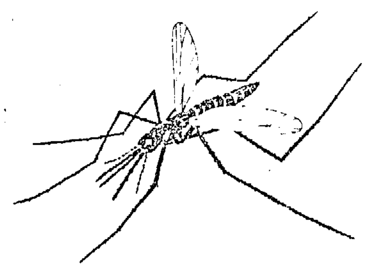
* Not suitable for discharge of wastes. Susceptible to aesthetic and micro-biological (public health) degrada-tion.

INVENTORY OF BEACHES

Locations of beaches on the three islands are shown in Figures 28 and 29. St.

Thomas and St. John, because of their more irregular shorelines, have more beaches than St. Croix.

In addition, much of the gently sloping shoreline of St. Croix, physically described as beach, is poorly suited for swimming because of beach rock, nearshore reefs and, in some areas, highly turbid water or exposure to strong sea and currents. On the other hand, because of its straighter shoreline, St. Croix possesses longer stretches of beach than the other islands. The continuous sandy beach from Concordia to Frederiksted is unparalleled anywhere else in the Virgins.



ROCKY SHORES

Rocky shorelines are here defined as steep slopes or cliffs formed by weathering and wave action on rock outcrops or promontories. These are distinguished from rocky beaches which have a gentle seaward slope but are covered with rock and/or coral rubble.

Rocky shorelines vary from vertically exposed rock faces (parts of the windward slides of most islands and cays) to angular sloping blocks of bedrock (northwest St. Thomas) to boulder strewn shorelines (occurring scattered on all coasts). Occasionally there are eroded outcrops of sandstone or fossil reef areas, particularly on southern St. Croix. The shoreline at the tidal level and some distance below is strewn with boulders derived from the land or eroded projections of the bedrock.

ECOLOGY

Rocky shores are rigorous environments, but far from sterile. The area above the water supports a few specialized salt tolerant plants and related fauna, but below the water there may be well developed coral growth attached to the bedrock and boulder rubble (Figure 35).

Hardy members of the adjacent terrestrial vegetation may cling to the uppermost rocky area where there are pockets of soil or fissures in the rock. Common types are Agave (century plants), barrel cactus, pipe organ cactus and grasses. On some remote rocky cliffs sea birds roost and nest. Lower down where sea

Rocky Shores

WEATHERED OUTCROP	SPLASH ZONE	HARD CORAL ZONE	SOFT CORAL ZONE
Worn by wind, waves and rain usually to bed-rock.	Snails, chitons, seaweeds. Boulders and bed-rock.	<u>Acropora</u> corals dominate coral growth on boulder and rubble substrate.	Sea fans, Gorgonia on hard bottom. Sand cover thin. Water clear.

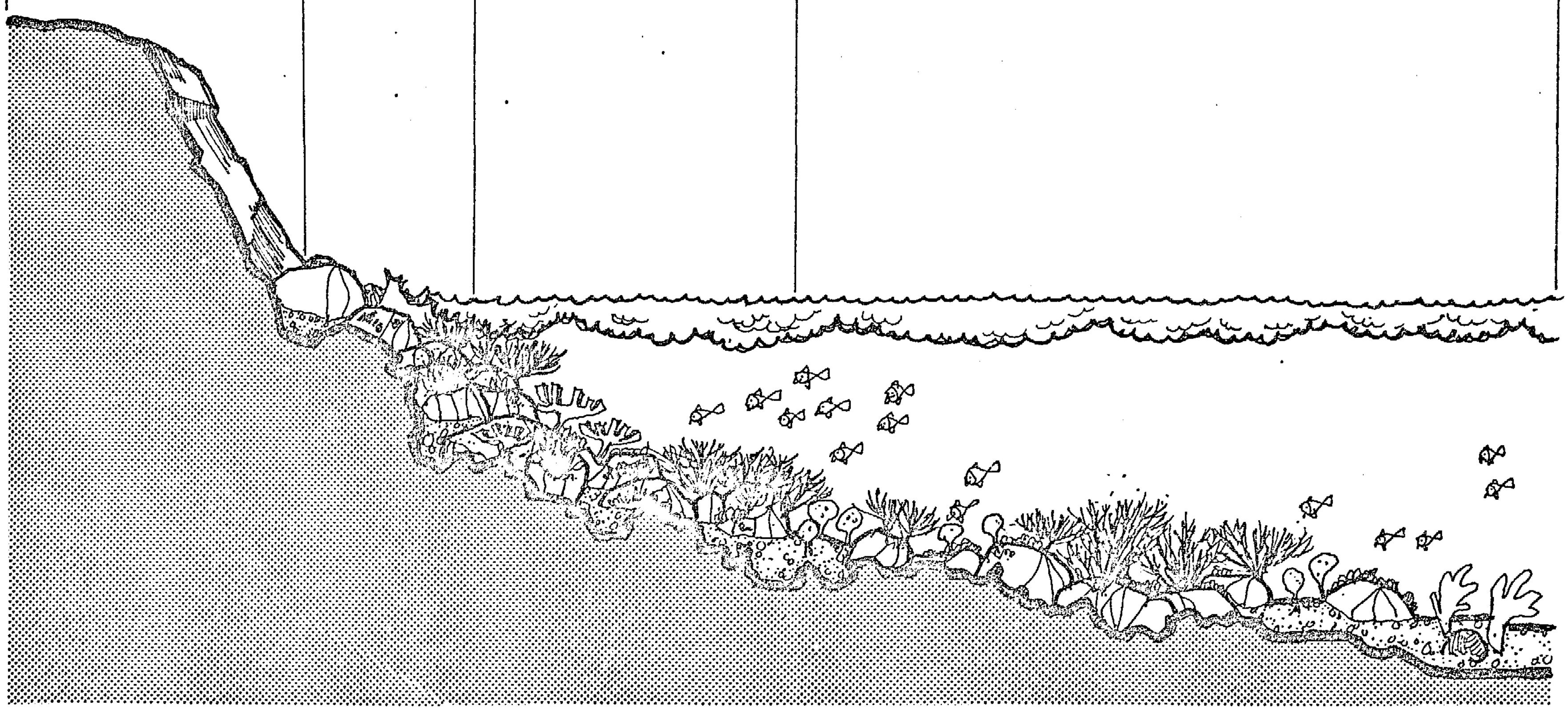


Figure 35. Typical rocky shoreline of eroded volcanic rock with boulder and rubble bottom.

spray occasionally hits the rock a few hardy marine animals can be found: periwinkles and an occasional crab. Closer to the water, the numbers and kinds of organisms increase. In the splash zone oysters, small fish, sea urchins and a wide variety of molluscs can be found, including the edible whelk (Cittarium pica).

The underwater rocky substrate is perfect for coral attachment and the shallow, clear, turbulent water ideal for their growth. In these areas, coral usually follows the hard bottom contour around the land. Adjacent areas - where the shoreline slope is gradual and wave attack is gentler - usually have sandy or intermittently rocky beaches.

At the deeper subsea base of the rocky shore, the reef is often composed of sea fans, sea whips, etc. (gorgonians or "soft" corals). Here land-derived boulders and rock may also be found, but, frequently, the shoreline bedrock is exposed or lies under a very thin layer of sand. Both "hard" and "soft" corals require a hard, stable substrate for attachment. Further offshore, the sand layer becomes thicker, and beds of sea grasses and algae may develop if the water is not too deep. There is almost always a band of bare sand, one or more meters wide, separating the rock and reef area from the sea grass beds. This sandy strip is maintained by browsing fishes and sea urchins which live on the reef and forage on the edge of the grass areas.

Because of the steep slope into the water and their usual occurrence on headlands and points, rocky shores are areas of high wave energy and turbulence. This activity keeps the water well mixed and aerated and discourages siltation. Because of the immediate shore topography, there is usually no local source of concentrated drainage discharge.

ATTRIBUTES, USE OPTIONS

* Frequently good spots for hard line fishing.

* Good spots for snorkelling and SCUBA - often have whelks and lobsters.

* Because of turbulence and water movement, are relatively well suited to receive treated effluents but outfall must be some distance offshore.

* Provide scenic vistas from sea and shore.

* Locally may be important rookeries for sea birds.

USE LIMITATIONS

* Usually rugged and inaccessible, making construction difficult.

* Because of exposure, sites face heavy sea and wind damage in storms.

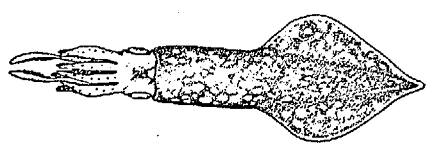
* Rock and coral bottom and turbulence

precludes safe boat docking and anchorage.

* Lack of topsoil precludes use of septic tank and drain fields.

INVENTORY OF ROCKY SHORES

Rocky shores are extensive on all islands, especially on the north (windward) coasts. St. Thomas and St. John are rockier and steeper than St. Croix, even on their southern coasts. The south of St. Croix is mostly flat with beach shores, although these may be low level rocky or gravel beaches. The distribution of steep rocky coasts on the islands is included in Figures 28 and 29.



SALT PONDS

DESCRIPTION (Figure 36)

Most salt ponds are isolated former bays or parts of a bay. Over time, they have become closed by reef or mangrove growth across the bay. The closure may be accelerated by sand and rubble tossed up on the shallow closing bank by storms. They may receive outside bay water slowly by percolation through the berm if it is porous enough. Evaporation in a closed pond is very rapid so that the salinity increases and the pond, if not replenished from the bay or by rain water, will dry up completely leaving crystallized salt on the surface.

Occasionally, a pond berm will be breached by storm water from the land or sea. When this occurs, the pond can be reinvaded by marine animals, usually crabs and fishes. These will die off as the pond recloses and salinity increases again.

ECOLOGY

The biota of a salt pond is very specialized and limited compared to that of the adjacent bay, but its ecology is complex and dynamic. Common animals are fiddler crabs and larger land crabs (*Cardisoma guanhumi*). Several kind of insects which prefer saline environments live or breed there, including a fly (*Salina gracilis*) and several kinds of midges. Mosquitoes may breed there during brief periods when heavy rains lower the salinity sufficiently. Several kinds of microscopic algae float in the water sometimes giving it a green, pink, orange, brown, or red color. Other micro-algae grow as mats on the shallow margins. A number of wading

Salt Ponds

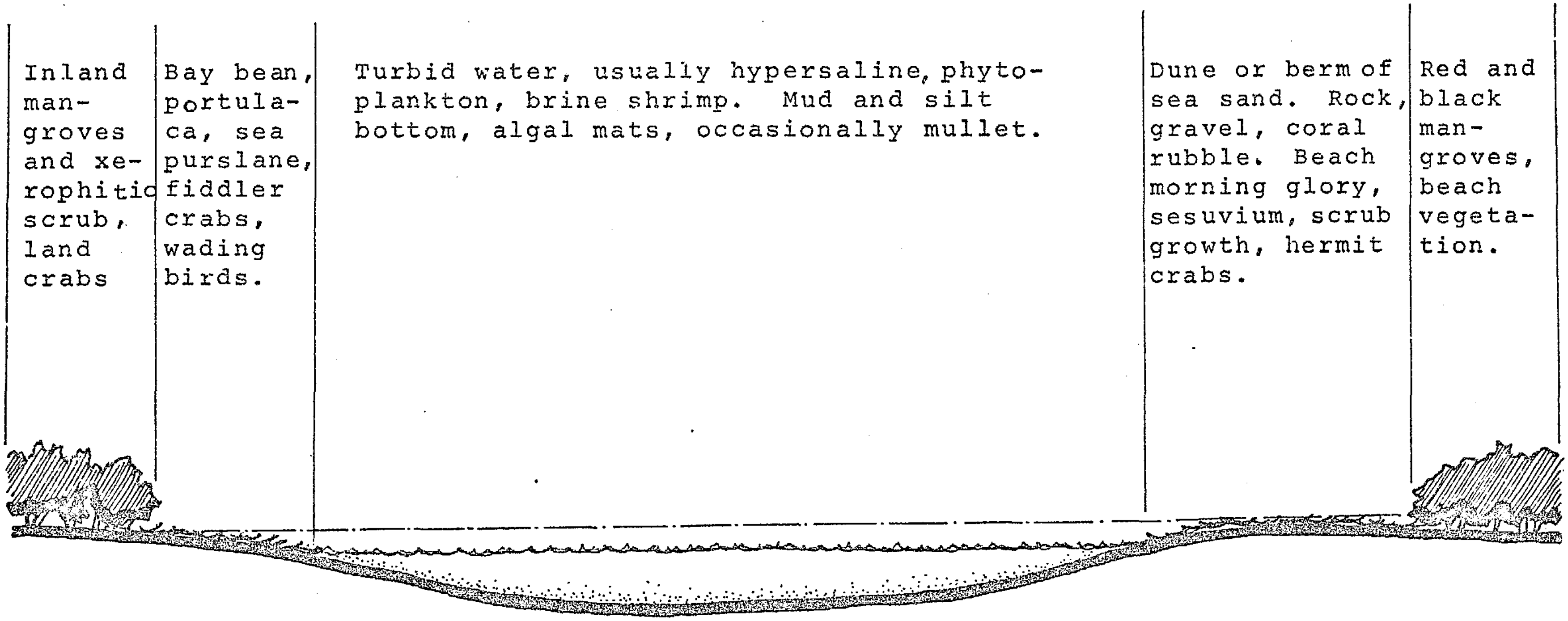


Figure 36. Cross-section of a salt pond. Slopes to beach at right; landward at left.

birds (stilts, sandpipers) feed along the edges of the ponds on crabs, insect larvae and other small animals. Ponds frequently contain large numbers of brine shrimp (Artemia) which is in great demand throughout the world as food for aquarium fish, aquaculture and research organisms. Thick blooms of Artemia can give the pond water a brownish-pink tinge. If the pond is or has been recently open, it will contain fishes (sennet, small barracuda, mullet, tarpon, snook) and marine crabs. These are fed upon by kingfishers, herons and ospreys. Kingbirds ("chincheri") martins and swallows frequently feed on flying insects over the water.

The local animals and plants associated with salt ponds are not well known, and the complex ecology of the ponds can only be inferred in simple outline. They have never been studied properly. We do know that salinity changes over a very wide range. It may concentrate to more than three times that of sea water (over 100 parts per thousand) or be depressed by heavy flooding to almost fresh water (depending on the volume of flood water, the size of the pond and the permeability of the pond-bay barrier). Periodic changes of even one-third of this magnitude would cause significant changes in the types and numbers of organisms inhabiting the pond. Slow changes, as by evaporation concentrating the salt, would promote a gradual die-off of some forms and a gradual invasion and development of others. There would be a constant, slow modification of the natural community in response to this change.

Sudden changes in salinity, as by flood water, causes catostrophic changes in the biota. Masses of halophilic (salt-loving) forms are killed while other types, suited to the new, less saline environment, quickly invade the pond and become established. Following heavy flooding, many ponds contain great amounts of dead halophilic algae, insects, etc. These often account for the occasionally bad odor of a pond.

Other environmental characteristics of salt ponds are high concentrations of hydrogen sulfide, especially in the sediments (from the decay of dead organic matter), high temperature (from isolation with lack of shade), low dissolved oxygen (from high temperature, salinity and B.O.D.), and high turbidity (from large concentrations of land and pond-derived solids).

Although no specific data is available, it is safe to assume that ponds also contain higher concentrations of most pollutants than, for example, their adjacent associated bays. This is likely because of the natural ecosystem function of salt ponds as buffer zones and sumps. As they are located between the bay and its upland watershed, they receive and trap most of the runoff from the land, thus protecting the bay.

Sediment corings in several local ponds have revealed thick layers of terrigenous (land-derived) mud and silt interbedded with layers of organic muck, algal mats and occasional sand lenses. The latter may have been deposited when a hurricane or other violent storm broke open the pond or threw waves over the berm bringing sea sand into the pond. Somewhere at the bottom (depending on the age and depth of the pond) lies the original bay bottom and, below that, bedrock.

Because most of the upper layers of pond sediment are highly organic and being anaerobically decomposed, disturbing these sediments usually releases obnoxious sulfide orders. When these materials are dispersed, they use up the available oxygen rapidly. This can kill animals in the water.

ATTRIBUTES, USE OPTIONS

* Act as natural catchment and settling basins to protect marine resources.

* Provide feeding places for wading birds, insects and fish eating birds.

* Low in dissolved oxygen, frequently less than 4 parts per thousand.

* Biota limited to few organisms which are tolerant of high and changeable salinity.

USE LIMITATIONS

Use constraints include, but may not be limited to, the following:

* Sediments unstable for foundations; pilings almost always required.

* Sediments - fine, toxic, and with high B.O.D. and C.O.D. - can be dangerous to adjacent marine biota if released.

* Modification may adversely alter drainage and runoff patterns.

* If filled, weight of overburden may, depending on nature of pond sediments, extrude pond sediments at certain points. Overburden may be plastic.

* Nature of sediments may limit use of deep-rooted vegetation on overfill.

* Modification will alter or destroy habitat for associated birds.

Tolerances of the system appear to be wide, but this appearance is largely because we know very little about the functioning of the system. All systems and their components have tolerance limits. Obviously, massive inputs of toxic materials will destroy the ability of the system to function. Filling a pond will completely destroy its function as a catchment basin and aquatic habitat. Opening it to the sea will significantly change its ecological function and perhaps that of the adjacent bay.

INVENTORY OF SALT PONDS

The locations of salt ponds on the three main islands are given in Table 3 and shown in Figures 28 and 29. They have been identified from personal knowledge, aerial photographs and various charts. Some very small ponds may not have been accounted for, and some areas with only minimal topographic depressions which hold very shallow lenses of water for short periods after heavy rains have not been included. St. Thomas and St. John have many more ponds than St. Croix and, like the many pocket beaches, this is largely a consequence of the difference in shoreline irregularity. Most salt ponds form at the head of embayments, a setting which also favors beach formation. In fact, in most cases, beaches and salt ponds occur together - a characteristic association in the Virgin Islands coastal zone.

Table 3. Location of Virgin Islands salt ponds, excluding cays.

St. John	
Hawksnest Bay (west)	small
Foot of More Hill	small
Newfound Bay	small
Calabash Boom	small
Turner (Enighed Pond)	large
Chocolate Hole	2 small
	1 large
Hart Bay	small
Europa Bay	medium
Great Lameshur Bay	small
Grootpan Bay	large
Kiddel Bay	small
Salt Pond - Drunk Bay	medium
Harbor Point, Coral Bay	small
Fortsberg	small
Turner Point	small
Elk Bay	small
Haulover Bay	small
Pond Bay	medium
Privateer Bay	small
St. Thomas	
St. John Bay	1 large
	2 small
Smith Bay	1 (cove)
Foster Point	2 small
Mandahl Point	1 very large
Foot of Flag Hill	1 small
Frenchman Bay	1 medium
Little Coculus Bay	3 small
Coculus Point	1 small
Bolongo Bay	1 medium
Cabrita Hill	2 small
Water Point	1 medium
	3 small
Great Bay	2 medium
St. Thomas (continued)	
Muller Bay	2 medium
Vessup Bay	1 large
Krabbepan Point	1 small
Compass Point	1 medium
Mandahl Bay	large
Smith Bay	2 small
St. John Bay	small
Red Bay	large
Vessup Bay	large
Great Bay (north)	small
	medium
Great Bay (south)	small
Water Point	small
Scott Beach	small
Benner Bay	large
Mangrove Lagoon	2 large
Long Point	small
Bovoni Bay	small
Bolongo	small
Little Coculus Bay	2 small
Frenchman Bay	small
Cove between Frenchman and Morningstar	small
Perserverance	small
Fortuna	small
St. Croix	
Great Pond Bay	very large
Robin Bay	large
West End	very large
Coakley Bay	large
Chenay Bay	large

MANGROVES

DESCRIPTION

Mangrove habitats are limited in the Virgin Islands, probably because of the lack of rivers or streams. The largest areas which did exist have been destroyed by filling for land development. Mangrove plants, in narrow strips along the coast, are fairly common, but well developed mangrove forests and their associated marine nursery areas survive only at Salt River, St. Croix (Figure 37) and Jersey Bay, St. Thomas (Figures 8 and 18).

The greatest mangrove lagoon systems in the islands - Krause Lagoon on St. Croix and Mosquito (Lindbergh) Bay on St. Thomas - have been filled for land development. Some of the remaining mangrove plants at Krause Lagoon are slowly succumbing to air and water pollution and continued construction.

Mangroves are flowering trees which can live in salt or brackish water. Several different trees are referred to by the common name "mangrove," but the most common are Red Mangrove (Rhizophora mangle), White Mangrove (Languncularia racemosa) and Black Mangrove (Avicenia nitida). Rhizophora, known as "the plant that makes land," is the most typically recognized species. It grows at the water's edge, and new seedlings become established to seaward. Besides providing support and hiding places for a wide variety of marine animals, the prop root system of the plants traps sediments that

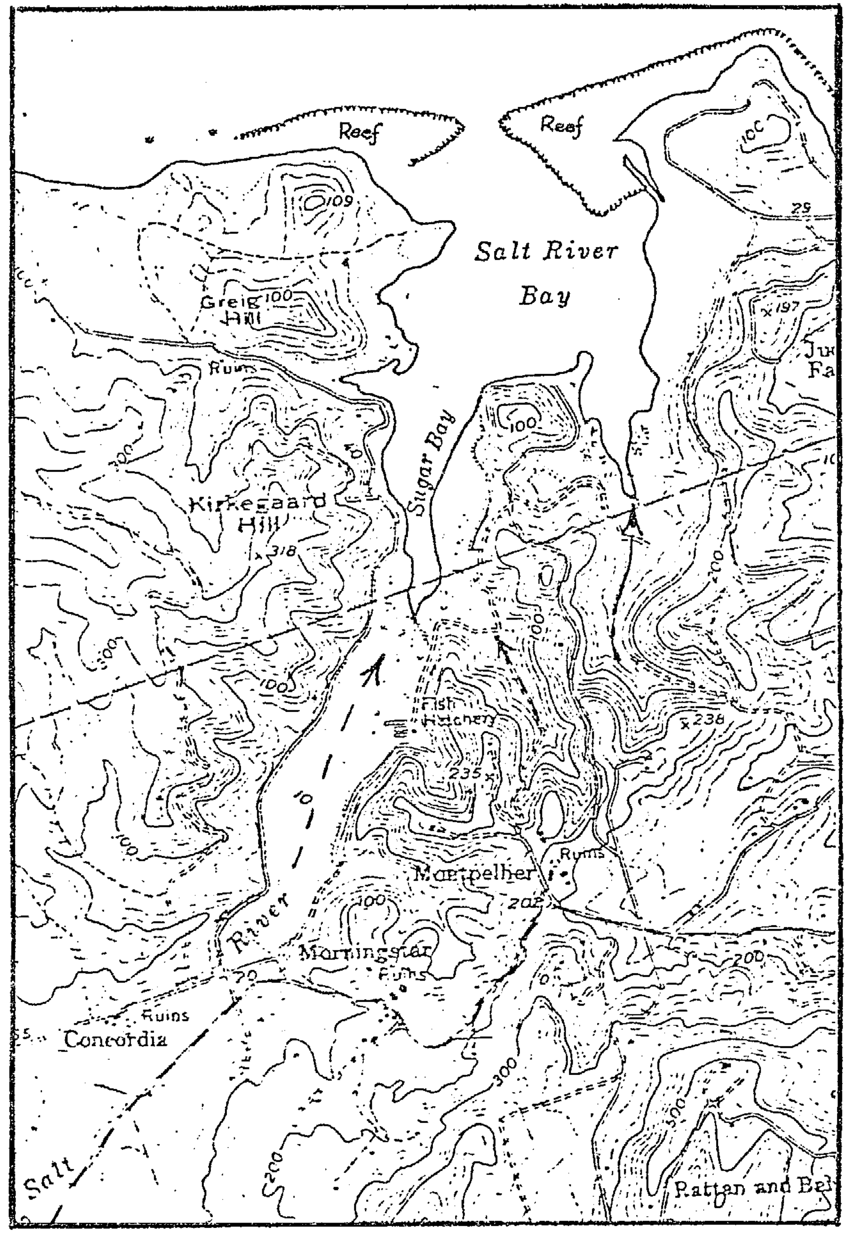


Figure 37. Salt River, St. Croix, showing drainage patterns and protective reefs. From U.S.G.S. 1954 Topographic Chart.

Mangroves

Red mangroves growing at edge of quiet shallow lagoon. Black mangroves on higher wet soil, white mangroves on drier inland soil. Red mangrove prop roots trap sediment, support and shelter organisms, extend shore. Litter contributes organic matter to water and sediments. Lagoonal grass and algae provide oxygen, food, shelter for other organisms. Nurseries for juvenile reef and pelagic fish.

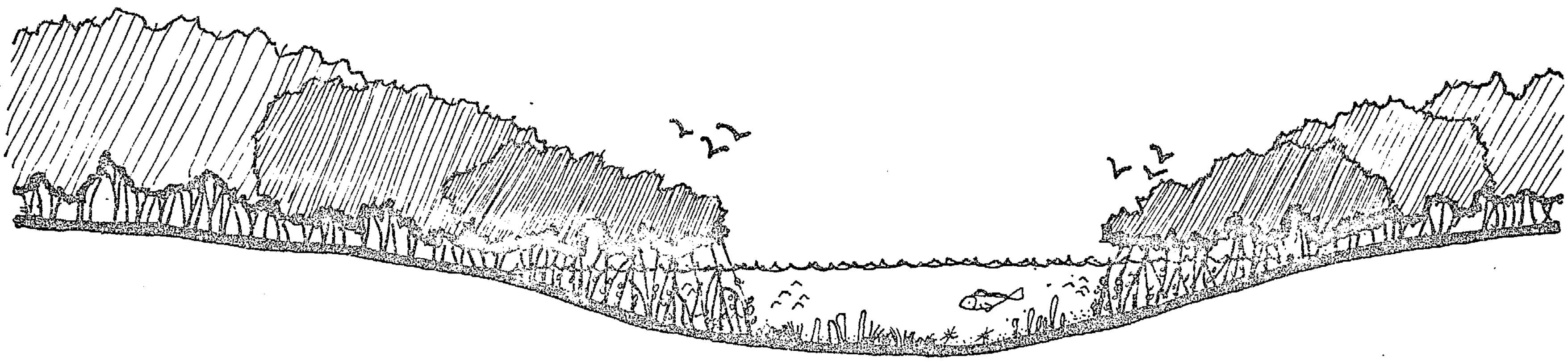


Figure 38. Profile of a mangrove forest showing typical zonation and associated habitats.

accumulate from the plants or are washed down from the land. By this process, the shoreline is slowly extended. Once the sediment becomes rather firmly established, the red mangroves die off naturally and are succeeded by other plants, initially black and then white mangroves. This sequence of succession creates a pattern of zonation (Figure 38) in which the pioneer red mangrove is at the water's edge, black mangroves occupy a zone behind and white mangroves are more inland, but still in sand soil. Mangroves, therefore, by their dense coverage and complex root structures at the shoreline, interrupt runoff from the land and help to trap fresh water, sediment and debris at the shoreline, thus protecting offshore marine areas from these pollutants.

ECOLOGY

Each year red mangroves drop large quantities of leaves and seedlings, all of which do not survive to become new plants. The natural decomposition of these materials sustains a complex food web beginning with micro-organisms and scavengers and culminating in such higher trophic members as snappers, barracuda, lobsters and birds. The nutrients and other food energy supplied by plant litter decomposition account for the large numbers and wide variety of plants and animals which are found in climax mangrove communities. Biotopic maps have been constructed for Jersey Bay Lagoon (Figure 38) by McNulty, *et al* (1968) and for Salt River (Figure 39) by Gerhard and Bowman (1975).

Mangroves require certain conditions for establishment and sustenance and, in turn, modify the environment in a characteristic way which further favors their proliferation. Red mangroves grow from a floating cylindrical seedling which may float miles from the parent tree. As these mature, the root end becomes heavier so that it hangs downward with the future leaf end sticking up. Eventually, the pod sinks. When it does, it must encounter a muddy or sandy bottom with sufficient nutrients (fertilizer). The water must be shallow enough to allow the seedling to reach air and sunlight. The water must be calm enough to allow the seedlings to take root and grow. These requirements explain why mangroves do not usually establish on windward coasts except where some shoreline features offer necessary protection and substrate. Salt River, St. Croix, is a good example where protective reefs and the long channel-like embayment offer suitable conditions (Figure 37).

By their development, mangrove areas further promote sedimentation and quiet waters. In turn, expansion of mangrove growth is facilitated. Wildlife diversity in mangrove ecosystems is second only to the coral reefs locally. Considering that both Jersey Bay and Salt River mangrove areas are immediately adjacent to beautiful, rich reefs, these combined environments are incomparable resource pools. But the mangrove forests are by far the most noteworthy because only two such areas remain while we have hundreds of fine reefs. Perhaps because reefs have attracted more attention, we are now in the process of constructing additional artificial reefs. An attempt has not been made yet to construct a mangrove lagoon.

The large numbers of fishes, birds, crustaceans and other animals that live in a mangrove area are dependent basically on the nutrients and vegetable matter produced from the leaves of mangroves and sea grasses. This material is eaten by vegetarian and omnivorous animals. Their excrement and the organic soup from rotting of other leaf litter provide food for

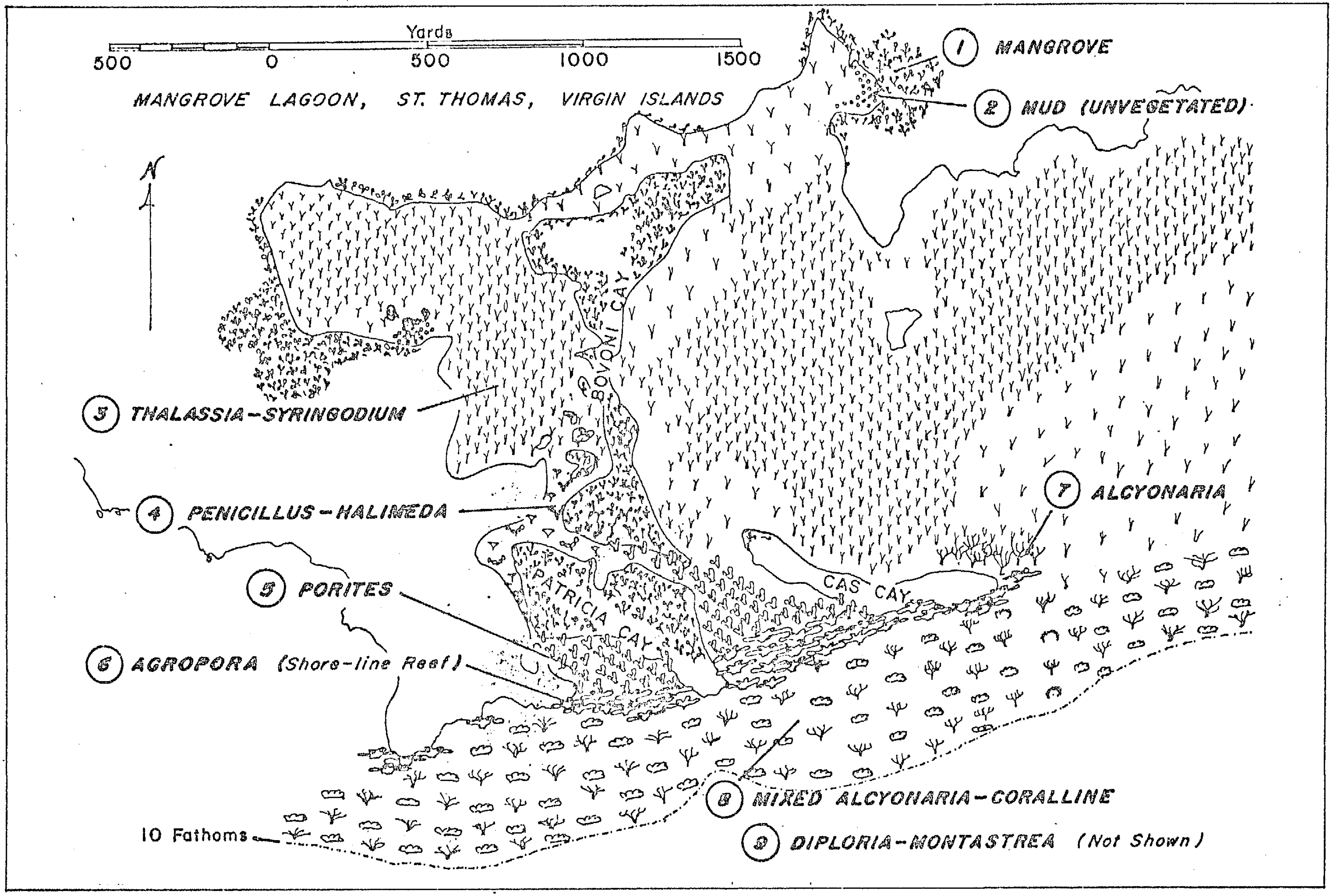


Figure 39. Marine ecological zones of Jersey Bay and Mangrove Lagoon, St. Thomas.
From McNulty, Robertson and Horton, 1968.

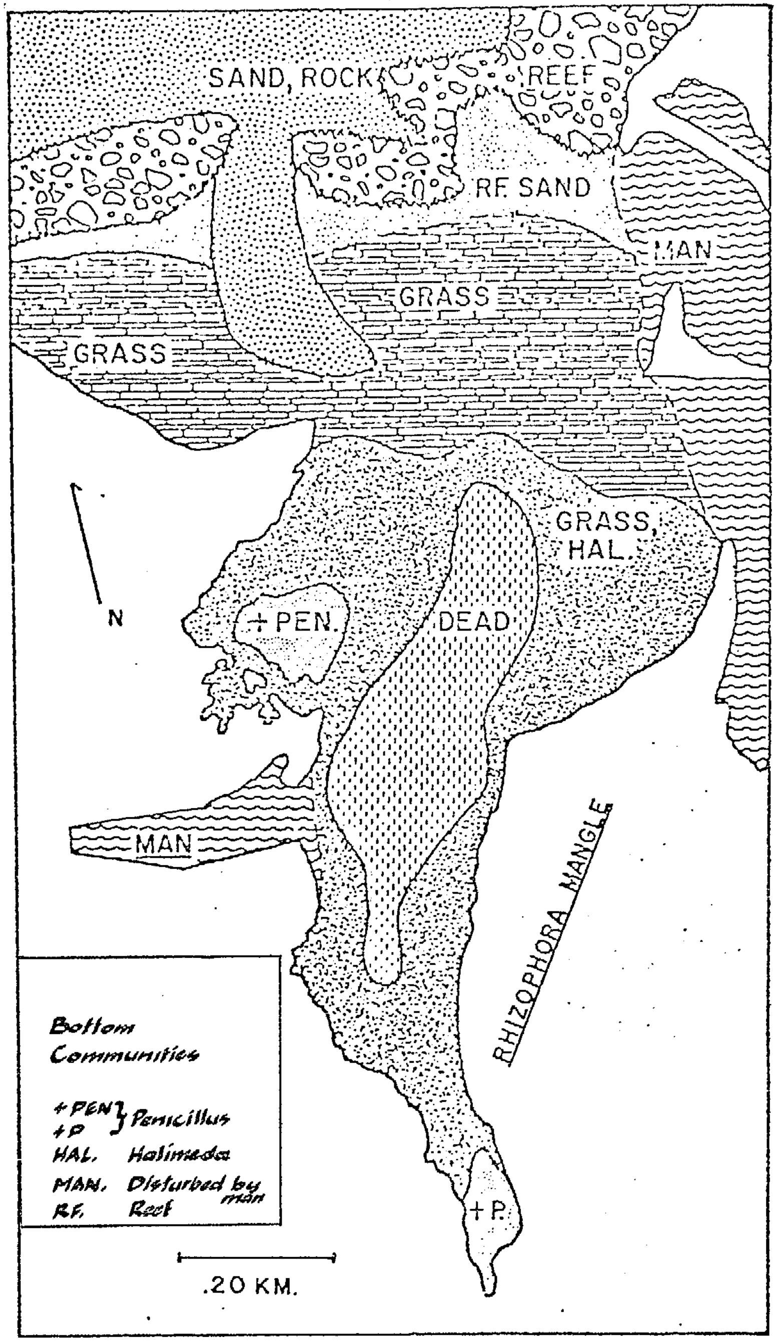


Figure 40. Benthic communities of Salt River estuary. Source: Gerhard and Bowman, 1975.

plankton (single-celled plants, larval animals) and bacteria. These, in turn, are eaten by larger animals, including those harvested by man.

Natural development of mangrove forests tends toward the formation of closed ponds. As the plants continue to grow across a shallow bar or spit, they may eventually merge with other mangroves or a headland on the other side of a body of water. For a time the water behind the mangroves may have limited communication with the outside through the prop roots or via narrowing channels. Such channels may be maintained indefinitely if a sufficiently strong current runs through periodically. This sweeps sedimentation out of the channels so that they are often surprisingly deep in relation to the general shallows within the lagoon. Current flow and depth also work to prevent new seedlings from rooting and thereby closing the channel.

Under other conditions, however, mangrove growth eventually seals off a body of water. For a while, high tides may be able to wash water through the mangroves into the pond, but eventually the pond is cut off from open water and a salt pond is formed. Salt ponds may also be formed through a similar sequence by the growth of a coral reef. They are discussed in more detail in the section on salt ponds. Tidal ponds, flats and salt ponds, therefore, are frequently associated with mangrove forests, but they may also develop where there is little or no mangrove growth.

Mangrove forests frequently develop at the mouths of streams and rivers. On larger tropical islands and mainlands where these occur, really spectacular mangrove estuaries can be found. Although historical records indicate that there used to be several perennial streams in the Virgin Islands, none exist now. Therefore, local mangrove areas are not estuaries in the usual sense except periodically when the guts which terminate in mangrove bays discharge storm water. At these times, extensive lenses of fresh water can be found in the lagoons. Salinity as low as 10.8 parts per thousand (ppt.) has been measured in the Jersey Bay Lagoon after heavy rains. The usual range is 35-37 ppt.

Actually, under usual local conditions of low rainfall and intense radiation, the shallow, quiet inner regions of the lagoon experience considerable evaporation, and salinity in some places may increase above 38 ppt. to higher levels in the backwaters at the head of the lagoon. This condition has sometimes been described as a "hypersaline estuary." At any rate, the lack of a regular brackish water zone has several consequences for local mangrove areas. One is that many organisms requiring low salinities for all or part of their life cycle and found in "true" estuaries are absent or rare here. Some of these are species of crabs, shrimp, fish and bivalve mollusks. Besides many commercially valuable, edible species, the relatively narrow salinity range precludes the establishment of a host of other organisms which are physiologically dependent on low or variable salinity. This is a manifestation of a basic biological rule: habitat diversity - at any level - fosters biotic diversity.

A further consequence of the local salinity regime is that since local lagoon inhabitants are adapted to normal or high salinity, when the salinity is suddenly reduced by flooding rain, many of the organisms perish. At such times, large amounts of plant and animal debris from dead and damaged organisms are released into the lagoon water. This organic material has been observed in Jersey Bay to reach a peak about a week following flooding, after most of the washed in mud had settled. At such times, also, phytoplankton blooms usually occur, probably triggered by the unusually high levels of nutrients coming from the land and the decaying plant and animal matter.

Within weeks normal salinity can be reestablished by a variety of forces, and the organisms begin to resume their natural mode of existence. Bioturbation (the mixing of sediment by animals living in and on it) incorporates alluvial mud into the natural sediments. Organic debris is assimilated and water clarity improves again.

MANGROVES AS WILDLIFE HABITATS

Large mangrove areas provide home and food for thousands of plants and animals. Numerous kinds of birds roost, feed and nest in and around the mangroves. Among the more important of these are doves and pigeons, pelicans and the osprey or fish hawk. The cattle egret also roosts and nests in mangroves although it makes a daily trip inland to feed on insects near cattle. Some of our rarer species of reptiles are also found in mangroves, very possibly because they are less accessible to predation by humans, mongoose and domestic animals. Iguanas find good protection there. The small local snake Alsophis occurs in the Jersey Bay area as well as ground lizards (Ameiva).

Other than marine life, the main wildlife value of the mangroves is as a habitat for birds. Jersey Bay Lagoon is a major habitat for about twenty species of herons, egrets, dudes, gallinules, mountain doves, white-crowned pigeons and Bahama pintail ducks. Table 4 lists birds observed in the lagoon area. Several are rarely, if ever, seen elsewhere on the islands, and so the mangrove lagoon is critical for their survival locally. This list does not pretend to be complete. Observations of birds and other wildlife in the lagoon, as

Table 4. Partial list of birds from Jersey Bay mangrove lagoon including cays.

SPECIES	SOURCE
Great Blue Heron	1
Common Egret	1
Louisiana Heron	1
Snowy Egret	1, 2
Clapper Rail	1
White Crowned Pigeon	1, 2
Mountain (Zenaida) Dove	1, 2
Osprey	2
Bahama Pintail Duck	1
Blue (scaly-naped) Pigeon	2
Mangrove Cuckoo	2
King Bird	2
Kingfisher	2
Bananaquit	2
Antillean Crested Hummingbird	2
Brown Pelican	1, 2
Cattle Egret	2
White Tailed Tropic Bird	1
Red Billed Tropic Bird	1
American Oystercatcher	1
Roseate Tern	1
Least Tern	1

Sources: (1) McNulty, Robertson, Horton, 1968; (2) personal observation.

in most other locales in the islands, has been brief and at scattered times.

Fish trapping in Jersey Bay, St. Thomas and Manning Bay, St. Croix (Olsen, Dammann, et al, 1972), produced 79 and 61 species, respectively, in addition to spiny lobsters. These are only types that enter traps - many species do not. For the species trapped, it was estimated these mangrove areas supported populations of more than 50,000 at Jersey Bay and more than 68,000 at Manning Bay. The majority of the fishes were ones also found on coral reefs. Many of the species trapped in the mangroves were juveniles or both adult and juvenile, indicating that the fishes use the areas as nursery grounds.

ENVIRONMENTAL CHARACTERISTICS OF MANGROVE ECOSYSTEMS

The following list attempts to identify some of the unique and characteristic physical and biological aspects of mangrove ecosystems that account for their high intrinsic value and productivity.

1. Energy production (food supply) is high from mangroves, grasses, and plankton.

2. Protection from strong waves and swell creates quiet water.

3. Relatively rapid sediment deposition via plant litter, biogenic sand, terrigenous silt.

4. Wide variety of habitats and niches, e.g., shoreline forest, prop root zone, bare sand, muddy areas, algal beds, sea grass meadows, coral areas.

5. Usually receive some degree of periodic fresh water inflow.

6. Subject to greater spatial and temporal salinity variation than other coastal zones (excepting salt ponds).

7. Shallow depths, quiet waters and secluded setting restricts larger predators (sharks, etc.).

8. Usually backed upland by flat flood plain or tidal marsh of black and white mangroves, buttonwood, marsh plants, etc., which affords protection from excessive siltation.

9. Because of the wide variety of environmental conditions and ecological niches in a rather small area, mangrove forests are characterized by an unusually wide variety of wildlife, particularly marine life and birds.

MANGROVE AREAS IN THE VIRGIN ISLANDS

* Jersey Bay, St. Thomas - The most extensive system remaining in the Virgin Islands. Includes several cays, salt ponds, lowland marshes and reef areas in about 850 acres.

* Salt River, St. Croix - Second only to Jersey Bay in size and complexity.

* Manning Bay, St. Croix - South of the airport and racetrack. Small area stressed by effects of nearby open shoreline garbage dump (now closed) and heavy industrial area. Very rich fish population.

* Great Pond, St. Croix - Primarily black mangrove.

* Westend Salt Pont, St. Croix - Mostly black mangrove.

* Altona Lagoon, St. Croix.

* Krause Lagoon, St. Croix - No longer exists. Lagoon filled. Some plants of all three species remain mostly in nearshore bands, but suffering from effects of industrialization.

* Lameshur, Leinster, and Coral Bays, St. John have small stands of mangroves.

* Miscellaneous small patches on the perimeter of most remaining undisturbed salt ponds.

These areas are located on Figures 28 and 29.

CORAL REEFS

A tropical coral reef is a complex association of hundreds of kinds of plants and animals. Corals are the dominant organism in terms of area coverage and, more importantly, they comprise the basic physical structure of the reef. Corals are colonial animals. The pores in a piece of coral each contain a small animal - a polyp. One of their life processes is extracting soluble calcium carbonate from the water and precipitating it in solid form to comprise the rock skeleton which surrounds the polyps. Coral colonies grow by asexual budding - polyps split into two. This increases the size of the colony laterally and upward. New growth piles up on top of old skeletal material, so that below the living part of the reef there may be hundreds of feet of fossilized coral rock from previous reef growth.

Corals can also reproduce sexually. Periodically, the polyps expell clouds of eggs and sperm into the sea. Fertilization results in a microscopic larva which is distributed by ocean currents. After a period of development in the plankton, the larva settles to the bottom. If they encounter suitably clean, hard, stable substrate, they attach and begin a new colony by budding. Many of the planktonic larvae are eaten by other animals, including coral colonies which feed by filtering a host of small plants, animals, eggs and larva from the water.

Corals as a group require warm water and their global distribution is generally confined between the tropics of Cancer and Capricorn. They also require clean, clear water so that within suitable temperatures their occurrence is also locally interrupted in areas subjected to outpourings of large rivers and pollutants.

Close relatives of the stony, reef building corals are the gorgonians or soft corals. These include such forms as sea fans, sea whips, and sea pens which are common on reefs. As a group, they tend to do better in deeper or murkier water than the hard corals, although there are numerous individual exceptions.

Coral reefs are common characteristic features of the islands' coastal zone and are of fundamental environmental and economic value. Besides their intrinsic beauty which is apparent only to the relatively few who observe them directly, they are important as producers of sand for natural and man-made beach cover and for construction. As such, they represent one of the territory's few naturally replaceable resources available for extraction. Reefs also provide protection for harbors, shorelines and shore structures by abatement of waves and dissipation of their energy which otherwise would be expended on the shore with great force. Thirdly, reefs provide perhaps the largest portion of seafood presently harvested in the islands. Most species of fish consumed locally either live on the reefs or depend on them in some measure for their food. Lobsters, too, are taken primarily from reef areas.

The new sciences of mariculture and marine pharmacology promise to bring even more awareness of the productive capacity of reefs and probably greater pressures for their exploitation and the need for sound management.

REEF ECOLOGY

Reefs are among the most diverse natural communities and in terms of productivity are comparable to prime farm land. Productivity - the rate at which inorganic carbon (from the water in the case of marine plants and from the atmosphere in the case of land plants) is converted to plant tissue - is rapidly utilized by other reef organisms for community maintenance and growth. This primary productivity, or photosynthesis, also produces oxygen for the support of respiratory organisms both on land and in the sea.

Most studies of reef productivity have been conducted in the Pacific, but the results are generally applicable to estimates of production on other tropical reefs. These studies indicate reef height increases at 8 - 13 millimeters per year. This actual net increase in reef height does not represent the total gross growth and production of the reef corals because their structures are constantly being reduced by living and physical forces. One Hawaiian study estimated that calcium carbonate (the mineral material of which coral skeletons - as well as shells and sand - is composed) is produced at the average rate of 0.32 pounds per square foot per year. Roughly half of this was in reef framework and half was sediment. Many fishes, crustaceans, echinoderms, sponges, mollusks and algae chew off pieces of coral or bore into it. Waves and other physical forces break off pieces. Physiological and physical factors slow down the rate of coral growth as the colony reaches the water surface. The surface experiences greater fluctuations in temperature, salinity and pollution levels. Corals near the surface are subject to wave destruction and at low tides may be exposed to drying and heating. These factors operate to slow down and finally stop reef growth as it reaches the water surface.

One estimate indicated that rasping reef fishes alone (parrot fishes in particular), by feeding on the coral, redeposited about 108 grams of calcium carbonate per square meter per year. This is one route for sand production. Others are via wave breaking and grinding of coral and other plant and animal skeletons. Other organisms contributing to sand production are certain algae, mollusks, crustaceans, echinoderms and foraminifera. In short, an animal or plant with a hard shell or exoskeleton will contribute to the sand supply when it dies or is killed and its hard parts disintegrate. In some localities, species of green algae which deposit calcium carbonate in their tissues (e.g., Halimeda) can account for large volumes of sand, sometimes piled in deep deposits where the plants are numerous and wave action does not rapidly disperse the resulting sediment. It is often possible by microscopic examination to determine the origin of sand particles and sometimes to estimate roughly the percentage contribution from various organisms.

The biogenic origin of sand makes it a renewable natural resource which, provided proper management is employed, can be harvested indefinitely within rates which will allow for its replenishment. The problem in most cases - as it is with the utilization of any renewable resource - is that not enough is known about local rates of replenishment, sources of production or factors controlling it.

Given other suitable conditions, reefs develop upon hard, stable substrates: rocks or other reef structures. Small reef areas occur at the base of most rocky promontories. Patch reefs of various sizes occur scattered in many areas. Long offshore barrier reefs, roughly parallel to the shoreline, have developed on the edges of ancient island platforms now submerged (Figure 41).

ATTRIBUTES, SENSITIVITY AND CONSTRAINTS

Attributes of reef areas include the following:

* Valuable production of marine life including most species harvested for food.

* Scenic value for underwater recreation.

* Educational value.

* Shore protection by sea abatement (energy absorption).

* Sand production.

* Produces other potentially valuable products, i.e., anti-biotics, other drugs, sea urchins, precious coral.

Tolerances are known mostly in a general sense relating to reef building corals as a group. Corals are generally acknowledged to have a narrow range of tolerances to many environmental variables. These limits vary, however, with species and with the setting. The following are some general descriptions of forms with differing sensitivities; blanket statements are difficult and at best broadly applicable.

* Temperature tolerance $16^{o} - 36^{o}$ C, optimum development between $23^{o} - 25^{o}$ C.

* Salinity below 25 parts per thousand (ppt.) or greater than 40 ppt. usually harmful. Optimum for most appears to be 34 - 38 ppt.

* Siltation - tolerances of various local species vary widely and has not been quantified for most. Reefs are generally considered to be relatively susceptible to continued heavy silta-

LAGOONAL INSHORE	LAGOONAL PATCH REEF	BARRIER REEF CREST
Sand and grass areas leading to shore beach or mangroves. Abundant bottom fauna among plants.	Quieter water. Finger corals common forming large masses to four feet high. Numerous small fishes and invertebrates. Sea grasses often on surrounding sand.	Dominated by elkhorn and staghorn corals. Deeper face with organ pipe and other hard corals, sea fans, sea whips. Abundant fish and invertebrates.

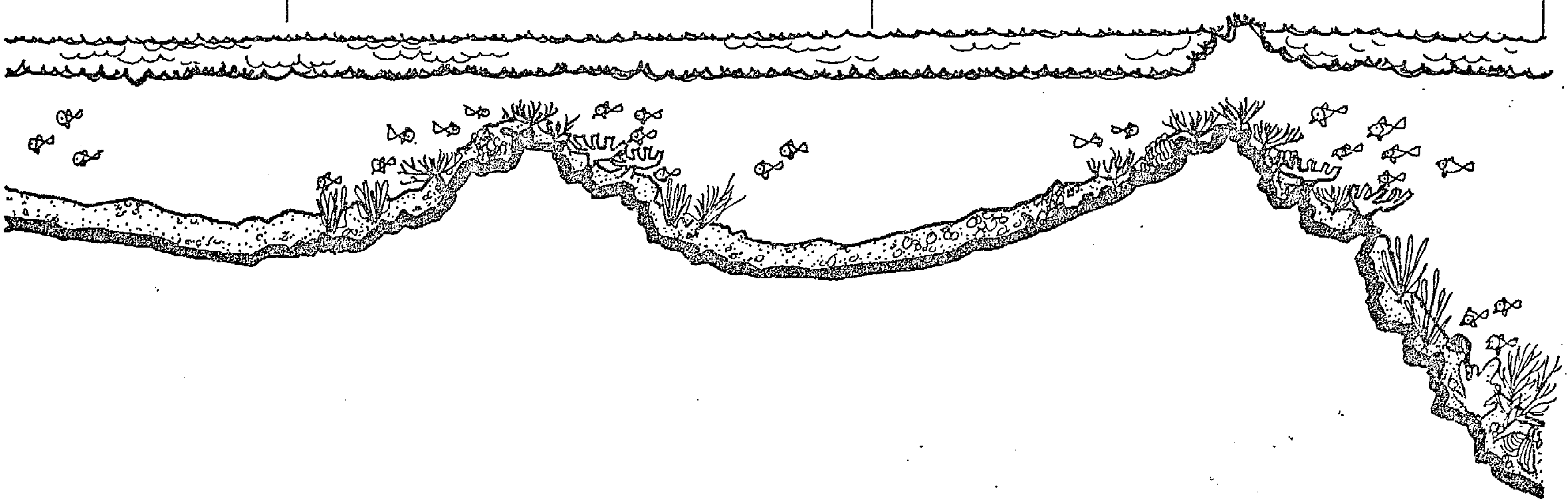


Figure 41. Diagramatic profile of an offshore reef system. Seaward barrier reef drops to deep water.

tion. The definition of "heavy" is not available in the literature. Corals have a limited ability to cleanse themselves, but may expend too much energy in eliminating non-nutritive particles or may be literally smothered. Organic sediment, particularly, can deplete the oxygen supply to lethal levels. Siltation is closely related to turbidity, being caused by solid particles, and their effects may be difficult to separate. A great deal of siltation occurs during most dredging operations as finer particles settle slowly and siltation, therefore, can continue for some time after dredging and may occur at far removed sites. Its effects can be catastrophic for sessile organisms. If the rate of fall-out is too great, many sedentary organisms, particularly corals, are literally smothered if they cannot cleanse themselves rapidly enough.

Beyond this, the coating of the substrate by silt size particles is disadvantageous to the settling of most invertebrate larvae and so recolonization is obstructed. Such surfaces are favored by some species of algae which give the advantage of stabilizing the bottom, but also effectively exclude the establishment of reef-builders. In fact, such alteration of the environment has been known to banish corals forever from an area where they were formerly well-developed.

* Turbidity - corals contain symbiotic algae which are critical to the life of the coral. These algae, if not the coral polyps themselves, require light. They apparently produce oxygen which is used by the coral polyps. Because light is absorbed rapidly as it penetrates the water, reef building corals are seldom found below 150 feet in clear water. Really good reef growth occurs in 90 feet or less. In turbid water the amount of light reaching the bottom is further reduced. Prolonged light reduction may alter the species composition of a reef or kill it completely. Specific light requirements for corals are not known. It is reasonable to assume, however, that local reefs, accustomed to very clear water, are very sensitive to light reduction. This assumption seems proven by qualitative observations on reefs subjected to prolonged turbidity.

* Eutrophication - enrichment of water in the vicinity of reefs may be beneficial up to a point. Corals are filter feeding animals and take fine digestible organic matter and small organisms from the water. Enriched water may increase the supply of these items but will also increase the growth of algae and other forms which can overgrow, smother and compete with the corals for food and oxygen. In addition, enriching nutrients in excessive concentrations can be toxic or be accompanied by substances toxic even

in low concentration. Artificial enrichment of naturally low-nutrient environments is a dangerous business and not to be recommended generally. Simple common sense dictates against eutrophying an ecosystem which has developed and flourished under native conditions. Use constraints and limitations for reefs derive primarily from their relatively stringent environmental requirements. The following are some representative activities inconsistent with the maintenance of healthy reef ecosystems.

* Effluent Discharges - any discharge except almost pure sea water may be expected to have some detrimental effect on a reef. Fortunately, the location of most reefs in active, flowing water, usually assures rapid dilution and dispersal of pollutants. Only a relatively small area immediately surrounding the discharge may be affected, but this depends on the nature and rate of the discharge and the effectiveness of dispersal. Hot discharges, although they may be clean, are nevertheless destructive. Most tropical organisms exist near their upper temperature limits. Corals, made up of countless minute individual delicate polyps, have an extremely high surface to mass exposure. Heated effluents mounting water temperatures above 30°C will adversely affect many corals. Prolonged temperatures above 40°C will kill most corals. Prolonged exposure to hypersaline discharge elevating salinities above 40ppt. is detrimental to reefs. Fresh water discharges lowering salinity below 30 ppt. can be expected to affect reef composition. Sediment and other pollutants in the discharge can be harmful to reefs.

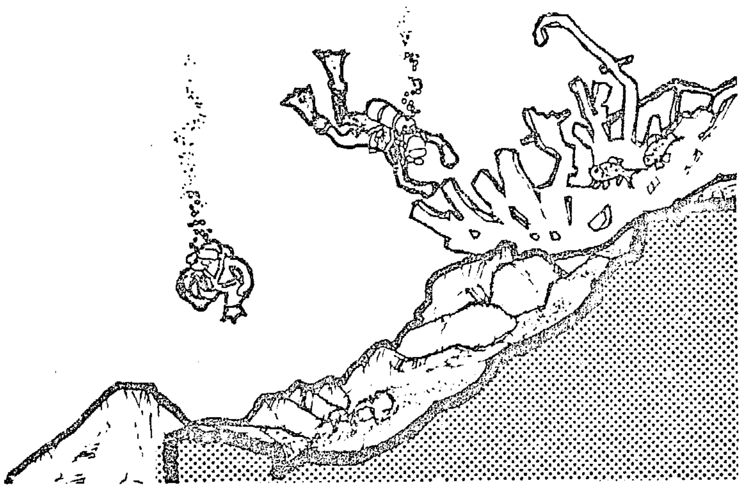
Sewage discharges add a wide variety of ingredients to the water which have a number of effects. The more obvious contributions of sewage are lower salinity, high oxygen demand, high nutrients, turbidity, sediment and toxic compounds.

REEF INVENTORY

Shoreline reef areas and major offshore reef banks are shown in Figures 28 and 29. An original detailed bottom map of the nearshore area to ten fathoms has been prepared as a segment of this study but is not included with this report. It is available at the Virgin Islands Planning Office.

Reefs of various types and sizes are widespread and common around the islands. Most of the best examples of extensive reef development are on St. Croix where the submarine shelf is especially wide and relatively shallow. The more notable are Long Reef at Christiansted, Buck Island Reef, Tague Bay Reef, Long Bank on the east end, Great Pond Bay Reef and Long Reef on the south central coast. The latter has been extensively damaged by industrial development. On St. Thomas large, well developed reefs occur at Long Point, fronting the mangrove lagoon, at Flat

Cays off the southwest coast and at Triangle reef just east of the harbor entrance. On St. John large reefs occur at Ramshead on the southeast and Johnson reef on the northwestern coast.



SANDY BOTTOMS

DESCRIPTION

Sandy bottoms are defined as areas with, at most, sparse sea grass or algal cover.

Large areas of sandy sea bottom are scattered throughout the platform. Sometimes they occur in shallow bays without apparent reason, as most shallow bays are vegetated. The most extensive areas of essentially bare sand occur below 60 feet depth. Even here, the lack of extensive plant growth is not easily explained, but may be due to low light intensity and/or the nature of the sediment. Another possible explanation may be that the sand is shifting at a rate which prevents plant establishment.

ECOLOGY

These areas are not, of course, barren. They usually support scattered algae and the flowering plant Halophila. Occasional sponges, anemones, tunicates and small solitary corals are usually present (Figure 42) especially where there is some solid object - usually a piece of debris - for attachment. Bottom fishes are few, but lizard fish and tile fish are not uncommon. Conch, especially the small fighting conch, and hermit crabs may sometimes be numerous. The preponderance of animals in this habitat are infauna, burrowing or tube dwelling forms in the sand. Among the most numerous are several kinds of worms which may occur in densely packed beds. A large variety of mollusks,

Sand Bottoms

Dominated by sand, usually with worm and shrimp burrows and hummocks. Thin, slattered coverage of algae, grasses, sponges, occasional solitary corals and fish (mostly pelagic with few bottom-associated types).

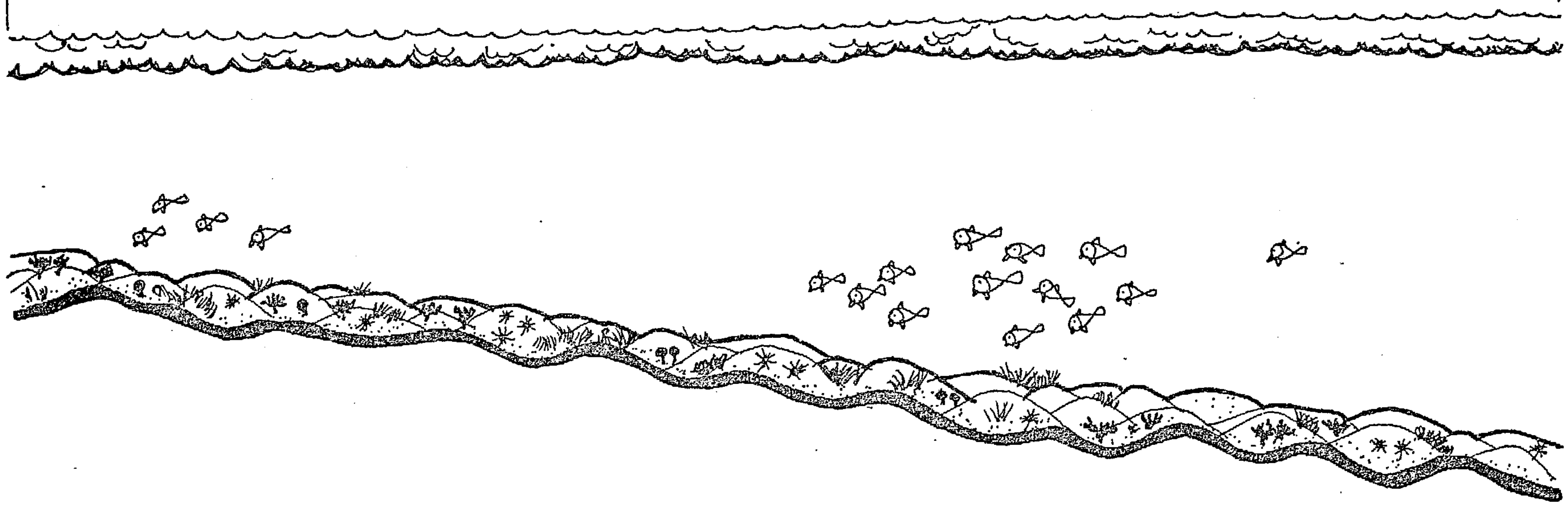


Figure 42. Profile of a sand-dominated bottom, usually grades into a reef or grass area.

crabs and shrimp live in the sand. Most of these animals are rarely seen unless the sediment is dug up. Many are nocturnal feeders and when they emerge at night, fish, lobsters, rays, sharks and other predators from adjacent areas move in to feed on them.

ATTRIBUTES, USE OPTIONS

Sandy areas are not well understood, and the extent of their significance to regional ecosystems is unknown. It may be that they represent areas of active sand transport via which sediment is slowly moved inshore and offshore. They are potentially good sites to consider for sand mining providing the depth is not financially or technically prohibitive and that adjacent, more sensitive resources will not be unduly affected.

As a group the associated organisms are relatively tolerant of turbidity and siltation. This, coupled with the usual deeper open water location of sandy areas, makes them more suitable than most other habitats for effluent discharges.

LIMITATIONS, USE CONSTRAINTS

Limitations on uses of sandy bottoms derive principally from their relative inaccessibility. Possible limitations deriving from their environmental importance are, at best, speculative because of the degree of their importance is unknown.

INVENTORY OF SAND AREAS

Sandy areas are mapped on separate charts available from the Virgin Islands Planning Office.

GRASS BEDS

DESCRIPTION

Grass beds are frequently referred to as marine pastures because they are areas of thick growth of sea grasses and algae resembling pastures on land and serving essentially the same functions. Most inshore bay bottoms are covered with such pastures as are some extensive areas outside of bays. The distribution of a marine pasture is controlled by a number of factors including sediment quality and stability, depth, water clarity, currents, grazing by herbivorous animals and, in some instances, factors which are not apparent. The pastures usually do not extend below 60-70 feet depth. Their growth is interrupted in channels or other areas with swift currents or in surge areas when the sediment is constantly tossed, for example, close to a beach.

Their edges are grazed away near reefs or other solid objects by fishes and sea urchins which live there and forage on the edge of the pasture. Thus, there is almost always a band of bare sand between a reef or rubble pile and the surrounding pasture.

The dominant plant in local marine pastures is turtle grass (*Thalassia testudinum*). The second most abundant is manatee grass (*Syringodium filiforme*) a grass with thin cylindrical blades (about one millimeter diameter). A third, less frequently encountered grass is *Diplanthera wrightii*, variously called shoal grass or eel grass, although elsewhere these common names apply to other species. On some shallow banks with fine sand, Diplanthera may form large beds as on the inshore south coast of St. Croix. The three plants are usually referred to as sea grasses. They are unlike the majority of marine plants, which are algae, in that they are true flowering plants. Annually they produce flowers and seeds. However, the prolific growth is mostly due to spreading via runners with emergent shoots. A fourth flowering plant, often found intermixed in small amounts in the grass beds is Halophila baillonis, but it is more common in deeper water where it sometimes dominates the flora.

Scattered among the sea grasses in the pasture is a large variety of algae in various shapes and colors (Figure 43). However, the largest and most numerous are staked greens. Commonly encountered genera are Penicillus (shaving brush), Udotea (fan algae), several species of Caulerpa and Halimeda which has hard calcareous blades and becomes sand when it dies.

ECOLOGY

Marine pastures produce a significant amount - perhaps most - of the oxygen generated in local inshore waters. On a bright day dissolved oxygen over a healthy grass bed will exceed the saturation value (i.e., the water becomes supersaturated), and small bubbles rise from the leaves to the surface.

Several species of small fish live in the pastures, but more important, a larger variety of others come here to feed on the plants and myriad creatures that live here. This is the habitat of the queen conch (Strombus gigas) and feeding grounds of the sea turtles. A diverse group of animals live in the sand between the plants, and the bottom is often heaped into mounds marking the burrow entrances of large worms and shrimp.

Grass beds help to stabilize the sand, and where they front a beach it has been postulated that they act as a "footing" to retard seaward loss of sand from the beach.

There is a very close knit relationship between the plants and animals in this habitat, both spatially and physiologically. The pasture is a low profile environment. The plants usually do not exceed eight inches in height, and all but a few of the associated animals live within this zone or in the sediment. Thus, except for visiting foragers and predators, the majority of community energy cycling goes on in close quarters. Wastes from the animals are utilized by the plants which produce oxygen and forage.

Mild enrichments of the water as by small continuous sewage discharges can cause affected areas of grass to grow extremely rapidly and produce long leaves. Prolonged enrichment usually encourages atypical species of algae, indicative of pollution (Ulva, Enter-

Grass Beds

Primarily turtle grass with various green algae. High oxygen and biological productivity. Great diversity of inhabitants, many edible species: turtles, conch, fishes. Stabilizes and assimilates wastes, and absorbs wave energy thereby protecting adjacent beaches.

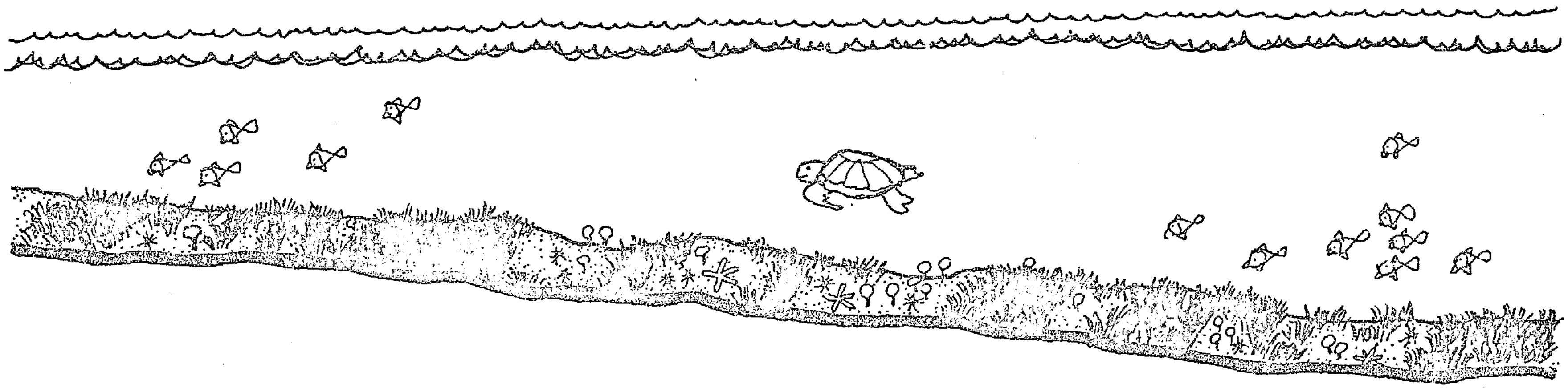


Figure 43. Typical shallow water sea grass bed.

omorpha, Cladophora).

For unexplained reasons, patches of grass removed by various means (dredging, boat anchors) may not be replaced for years. In most bays which have been dredged, the marine pasture has not become re-established in the dredged areas for many years. In the case of Lindbergh Bay, St. Thomas, 40 years have elapsed, and a barren hole remains off the western portion of the beach. Even small swatches cut by an anchor, a dredge or a boat's propeller may remain bare for a year or longer.

ATTRIBUTES, USE OPTIONS

* Grass areas have mild capabilities for assimilating wastes, but good flushing of the overlying water is advantageous.

* Usually are associated with clear water, but can tolerate some increased turbidity; limit has not been quantified.

* Associated animals can remove silt from periodic flooding, incorporate it in sediment and "cleanse" the bottom.

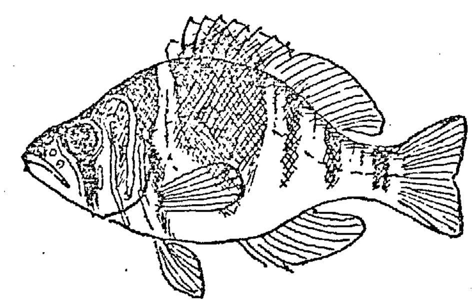
LIMITATIONS, USE CONSTRAINTS

* Once destroyed, marine pastures usually require a long time to recover. Deep holes may never recover.

* Since the community is dominated by plants a critical minimum amount of light is needed. Chronic, heavy turbidity is destructive. Quantitative tolerances have not been determined.

DISTRIBUTION OF GRASS BEDS

Shallow water sea grass beds are widely distributed in the islands. Major distribution patterns are shown on large scale charts available separately from the Virgin Islands Planning Office.



OFFSHORE CAYS

DESCRIPTION

The small offshore islands vary in size from bare protruding rocks to over 170 acres. Most are 5 - 50 acres. A few are inhabited by one or two families - and many are difficult to get onto even by boat. Simple rock protrusions like Booby Rock, Sail Rock and Cricket Rock serve mainly as roosting and nesting sites for sea birds. The larger islets have beaches, rocky shores, cliffs, and some vegetation, mainly xeric scrub. Most have at least one salt pond and are surrounded by some degree of reef development. Most of the more than 60 emergent rocks and cays are around St. Thomas.

ECOLOGY

Because of their remoteness, the cays are popular nesting sites for many local birds including migratory sea birds and are the last remaining local rookeries for several species. Although they usually harbor rats, with a few exceptions there are no mongooses. A major exception is Buck Island, St. Croix. The lack of these vocacious predators permits ground nesting by many birds and the survival of some lizards and snakes which have been extirpated on the main islands. However, considerable poaching of sea bird and dove nests as well as illegal hunting has been practiced by man, despite the prohibition of hunting on publicly owned cays at any time, a law which is difficult to enforce. The value of the cays as bird sanctuaries has been stressed in the past (McNulty, Robertson and Horton, 1968) and Dr. Arthur E. Dammann of the Virgin Islands Department of Conservation and Cultural Affairs is presently preparing an atlas of the cays in an attempt to draw attention to their value and uniqueness. This document should be a useful management tool.

Among the birds which nest on our cays is the brown pelican, a species which is in danger of extinction. Resident colonies breed on Whistling, Congo and Dutch Cap cays off St. Thomas and St. John and on Buck Island, St. Croix. A large colony of terns nests on Flanagan Island. The beautiful tropic birds nest on some cays, and mountain doves use most cays, but favor Turtledove, Saba, Buck, Capella and Flat Cays. Other important nesting sites are Little Hans Lollick, Cockroach, Sula, Sail Rock, French Cap, Kalkun and Dog Island.

The salt ponds on most cays seasonally harbor some ducks, including the locally rare Bahama pintail.

One attribute of the numerous cays around St. Thomas and St. John is their abatement of large ocean waves and swell and protection of the coastal areas of the main islands.

ATTRIBUTES, USE OPTIONS

* Unique wildlife habitats, mostly mongoose-free.

* Usually have unspoiled reefs.

* Provide coastal protection for main

islands.

* Most are suitable and recommended as wildlife sanctuaries, others as recreational parks or multiple use resources in keeping with their fragile nature.

LIMITATIONS, USE CONSTRAINTS

* Small size, easily subject to environmental damage.

* Lack fresh water resources.

* Exposure to drying wind and salt spray.

* Many poorly accessible.

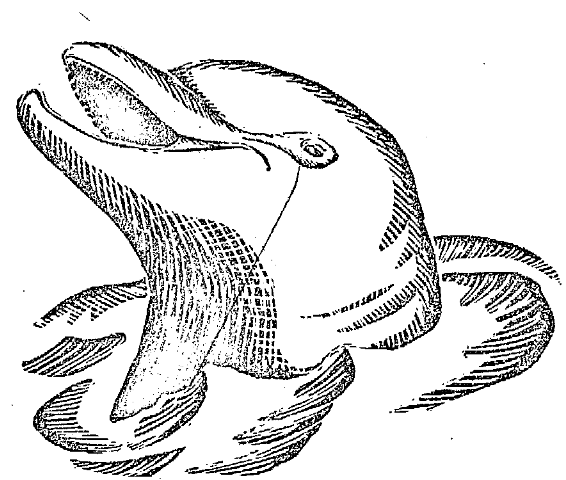


Table 5. Inventory of offshore cays.

	Acres	Elevation (Feet)	Beach Shore	Rocky Shore
Booby Rock	0.5	35	--	all
Bovoni Cay	50	75	(all mangroves)	
Brass, Inner	128	256	east, so., west, n.e.	north, n.w.
Brass, Outer	108	412	--	all
Buck I., St. Croix	179	330	south	north
Buck I., St. Thomas	41	125	--	all
Capella I.	22	121	--	all
Carval Rock	0.5	67	--	all
Cas Cay	16	99	northwest	east
Cinnamon Cay	1	32	--	all
Cockroach I.	19	151	--	all
Cocoloba Cay	1	36	south	north
Congo Cay	25	170	south	north
Cricket Rock	3	46	--	all
Current Rock	0.4	13	--	all
Dog Island	12	78	--	all
Dutchcap Cay	32	278	--	all
Fish Cay	3.5	21	--	all
Flannagan I.	21.5	127	west	north, east, south
Flat Cay, Big	3	32	scattered	scattered
Flat Cay, Little	0.4	11	scattered	scattered
Frenchcap Cay	10.5	183	--	all
Grass Cay	49	230	south	no., so., east, west
Green Cay, St. Croix	13	63	southeast, east	north, northwest
Green Cay, St. Thomas	0.7	24	west	south, east
Gr. Hanslollik I.	489	704	northeast, southeast	no., so., east, west
Lt. Hanslollik I.	100.5	204	southeast	no., so., east, west
Hassel I.	139.5	267	west	south, east, north
Henley Cay	11.5	70	south	northeast, west
Kalkun Cay	3.5	73	--	all
Leduk I.	13.5	85	south	north
Lovango Cay	118	255	west, south	north, east
Mingo Cay	48	186	south	north, west, east
Patricia Cay	33.5	75	south (mangroves elsewhere)	

	Acres	Elevation (Feet)	Beach Shore	Rocky Shore
Pelican Cay	4.5	15	--	all
Perkins Cay	0.5	25	--	all
Protestant Cay	4	33	west	east
Ramgoat Cay	2.7	30	--	all
Range Cay	4.6	25	--	all
Rotto Cay	2	33	(all mangroves)	
Saba I.	30.3	202	north	south, west, east
Sail Rock	1.6	125	--	all
Gr. St. James I.	156.8	175	north	all
Lt. St. James I.	68.7	142	scattered	scattered
Salt Cay	55.8	242	south	north, east, west
Savanna I.	173.3	269	--	all
Shark I.	1.25	32	--	all
Steven Cay	2	32	northwest, rubble	southeast, southwest
Sula Cay	1.8	100	--	all
Thatch Cay	236.8	482	south	north
Trunk Cay	1	48	north, northwest	east, northeast, west
Turtledove Cay	3.8	50	south	north, east, west
Two Brothers	0.4	10	--	all
Water I.	491.4	294	scattered	scattered
Water Lemon Cay	0.7	35	southeast	south, west, north
West Cay	40.3	121	scattered	scattered
Whistling Cay	18.6	202	south	north

Other Marine Resource Elements

Although the waters of the island shelves are noticeably low in dissolved nutrients (nitrates, phosphates, silicates) and of uniformly warm temperatures down to about 125 feet, the deep water of the submerged shelf faces and trenches is cold and high in dissolved nutrients. This deep water is below the photic zone, the depth limit at which sufficient light is available for grass, algae and plankton growth which would use up nutrients. The lack of current upwelling prevents this water from reaching the photic zone and enriching the upper levels of coastal water. Thus, this denser (colder, richer) water is stratified and essentially confined vertically.

Temperatures in the deep basins are 5-10° C and nutrient concentrations are up to 200 times as high as surface water. These temperature and nutrient differentials are a potentially valuable resource of enormous scale (Gerhard and Rohls, 1970). Off the southeast coast of St. John and the north coast of St. Croix deep water occurs fairly close to shore. If drawn to the surface, this cold water is potentially valuable for mariculture, industrial cooling, fresh water production by condensation, and power generation.

Columbia University's mariculture research project at Rust-op-Twist on St. Croix's north shore has proven the technical, if not the financial, feasibility of the mariculture aspect. For other applications, considerable technological development is needed, but the possibilities are certainly worth exploring. Discharging the high nutrient water into the coastal waters is an aspect that deserves to be monitored closely for adverse effects.

Of the innumerable species of marine life around the islands, only a handful are presently used by man. A considerable number of others are suitable for food and other uses but have traditionally been ignored. Snails of the genus Astrea occur in similar habitats to Cittarium (the welk), sometimes in large numbers. While they do not grow as large, they reach sizes comparable to that of harvested welk and are just as tasty. The small fighting conch (Strombus pugilus) frequently occurs in large aggregations at accessible depths, is similar to queen conch in taste and is larger than all but the largest welk, which are extremely rare. A crab of the family Portunidae, similar to the North American blue crab, but slightly smaller, has been taken incidentally in local fish pots for years but never considered as a food item. The Virgin Islands Division of Fish and Wildlife is now trapping selectively large numbers of these crabs from flat bottoms greater than 100 feet deep. Their work indicates that this crab is numerous on most of the deep, flat shelf areas around St. Thomas.

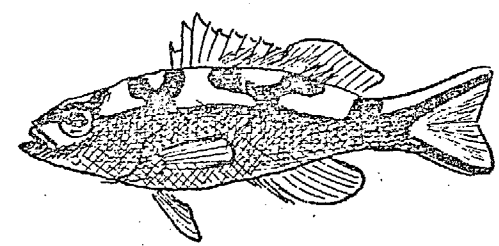
Recently in California a commercial

fishery has been developed for spiny sea urchins similar to our Diadema antillarum (sea egg). The roe is extracted and used as a sort of "caviar". In some other West Indian islands the roe of the larger short-spined sea urchin Tripneustes, which also occurs locally, is relished as a delicacy.

Shark meat and by-products are in great demand all over the world. They are fished in other parts of the Caribbean and the world, and a small venture had been operating locally for a time. There is a market for virtually every part of a shark. The meat is used as human and pet food. The skin is used like leather for a variety of products, and vitamin rich oil is extracted from the liver. Other parts including fins and eyes are marketable for various uses. There probably are sufficent numbers of sharks in local offshore waters to support some commercial effort.

Various kinds of precious coral occur locally, mostly at depths beyond 100 feet. These are bush or tree-like forms with hard horny skeletons which can be polished to a rich texture and color. The most popular is black coral (Antipatharia) which occurs locally. Other precious corals are pink, rose or white, but their occurrence locally is unknown although possible. Precious corals are made into jewelery which brings a good price. Traditionally it is harvested by SCUBA divers, but recently in Hawaii commercial collectors have begun using a submersible vehicle with mechanical arms.

Black coral grows very slowly, and harvesting needs to be regulated to avoid extirpation. Research on growth rates of Antipatharia is currently being carried out in Curacao at the Caribbean Marine Biological Institute.



Classification of Coastal Ecosystems

The composition of coastal ecosystems varies considerably, but certain combinations of habitats occur frequently in the island areas. The Virgin Islands are no exception, and the following typical systems have been chosen for illustration.

ROCKY SHORELINE ASSOCIATIONS (Figure 44)
Dominant features: shoreline of hard resistant, highly fractured rock extending under and resulting in active coral growth on the rocky base along shore and extending onto hard substratum at greater depth.

Characteristics: salt-tolerant plants on shore; turbulent, usually clean, clear well oxygenated water with tough hard and soft coral community and other living forms highly resistant to wave action. Bedrock usually lies beneath thin sand cover up to several meters offshore.

Suitability: snorkelling, fishing, good dispersal for treated effluents, scenic value above and below the surface of the water.

Restrictions: wave action precludes mooring, anchorage; light structures on shoreline rocks subject to wave, storm and corrosion damage.

SALT POND - BAY ASSOCIATIONS (Fig. 45)
Dominant features: protected bay with sea grass bottom and beach shoreline sometimes with near-shore patch reefs, hypersaline and separated from sea by sand or pebble beach and berm combinations, often surrounded by mangrove.

Characteristics: very low energy water motion in bay, pond acts as catchment and filter for flood water from land, usually supports wading birds and other wildlife in associated mangrove.

Suitability: low energy bay usually good for watersports, boat anchorage. Ponds may be filled for development or opened for marinas.

Restrictions: structures on filled ponds need pilings, opening of ponds can release fine sediments and toxins to upset bay organisms and water quality. Filling or opening pond incurs water quality stresses on the adjacent bay.

SAND BEACH - GRASS BEDS ASSOCIATIONS (Figure 45)
Dominant features: sandy beach, with gently sloping bottom leading to sea grass and algal pasture on bottom of protected bay.

Characteristics: beach sediments, grain size and profile change constantly in response to wave and currents. Sea grass acts as stabilizing factor in offshore movement of sand. Plants

Rocky Shoreline Associations

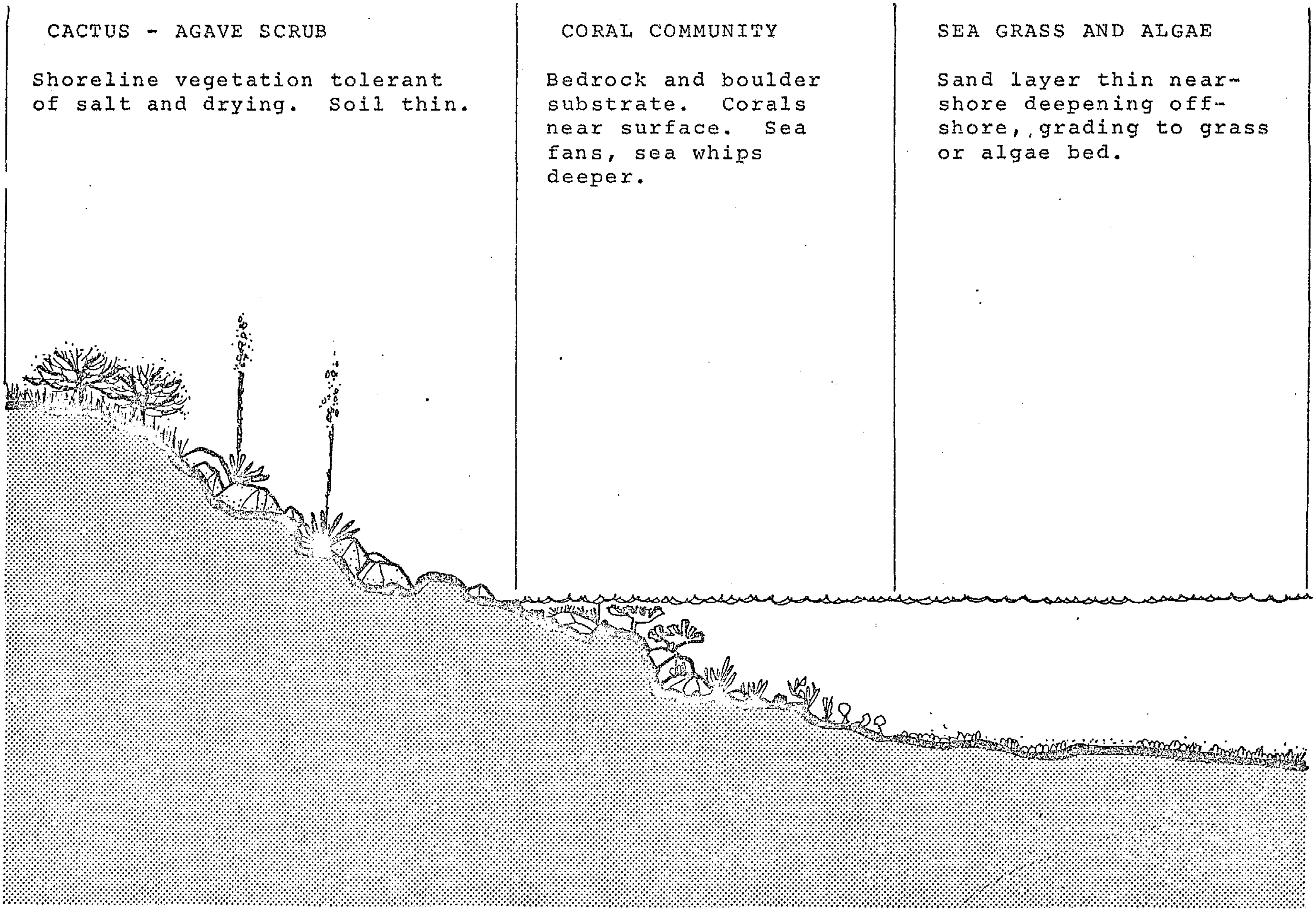


Figure 44. Rocky shoreline and associated sea bottom.

Sand Beach - Grass Beds - Salt Pond - Reef Associations

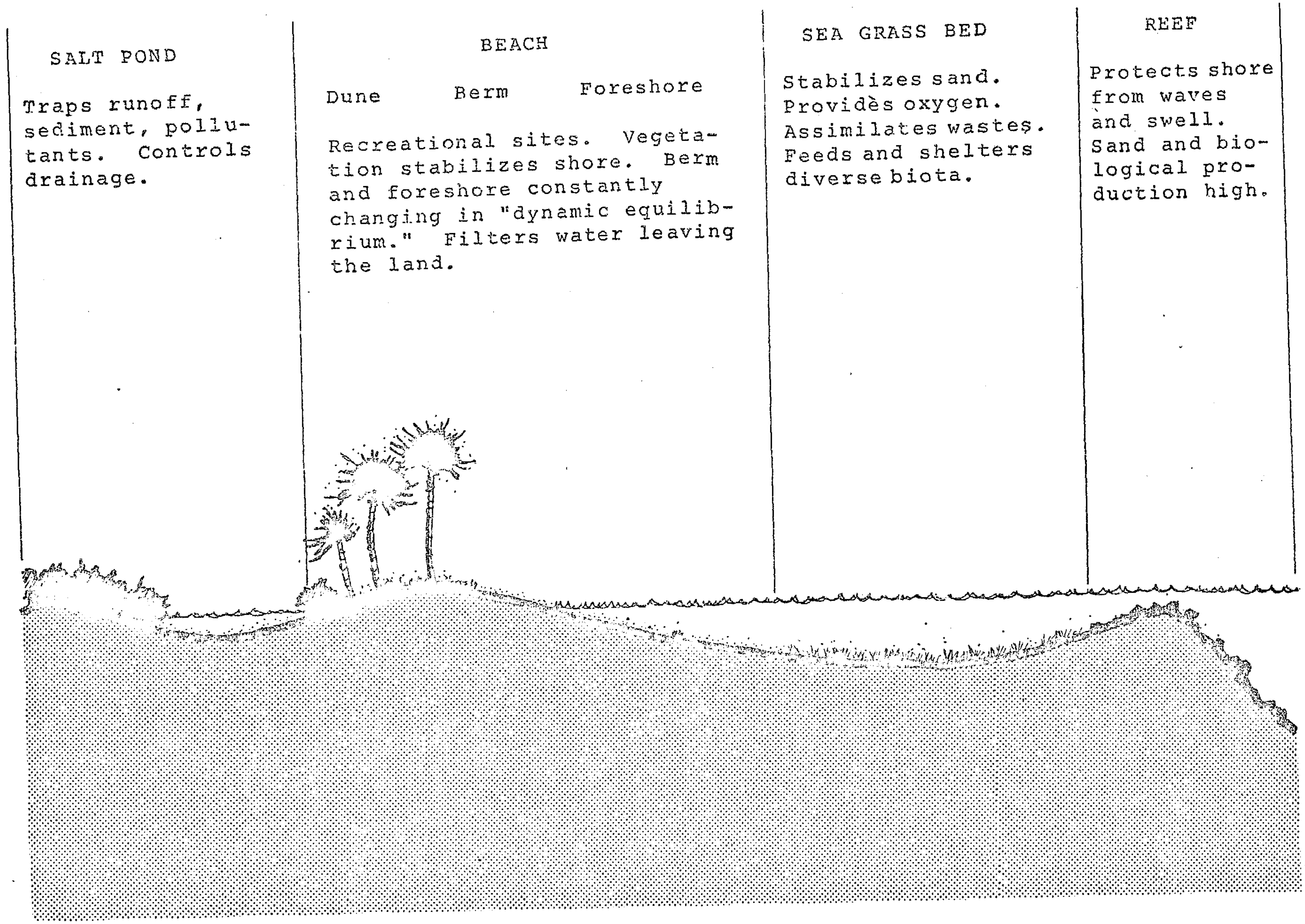


Figure 45. Typical sand beach ecosystem showing relationship of component habitats.

oxygenate water, assimilate community wastes, provide food and shelter for wide variety of animals.

Suitability: good swimming and recreation areas, usually suitable for small boat anchorages and moorings. Attractive areas for shoreline development. Frequently provide harvestable quantities of reef fish and conch.

Restrictions: solid structures on the submerged beach act as barriers, interrupt sand transport, change beach shape and quality. Structures on pilings less so. Excessive development in the watershed can result in deterioration of water quality, affecting recreational potential. Excessive and/or poorly designed dredging for sand can severely damage beach, coral communities and marine vista.

MANGROVE - LAGOON - REEF ASSOCIATIONS
(Figure 46)
Dominant features: mangrove fringed shore or dense multi-species mangrove forest, mangrove mini-islands, landward salt ponds or tidal flats, quiet small lagoons between mangroves and protective adjacent offshore reefs, usually shallow with narrow entrance channels.

Characteristics: extremely high system productivity and utilization of energy, rich in edible and other organisms, food chain based on mangrove leaf litter, quiet water with low flow promotes sedimentation. Area is important feeding and breeding ground for many birds, juvenile fishes and shellfish.

Suitability: recreation, education, faunal preserves, fishing, marinas.

Restrictions: low water flow makes areas unsuitable for waste discharges. Filling land to shoreline will kill ecosystem base - the mangrove plants. Susceptible to turbidity and rapid sedimentation. While potentially good sites for marinas and sand dredging, they are generally intolerant of the impacts generated by these activities. Natural attributes of mangrove areas subject them to secondary environmental stresses they cannot tolerate.

MAN-MADE SHORELINE AND STRUCTURES
(Figure 47)
Dominant features: developed shoreline with altered topography and drainage, high percentage of impermeable surface, unnatural shoreline (bulkhead, landfill, docks, etc.), usually low-energy quiescent protected bay.

Characteristics: high use levels, increased addition of pollutants and toxins to the bay, abnormally high turbidity and pollutants, impoverished floral and faunal communities, increased sedimentation, subject to rapid runoff, frequent hydrocarbon slicks, often develop colored phytoplankton blooms.

Suitability: as previously modified natural systems, these areas could have priority consideration for sand dredg-

Mangrove – Lagoon – Reef Associations

SALT POND	MANGROVE SHORELINE	SEA GRASS FLAT	MANGROVE CAY	BACK REEF FLATS	FRINGING REEF
Traps run-off. Black and white mangroves landward.	Red mangroves seaward. Black and white mangroves landward. Traps sediment expanding shoreline.	Quiet water, silty sand sediment, thick sea-grass growth, abundant sea life.	Trapped sediments and mangrove roots. Larger cays with mangrove zonation and terrestrial vegetation. Wildlife sanctuary.	Sea grass, algae, scattered corals, clean sand, reef rubble.	Typically Acropora near surface. Organ corals, sea fans, etc. seaward. Finger coral landward. Abundant sea life. Wave protection. Sand production.

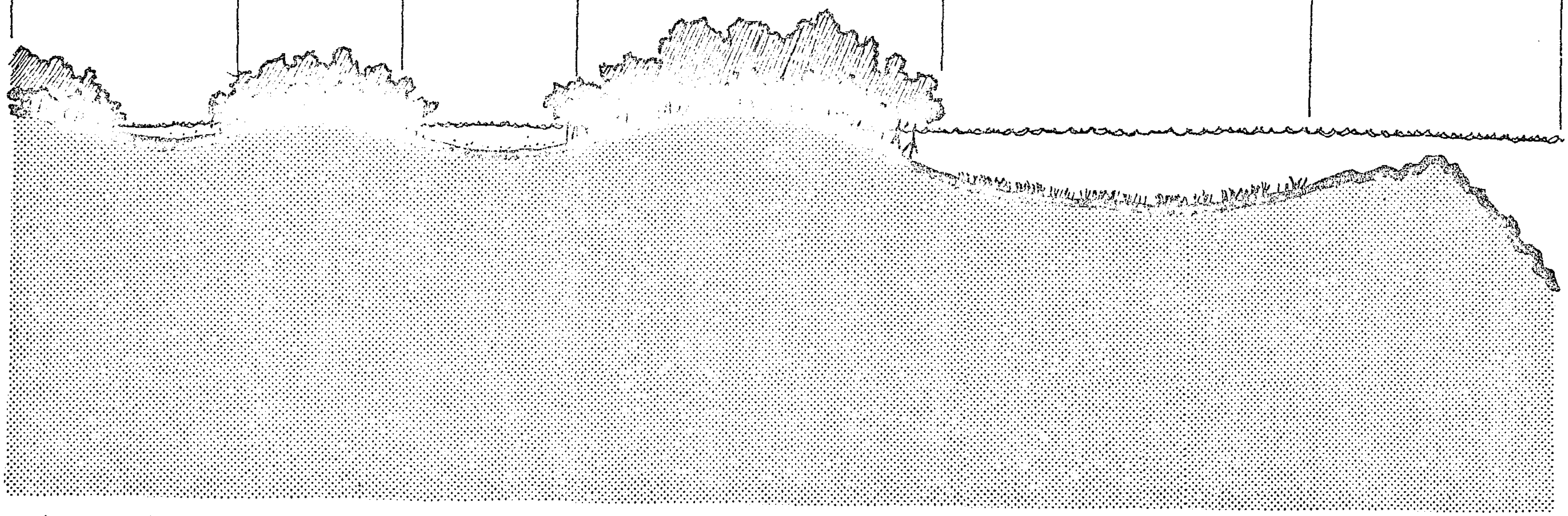


Figure 46. Mangrove dominated ecosystem with lagoonal flats and protective reef. Food chain centered on sea grasses and mangrove litter.

Man-made Shoreline & Structures

DEVELOPED SHORELINE
Heavy use, altered drainage, high proportion of impervious surface, vegetation cleared, high runoff, pollution sources.

STRESSED BAY
Heavy use, increased turbidity, silty bottom, reduced bottom diversity and productivity, possible phytoplankton blooms, boats disturb bottom, contribute hydrocarbons, heavy metals, sewage, structures may reduce circulation. Often require maintenance dredging.

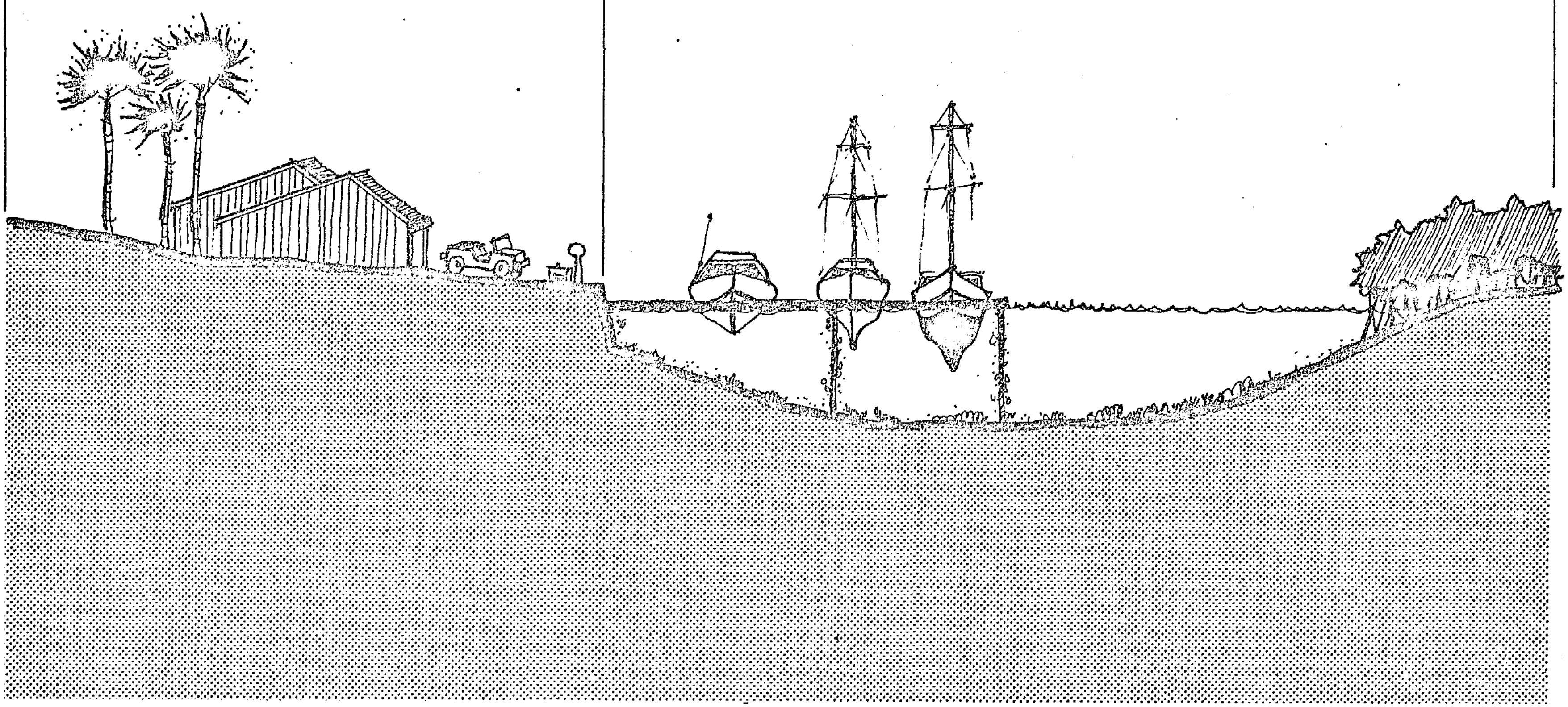
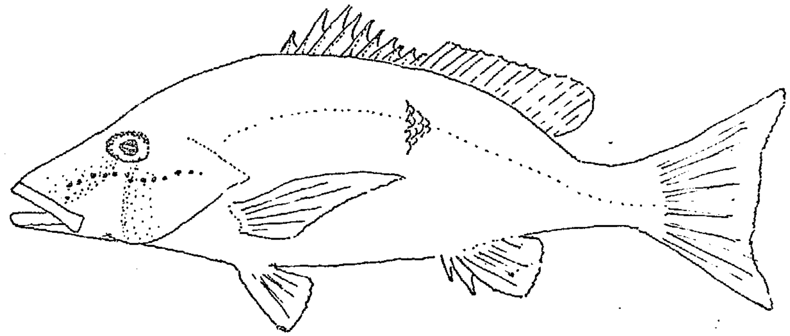


Figure 47. Man-dominated Bay Ecosystem.

ing for channel maintenance or construction sand (if properly executed) to protect adjacent resources. Within limitations of the ecosystem these bays should be considered first as sites for further development.

Restrictions: because of limited circulation and existing pollution loading, should not be considered for direct waste discharge of any type. Future development needs to be gauged carefully to avoid exceeding ecosystem capability and acceptable pollution loading levels.



Dog Snapper or Dog Tooth (Lutjanus jocu)

Critical Areas

Areas of High Productivity

Few quantitative measurements of productivity have been made in the Virgin Islands. The following areas are listed because the site-specific environment there is known generally, from research on similar sites, to be highly productive, or because it yields especially large amounts of seafood, although production may not be *in situ*. Thus, the list is conservative. Most reef banks are fished by traps and handlines. All grass beds sometimes contain harvestable quantities of conch.

ST. THOMAS

1. Jersey Bay Mangrove Lagoon - breeding area, wildlife refuge.
2. Southern Shelf Edge (100 fathom drop-off) - high fish concentrations, heavily fished.
3. North Central and West Shelf - productive fishing areas.

ST. CROIX

1. Sandy Point - traditional fishing area apparent good sand source.
2. Manning Bay Mangrove Area - wildlife habitat, fish and bird breeding.
3. West Coast Shelf - heavily fished.
4. East End Reefs (Lang Bank) - biologically productive area.

ST. JOHN

1. South Shelf Edge - popular fishing area.
2. Coral Bay and environs - heavily fished area, some mangroves.

Areas Under Stress

ST. THOMAS

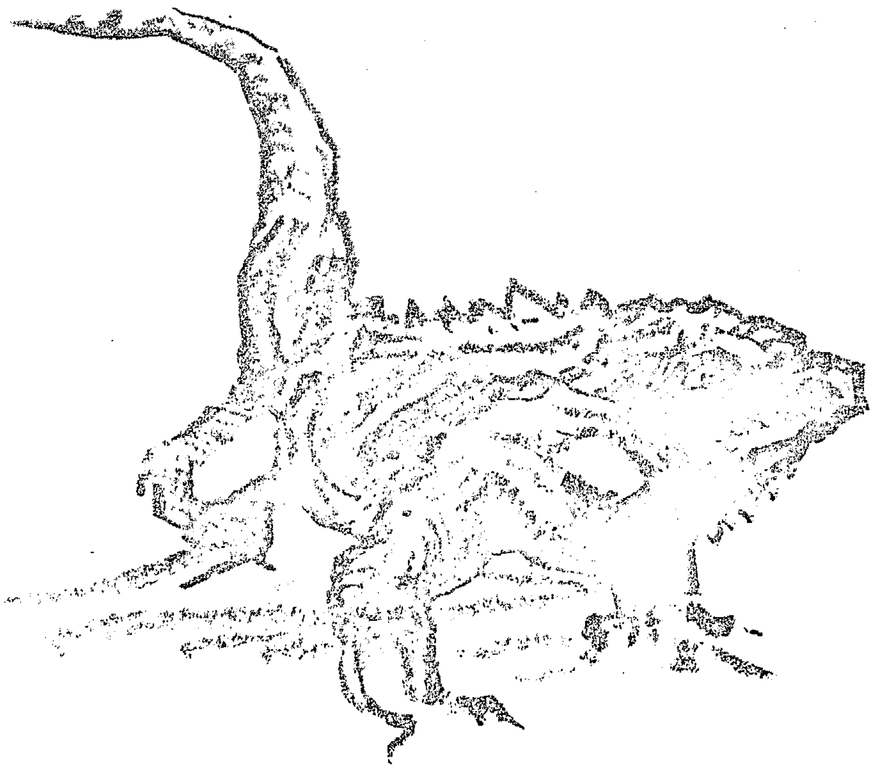
1. St. Thomas Harbor and Crown Bay - urban runoff, sewage, dredging, marinas and ship traffic.
2. Lindbergh Bay - urban runoff, sewage, thermal-saline effluent, dredging.
3. Fortuna Bay - periodic stress by runoff from Estate Bordeaux and surrounding residential area. Apparently tolerating stress, recovers quickly from each episode but cumulative effects of continued increasing stress may produce long-term noticeable degradation.
4. Stumpy and Santa Maria Bays - ambient turbidity appears to be increasing, caused by runoff from developing north shore mountain slope areas.
5. Water Bay - attrition of nearshore grasses and algal beds probably due to dredging, filling of salt pond and increasing siltation from residential development.
6. Vessup Bay - stress sources: marinas, boat traffic, sewage, runoff.
7. Jersey Bay Mangrove Lagoon - stress sources: marinas, boat traffic, sewage, runoff, filling of ponds, cutting mangroves, canalizing drainage.

ST. CROIX

1. Christiansted Harbor - stress sources: dredging and filling, urbanization, runoff, sewage, thermal-saline effluents, marinas, boat traffic.
2. Altona Lagoon - stress sources: channel restriction, urban runoff.
3. Canegarden Bay to Port Harvey - stress sources: dredging, filling, runoff, oil spills, air pollution, thermal-saline discharges, ship traffic.
4. Manning Bay - stress sources: garbage, dumping, periodic petroleum spills.

ST. JOHN

1. Cruz Bay - stress sources: dredging, pond-filling, marina, boat traffic, sewage.
2. Great Cruz Bay - stress sources: dredging, pond filling.
3. Enighed Pond - stress sources: garbage, solid wastes.



Unique Areas

ST. THOMAS

1. Jersey Bay Mangrove Lagoon - largest original surviving mangrove stand in the Virgin Islands.
2. Coki Point Peninsula - unique pre-tertiary marine fossils.
3. Magens Bay Valley and Beach area - significant concentration of documented pre-Columbian archaeological sites. Superb public beach, archaic botanical garden, publicly acknowledged as an aesthetically unique element of the Virgin Islands coastal zone.
4. Botany Bay Estate - deciduous forest, high diversity, adjacent patch and fringing reef, scenic - high recreation potential for territorial park.
5. Most offshore cays, especially Savana, Little Saba, Turtledove, Cockroach, Cricket Rock, Flat Cay, Whistling, Congo and Dutch Cap Cays - all are important nesting sites for doves and sea birds, the last three especially for pelicans which are an endangered species.

ST. CROIX

1. Lang Bank - unusually large area of reefs extending westward on both north and south sides of island.
2. Salt River - largest remaining mangrove estuary on St. Croix.
3. Westend Salt Pond - unique combination of large pond, sand dunes, and xeric forest.
4. Great Pond - the largest remaining marsh area on St. Croix with fringing mangroves, partially dedicated to public use.

ST. JOHN

1. Lagoon Point, Coral Bay - excellent well developed fringing reef, broad coral flat, inner shallow lagoon with turtle grass stands, associated red mangrove and salt pond. Warrants inclusion in territorial park system.
2. Newfound Bay - excellent example of reef-choked bay combining classic fringing reef complex and coastal land-formation dynamics.
3. Carval Rock and Congo Cay - important nesting sites for sea birds, scenic.

Miscellaneous

Attention is directed to the published inventory of "Potential National Natural Landmarks" of the U.S. Virgin Islands, prepared by the West Indies Laboratory for the National Park Service (May, 1975); a priority rating system is used.

Synthesis- Coastal Zone Planning Guidelines

Regional Context

Formulation of a Virgin Islands Coastal Zone Management Plan should reflect overall requirements for services, facilities environmental diversity, and the preservation of natural and cultural assets.

We recommend that, in consonance with local requirements, an evaluation be made of the regional need for various resource allocations. There is probably no defensible basis on which to argue for the absolute protection of all of the approximately 100 remaining salt ponds, but it is also indefensible to argue that they should all be filled for construction or opened as marinas, given the interdependent relationships of the U.S. Virgin Islands to adjacent island areas to leeward and windward

Local planning should be geared to providing rational resource allocation consistent with maintaining regional environmental diversity. The development of marinas, as one example, should not be limited only by current economic demand or the availability of suitable sites, but ultimately by the regional need for allocating available sites for alternate uses, given the pattern of small boat visitation in the eastern Caribbean. The need for this type of evaluation for many coastal resources is mounting and, in at least two site-specific cases, is long overdue. Of the several extensive mangrove forest areas originally found in the islands, only two remain. The majority have been committed to the single purpose of land development and virtually obliterated. The remaining two sites represent the Virgin Islands' only surviving opportunities to provide alternate allocations of these extremely important, highly threatened and presently unique resources.

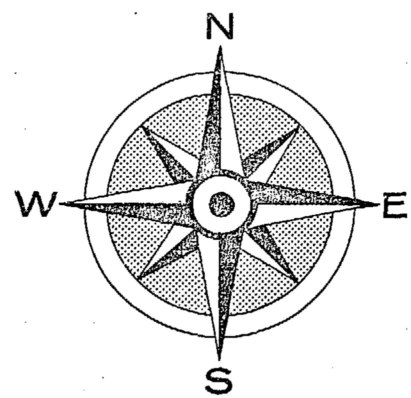
A second example is the last remaining areas of native rainforest vegetation, primarily on St. Croix with a small area on St. Thomas. Although not coastal, they provide glaring examples of how individual resources may be decimated for a single purpose without thought to alternate uses.

Planning Concept : Ecosystem Approach

The foregoing descriptions of coastal and marine habitats have touched frequently on interactions between these component units. Future assessment of the Virgin Islands coastal zone and development of management strategies needs to keep the interactive perspective of natural systems in focus in understanding coastal processes for planning purposes. Management plans must be built on a comprehensive approach reflecting an appreciation of the interactions and interdependencies of the various physical and biological components within the larger scale. This ecosystem approach must consider the integrity of larger systems as related to singular manipulations of component parts. Inherent in this approach is the consideration of the secondary impacts of all resource manipulations, for whatever purpose.

An "ecosystem" comprises a complete integrated unit of physical and biological components within which no part functions independently of the others. As such, coastal ecosystems can logically exclude neither the contributing inland watershed nor the adjacent marine area.

Management of any ecosystem should have the fundamental purpose of maintaining the system at "best achievable ecosystem function" (Clark, 1974).



Guidelines for Resource Management

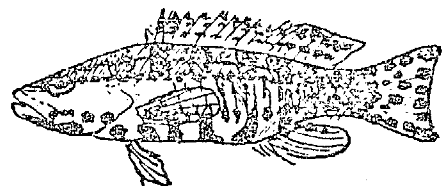
Concepts of resource management have been developed along the lines of Clark's (1974) Coastal Ecosystems: Ecological Considerations for Management of the Coastal Zone, which is highly recommended for the planner and decision-maker. The principles therein have been applied to specific local resources and their management requirements so far as we now understand them.

In this regard, it is necessary to broadly classify and identify coastal areas according to their needs for planning concern. Clark describes three categories of concern: (1) Vital Areas are ecosystem elements of such high value and critical importance that they must be set aside as preserves, protected intact from outside stresses. They must be encompassed within (2) an Area of Environmental Concern which serves as a buffer zone. Areas of Environmental Concern are conservation areas which require special conservation and management protection because of broad environmental sensitivity. (3) Areas of Normal Concern are areas where only normal, but planned and enforced, methods of utilization and exploitation are necessary.

Vital Areas

CAYS

Most offshore cays must be considered vital. Specifics on individual importance and management requirements should come out of work now being done by the Virgin Islands Department of Conservation and Cultural Affairs. These areas are extremely important to vanishing local as well as internationally migrating bird species. Because of their small size, the cays are very susceptible to man-made stresses, inadvertant or otherwise.



Areas of Environmental Concern

MANGROVES

Jersey Bay mangrove forest, St. Thomas, and Salt River and Great Pond on St. Croix represent ecosystems of proven importance to local commercial fish and lobsters as well as many birds. Much of their actual and potential value is still not appreciated or understood. They are extremely critical also because they are the only remaining areas of their kind in the Virgin Islands.

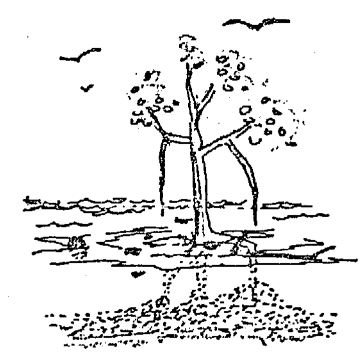
It may be necessary to set aside small, special sections as vital areas, and this is strongly indicated in the case of Cas Cay and Patricia Cay in the Jersey Bay lagoon.

RAIN FOREST

Remaining rain forest areas on St. Thomas and St. Croix are vital for the same reasons. Although not coastal, the protection of the large watershed areas which they cover is important in the management of the coastal receiving waters. Again, they represent the last remnants of original "coastal" vegetation and are a refuge for numerous plants and animals not found elsewhere in the extant coastal zone.

SURFACE WATER

Caledonia Gut and Cregue Dam on St. Croix are the most impressive fresh water habitats left in the islands and deserve special efforts for protection and management. All remaining fresh water streams and perennial ponds in the islands need special status and enforcement of existing laws for their protection. Turpentine Run Gut on St. Thomas formerly harbored a variety of fishes, crustaceans and water birds. It has been decimated by constant sewage and laundry waste discharges, and most of its biota has vanished. Again, these guts have significance for coastal water quality in addition to their own intrinsic value. These surviving areas are now unique in the Virgin Islands and require stringent, well planned protection and management. It is probably not necessary to set them aside as inviolate preserves. They can be maintained as sanctuaries for important wildlife while providing properly controlled, multiple usage for recreation, education, research, water storage and agriculture.



Areas of Normal Concern

All other habitats and ecosystems in the islands are sufficiently extensive so that requirements for their protection are not yet critical. Some specific sites are approaching the point of needing special restricted management to insure their continued use, consistent with maintaining basic environmental quality.

What is critical, however, is the need for regional and local assessment of resource allocation requirements and a local management plan to insure proper allocation and environmental maintenance constraints. It should never be construed that areas not specified as vital or requiring environmental concern do not warrant management controls. Uncontrolled resource exploitation will lead to crisis situations in all ecosystems eventually, and proper management of the entire coastal area is in order.

Areas of Regional, National, and International Significance

The areas already cited as vital to the Virgin Islands and requiring special concern are significant in a larger sense, outside of their site-specific natural value. On one hand, they represent unique remnants of the islands' natural heritage and, as such, should be maintained for future generations. In a larger frame, we suggest that mangrove areas, for example, may be significant to the production of regional populations of lobsters and several species of commercially important fishes. In an even larger sense, mangroves, cays, and rain forests are known to be critical habitats for many species of migratory birds, some in danger of extinction. In addition, they harbor many of our locally rarer reptiles and birds.

Guidelines for Ecosystem Management

The following general principles of coastal ecosystem management are cited from Clark (1974).

ECOLOGIC PRINCIPLES

Eleven principles derived from ecology that underlie major management functions are given below:

1. Ecosystem integrity - no one part of an ecosystem operates independently of any other.

2. Linkage - water provides the essential linkage of land and sea elements of the coastal ecosystem.

3. Inflow - the natural volume, pattern and seasonal rate of fresh water inflow provides for optimum ecosystem function.

4. Basin circulation - the natural pattern of water circulation within basins provides for optimum ecosystem function.

5. Energy - the flow and amount of available energy governs life processes within the coastal ecosystem.

6. Storage - a high capability for energy storage provides for optimum ecosystem function.

7. Nitrogen - productivity in coastal waters is normally governed by the amount of available nitrogen.

8. Light - the natural light regime provides for optimum ecosystem function.

9. Temperatures - the natural temperature regime provides for optimum ecosystem function.

10. Oxygen - high concentrations of dissolved oxygen provide for optimum ecosystem function.

11. Salinity - the natural salinity regime provides for optimum ecosystem function.

MANAGEMENT PRINCIPLES AND RULES

1. Ecosystem integrity: each coastal ecosystem must be managed with respect to the relatedness of its parts and the unity of its whole.

2. Drainage: A fundamental goal of shoreland management is to retain the system of land drainage as near to the natural pattern as possible.

3. Drainageway buffers: the need to provide vegetative buffer areas along drainageways increases with the degree of development.

4. Wetlands and tidelands: the need to preserve wetlands and vegetated tidelands increases with the degree of development.

5. Storage: storage components of ecosystems are of extreme value and should always be fully protected.

6. Energy: to maintain an ecosystem at optimum function, it is necessary to protect and optimize the sources and the flows of energy that power the system.

MANAGEMENT RULES

1. Drainageways: alteration of any drainageway by realignment, bulkheading, filling, impounding, or any other process that short-cuts the natural rate or pattern of flow or blocks or impedes its passage is unacceptable.

2. Basin circulation: any significant change from the natural rate of water flows of a coastal water basin is presumed to be ecologically detrimental and is unacceptable.

3. Nutrient supply: reduction (or increase) of the natural supply of nutrients to the coastal ecosystem by alteration of fresh water inflow is unacceptable.

4. Nitrogen: discharge of nitrogenous compounds into confined coastal waters is presumed to have adverse effects through eutrophication and is unacceptable.

5. Turbidity: turbidity of higher than natural levels is to be presumed detrimental to the coastal ecosystem and is unacceptable.

6. Temperature: significant alteration of the natural temperature regime of the coastal ecosystem is presumed adverse and is unacceptable.

7. Oxygen: any significant reduction from the natural concentration of oxygen is presumed to be adverse and is unacceptable.

8. Salinity: any significant change from the natural salinity regime is presumed ecologically detrimental and is unacceptable.

9. Runoff contamination: any significant discharge of suspended solids, nutrients, or toxic chemicals is to be presumed adverse and is unacceptable.

CONTROLS

Because both land and water use controls are necessary for best achievable ecosystem function, it is necessary to regulate both the location and the design of projects in shoreland and coastal water provinces. Also, many types of human activities must be controlled to some degree. In addition, the construction of many types of projects and their operations will have to conform to certain performance standards.

* * * *

In addition to general principles applicable to specific types of environments, management guidelines should be flexible enough to allow for site-specific evaluations of control and management needs. The following guidelines are provided as a preliminary basis for developing management plans for the ecological units described in this report.

MANAGEMENT GUIDELINES FOR BEACHES

1. Dredging in bays with beaches should not be allowed except under carefully designed plans to prevent loss of important sea grass beds, the creation of deep depressions, water quality degredation and deleterious changes in sand transport mechanisms.

2. Beach restoration with dredged sand should never be accomplished by simply pumping the sand onto the shore. It should be pumped into settling ponds and later spread on the beach mechanically, not hydraulically.

3. Structures (pipes, docks, groins, walls) should never be constructed across (or at right angles to) a beach unless carefull extensive study of alongshore sand transport regimes indicate they will be innocuous or advantageous.

4. Sand should not be removed from beaches.

5. Shoreward earth change and drainage modifications must be controlled to protect beach areas from pollution by storm water.

MANAGEMENT GUIDELINES FOR ROCKY SHORES

1. Structures on rocky shores should be securely anchored to stable footings.

2. Soil and other land materials should not be pushed over the shore into the sea.

3. If effluent discharges are contemplated, site studies are needed to determine where currents will carry pollutants, perhaps to more sensitive adjacent communities. If so, alternate outfall locations should be selected.

4. On cliffs, a construction set-back requirement may be advisable in some locations for safety and to avoid effects of erosion on nearshore resources.

MANAGEMENT GUIDELINES FOR SALT PONDS

Management and use allocations of salt ponds should be approached generally on an individual basis. Decisions need to be based on a fairly thorough understanding of the functions and relative importance of the salt pond in relation to its total ecosystem setting, that is, its importance to surrounding resources and other use requirements. It is probably not necessary that every salt pond in the islands be preserved as is. Salt ponds vary in their relative importance to the surrounding watersheds and as wildlife habitats. The potential impact of pond modification, therefore, is a site specific function. However, the following considerations generally should be applied:

1. In any case where a pond is to be opened to the sea, or an existing opening enlarged or otherwise modified, an adequate description of pond bathymetry and sediments based on soundings and borings should be available.

2. Sediments dredged from a pond should not be deposited directly in the sea or on the bay shoreline. Such disposal should only be considered if the sediments are clean sand or coarser material, a condition which usually does not occur under such circumstances.

3. Where a pond is deepened and opened to the sea, as for a marina basin, the connecting channel depth should be continuous with the depth of the pond basin.

4. Openings to the sea should not be made until all internal work in the pond is completed.

5. Based on the sediment profile of the pond bottom, nature of the adjacent bay environment and action of flushing currents, dredged pond and access channel depths should be designed to avoid releasing extremely fine, toxic pond sediments to dispersal in the sea.

6. The relationship of the pond to the surrounding watershed should be determined. This consideration may determine whether or not pond modification is advisable and what alternate or restorative drainage provisions are required.

7. Because of the smallness and close spatial relationship of most Virgin Islands, the importance of a salt pond as a wildlife habitat should be determined in advance as it relates to the availability of similar habitats in the islands.

8. If the pond is to be opened to the sea, it is advisable to know something of the surrounding marine environment, including water movement and biota.

MANAGEMENT GUIDELINES FOR MANGROVE AREAS

1. The remaining large mangrove areas (especially Salt River, St. Croix and Jersey Bay, St. Thomas) should be placed in the territorial park system. Their development should be stringently restricted only for recreational, aesthetic and academic use. Only minimal, carefully planned construction, compatible with their protected status, should be permitted.

2. Dredging and filling as a rule should be prohibited except on a small, carefully controlled scale and only if thorough study has indicated its absolute necessity for some purpose consistent with protective management.

3. Collection of marine or terrestrial living or physical materials should be prohibited except under a carefully controlled permit system for educational or scientific purposes. Guidelines for such a permit system may be adapted from the similar National Park Service permit system. Commercial exploitation should generally not be allowed.

4. Sport fishing may be permitted, but it may be necessary to specify allowable areas, fishing gear and perhaps species, seasons and size limits.

5. Boat traffic within the area must be strictly controlled. Some portions may be opened to small outboard powered boats, while other areas (shallows, quiet waters, muddy bottoms) should be closed to all motor boats.

6. No anchorage for boats should be permitted anywhere in the mangrove system. No live-on boats should be allowed.

7. Cutting of shoreline mangroves or of a trail through the mangroves for boat mooring or any purpose other than the planned area management and use program should be prohibited.

8. Points for small boat docks, launching ramps or other access structures should be carefully selected and structures carefully planned, constructed, licensed and managed.

9. No waste discharges or polluting substances of any kind should be permitted into the area. Sewage systems should provide for treatment and recycling of the effluent unless suitable soil is available for septic tanks and leach fields which would not allow seepage of effluents to shore waters.

10. By zoning, licensing or other appropriate controls, buffer zones

should be maintained adjacent to the mangrove area to minimize runoff, erosion, air or water pollution which may adversely affect the mangrove area. Buffer zones adjacent to water areas should be at least 150 feet wide to provide runoff interruption, soil infiltration and plant absorption of ground water. The width of the buffer zone should be wider where vegetation is sparse or the slope is steep or the soil is not porous. In some cases reforestation may enhance the buffer zone.

11. Hunting of birds or the taking of eggs should be prohibited.

12. Restraint must be employed in constructing access roads. In keeping with recreational, educational and preservational objectives, access roads should be of minimum number and size, consistent with management goals. In no case should causeways be built across channels or ponds.

13. Development restraints should be promulgated for the watershed which drains into the mangroves to control the volume and frequency of runoff. Canalization and other drainage modifications which would adversely affect the marine mangrove area should be prohibited. New drainage systems should utilize natural drainage ways wherever possible and should be designed so as not to increase stream discharge to the mangroves. Subsoil infiltration should be strictly controlled. Revegetation of cleared upland areas should begin as soon as possible.

14. Impervious surfaces (asphalt, concrete, etc.) should be kept at a minimum and provisions made to impound runoff from such surfaces and store it for use or percolate it into the soil.

SUGGESTIONS FOR MANAGED MULTIPLE USES OF MANGROVE AREAS

Within the context of the recommended protective status, the natural attributes of the two large mangrove areas should be developed to translate these attributes into useable social resources. Possible use of the areas include the following:

1. Recreation.
   * Nature trails, underwater trails, bird watching, hiking.
   * Fishing on a controlled basis by conservative methods.
   * Swimming.

2. Education. The potential for educating students at all levels in areas of West Indian natural history is limitless. The mangrove lagoon on St. Thomas has already been used on a limited basis by the Environmental Studies Program

of the Virgin Islands Department of Education.

3. Research. The mangrove areas provide the opportunity for research into (1) coastal geological processes, land formation and sediment production and (2) life histories and ecology of many forms of terrestrial and marine life, many of them important and valuable food species.

4. Commercial activity. For areas already irrevocably committed to marina/small boat/dockage/service functions, a non-expansive management plan should be developed, imposing flexible constraints on current practices and non-flexible constraints on all proposed utilization.

MANAGEMENT GUIDELINES FOR REEFS

1. Except where absolutely necessary, reefs should not be subjected directly to filling, cutting, blasting or waste discharge of any type.

2. Heated effluents should never be discharged in reef areas.

3. Except under careful control and licensing, corals and other reef organisms should not be collected commercially. Recreational collecting should be discouraged.

4. Dredging operations adjacent to reefs should be designed to minimize impact on the reef. Monitoring is essential.

5. All shore and water related development should be evaluated for their relationship and possible effects upon adjacent reefs.

MANAGEMENT GUIDELINES FOR SANDY BOTTOMS

1. Use options should be considered in light of the relatively tolerant quality of the habitat.

2. Where sand mining is proposed, adequate prior borings and sediment analyses should be conducted to describe the nature of the sediments and determine spoil handling requirements.

3. Where dredging is proposed, final depth contours should be as natural as possible, eliminating deep isolated holes.

4. Uses of sandy areas should be consistent with maintenance of adjacent reefs, beaches, grass beds, etc.

MANAGEMENT GUIDELINES FOR GRASS BEDS

1. Dredging should be avoided in these areas wherever possible. If necessary, it is absolutely essential that the design slopes be natural and open the dredged area to free communication with the rest of the bottom. Isolated

deep holes are definitely to be avoided. To this end, it may be better to make shallower cuts over bigger areas to obtain a given volume of sand. While areas stripped of grass and algae take surprisingly long to recover, deep pits create and perpetuate a number of other problems which can permanently alter the ecology of an entire bay.

2. Dredging, where permitted, should begin at the mouth of a bay and proceed inward with an upward slope. It is preferable to restrict dredging to bay mouths rather than the inner shallower bottom. Dredging close to the beach should be absolutely prohibited. At least several hundred feet of shoreward grass beds in front of a beach should be left untouched.

3. Boat anchorages in enclosed bays with grass beds can be destructive if vessel density over time becomes too high. Unless a bay has been committed specifically for anchorage, it may become necessary to specify permitted anchorage areas and boat density. Fixed moorings, privately or publicly maintained and leased, are to be preferred.

MANAGEMENT GUIDELINES FOR CAYS

1. In conjunction with planning recommendations from the Virgin Islands Department of Conservation and Cultural Affairs, certain cays should be set aside as inviolate wildlife sanctuaries.

2. Other publicly owned cays should be developed for multiple use as recreation and nature areas, but any alternate or coincident use of a cay should be compatible with maintaining its value as a wildlife area.

3. Consideration should be given to establishing ranger or warden stations on strategically located cays, from which it would be easy to patrol and monitor the other islets.

4. Each cay should be evaluated individually to determine its use potentials.

Recommendations for Further Study

* The general inshore current regimes of the islands need to be investigated and determined. Prevailing, as well as periodic, departures from the norm need to be quantified, especially in any areas programed for a change in use patterns. A prime example is the industrial southwestern half of St. Croix where, despite at least two large scale environmental studies, current patterns are unknown except primarily from qualitative subjective descriptions from local residents.

* Long Reef in Christiansted harbor should be restudied at intervals to follow up on two previous studies which indicate damage from several sources. Also a unique opportunity exists to study reef recovery after termination of sewage discharge, which is expected shortly.

* Techniques need to be developed for tracing sources of oil pollution. Procedures should be developed and implemented for enforcing Virgin Islands laws relating to oil and hazardous materials spills.

* Offshore cays should be studied continuously for the purpose of developing management plans consistent with their frailty, ecologic and recreational value. They represent an irreplaceable local resource especially in view of the present population density loading on the larger islands.

* Sand resources inventories should be conducted in offshore areas around all islands to locate deposits which can be mined economically with minimal environmental impact.

* The effects to turbidity on local marine organisms and communities should be quantified as a means of assessing the possible impact of runoff, dredging, waste discharges, etc. Local water quality criteria for turbidity should reflect the findings of such a study.

* Periodic monitoring of heavy metals should be conducted in marine sediments subjected to municipal and industrial discharges.

* Runoff from the land should be investigated during the rainy season to identify areas subjected to turbidity and siltation. Analysis of the watershed, rainfall and other information should be used to estimate discharges.

* Quantitative studies should be mounted to describe the marine environment in strategic areas, i.e., all harbors, the south shore of St. Croix, the mangrove lagoons, and Fortuna and Perseverance Bays on the southwestern end of St. Thomas. These should be followed annually by quantitative surveys to assess change.

* Detailed studies should be conducted on major salt ponds to quantify their functions and natural values and to provide rational basis for management and use allocations.

* Establishment of "marine preserves" should be given immediate priority, especially in the last remaining mangrove areas: Salt River and Great Pond, St. Croix and Jersey Bay, St. Thomas.

* Existing and planned municipal and industrial facilities on the south shore of St. Croix dictate a need for a comprehensive environmental assessment of the entire area. Such an assessment should stress the cumulative and secondary impacts of the total south shore development.

* The feasibility of restorative action in bays damaged by past destructive dredging should be investigated. In certain cases, it is apparent that considerable environmental damage resulted, not simply because the bay was dredged, but because the operation was poorly designed and executed.

* A permanent committee, similar to Florida's Coastal Coordinating Council, should be established to coordinate the Coastal Zone Management Plan.

* Because of the small size and steep terrain of the islands, it is impractical to separate Coastal Zone Management from environmental management in general. Responsibility for enforcing all aspects of environmental controls should be consolidated in a single agency.

* The government should secure title to critical offshore cays, declare certain ones as closed wildlife preserves and develop multiple use conservation plans for others.

* The taking and sale of seabird eggs should be prohibited.

* Laws relating to the clearing and development of guts should be strengthened and enforced. The "earth change" law should be rigorously enforced. These measures are needed to protect the unique and vanishing flora and fauna of the guts and to reduce destructive runoff to the area.

Summary

INTRODUCTION

With greater understanding of the complex interactions of natural coastal systems, we can develop improved plans for maximum multi-use management of the Virgin Islands' limited coastal resources. Appropriate resource protection and wise use are imperative to maintain natural productivity and aesthetic values and to preserve options for future generations.

The preceding compilation is intended as a first effort survey of the Virgin Islands' coastal resources describing our present knowledge of their interactive processes, values and capacities and our needs for additional information. The report deals with the major biological and physical components of the marine resource base and their intrinsic limits to man-induced perturbations.

The Inventory section describes important oceanographic, climatological, geomorphological, and marine ecology features of the islands' coastal zone. Beaches, rocky shores, salt ponds, mangroves, reefs, sandy bottoms, and grass beds are defined and described, as well as small cays and major biota. As far as possible, natural attributes, tolerances and constraints are identified.

The Analysis section reviews biophysical resource information, classifies coastal ecosystems and processes, identifies critical areas of high productivity, under stress or of a unique quality, and indicates some of the existing and potential impacts along the coastal zone.

The Synthesis and Guidelines sections provide management recommendations for vital areas, areas of environmental concern, areas of normal concern, and for ecosystem quality control. Where possible, site specific constraints, degradation thresholds or limiting factors are also cited. The study concludes with a list of recommendations for further investigation and an annotated bibliography.

INVENTORY

OCEANOGRAPHY AND CLIMATOLOGY - (1) TIDES

In the Virgin Islands, tidal ranges are not great, and tidal currents, except in some inshore localities, are not significant. There is one high and one low tide per day on the north coasts of St. John and St. Thomas, on the south coasts of St. John and St. Thomas, and on all St. Croix coasts there is a second, reduced cycle of high and low tides. Fortunately, waves, swell and ocean currents usually do a good job of flushing most bays. These forces, however, are considerably reduced by the time they reach the heads of deep embayments. As a result, circulation may be very poor in the inner reaches of some of our larger embayments. These conditions are important for the planner because pollutants introduced to these calm areas will be very slowly dispersed. These quiet areas also are sites for relatively rapid deposition. Sand transported naturally through these bays, as well as silt and debris from the land, tends to settle out, filling the bottom and eventually extending the shoreline.

(2) CURRENTS

Many factors interact to determine the direction of water flow in a bay. These include relative strengths of tides, winds, waves, swell, water density and pressure as well as the bay's bathymetry, shoreline shape and size. Thus, patterns of water movements are changeable. This fact is important for the planner because it demonstrates the need for site specific studies of currents to determine prevailing conditions and variations. Generally, currents around the islands are driven by the North Equatorial or Canary Current which moves through the Caribbean from east to west and eventually joins the Gulf Stream off the south coast of North America. Local currents in individual bays vary considerably due to exposure, winds, tides, shoreline, and bottom geometry.

(3) WAVES AND SWELL

Waves are the main source of energy that moves beach sediment and that affects shipping and shoreline structures during storms. The deepwater wave regime is driven by the northeast trade winds most of the year. Besides the normal easterly swell that affects windward coasts on the islands, there are two seasonal modes of wave approach that affect leeward coasts: a southeasterly chop and swell and a northern swell.

Along coasts fronted by partly submerged reefs, waves play a significant role in circulating back reef water, thus dispersing pollution and diluting its effects.

(4) STORM WAVES AND TIDAL FLOODING

Tidal flooding, created by major hurricanes having an average frequency of once in 33 years, raise water levels in St. Thomas from five to twelve feet above normal. A six foot height floods lower parts of Charlotte Amalie for 800 feet landward from the shoreline. Besides flooding, damage to waterfront facilities and erosion of shores by storm waves can be heavy. Moreover, passing hurricanes may create a minus tide of as much as 1.0 feet below mean low water that can temporarily affect grounding of vessels in shoal water and exposure of tidal flats.

Large sea waves of extraordinary length called tsunamis are associated with submarine seismic disturbances. These waves seem to occur about once every 10 or 15 years in the Caribbean area.

(5) WATER QUALITY

Water quality may be defined by any number of parameters depending on what information is required. Common quality indicators are temperature, salinity, dissolved oxygen, transparency and bacteria. Additional measurements often required are biochemical oxygen demand (B.O.D.), chemical oxygen demand (C.O.D.), nitrogen, phosphorous, silicon. Estimates of water color have limited value.

The effects of these constituents on water quality are significant to the well-being of individual organisms, whole communities and entire ecosystems. All of these water components may assume pollution roles if changed from normal levels.

Shoreline waters of the Virgin Islands have temperatures of 25.5 - 28.0° C between December - April and 27.0 - 29.0° C between June - October. Salinity (the amount of salt in the water) generally averages 35.5 - 36.2 parts per thousand and 34.0 - 35.2 parts per thousand during the same periods. Almost all our waters contain dissolved oxygen near saturation. Turbidity in local waters is generally low, and in most bays the sea bottom is visible. In areas where runoff from the land, sewage and boat traffic cause murkiness, the bottom is often not visible at ten feet depth. Local waters are low in nutrients which accounts for the low levels of planktonic productivity. However, localized productivity by reefs and sea grasses is very high.

(6) PREVAILING WINDS AND HURRICANES

The Trade Winds approach the islands with great constancy in direction primarily from the east-northeast and east. Hurricanes or tropical cyclonic storms constitute a seasonal threat of potentially catastrophic proportions. Frequency, probability, seasonality and dimensional aspects are reviewed in the basic text. Adequate preventative natural disaster planning is an essential element of any coastal zone management plan, and greater emphasis is needed on this requirement.

(7) PRECIPITATION AND EVAPORATION

Rainfall is low, evaporation is high, producing very dry conditions over most of the islands excepting some high mountain forests. Dryness and water loss are heightened by steep slopes which promote runoff, shallow rocky soil which holds little moisture, and strong sun and constant breezes which promote evaporation.

Rainfall varies over the year, by island and by areas within a given island. On the average, St. Croix receives 40 inches per year, St. John 47 inches and St. Thomas 42 inches. Heaviest rainfall occurs at Dorothea on St. Thomas and Analy on St. Croix. The wettest months are September - December; the driest, February - July.

Rainfall is important to the coastal zone as it promotes runoff into the sea. Development in the watershed increases runoff. Bays suffering the effects of runoff (turbidity, siltation, eutrophication, etc.) are St. Thomas and Christiansted harbors and Water Bay and Stumpy bays on St. Thomas.

Evaporation affects the coastal zone by increasing salinity in salt ponds and shallow restricted parts of embayments. Biotic composition shifts in adaptation to high salinities, but when heavy rains catostrophically depress salinity to very low levels, many halophilic (salt tolerant) organisms die.

GEOPHYSICAL FACTORS - (1) BATHYMETRY

St. Thomas and St. John lie on the Puerto Rican Plateau, a submerged ancient island mass. This submarine shelf extends from the shoreline to the 100 fathom depth, where coral reefs, other bottom irregularities, winds, shoreline configuration and tides act to divert and diverge prevailing ocean currents.

St. Croix lies on a shallow platform, separated from the Puerto Rican Plateau by the Virgin Islands basin with depths to 4,500 meters. North of the Virgins, the Puerto Rican Trench with depths to 9,170 meters is the deepest known area of the Atlantic. Other deep Caribbean basins around the Virgins are the Anegada and St. John passages and the St. Croix and Jungfern passages to the east and west, respectively, of St. Croix.

(2) SEISMIC ACTIVITY

Since the Caribbean island arc marks a transition zone between continental and oceanic crustal masses, it is a nearly continuous belt of shallow focus earthquakes, none of which seriously affect the Virgin Islands.

MARINE ECOLOGY - (1) FISHERIES

The striking similarity of various studies of fishing in the Virgin Islands going back over forty years emphasizes how fisheries have been relatively static in a period of generally rapid change. As the economy and population have burgeoned, the demand for fish and the price per pound have climbed, but the number of fishermen has not changed significantly.

The limited pelagic fish resources (billfish, tuna, wahoo, etc.) of the northern Virgin Islands support a sport fishery along the edges of the shelf, but repeated exploratory fishing has made it clear that stocks are not sufficient to support an industrial fishery. The primary commercial resources are demersal fish (and invertebrates) associated with coral reefs and tending to be concentrated around small irregularities at the bottom which provide refuge. A secondary finfish resource is inshore schooling fish, generally jacks, which are traditionally taken with haul seines.

Finfish stocks alone among the living marine resources offer long-term potential for increased yields, primarily by fishing stocks which are now only lightly exploited. Other species currently exploited include the sea turtle (often illegally), the conch, whelk, billfish (by sport fishermen), and the spiny lobster (currently reduced by over exploitation).

The low productivity of the fishery (both in total catch and catch per unit·effort) is also a reflection of the naturally low primary productivity (little growth of phytoplankton, the base of oceanic food chains) of Virgin Islands waters. Most primary production inshore is benthic - the coral reefs, algae and grass beds - and most fish are caught in these areas. Much of the open shelf of the Virgin Islands is relatively flat but too deep (thus the light is too dim) for sea grasses or vigorous coral reef growth.

Thus, while there is room for improvement in fisheries, local conditions which limit production and harvesting do not allow development of a fishing industry akin to that of continental shelf areas.

(2) BEACHES

As a buffer zone, beaches protect property from wave attack. They are also valuable for recreation for which they are in great demand. Beach sediments are highly mobile and thus beaches are constantly changing their form and dimensions. Stability depends on a supply of sediment either from the land or from the sea which is the main source. Consequently, most beach sands are a mixture of different types of material that vary in size and composition, according to the source and rate of supply, as well as according to the wave and current processes acting on it. Backshore dunes act as a reservoir of sand and prevent massive flooding by storm tides. When sand is placed on a beach in an attempt to rebuild it artificially, natural processes continue unhampered, erosion is checked and sand is supplied to adjacent beaches. Grain size of artificially placed sand should approximate natural beach sand found on the site.

BEACH ROCK

Many sand beaches of the Virgin Islands are broken by a ledge of rock that typically runs parallel to the beach or may be partially or completely submerged offshore. Beach rock is formed in place, below the beach surface, by the natural cementing action of ground water as dissolved calcium carbonate precipitates. Biological activity contributes to the cementation processes which take place quickly, probably within a few decades, perhaps even faster.

IMPACT OF MAN ON BEACHES

Human interference with natural processes is one of the major causes of beach erosion in the Virgin Islands. (1) Mining large quantities of sand can cause rapid erosion by changing the wave refraction patterns. (2) Dredging nearshore sand deposits induces erosion and/or slumping. Turbidity generated by dredge spoil fines reduces nearshore grass cover which normally absorbs wave energy. (3) Sites once used for waste disposal on beaches to fill and to extend low land are now subject to erosion. Release of former wastes also presents a potential for pollution. (4) Engineering structures intended for shore protection, such as jetties and sea walls, often cause deleterious effects when they interfere with natural coastal processes such as littoral drift. (5) Unregulated construction and improperly designed structures present a potential threat to life and property when they fail during storms. (6) Recreation can contribute to littering and pollution. A critical factor for upper backshore dune stability is vegetative cover. Motorcycles, automobile traffic, trampling, etc. can trigger erosion.

(3) ROCKY SHORES

Whether steep and cliff-like or sloping and irregular with rock rubble at the water's edge, rocky shore areas are probably the most stable, least threatened component of the Virgin Islands coastline. They require little immediate concern, *per se*.

(4) MANGROVES

Mangroves are flowering trees which can live in salt or brackish water. Several different trees are referred to by the common name "mangrove," but the most common are red mangrove, white mangrove and black mangrove. *Rhizophora*, known as "the plant that makes land," is the most typically recognized species. It grows at the water's edge, and new seedlings become established to seaward. The prop root system of the plants, besides providing support and hiding places for a wide variety of marine animals, traps sediments that accumulate from the plants or are washed down from the land. In so doing, the shoreline is slowly extended. Once the sediment becomes rather firmly established, the red mangroves die off naturally and are succeeded by other plants, initially black and then white mangroves. With their dense coverage and complex roots at the shoreline, they interrupt runoff from the land and help to trap fresh water, sediment and debris at the shoreline, thus protecting offshore marine areas from these pollutants.

Each year red mangroves drop large quantities of leaves and seedlings, all of which do not survive to become new plants. The natural decomposition of these materials sustains a complex food web beginning with micro-organisms and scavengers and culminating in such higher trophic members as snappers, barracuda, lobsters, and birds. The nutrients and other food energy supplied by plant litter decomposition accounts for the large numbers and wide variety of plants and animals which are found in climax mangrove communities.

(5) SALT PONDS

Natural development of mangrove forests tends toward the formation of closed ponds. Plants growing across a shallow bar or spit may merge with other mangroves. Channels may be maintained if a sufficiently strong current runs through periodically, or a body of water may be sealed off. When the pond is cut off from open water, a mangrove or coral growth, for example, a salt pond is formed. An inventory of salt ponds in the Virgin Islands is included in the basic text.

(6) CORAL REEFS

A reef is an area of extremely diverse marine life. Structurally, it is composed of the stoney skeletons of hard corals which also are the dominant life forms. This living structure provides shelter and food for innumerable other organisms.

Coral reefs are common characteristic features of the islands' coastal zone and are of fundamental environmental and economic value. Besides their intrinsic beauty, they are important as producers of sand for natural and man-made beach cover and for construction. As such, they represent one of the territory's very few naturally replaceable resources. Reefs also provide protection for harbors, shorelines and shore structures by abatement of waves and dissipation of their energy which otherwise would be expended on the shore with greater force. Also, reefs provide perhaps the largest portion of seafood presently harvested in the islands. Most species of fish consumed locally either live on the reefs or depend upon them in some measure for their food. Lobsters, too are taken primarily from reef areas.

The high productivity of coral reefs, through photosynthesis, produces oxygen for the support of respiratory organisms both on land and in the sea.

The most damaging effect upon coral reefs of dredging in most cases is the clouding of the water by very fine suspended particles. This turbidity cuts down the amount of light which reaches the corals and other reef organisms, threatening their survival. Another result of dredging is siltation of solid particles. Corals can be smothered because of their inability to cleanse themselves of heavy loads of sediment over time.

(7) SANDY BOTTOMS AND GRASS BEDS

Large areas of sandy sea bottom are scattered throughout the platform. Sometimes they occur in shallow bays without apparent reason as most shallow bays are vegetated. The most extensive areas of essentially bare sand occur below 60 feet depth. Even here, the lack of extensive plant growth is not easily explained but may be due to low light intensity and/or the nature of the sediment. Another possible explanation may be that the sand is shifting at a rate which prevents plant establishment. These areas are not, of course, barren. They usually support scattered algae and the flowering plant Halophila.

Sandy areas are not well understood, and the extent of their significance to regional ecosystems is unknown.

Grass beds are frequently referred to as marine pastures because they are areas of thick growth of sea grasses and algae resembling pastures on land and serving essentially the same functions. Most inshore bay bottoms are covered with such pastures as are some extensive areas outside of bays.

Marine pastures produce a significant amount - perhaps most - of the oxygen generated in local inshore waters. On a bright day dissolved oxygen over a healthy grass bed will exceed the saturation value (i.e., the water becomes supersaturated), and small bubbles rise from the leaves to the surface. Grass beds help to stabilize the sand.

Several species of small fish live in the pastures, but more important, a larger variety of others come here to feed on the plants and myriad creatures that live in the pastures. This is the habitat of the queen conch (Strombus gigas) and feeding grounds of the sea turtles.

There is a very close knit relationship between the plants and animals in this habitat, both spatially and physiologically. The pasture is a low profile environment. The plants usually do not exceed eight inches in height, and all but a few of the associated animals live within this zone or in the sediment. Thus, except for visiting foragers and predators, the majority of community energy cycling goes on in close quarters. Wastes from the animals are utilized by the plants which produce oxygen and forage.

Once destroyed, marine pastures usually require a long time to recover. Deep holes may never recover. Since the community is dominated by plants, a critical minimum amount of light is needed. Chronic, heavy turbidity is destructive. Quantitative tolerances have not been determined.

(8) OFFSHORE CAYS

The small offshore islands vary in size from bare protruding rocks to over 170 acres. Most are 5 - 50 acres. A few are inhabited by one or two families - and many are difficult to get onto even by boat. Simple rock protrusions like Booby Rock, Sail Rock and Cricket Rock serve mainly as roosting and nesting sites for sea birds. The larger islets have beaches, rocky shores, cliffs, and some vegetation, mainly xeric scrub. Most have at least one salt pond and are surrounded by some degree of reef development. Most of the more than 60 emergent rocks and cays are around St. Thomas.

ANALYSIS AND SYNTHESIS OF BIOPHYSICAL ASSOCIATIONS

The composition of coastal ecosystems varies considerably, but certain combinations of habitats occur frequently in the island areas. The Virgin Islands are no exception, and the following typical systems have been chosen for illustration.

(1) ROCKY SHORELINE ASSOCIATIONS

Dominant features: shoreline of hard resistant, highly fractured rock extending under the surface, resulting in active coral growth on the rocky base along shore.

Characteristics: salt-tolerant plants on shore; turbulent, usually clean, clear well oxygenated water with tough hard and soft coral community and other living forms highly resistant to wave action. Bedrock usually lies beneath thin sand cover up to several meters offshore.

Suitability: snorkelling, fishing, good dispersal for treated effluents, scenic value above and below the surface of the water.

Restrictions: wave action precludes mooring, anchorage; light structures on shoreline rocks subject to wave, storm and corrosion damage.

(2) SALT POND - BAY ASSOCIATIONS

Dominant features: protected bay with sea grass bottom and beach shoreline sometimes with near-shore patch reefs, hypersaline and separated from sea by sand or pebble beach and berm combinations, often surrounded by mangrove.

Characteristics: very low energy water motion in bay, pond acts as catchment and filter for flood water from land, usually supports wading birds and other wildlife in associated mangrove.

Suitability: low energy bay usually good for watersports, boat anchorage. Ponds may be filled for development or opened for marinas.

Restrictions: structures on filled ponds need pilings, opening of ponds can release fine sediments and toxins to upset bay organisms and water quality. Filling or opening pond incurs water quality stresses on the adjacent bay.

(3) SAND BEACH - GRASS BEDS ASSOCIATIONS

Dominant features: sandy beach, with gently sloping bottom leading to sea grass and algal pasture on bottom of protected bay. Sometimes combined with salt pond habitat.

Characteristics: beach sediments, grain size and profile change constantly in response to wave and currents. Sea grass acts as stabilizing factor in offshore movement of sand. Plants oxygenate water, assimilate community wastes, provide food and shelter for wide variety of animals.

Suitability: good swimming and recreation areas, usually suitable for small boat anchorages and moorings. Attractive areas for shoreline development. Frequently provide harvestable quantities of reef fish and conch.

Restrictions: solid structures on the submerged beach act as barriers, interrupt sand transport, change beach shape and quality. Structures on pilings less so. Excessive development in the watershed can result in deterioration of water quality, affecting recreational potential. Excessive and/or poorly designed dredging for sand can severely damage beach, coral communities and marine vista.

(4) MANGROVE - LAGOON - REEF ASSOCIATIONS

Dominant features: mangrove fringed shore or dense multi-species mangrove forest, mangrove mini-islands, landward salt ponds or tidal flats, quiet small lagoons between mangroves and protective adjacent offshore reefs, usually shallow with narrow entrance channels.

Characteristics: extremely high system productivity and utilization of energy, rich in edible and other organisms, food chain based on mangrove leaf litter, quiet water with low flow promotes sedimentation. Area is important feeding and breeding ground for many birds, juvenile fishes and shellfish.

Suitability: recreation, education, faunal preserves, fishing, marinas.

Restrictions: low water flow makes areas unsuitable for waste discharges. Filling land to shoreline will kill ecosystem base - the mangrove plants. Susceptible to turbidity and rapid sedimentation. While potentially good sites for marinas and sand dredging, they are generally intolerant of the impacts generated by these activities. Natural attributes of mangrove areas subject them to secondary environmental stresses they cannot tolerate.

(5) MAN-MADE SHORELINE AND STRUCTURES

Dominant features: developed shoreline with altered topography and drainage, high percentage of impermeable surface, unnatural shoreline (bulkhead, landfill, docks, moorings, etc.), usually low-energy quiescent protected bay.

Characteristics: high use levels, increased addition of pollutants and toxins to the bay, abnormally high turbidity and pollutants, impoverished floral and faunal communities, increased sedimentation, subject to rapid runoff, frequent hydrocarbon slicks, often develop colored phytoplankton blooms.

Suitability: as previously modified natural systems, these areas could have priority consideration for sand dredging for channel maintenance or construction sand (if properly executed) to protect adjacent resources. Within limitations of the ecosystem, these bays should be considered first as sites for further development, rather than opening up new areas.

Restrictions: because of limited circulation and existing pollution loading, should not be considered for direct waste discharge of any type. Future development needs to be gauged carefully to avoid exceeding ecosystem capability and acceptable pollution loading levels.

CRITICAL AREAS - (1) AREAS OF HIGH PRODUCTIVITY

Few quantitative measurements of productivity have been made in the Virgin Islands. The following areas are listed because the site-specific environment there is know generally, from research on similar sites, to be highly productive, or because it yields especially large amounts of seafood, although production may not be *in situ*. Thus, the list is conservative. Most reef banks are fished by traps and handlines. All grass beds sometimes contain harvestable quantities of conch.

St. Thomas - Jersey Bay Mangrove Lagoon
Southern Shelf Edge
North Central and West Shelf

St. Croix - Sandy Point
Manning Bay Mangrove Area
West Coast Shelf
East End Reefs (Lang Bank)

St. John - South Shelf Edge
Coral Bay and Environs

(2) AREAS UNDER STRESS

St. Thomas - St. Thomas Harbor, Crown Bay
Lindbergh Bay
Fortuna Bay
Stumpy and Santa Maria Bays
Water Bay
Vessup Bay
Jersey Bay Mangrove Lagoon

St. Croix - Christiansted Harbor
Altona Lagoon
Canegarden Bay to Point Harvey
Manning Bay

St. John - Cruz Bay
Great Cruz Bay
Enighed Pond

(3) UNIQUE AREAS

St. Thomas - Jersey Bay Mangrove Lagoon
Coki Point Peninsula
Magens Bay Valley and Beach
Botany Bay Estate
Most Offshore Cays

St. Croix - Lang Bank
Salt River
Westend Salt Pond
Great Pond

St. John - Lagoon Point, Coral Bay
Newfound Bay
Carval Rock and Congo Cay

REGIONAL CONTEXT

Local planning should be geared to providing rational resource allocation consistent with maintaining regional environmental diversity. The development of marinas, as one example, should not be limited only by current economic demand or the availability of suitable sites, but ultimately by the regional need for allocating available sites for specialized uses, given the pattern of small boat visitation in the eastern Caribbean. The need for this type of evaluation for many coastal resources is mounting and is long overdue. Of the several extensive mangrove forest areas originally found in the islands, only two remain. The majority have been committed to the single purpose of land development and virtually obliterated. The remaining two sites represent the Virgin Islands' only surviving opportunities to provide alternate allocations of these extremely important, highly threatened and presently unique resources. They represent valued remnants of the islands' natural heritage and, as such, should be maintained for future generations. In a larger frame, we suggest that mangrove areas, for example, may be significant to the production of regional populations of lobsters and several species of commercially important fishes. In an even larger sense, mangroves, cays, and rain forests are known to be critical habitats for many species of migratory birds, some in danger of extinction. In addition, they harbor many of our locally rarer reptiles and birds.

SUMMARY GUIDELINES FOR MANAGEMENT OF COASTAL FEATURES

In addition to general principles applicable to specific types of environments, management guidelines should be flexible enough to allow for site-specific evaluations of control and management needs. The following summary provides a preliminary basis for developing management plans for the ecological units described elsewhere in this report. See the full section (page 131 *et seq*) for detailed recommendations.

(1) PLANNING GUIDELINES FOR BEACHES

1. Dredging in bays with beaches should not be allowed except under careful supervision and rigid controls.

2. Beach restoration with dredged sand should never be accomplished by simply pumping the sand onto the shore.

3. Structures on beaches should not be permitted except after careful study of potential impact.

4. Sand should not be removed from beaches.

5. Shoreward earth change and drainage modifications near beaches must be carefully regulated.

(2) PLANNING GUIDELINES FOR ROCKY SHORES

1. Structures on rocky shores should be securely anchored to stable footings.

2. Soil and other land materials or waste products should not be pushed over the shore into the sea.

3. If effluent discharges are contemplated, site studies are needed to determine where currents will carry pollutants and reduce impact.

4. On cliffs, a construction set-back requirement may be advisable in some locations for safety and to avoid effects of erosion on near-shore resources.

(3) PLANNING GUIDELINES FOR SALT PONDS

Management and use allocations of salt ponds should be approached generally on an individual basis. It is probably not necessary that every salt pond in the islands be preserved as salt ponds vary in their relative importance to the surrounding watersheds and as wildlife habitats.

1. In any case where a pond is to be opened to the sea, or an existing opening enlarged or otherwise modified, an adequate description of pond bathymetry and sediments should be prepared and analyzed.

2. Sediments dredged from a pond should not be deposited directly in the sea or on the bay shoreline.

3. Mangrove stands should be maintained as a high priority component.

4. Openings to the sea should not be made until all internal work in the pond is completed.

5. The relationship of the pond to the surrounding watershed and its importance as a wildlife habitat should be determined in advance as it relates to the availability of similar habitats in the islands.

(4) PLANNING GUIDELINES FOR MANGROVES

1. The remaining large mangrove areas (especially Salt River, St. Croix and Jersey Bay, St. Thomas) should be placed in the territorial park system. Their development should be stringently restricted only for recreational, aesthetic and academic use.

2. Dredging and filling as a rule should be prohibited except on a small, carefully controlled scale and only after thorough study.

3. Collection of marine or terrestrial living organisms or physical materials should be prohibited or at least discouraged and regulated.

4. Limited sport fishing may be permitted, but it may be necessary to specify allowable areas, fishing gear and perhaps species, seasons and size limits.

5. Boat traffic within the area must be strictly controlled.

6. No anchorage for live aboard boats should be permitted.

7. Cutting of mangroves for any purpose other than the planned area management and use program should be prohibited. Annual mapping is recommended.

8. Access points for small boat docks, launching ramps or other access structures should be carefully selected and structures and operations closely monitored.

9. No waste discharges or polluting substances of any kind should be permitted into the area.

10. By zoning, licensing or other appropriate controls, buffer zones should be maintained adjacent to the mangrove area to minimize human impact.

11. Hunting of birds or the taking of eggs should be prohibited.

12. Restraint must be employed in constructing access roads to maintain optimum natural tidal flushing and water circulation.

13. Development restraints should be promulgated for the watershed which drains into the mangroves to control the volume and frequency of runoff.

14. Possible permissible uses include:

    * Recreation as nature trails, underwater trails, for bird watching, hiking, and fishing on a controlled basis by conservative methods.

    * Education and research developing potential for use by students at all levels in areas of natural history.

    * Commercial activity for areas already irrevocably committed to marina/small boat/dockage/service functions.

(5) PLANNING GUIDELINES FOR REEFS

1. Except where absolutely necessary, reefs should not be subjected directly to filling, cutting, blasting or waste discharge of any type.

2. Heated effluents should never be discharged in reef areas.

3. Except under careful control and licensing, corals and other reef organisms should not be collected commercially. Recreational collecting should be discouraged and eventually regulated as in the case of Florida.

4. Dredging operations adjacent to reefs should be designed to minimize impact on the reef. Monitoring is essential.

5. All shore and water related development should be evaluated for their relationship and possible effects upon adjacent reefs.

(6) PLANNING GUIDELINES FOR SANDY BOTTOMS

1. Use options should be considered in light of the relatively tolerant quality of the habitat.

2. Where sand mining is proposed, adequate prior borings and sediment analyses should be conducted to describe the nature of the sediments and determine spoil handling requirements. Final depth contours should be as natural as possible, eliminating deep isolated holes.

(7) PLANNING GUIDELINES FOR GRASS BEDS

1. Dredging should be avoided in these areas wherever possible. If necessary, it may be better to make shallower cuts over bigger areas to obtain a given volume of sand.

2. Dredging, where permitted, should begin at the mouth of a bay and proceed inward with an upward slope. Dredging close to the beach should be absolutely prohibited. At least several hundred feet of shoreward grass beds in front of a beach should be left untouched.

3. Boat anchorages in enclosed bays with grass beds can be destructive if vessel density over time becomes too high. Fixed moorings, privately or publicly maintained and leased, are preferred.

(8) PLANNING GUIDELINES FOR CAYS

1. In conjunction with planning recommendations from the Virgin Islands Department of Conservation and Cultural Affairs, certain cays should be set aside as inviolate wildlife sanctuaries.

2. Other publicly owned cays should be developed for multiple use as recreation and nature areas, but any alternate or coincident use of a cay should be compatible with maintaining its value as a wildlife area and its scenic,

aesthetic value as part of the marine landscape.

3. Consideration should be given to establishing ranger or warden stations on strategically located cays, from which it would be easy to patrol and monitor the other islets.

<u>OVERVIEW</u>

The Virgin Islands constitute a unique island system - a place of value, beauty, and inspiration, possessing a rich history, spectacular marine life, diverse coastlines and a salubrious climate. They also have a promising future as a habitat for resident faunal, floral, and human species, living in a balanced, natural harmony.

There is, however, mounting evidence that the human component of our islands' population has, through oversight, uncontrolled expansion, and ill conceived actions, induced a broad spectrum of stresses that threaten the natural viability of the island system and could destroy what Alexander Pope referred to as "the genius of the place." This process is especially apparent in the coastal zone of the Virgin Islands where competing human interests and dynamic components of natural ecosystems interface and interact.

The present effort to develop a management plan for this critical zone of man-environment inter-relationship offers the promise of minimizing environmental conflict, improving resource allocation decisions, preserving our insular heritage and restoring the intricate balance with natural systems. The suggested guidelines outlined in the preceding pages are only a beginning. They will need continuous upgrading, updating and refinement, as independent and government sponsored research and more site-specific inventory data become available and as the competing interests and users of our coastal zone resources improve and expand upon their articulation of specific needs and objectives. Developing an ecologically sound, informed and balanced perspective on resource allocation is one of the principal objectives of planning. Coastal zone planning is no exception.

Selected Bibliography

These selected references, all of which are now available in the Virgin Islands, have been reviewed and are recommended as basic documentary sources for future Virgin Islands coastal zone planning. Each annotation concludes with an evaluation code based on the following system keyed to documents of intrinsic utility to the planner.

- **** Essential Planning Reference
- *** Useful Planning Reference
- ** Marginal (Technical, Scientific)
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Heald, E.J. and Odum, W.E., May 1970. "The Contribution of Mangrove Swamps to Florida Fisheries," Proceedings of the Twenty-Second Annual Gulf and Caribbean Fisheries Institute. University of Miami, Rosenstiel School of Marine and Atmospheric Sciences. A classic and often cited, energetics oriented summary. ***

Heald, E.J. and Tabb, D.C., 1973. Rookery Bay Land Use Studies. Environmental Planning Strategies for the Development of a Mangrove Shoreline, Study No. 6: Applicability of the Interceptor Waterway Concept to the Rookery Bay Area. The Conservation Foundation, Washington, D.C. Part of a larger series of studies of a major tropical mangrove area. See also references under Clark. A very useful set of documents, with guidelines and planning strategies directly relevant to the Virgin Islands. *

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Herrnkind, W. and Olsen, D., April 1970 - June 1971. Ecological Study for the Development of Lobster Management Techniques. Caribbean Research Institute, College of the Virgin Islands, St. Thomas (Sea Grant GH-86). Contains useful data but falls short of recommending workable management guidelines. Valuable only as historical document and research source. *

Hite, J.C. and Stepp, J.M., editors, 1971. Coastal Zone Resource Management. Massachusetts Institute of Technology Press. Basic early text on coastal zone problems and program design. Some continuing value. *

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Hogben, N. and Lumb, F.E., 1967. Ocean Wave Statistics. National Physical Laboratory, Ministry of Technology, Great Britain. Basic reference document. *

Insular Environments, Inc., April 1972. Marine and Environmental Factors in Red Hook Bay, St. Thomas. Prepared for P.F. Lopez Associates, St. Thomas. Site specific consulting report. **

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Jacobsen, A.R., 1951. A Study of the Pollution of the Harbor Waters of the Virgin Islands. Government of the U.S. Virgin Islands, Department of Health. Early survey resulting from Department of Health concern about pollution from sewage, industrial waste and night soil disposition. Historical value only. *

Jadan, Doris, July 1971. A Guide to the Natural History of St. John. Virgin Islands Conservation Society and Promotion Graphics. Discusses natural resources on St. John, the Virgin Islands Department of Education's Environmental Studies Program (ESP) and details of study areas including Salt Pond Bay, Annaberg, Reef Bay. With bird list, vegetation list and many illustrations. Not scientific.*

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Kesterman, F. and Towle, E.L., 1973. "Caribbean Weighs Impact of Stepped Up Oil Industry Activity," Journal of Maritime Law and Commerce, Vol. 4, No. 3; also, Island Resources Foundation, St. Thomas, Occasional Paper No. 8. Summarizes potential impact of expanded petroleum related activity (production, transhipment, storage, refining, and marketing) upon the Caribbean. Primarily of historical value. *

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Prepared for the Government of the U.S. Virgin Islands, Department of Conservation and Cultural Affairs. Contains useful graphic presentation of annual rainfall and monthly temperature records, plus a preliminary analysis of use patterns and preferences for marine recreation sites. *

McEachern, J. and Towle, E.L., 1974. Ecological Guidelines for Island Development. International Union for Conservation and Nature and Natural Resources, Morges, Switzerland. Useful general planning recommendations. Designed as companion volume to Dasmann, Milton and Freeman study. ***

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McNulty, J.K., Robertson, W.B., and Horton, B.F., 1968. Departmental Study Team Report and Recommendations on Proposed New Jet Airport, St. Thomas, U.S. Virgin Islands. U.S. Department of the Interior, Washington, D.C. Accepting as fact the proposed development of the St. Thomas mangrove lagoon for a new airport site, this study first discusses the value of the present coastal resources - terrestrial ecosystem, water bird and wildlife habitats, offshore islands and cays, salt ponds alteration, fish - and corals, currents and tides. The conclusions are drawn as to likely damage resulting from airport construction. Not a completely candid report. What is reported is accurate; what is not reported is important. *

Mann, R., et al, 1975. Aesthetic Resources of the Coastal Zone. Cambridge, Massachusetts. A planners handbook, prepared for the Office of Coastal Zone Management, NOAA, U.S. Department of Commerce. Provides a conceptual framework, an evaluation methodology, a listing of permissible uses, and suggestions for public participation mechanisms. *

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Mattson, P.H., editor, 1969. Transactions of the Fifth Caribbean Geological Conference, St. Thomas, July 1968. Queens College, Flushing, New York. Papers on geophysics, marine geology, regional geology, geomorphology, hydrology, igneous petrology, paleontology, and stratigraphy, including several directly relevant to the Virgin Islands. *

Menasco-McGuinn Associates, August 1973. Virgin Islands Highway Functional Classification and Needs Study, Summary Report. Prepared for the Government of the Virgin Islands, Department of Public Works in cooperation with the U.S. Department of Transportation, Federal Highway Administration, Helena, Montana. Includes more than 30 maps developed by the contract firm from aerial photographs and field investigations and officially accepted by the Public Works Department. In addition to inventories and traffic counts, standards are established for design, pavement, present and anticipated use, routes, capital improvements, continuing data collection, and transportation planning. *

Michel, J.F., 1970. A Study of the Hydrodynamic Effects of the Proposed Airport at Long Beach Point, St. Thomas, Virgin Islands. University of Miami, Rosenstiel School of Marine and Atmospheric Sciences, Consulting Report to the Virgin Islands Port Authority. Useful for site specific data; otherwise of largely historical value. *

Michel, J.F. and Tabb, D.C., 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. University of Miami, Institute of Marine Sciences. Contains valuable base line data; otherwise useful only as an historical document on earlier development planning methodology with narrowly defined terms of reference. See also Tabb and Michel, 1968 for Part I. *

Millas, J.C., 1968. Hurricanes of the Caribbean and Adjacent Regions, 1492-1800. Academy of the Arts and Sciences of the Americas, Miami, Florida. An historical summary based on an intensive search of sources. Useful for the researcher but of little use to the planner. **

Miller, J.W., VanDerwalker, J.G., and Waller, R.A., editors, August 1971. Tektite 2: Scientists-In-The-Sea. U.S. Department of the Interior, Washington, D.C. Aquanauts conducted marine research from ocean floor habitat at Lameshur Bay, St. John. Discusses habitat engineering and training;

gives detailed results of specific marine biological research missions and ocean survey. Largely a technical report of limited use. **

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Murray, D., 1969. Birds of the Virgin Islands. Dukane Press, Hollywood, Florida. Ten watercolor plates by the author, marginal sketches. Brief popularized descriptions of common avian residents and migrants. Several taxonomic inaccuracies and sketchy information. Use with caution. *

Neurauter, T., 1974. Past Depositional Environments of Lower Salt River. West Indies Laboratory, Fairleigh Dickinson University, St. Croix. Open File Student Reports. Site specific useful data. *

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Ogden, J.C, Yntema, J.A., and Clavijo, I., July 1975. An Annotated List of the Fishes of St. Croix, U.S. Virgin Islands. West Indies Laboratory, Fairleigh Dickinson University, St. Croix. Special Publication No. 3. Intended for use in conjunction with standard guides. Also includes description of St. Croix environments, ciguatera, and game and spearfishing records. *

Olsen, D., et al, 1972. The Ecology of Fishes in Two Mangrove Lagoons in the U.S. Virgin Islands. Marine Resources Development Foundation, San German, Puerto Rico and Virgin Islands Department of Conservation and Cultural Affairs. Reports trapping study of fishes in Manning Bay, St. Croix and Jersey Bay, St. Thomas. See also the following reference. **

Olsen, D., 1975. Analysis of Catch Data for the Virgin Islands Commercial Fisheries. Virgin Islands Department of Conservation and Cultural Affairs, Bureau of Fish and Wildlife. Annual Report for Project No. 2-239-R-1. Excellent specialized work by a trained statistical biologist. Sound methodology. Best used in conjunction with variously cited reports by Olsen, Dammann, Brownell, Rainey. **

Owen, W. and Konrad, M., April 1972. Thermal Survey: Harvey Alumina Discharge, St. Croix, Virgin Islands. Prepared for Caribbean Research Institute, College of the Virgin Islands, St. Thomas by Vast, Inc., Frederiksted, St. Croix. Study of thermal plume of bauxite refining plant formerly owned by Harvey Alumina Corporation (now Martin Marietta), southwest of former Krause Lagoon area, St. Croix. Only study of its kind in Virgin Islands waters. Useful for base line data and methodology. *

Percious, D.J., vanEepcel, R.P. and Grigg, D.I., 1972. Reconnaissance Survey of St. Thomas Harbor and Crown Bay, St. Thomas, Virgin Islands. Caribbean Research Institute, College of the Virgin Islands, St. Thomas (Water Pollution Report No. 18). Useful survey with synoptic, site specific data. Principally historical value. **

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Pressick, M.L. and Towle, E.L., 1974. Marine Parks: Research and Education Programs as Feedback for Management. Paper presented at the Second International Conference on Underwater Parks and Reserves, Asilomar, California, April 23-26, 1974. Also, Island Resources Foundation, St. Thomas, Occasional Paper No. 6. Outlines value of advance planning for non-resident research activity for management of special marine park areas. Relevant to the Virgin Islands National and Territorial park systems. *

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Randall, J.E., 1964. "Contributions to the Biology of the Queen Conch Strombus gigas," Bulletin of Marine Science, Institute of Marine Science, University of Miami, 14, pp. 246-295. One of a very limited number of studies of this species found in the Virgin Islands. **

Randall, J.E., 1968. "Conservation In the Sea: A Survey of Marine Parks," Oryx, vol. 10, no. 4. Includes information on St. John and St. Croix (Virgin Islands National Park areas). *

Ray, G.C., 1975. A Preliminary Classification of Coastal and Marine Environments. International Union for Conservation of Nature and Natural Resources (IUCN), Morges, Switzerland, Occasional Paper No. 14. Brief, useful review of problem of ecosystem definition, contrast between terrestrial and marine areas, with a system for classification by zoogeographic regions, by coastal biotic provinces, and by habitats. **

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Reynolds, J.R., August 1970. Preliminary Study of Sewage Disposal Practices in Areas Not Served by the Public Sewage System of Charlotte Amalie, St. Thomas, Virgin Islands. Prepared for Virgin Islands Department of Health, Division of Environmental Health by Caribbean Research Institute, College of the Virgin Islands, St. Thomas (Water Pollution Report No. 6). Historical value only. Needs updating. Present practices apparently are more effective and less subject to personnel failures, due to training programs for sewage plant operators. See also Shatrosky reference. *

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Robinson, A.H., August 1973. Natural Versus Visitor-Related Damage to Shallow Water Corals: Recommendations for Visitor Management and the Design of Underwater Nature Trails in the Virgin Islands. National Park Service, St. John, Virgin Islands. Technical report summary of damage based on outside literature and National Park Service staff observation. Fuller visitor impact data is expected in future; in the interim, some generalizations are made concerning visitor management. Describes in detail reef corals of present and natural damage. Finds visitor damage minimal but feels future management needed. **

Robinson, T.M., et al, 1973. Water Records of the Virgin Islands, 1962-1969. U.S. Geological Survey. Covers surface-water, quality of water and ground water records of Virgin Islands (stream flow, chemical and physical characteristics of water and ground water levels). *

Robinson, T.M., 1971. Earthquake-Accelerated Decline of Water Level in an Observation Well in St. Thomas, Virgin Islands. U.S. Geological Survey, Professional Paper 750-B, in Geological Survey Research, pp. B252-B253. Describes increased rate of water level decline in a well near Turpentine Run following a 4.7 Richter shock centered about 30 miles north of St. Thomas at 60 kilometer depth. *

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Robinson, T., et al, 1970. Magens Bay Master Plan. Consulting report prepared by Design Collaborative, St. Thomas, for the Magens Bay Beach Commission, St. Thomas. Includes excellent summary of biological and hydrological features of the associated watershed, salt pond, mangrove, beach and bay area. Has useful base line information for future planning and management. Site specific. **

Rundel, P.W., 1974. An Annotated Bibliography of West Indian Plant Ecology. Published for the Island Resources Foundation, St. Thomas by the Virgin Islands Department of Conservation and Cultural Affairs, Division of Libraries and Museums. Result of Foundation sponsored research. Primarily useful as a research reference guide. *

Shatrosky, E.L., vanEepoel, R.P. and Grigg, D.I., October 1972. Operating Characteristics of Package Sewage Plants on St. Thomas, Virgin Islands, January-June 1972. Prepared for Virgin Islands Department of Health, Division of Environmental Health by the Caribbean Research Institute, College of the Virgin Islands, St. Thomas (Water Pollution Report No. 20). Continues analyses of 19 plants. Consummation of three prior reports. Principally of historical value. *

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Smith, J.W., 1974. Growth Studies on Gorgonian Octocorals (abstract only). Proceedings of the Florida Keys Coral Reef Workshop. State of Florida, Department of Natural Resources, Coastal Coordinating Council. Average growth rate for seven species of gorgonians, measured over thirteen months was 4.1 centimeters/year. Range for individuals was 2.4 to 5.5 centimeters/year. Studies at Key West. Ranges similar to those in Jamaica and Dry Tortugas. *

Sorensen, J. and Demers, M., 1973. Coastal Zone Bibliography: Citations to Documents on Planning, Resources Management and Impact Assessment. Sea Grant Publication No. 8, University of California, La Jolla, California. Standard bibliographical reference. **

Stephens, W.M., 1963. Mangroves: Trees That Make Land. Smithsonian Institution, Washington, D.C. Reprint from Smithsonian Report for 1962, pp. 491-496. Brief popular account of natural processes and value of mangroves. *

Stott, S., 1974. Economics of Conch (Strombus gigas) on St. Thomas, Virgin Islands. Unpublished survey by Island Resources Foundation, St. Thomas. Of limited value to planner. *

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Sverdrup, H.U., Johnson, M.W. and Fleming, R.H., 1942. The Oceans. Prentice Hall, Inc., Englewood. Standard reference work. *

Swingle, W.E., Dammann, A.E., and Yntema, J.A., 1969. Survey of the Commercial Fishery of the Virgin Islands of the United States. Proceedings of the Twenty-second Annual Session, Gulf and Caribbean Fisheries Institute, 26, pp. 110-121. University of Miami, Rosenstiel School of Marine and Atmospheric Sciences. Summary of information available in Dammann (1969) on Virgin Islands commercial fisheries. ***

Tabb, D.C., 1967. Report of Investigation: The Biological and Ecological Effects of Dredging for Sand in the Water and Brewers Bay Areas of St. Thomas, Virgin Islands. University of Miami, Institute of Marine Sciences. Consulting Report prepared for Office of the Governor, Government of the U.S. Virgin Islands. Very general appraisal based on brief site observations (apparently of shorelines only). Recommends allowing dredging of Brewers Bay. List of some organisms observed in rocky shoreline habitat. *

Tabb, D.C. and Michel, J.F., 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. University of Miami, Institute of Marine Sciences. Contains valuable base line data; otherwise useful only as an historical document. See also Michel and Tabb, 1968 for Part II. *

Thompson, J.R., 1973. Ecological Effects of Offshore Dredging and Beach Nourishment: A Review. Miscellaneous Paper No. 1-73, U.S. Army Corps of Engineers, Washington, D.C. Fine annotated bibliographic review article written for both the specialist and the layman/planner. Extensive summary of ecological processes intruded upon by dredging. ****

Towle, E.L., 1973. Environmental Management of Island Based Ocean Engineering Projects. Paper presented at the Third Technical Session of the First Caribbean Oceaneering Conference in San Juan, Puerto Rico, sponsored by Inter-American University. Also, Island Resources Foundation, St. Thomas, Occasional Paper No. 5. Critical analysis of St. John based Tektite undersea habitat project with special reference to local application problems and relevance to local research needs. ***

Towle, E.L., 1973. The Role of the Travel-Tourism Industry In International Marine Recreation Development. Presented at Ninth Annual Marine Technology Society Conference, Washington, D.C. Also, Island Resources Foundation, St. Thomas, Occasional Paper No. 19. Background for recreation planning, stressing need for educational dimension. *

Towle, E.L. and Hanif, M., 1973. National Parks in the Caribbean Area. Paper presented to the Conference on Science and Man in the Americas, Mexico City. Also, Island Resources Foundation, St. Thomas, Occasional Paper No. 2. *

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U.S. Government, Department of Agriculture, Virgin Islands Soil and Water Conservation District, 1971. Environmental Protection Handbook: A Guide to Assist in the Implementation of the Environmental Protection Act of the United States Virgin Islands. Kingshill, St. Croix. Standards and specifications for soil erosion control, slope control practices, water conservation, for persons applying for Virgin Islands "Earth Change" permits. Includes seven page glossary. See latest edition. **

U.S. Government, Department of the Army, Corps of Engineers, 1975. Flood Plain Information, Tidal Areas St. Thomas, St. Croix and St. John, U.S. Virgin Islands. Office of the Governor of the U.S. Virgin Islands, Virgin Islands Planning Office. Provides (1) historical data on hurricanes and related flooding and (2) future flooding predictions for major storms of 100 year frequency plus worst possible flood plates are fold out maps of coastline showing areas of expected flooding. ***

U.S. Government, Department of the Interior, Bureau of Outdoor Recreation, 1970. Islands of America. Excellent inventory of the island resources of the United States with a plan for an island heritage trust. ***

U.S. Government, Department of the Interior, Federal Water Pollution Control Administration, 1967. Biological Aspects of Marine Water Quality, St.

Thomas, St. Croix and St. John, U.S. Virgin Islands. Historical value only. *

U.S. Government, Naval Oceanographic Office, 1963. Oceanographic Atlas of the North Atlantic Ocean, Section IV, Sea and Swell. Standard reference. *

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University of Texas (Austin), Division of Natural Resources and the Environment, 1973. The Management of Bay and Estuarine Systems in the Texas Coastal Zone. Prepared for Office of the Governor, State of Texas. Describes coastal ecosystem units of Texas. Gives their attributes, beneficial and detrimental uses and inherent factors influencing uses. Many of these ecosystems are locally comparable. Useful document for planning insights. ***

vanEepoel, R.P., November 1969. Report on Effects of Dredging in Water Bay, St. Thomas. Prepared for Virgin Islands Department of Health, Division of Environmental Health by Caribbean Reserach Institute, College of the Virgin Islands, St. Thomas (Water Pollution Report No. 2). A controversial study with some continuing instructive value on how not to dredge close inshore and why. **

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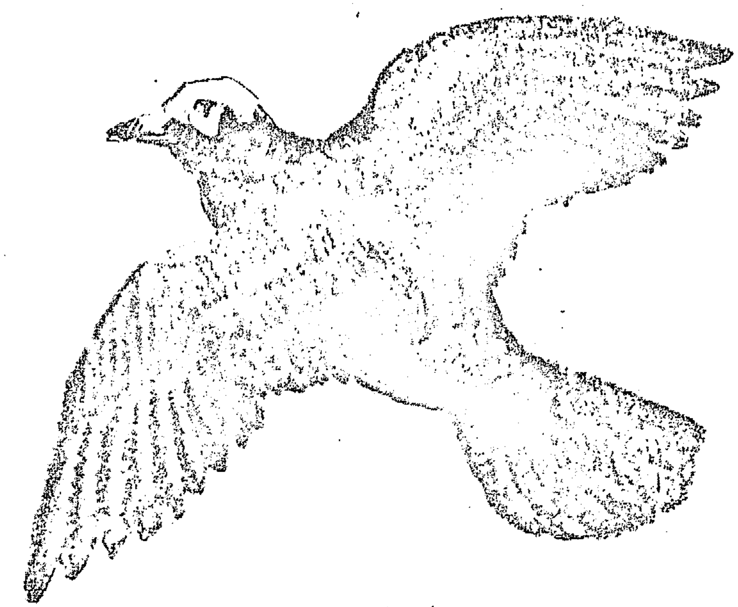

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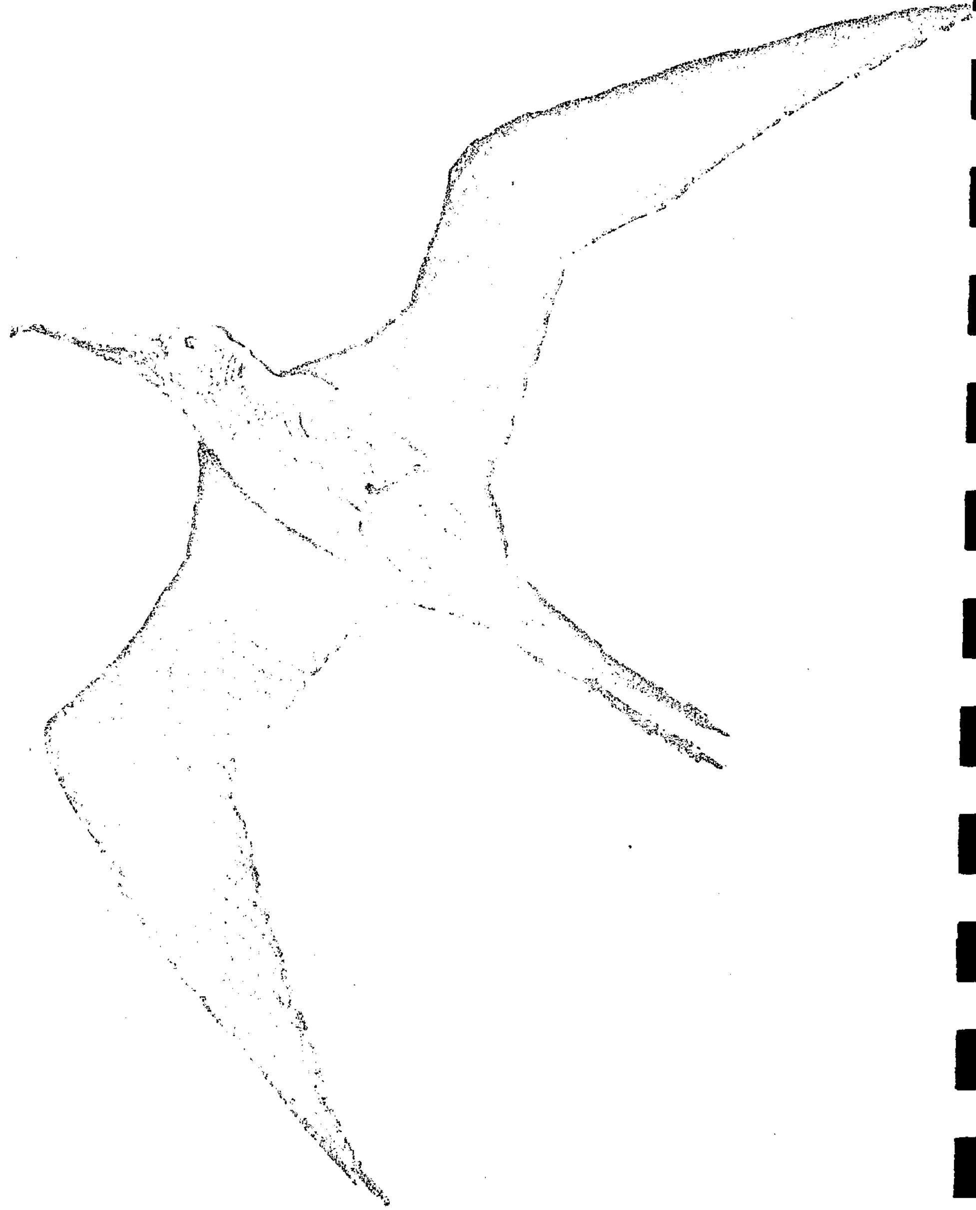

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