MARINE AND TERRESTRIAL ECOSYSTEMS OF THE VIRGIN ISLANDS NATIONAL PARK AND BIOSPHERE RESERVE

BIOSPHERE RESERVE REPORT NO. 29

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PREFACE

The Virgin Islands Resource Management Cooperative (VIRMC) is a relatively new, interdisciplinary grouping of resource professionals concerned with island environments and the role of parks and protected areas in sustainable development. After nearly five years of continuous effort involving more than a dozen institutions and over fifty researchers, graduate students, interns, and peer reviewers, the ubiquitous administrators and editors at Island Resources Foundation (IRF) have, in the name of VIRMC, completed the twenty-nine part technical report series, of which this "Synthesis" volume, by Dr. Caroline Rogers and Robert Teytaud, is the last of the formal publications.

The story of how this extended series of research projects got started and what it has to do with UNESCO and the Man and the Biosphere program is touched upon by William Gregg in the Foreword to this publication. There is no room to expand upon the subject in this short Preface, especially since the details and nuances lead into other more complex and sometimes unresolved issues including the role of the Biosphere Reserve Center and its longer term objectives for enlarging its training, education, research and environmental monitoring activities.

To be fair, one should mention that not everybody agrees that the idea of an eventual Eastern Caribbean multi-island, multi-site, multi-national Biosphere Reserve is workable or appropriate in the Eastern Caribbean. We certainly do not, as yet, have enough management experience to know if the biosphere reserve model, as it is being developed on St. John, has the potential for being more flexible than, for example, a national park as a resource protection and management strategy in selected small island settings.

But for the moment, thanks to the VIRMC baseline research effort and technical report series, and especially to this "user-friendly" synthesis, we do have a solid point of departure or information baseline for the next stage of this grand interdisciplinary experiment in island resource management. The U.S. National Park Service, the Virgin Islands National Park, and the Virgin Islands Resource Management Cooperative can be proud of what they have accomplished. The Foundation is pleased to have been associated with the adventure.

Dr. Edward L. Towle, President
Island Resources Foundation
and
Program Manager for VIRMC (1983-88)

FOREWORD

In 1983, resource planners, managers, and scientists from 13 Caribbean islands met on St. John in the U.S. Virgin Islands to discuss the role of biosphere reserves and other protected areas in the sustainable development of the Lesser Antillean province. For most participants, the conference was the first encounter with biosphere reserves and their potential benefits to the people of small tropical islands. For most, it was also their first contact with UNESCO's Man and the Biosphere Program (MAB), in which 114 nations are now participating.

The International Network of Biosphere Reserves is a cornerstone of the MAB program. In biosphere reserves, the emphasis is on developing and sharing information, locally, regionally, and internationally, to achieve the purpose of MAB. The base of operations for the ideal biosphere reserve includes one or more natural areas where the region's characteristic ecosystems may be studied as free as possible from human disturbance-- a baseline against which to assess the effects of human uses occurring in other parts of the biosphere reserve or nearby region. The biosphere reserve also includes experimental research and demonstration areas where scientists, managers, and local people work together to plan, test, and implement economic uses and activities which are culturally, ecologically, and institutionally appropriate.

As the region lacked a good model of biosphere reserve concepts in practice, the participants in the St. John workshop were interested in seeing whether one could be developed in the Virgin Islands so that they would have a better basis for evaluating the benefits. With this challenge in mind, the Virgin Islands Resource Management Cooperative, with substantial support from the U.S. National Park Service, began a multi-year research program to lay the foundation for building a biosphere reserve program in the Virgin Islands. A hub of the research effort was the Virgin Islands National Park, which comprises over half of the island of St. John, and is the only designated biosphere reserve unit in the Lesser Antilles. The program's scope, however, encompassed a much larger cultural and ecological region including all of St. John and parts of the adjacent British Virgin Islands ecosystem.

It was recognized from the start that building the biosphere reserve "model" would depend upon the cooperation of the park, its neighbors and resource users, the region's community of scientists and managers, and at least some measure of technical assistance from outside the region. While the Virgin Islands National Park had a large stake in building the model and providing some institutional leadership, it could not conduct the experiment or construct the edifice alone. Therefore a unique vehicle was developed -- the "Virgin Islands Resource Management

Cooperative" which provided the means to marshall the technical capabilities of more than a dozen local and regional agencies and organizations concerned with conservation, research, and economic development in the U.S. and British Virgin Islands and Puerto Rico. Locally known by the acronym VIRMC, it has provided the framework for carrying out research requiring interagency, interdisciplinary, and transborder cooperation.

During the first five years of the VIRMC biosphere reserve baseline research program, Dr. Edward L. Towle, President of Island Resources Foundation (a charter member of VIRMC) served as program manager, while Island Resources Foundation served as prime contractor for VIRMC, coordinating 31 separate projects which were primarily subcontracted to other active members of the Cooperative. In addition to the financing support received from the U.S. National Park Service, various projects received direct or in-kind support from the College of the Virgin Islands, Eastern Caribbean Natural Areas Management Program, Virgin Islands Division of Fish and Wildlife, the New York Botanical Gardens, the U.S. Forest Service, the U.S. MAB Project Directorate on Biosphere Reserves, the West Indies Laboratory, Yale University, and Island Resources Foundation.

This body of work reflects unprecedented institutional cooperation and has stimulated interest in biosphere reserves in the region. In 1987, the National Park Service dedicated the Virgin Islands Biosphere Reserve Center on St. John and is using the new facility as a focus for scientific cooperation, training, and interaction with the local community. The United Nations Environment Programme, in cooperation with UNESCO, has approved a project to assess the feasibility of building a Lesser Antillean network of biosphere reserves. The project will be coordinated through the Caribbean Conservation Association. The Virgin Islands experience and the specific VIRMC recommendations on institutionalizing the MAB Program in the Virgin Islands will be important considerations.

This final synthesis volume is the twenty-ninth in the VIRMC series. It summarizes what has been learned during the past five years about ecosystems and socioeconomic environment of a cluster of small tropical islands. It was prepared by Dr. Caroline Rogers, research biologist at the Virgin Islands National Park and executive officer of VIRMC, and Robert Teytaud. Dr. Rogers has been an enthusiastic proponent of the biosphere reserve approach, a principal investigator on several projects, and a key architect of the MAB program.

It is our hope that this synthesis and other preceding reports in the VIRMC biosphere reserve research report series, will be used by policymakers, scientists, managers, residents and other resource users. They should lead to the development of practical demonstrations of the value of biosphere reserve programs in understanding small island ecosystems and in establishing a productive marriage of conservation and economic development in the Virgin Islands and other islands of the Lesser Antilles.

Dr. William P. Gregg, Jr.
U.S. National Park Service.

INTRODUCTION

The history of research on St. John is a long and fascinating one which encompasses early observations by Danish settlers (Carstens c.1741) and Moravian missionaries (Oldendorp 1770). The following passage appears in Highfield & Barac´s 1987 translation of Oldendorp (1770) and provides an example of some of the earliest recorded observations of the island´s animals:

> The green turtle has a frog-like mouth, a short neck, and four short feet, or paws, which are suitable both for swimming and for moving on land. The hind feet are shaped like a goose´s foot, or like a flattened hand. The front ones, however, are narrower and longer and are shaped almost like wings. The entire body of the creature is covered up to its neck with a hard shell which consists of many-sided designs and encased by a narrow, notched border...Its head is decorated with small squares, just as is the underside of the body, where the shell, however, is soft in the middle. Its throat is of a greenish color, the rest yellowish and brownish. The head, as well as the legs, can be drawn through openings located on both sides of the shell, front and back. In that position, they are concealed from any danger. They are from three to nine feet in length and weigh from one hundred to eight hundred pounds.

Since the 18th century, numerous reports by territorial and federal government agencies, universities, private organizations, and individuals, and publications in professional scientific journals have described the natural resources of the island. The nature of the research currently required for management of the Virgin Islands Biosphere Reserve on St. John depends on building on earlier research and multi-disciplinary and multi-institutional cooperation. Since late 1983, an extensive amount of research, primarily on marine resources, has been carried out in the Virgin Islands under the auspices of the Virgin Islands Resource Management Cooperative (VIRMC). The National Park Service funded 30 projects which focused on Virgin Islands National Park and Biosphere Reserve (VINP/BR) on St. John, U.S. Virgin Islands (USVI) but included collection of data from the British Virgin Islands (BVI) and Buck Island Reef National Monument (BUIS), off St. Croix, USVI. The VIRMC studies of St. John´s marine and terrestrial ecosystems represent the most intensive research effort undertaken for a protected area in the Eastern Caribbean.

The Virgin Islands Resource Management Cooperative was founded in 1982. Signatories to the Memorandum of Understanding are: Virgin Islands National Park, the Department of Planning are: Virgin Islands National Park, the Department of Planning and Natural Resources of the USVI Government (Division of Fish and Wildlife and Division of Natural Resources Management), University of the Virgin Islands, West Indies Laboratory, Island Resources Foundation, Eastern Caribbean Natural Area Management Program, U.S. Geological Survey, U.S. Fish and Wildlife Service, Southern Forest Experiment Station, University of Puerto Rico (Sea Grant Program and the Center for Energy and Environment Research), Caribbean Fishery Management Council, the Ministry of Natural Resources and Labor of the British Virgin Islands Government, and the British Virgin Islands National Parks Trust.

Some of the VIRMC research has important implications for resource management in VINP and for other areas in the Eastern Caribbean. To date there has been no overall synthesis of research with resource management implications for park managers or others who have responsibility for managing Caribbean islands or for scientists interested in studying terrestrial and marine ecosystems of St. John or similar ecosystems in the Caribbean.

This synthesis/summary document has many objectives:
1) to present research which has been carried out by VIRMC and other investigators in Virgin Islands National Park as well as the extent of our knowledge of the marine and terrestrial ecosystems within this protected area;
2) to identify areas where future research is required;
3) to synthesize information from selected documents with implications for research and resource management within the Caribbean and specifically within VINP/BR;
4) to present management recommendations for ecosystems within VINP and the wider Caribbean; and
5) to provide a basis for making the VIBR more effective in linking conservation and development (UNESCO Action Plan for Biosphere Reserves 1984).

The report is organized into the following major sections: Marine Systems, Fisheries, Terrestrial Systems, and Geology of St. John. Dr. Caroline Rogers, Research Biologist for VINP, was largely responsible for the sections on marine systems and fisheries, as well as overall organization of the report, while Robert Teytaud was primarily responsible for the sections on terrestrial systems and island geology.

ACKNOWLEDGEMENTS

Thanks to R. Boulon, J. Dammann and M. Goodwin for help with the Fisheries Section, R. Norton for writing some of the section on birds, and D. Rankin for supplying photographs and portions of the text on geology. The following also provided constructive comments: Dr. B. Brown, Dr. W. Gregg, A. Reilly, A. Webster, and C. Weikert. Larry McLain and Jean-Pierre Bacle assisted with illustrations and figures. Lito Valls reviewed the section on history. Ian Jones worked on the bibliography and Sandra Tate handled the final assembly of the report. Thanks to all!

PHYSICAL SETTING AND CLIMATE

The Virgin Islands, with the exception of St. Croix, are a part of the Puerto Rico Bank, a submerged plateau usually defined by the 183 m depth contour, extending from eastern Puerto Rico to Anegada. The islands are high parts of the plateau which extend above sea level. Geologically the Virgin Islands are part of the Greater Antilles, of which they form the eastern terminus, rather than of the Lesser Antilles with which they are commonly grouped culturally. Ocean depths between the northern Virgin Islands and Puerto Rico are generally less than 91 m, but the Puerto Rico Bank itself is surrounded by steep slopes and deep water. The Puerto Rico Trench with depths to 9,166 m lies to the north, the Virgin Islands Basin with depths of 4,500 m to the south, and the St. John and Anegada Passages with depths of 2,000 m to the east.

The island of St. John (18o 18´-18o 22´N; 64o 40´-64o 48´W) lies in the Caribbean Sea about 88 km east of Puerto Rico (Fig. 1, Appendix I) and covers an area of about 48 km2. Its topography is very rugged, with deep valleys and hills that rise steeply from the shore. Over 80% of the slopes exceed 30% (CH2M Hill 1979a). The highest point, Bordeaux Mountain, is 387 m above sea level. There are numerous embayments along the coastline which has a total length of about 52 km. St. Thomas lies to the west and several of the British Virgin Islands are to the north and east, across channels 1.5 to 5 km wide. St. Croix is about 64 km to the south. On the northeastern shore of St. Croix across a shallow channel 2.6 km wide, one finds Buck Island, a National Monument managed by the National Park Service. The island has an area of 71 ha, and its highest point is about 100 m above sea level.

Winds

The Tradewinds (Easterlies) consistently approach the islands from the east. Changes in the position and intensity of the Bermuda High to the north and the Equatorial Trough to the south are responsible for major seasonal variations. The winds blow counterclockwise around the Equatorial Trough, a low pressure zone.

When the Bermuda High is intensified from December through February with only minimal pressure changes in the Equatorial Trough, the Tradewinds are at a maximum, blowing 11-21 knots about 60% of the time (Towle et al. 1977). During this period,

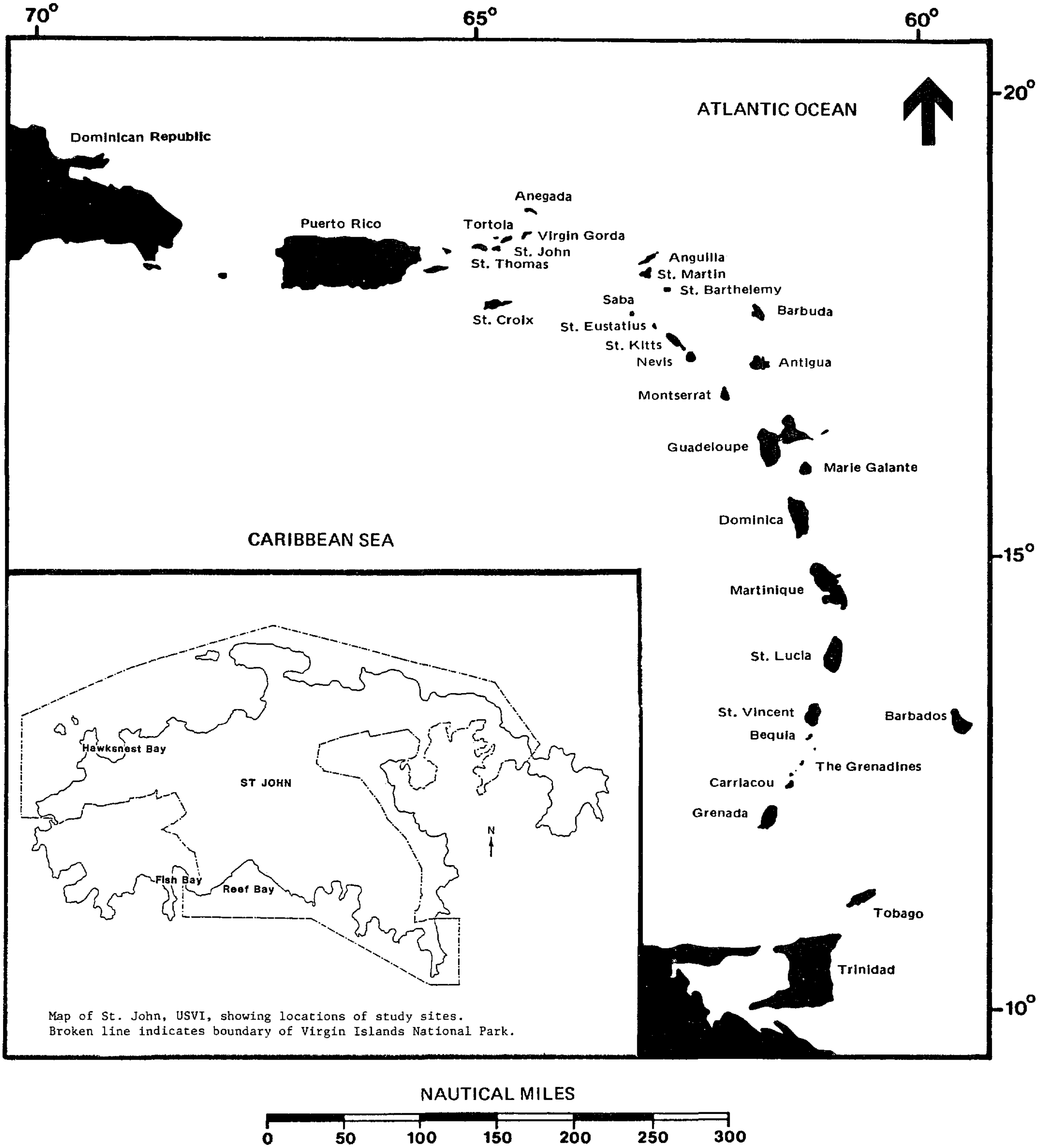


Fig. 1. Location of St. John, U.S. Virgin Islands.
From: Putney (1982).

the "Christmas winds", strong winds from the north, may appear as a result of weak cold fronts moving through the Caribbean. A decrease in the pressure of Equatorial Trough results in a reduction in wind velocities from March through May. From June through August, wind speeds approach those in December through February as the Bermuda High strengthens with a concomitant decrease in pressure in the Equatorial Trough. The lowest wind velocities occur from September through November as the Bermuda High weakens with only a small decrease in pressure in the Equatorial Trough.

Although hurricanes have occurred in every month of the year, most storms pass through the Eastern Caribbean between August and October with peak activity in September. Twenty-four hurricanes have passed within 50 miles of the Virgin Islands since 1900 (U.S. Army 1975). Major hurricanes occur about once every 33 years.

Rainfall

National Park Service records for Cruz Bay, St. John, from 1872 to 1986 indicate an average annual rainfall of 44 inches (112 cm) and a range of 23 to 74 inches. Rainfall varies considerably not only from year to year but from month to month. Although most rain typically falls from September to November, occasional storms, particularly in the Spring, can bring large amounts of rain. One storm in April 1983 dropped 15.6 inches of rain over a 24 hour period. Cosner (1972) estimated that evapotranspiration accounts for over 90% of the rainfall.

Waves and Currents

The mean tidal range in the islands is only 0.8-1.0 ft. (0.24-0.30 m), and tidal currents are usually weak (Towle et al. 1977). Diurnal tides predominate around St. Croix and on the south coasts of St. John and St. Thomas. Semi-diurnal tides occur on the north coasts of Puerto Rico, St. Thomas and St. John because of exposure to open water. Waves come primarily from the east in the winter and the southeast in the summer, in response to seasonal shifts in wind direction. Waves are 1-3 ft. (0.3-0.9 m) about half the time. southeasterly swells, occasionally reaching 10-12 ft. (3-3.7 m) nearshore, develop in winter. The northern swells create strong longshore currents. Wave energy is concentrated on projecting headlands, and shoreline configuration reflects variations in the resistance of specific rock types to erosion in these headlands.

BRIEF HISTORIC OVERVIEW

Archaeological finds at Lameshur Bay, St. John, provided evidence that seafaring Arawaks occupied the island as early as 770 B.C. (R. Reeves pers. comm.). These aborigines practiced a mixed subsistence economy that involved harvesting of shellfish and other marine organisms and some cultivation of manioc along with other foodstuffs. Most of the known settlement sites as in most of the Eastern Caribbean, are near the coast (Tyson 1987).

In 1493, Christopher Columbus claimed St. John for Spain during his second voyage to the New World. Columbus' men saw no human beings on the island but there is some evidence that the island was uninhabited from sometime before 1550 for over 100 years, and between 1671 and 1717 occupied only intermittently.

Colonization of St. John began in March 1718 as Danish authorities parcelled out land for plantations. All of the island, with the exception of some of the rockiest headlands, had been subdivided into plantations by 1728 (Larsen 1986). The plantation economy depended on the importation of slaves from Africa and other Caribbean colonies.

After 1765, the plantation system, which had been based on a diversity of crops including sugar cane, cotton, coffee and indigo, gave way to an economy based primarily on sugar. This economy was undermined after 1840 by loss of soil fertility, rising costs, falling prices and the 1848 emancipation of the slaves. Between 1805 and 1915, pressure on the island's resources declined substantially as the population fell from 2577 to 905 (Tyson 1987). The last commercial sugar production was at Par Force plantation in Reef Bay Quarter in 1897 (Fig. 2). After this, sugar was produced for local consumption only. By 1915, much of the island had reverted to secondary forest. The plantation system gave way to small scale agriculture as peasants raised livestock, grew fruit, and harvested and processed bay leaves (Tyson 1984, Olwig 1986). A distinct Afro-Caribbean culture evolved around these agricultural pursuits, fishing, boat building, and charcoal production (Olwig 1986).

The United States took possession of St. John in 1917, leading to an economy based on tourism. Much of the old plantation lands were incorporated into Virgin Islands National Park which was established in 1956 with donations of land by Laurance Rockefeller. The park occupies approximately 50% of the island. The island's fascinating history has resulted in a dynamic, cultural landscape which consists of a mosaic of protected land and private and public lands which are rapidly being developed.

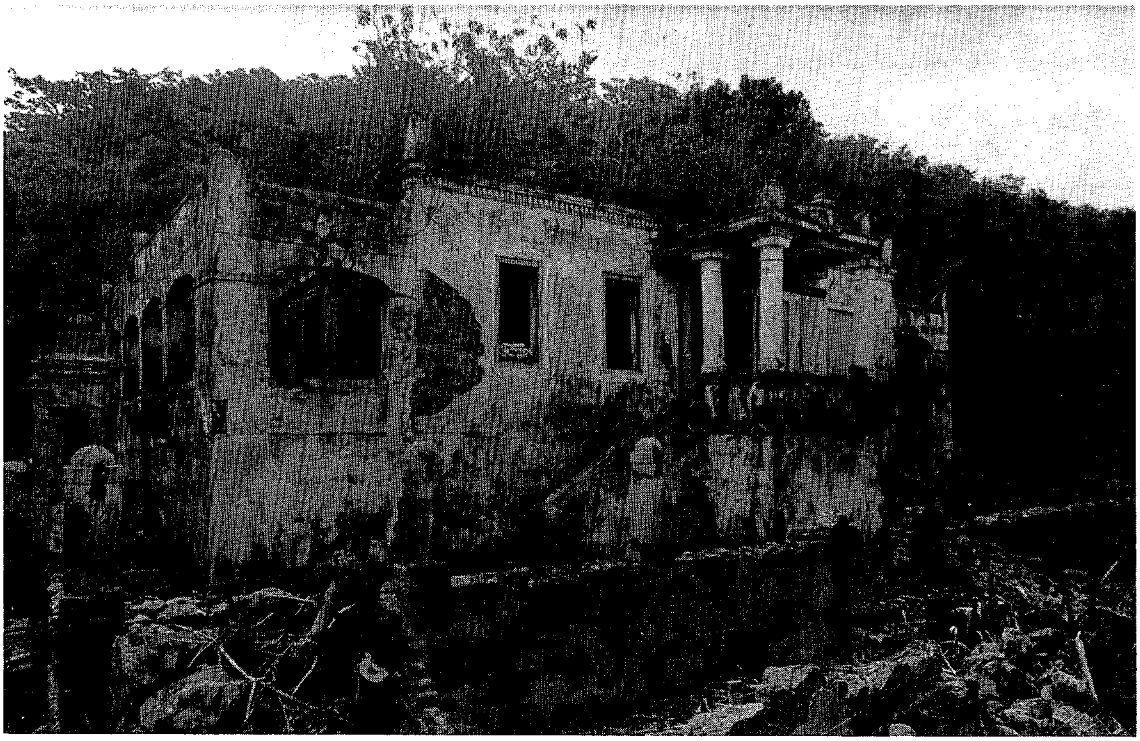


Fig. 2. Great House at Par Force Plantation, Reef Bay Quarter (1988). Photo: S. Barry.

MARINE SYSTEMS

HISTORY OF RESEARCH

Kumpf & Randall (1961) produced the first map of the benthic communities around St. John in 1959, showing the location of the following bottom types: coral or rock bottom, coral patches on sand, seagrass, sand or coral rubble, and mud (Appendix II). From 1958 to 1961, several studies focused on fish taxonomy and ecology (listed in Randall 1961). Randall established an artificial reef in Little Lameshur Bay in 1960 (Randall 1963). The Tektite I and Tektite II underwater habitat projects took place in Greater Lameshur Bay from 1969 - 1971 (Collette & Earle, 1972, Earle & Lavenberg 1975). These studies included research on lobsters (Cooper et al. 1975, Herrnkind et al. 1975, Olsen & Koblic 1975, Olsen et al. 1975), algae (Earle 1972, Mathieson et al. 1975), fishes (Collette & Talbot 1972, Clifton & Hunter 1972, Smith & Tyler 1972) and coral reef biomass (Lee et al. 1975).

Alan Robinson, the VINP scientist from 1970 to 1975, reported on recreational uses of the park (1973, 1976), salt ponds of St. John (1974), the soft bottom community in Caneel Bay (1972), and briefly summarized research in the park (1975). Small (1982) reported on sea turtle nesting within VINP and BUIS. Faculty and students (for example, from the School for Field Studies and Gustavus Adolphus College) based at the Virgin Islands Ecological Research Station, which is operated by the University of the Virgin Islands, have produced numerous reports, primarily on marine organisms in the Lameshur Bays. Studies of marine areas outside of park waters include those by Grigg (1978) on Cruz Bay, Brody et al. (1969, 1970) on Chocolate Hole and Cruz Bay, and by EPA (1988) on Turner Bay and in surrounding waters. Some abstracts on marine research in the USVI can also be found proceedings of meetings of the Association of Island Marine Laboratories in the Caribbean (e.g. AIMLC 1986).

Little research has taken place on physical oceanography. Dammann (1969) presents information on water temperature, salinity, transparency, and currents around the USVI. Towle et al. (1977) prepared a compendium on oceanography, seismic activity, and climatology in the islands. VanEepoel et al. (1971) present detailed oceanographic data and statistics on tropical storms and hurricanes (see also Bowden et al. 1974). Water quality data (dissolved oxygen, turbidity, temperature, salinity, and other parameters) for St. John's waters from 1973 to 1986 are available from the Dept. of Planning and Natural Resources (formerly Dept. of Conservation and Cultural Affairs).

The most comprehensive research on marine systems has taken place under the auspices of the Virgin Islands Resource

Management Cooperative, beginning with studies in 1983. Phase I of the VIRMC studies focused on obtaining baseline data on critical benthic habitats and fisheries around the island. Phase II studies emphasized an interdisciplinary approach to selected watersheds on St. John and the initiation of long-term monitoring of some of the ecosystems. Some Phase I and Phase II projects concentrated on areas in the BVI which potentially could join the VIBR to form a larger, yet to be designed, international biosphere reserve. In addition, two studies examined zoning and management of the Virgin Islands Biosphere Reserve. The third Phase included studies of the consequences of increasing recreational uses of marine resources, further work on long-term plots established in St. John's forests and watershed processes, an analysis of Buck Island fisheries, and compilation of this synthesis document (see Appendix III).

DESCRIPTION OF MARINE SYSTEMS

Environmental conditions on small Caribbean islands such as St. John are conducive to development of closely interrelated mangrove, seagrass, and coral reef systems (Towle et al. 1977). Fish and shellfish depend on all of these systems for food and shelter and link them to each other through their migrations and the resultant transfer of nutrients. Some fishes migrate daily from the shelter of the reefs to feed in adjacent seagrass beds at night. The seagrass beds are therefore subsidizing the reefs in terms of energy flow. Seagrass blades (particularly Syringodium) float for days after detachment by rough seas or by grazing animals such as parrotfishes and sea turtles. Drifting over reefs and seagrass beds, they are an important source of nutrients.

Juveniles of many organisms depend on mangroves and seagrass beds, moving to deeper waters and offshore reefs as they mature. Destruction of red mangroves with submerged prop roots decreases the habitat for juvenile fishes (Thayer et al. 1987). Cutting of mangroves which entrap sediments can result in excessive siltation for nearby seagrass beds and reefs from runoff after heavy rains. Runoff can be especially severe where there has been careless shoreline development or poor agricultural practices.

Fish can affect these ecosystems in a number of ways, some of them very complex. They can affect reefs by 1) grazing on dead coral, breaking down the skeleton and producing large quantities of sediment, 2) providing nutrients in their wastes, and 3) grazing on coral larvae, thereby influencing the reef's structure. Randall (1974) suggested that the continuous rain of sediments from parrotfish and surgeonfish feces adversely affects reef organisms. However, fish feces may enhance coral growth

(Meyer et al. 1983) and supply essential nutrients (Szmant-Froelich et al. 1981). In a recent synthesis of studies of the effects of fish grazing on coral reef structure, Hixon (1986) noted that damselfish which defend algal territories directly influence coral recruitment and growth, as well as bioerosion. Numerous studies demonstrate the effects of fish grazing on reef algae (e.g., Ogden & Lobel 1978). Economically important fish (e.g., snappers, grunts) and conchs feed on the benthic microalgae and invertebrates in reef sediments. Most fish seek coral colonies for shelter from predation, and a few species eat living coral. Fish eat other sessile animals of the reef including sponges.

Mangrove forests are not extensive on St. John because in many places the island's steep slopes extend down to the water's edge, and flat land for mangrove growth is limited. The absence of rivers or permanent streams reduces nutrient input for mangrove development, but the resultant water clarity also favors development of coral reefs close to shore. Seagrass beds occur in shallow waters which receive protection from heavy seas and in deeper water seaward of the reefs.

Coral Reefs

Most of the reefs around St. John are shallow fringing reefs which grow near shore or extend out from the headlands at entrances to the numerous bays which indent St. John's coastline (Fig. 3). Many of the reefs near shore slope down to about 12 m where there is an abrupt transition to a relatively barren, sandy plain. Scattered patch reefs with high coral diversity occur on geological features offshore at greater depths. True, extensive barrier reefs with well-defined lagoons do not occur around the island, although the reef in Newfound Bay could be considered a combination of a fringing and a barrier reef. Bank reefs which do not break the surface occur offshore. Isolated patch reefs can be found in Hawksnest Bay, Reef Bay and elsewhere. Elkhorn coral (*Acropora palmata*) is the most abundant species on the shallow reefs. Brain corals (*Diploria* spp.), lettuce corals (*Agaricia* spp.), and fire corals (*Millepora* spp.) are scattered throughout the elkhorn framework.

Many of the reefs are true coral reefs established on a framework of coral skeletons deposited over thousands of years. However, St. John has many coral communities comprised of coral colonies and other reef organisms growing on submerged boulders and rock ridges near shore such as occur at Leinster Bay.

Beets et al. (1986) produced 16 maps, based on aerial photographs and field observations, and described all of the island's bays. Each of their maps indicate major ecosystems and their subzones (Fig. 4). They observed a total of 36 hard coral species around St. John. Beets & Lewand (1986) collected over

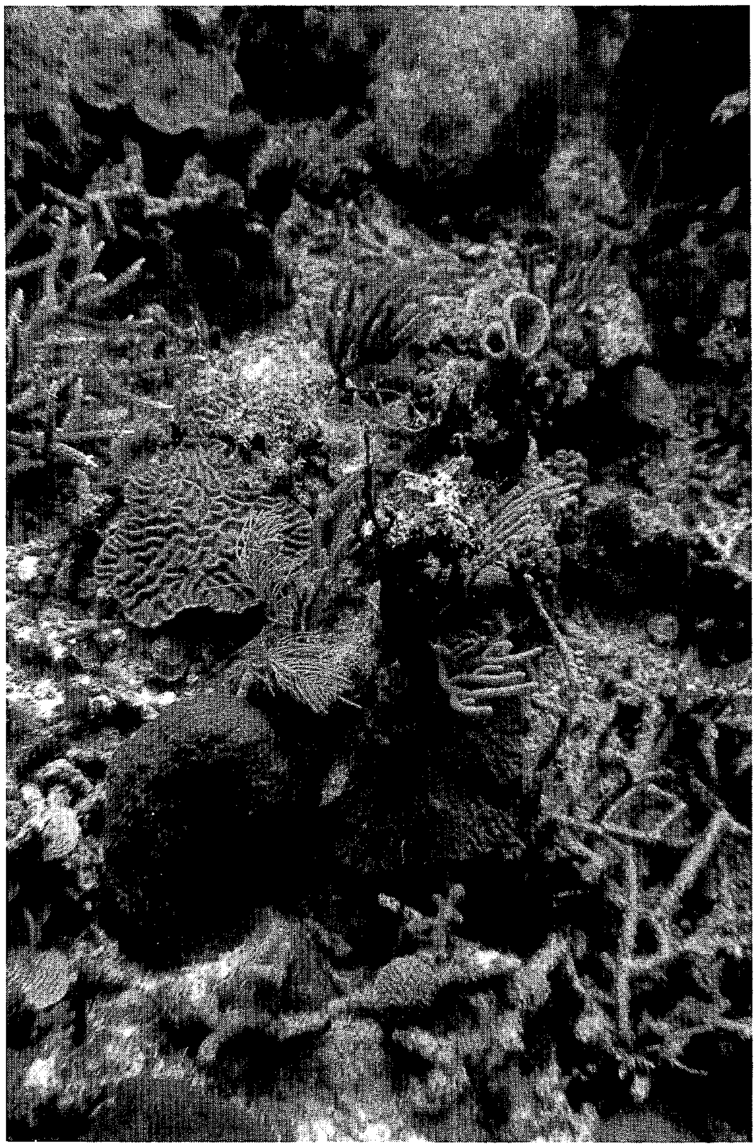


Fig. 3. Johnson's Reef at a depth of 60'.
Photo: C. Weikert.

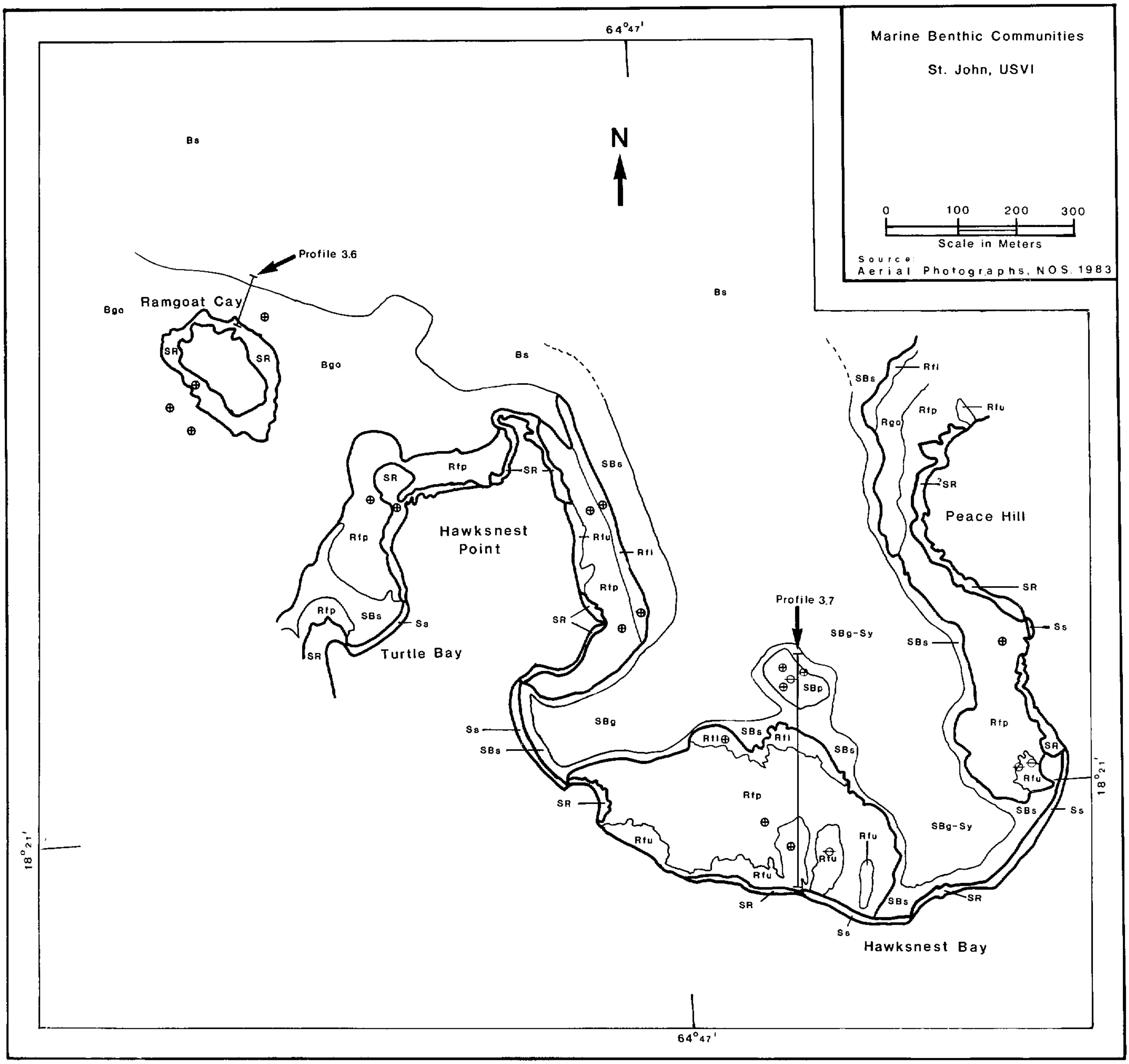


Fig. 4. Map of major benthic communities, Hawksnest Bay.
From: Beets, et al. 1986.

500 specimens of common marine organisms within VINP to supplement park collections by J. Randall, A. Dammann, and others in the 1960's. Hubbard et al. (1987) and Rogers & Zullo (1987) described reefs in Hawksnest, Fish, and Reef Bays. Dammann (1969) provided descriptions of reefs in Chocolate Hole and Mary's Creek.

In recognition of the need for quantitative baseline data to provide information for effective management of VINP coral reefs, Rogers & zullo (1987) initiated a long-term monitoring program in 1984. They established transects in Reef, Fish, and Hawksnest Bays. The watersheds for these 3 bays have different development histories. Reef Bay has remained undisturbed since the decline of the sugar plantation there in the late 1800's. The Hawksnest watershed is the site of a new medical clinic. The Fish Bay watershed is currently undergoing subdivision, roadbuilding, and construction of houses. Although the lands are outside the park, the study reefs are in park waters and could deteriorate with increased siltation from erosion associated with rapid development of this area. Tropical Storm Klaus in Nov. 1984 resulted in a statistically significant decrease in the mean percent cover of the dominant coral *Agaricia agaricites* at the study site in Fish Bay. Future measurements along these transects should allow tracking of their condition over time. Hubbard et al. (1987) studied reefs in these three bays as well. (See discussion of their work under Sedimentation).

Seagrass Beds

Seagrass beds are highly productive ecosystems which are extensive in the shallow waters around the USVI. Turtle grass (*Thalassia testudinum*), manatee grass (*Syringodium filiforme*), and shoal grass (*Halodule wrightii*) are the most abundant species. Seagrasses are true flowering plants, spreading primarily through growth of roots and rhizomes. These extensive root systems help to stabilize sediments and reduce shoreline erosion. Calcareous algae such as *Halimeda* and *Penicillus*, which have calcium carbonate or limestone in their tissues, grow in the grass beds and surrounding sand bottoms. Most beach sands are primarily composed of particles which arose from the decomposition and disintegration of these plants.

Several species of commercially important fishes, such as snappers and grunts, find shelter in coral reefs during the day and feed in the seagrass beds at night (Fig. 5). Seagrass beds are the primary habitat for the commercially important queen conch (*Strombus gigas*) which feeds on algae growing on the grass blades. The food web in grass beds is based both on direct herbivory (grazing) on grass blades and algae, and on detritus from the decomposition of these plants. Conspicuous halos or bare sandy zones around coral patch reefs within grass beds are

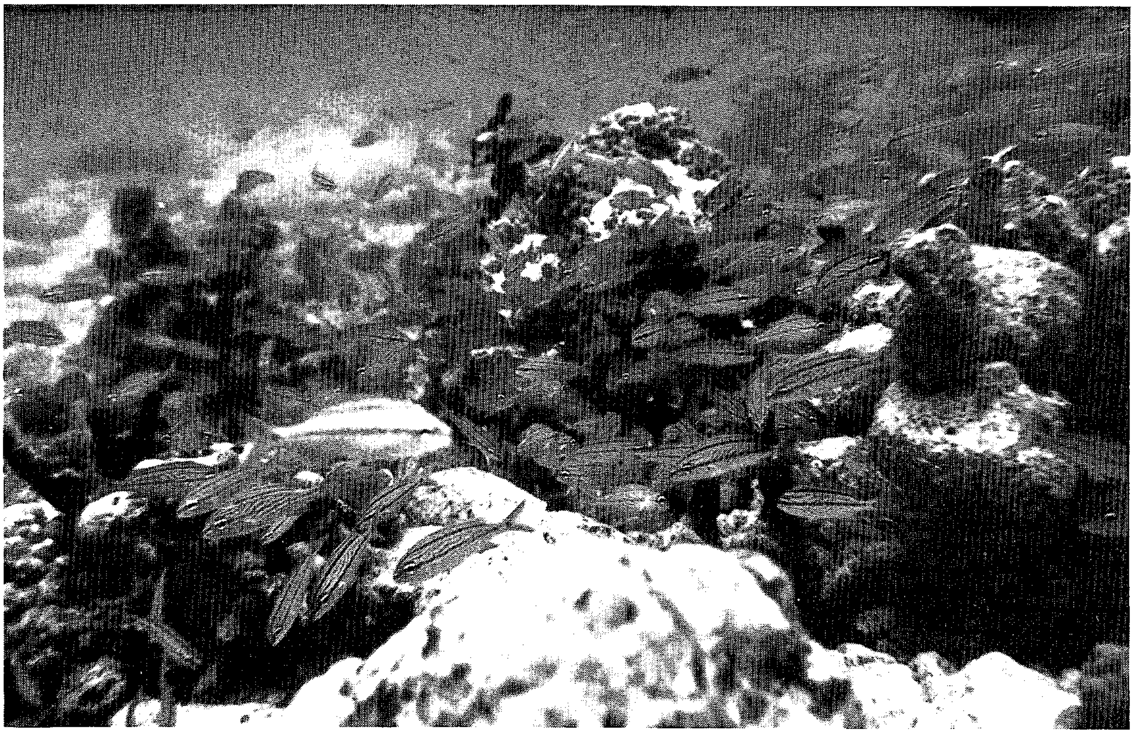


Fig. 5. School of grunts sheltering in a patch reef off Scott Beach. Photo: L. McLain.

the product of physical factors like currents but also of grazing by fishes and sea urchins (Ogden et al. 1973, Randall 1965).

Seagrass beds around St. John are not as extensive as those around St. Thomas and St. Croix. Beets et al. (1986) mapped and briefly described seagrass beds in many park bays while Williams(1988) mapped seagrass beds in Francis and Maho Bays. None of the northern bays have dense seagrass beds, and the best beds occur in Rendezvous and Reef Bay on the south side of the island.

Examination of aerial photographs from 1975 to 1983 suggest a serious decline in the seagrass beds in Francis and Maho Bays. Williams (1988) noted that anchors from the increasing number of boats visiting these bays are ripping up seagrass roots and rhizomes. (See also Rogers et al. 1988 and Recreational Uses section below.) The population of 50 individuals of the threatened green sea turtle *Chelonia mydas* grazes heavily on the turtle grass in these bays. *Thalassia* plants inside small fenced areas (4 m x4 m) which excluded turtles showed some recovery after 3 months, indicating that recovery or at least healthier growth of these plants can occur. (Anchoring was also prohibited in the plots.)

Williams (1988) noted that the stressed seagrasses in Francis and Maho had extremely low productivity and fragile, narrow leaves. She recommended prohibition of anchoring in these bays. Anchors may be partly responsible for deterioration of *Thalassia* beds in Caneel Bay (Beets, personal communication), although effluent from a desalination plant may have caused most of the damage. Robinson (1972) previously described the seagrasses in Caneel as "extensive".

Mangroves

Mangroves are very productive ecosystems which support a high diversity of fish, birds, and other wildlife. The mangrove food web, based largely on the release of nutrients from the decomposition of mangrove leaves, supports nearshore fisheries. Mangroves are vital feeding, nesting and roosting areas for several species of birds including ospreys, pelicans, egrets, herons and ducks. Many of the species are rarely seen outside this habitat.

Red mangroves (*Rhizophora mangle*) grow along the shoreline often in monospecific stands. In well-developed forests, red mangroves form the seawardmost zone, and black (*Avicennia germinans*) and white (*Laguncularia racemosa*) mangroves grow behind the red mangroves. The red mangroves are the most distinctive of the three major tree species, with their characteristic aerial prop roots (Fig. 6). These roots are usually partially submerged and support a diverse community of sponges, ascidians, algae and sometimes even corals. Juvenile reef and pelagic fishes as well as lobsters are abundant in these root communities (Thayer et al. 1987). The roots also trap sediments and over a period of several years can extend the shoreline seaward. Mangroves can reduce the amount of runoff (and associated sewage and pollutants) which reaches offshore seagrass beds and coral reefs.

Two of the four major physiographic types of mangrove forests described by Cintron & Schaeffer-Novelli (1983) occur in St. John. Fringe forests are found along protected shores such as those in Coral Bay, on shoals or spits, or around the margins of some salt ponds. In such areas steep gradients in topography, salinity, turbulence and tidal amplitude occur over a short distance. The inner parts of the fringe are subject to less variation in tidal amplitude and turbulence, and soil elevations are higher resulting in less flooding by seawater.

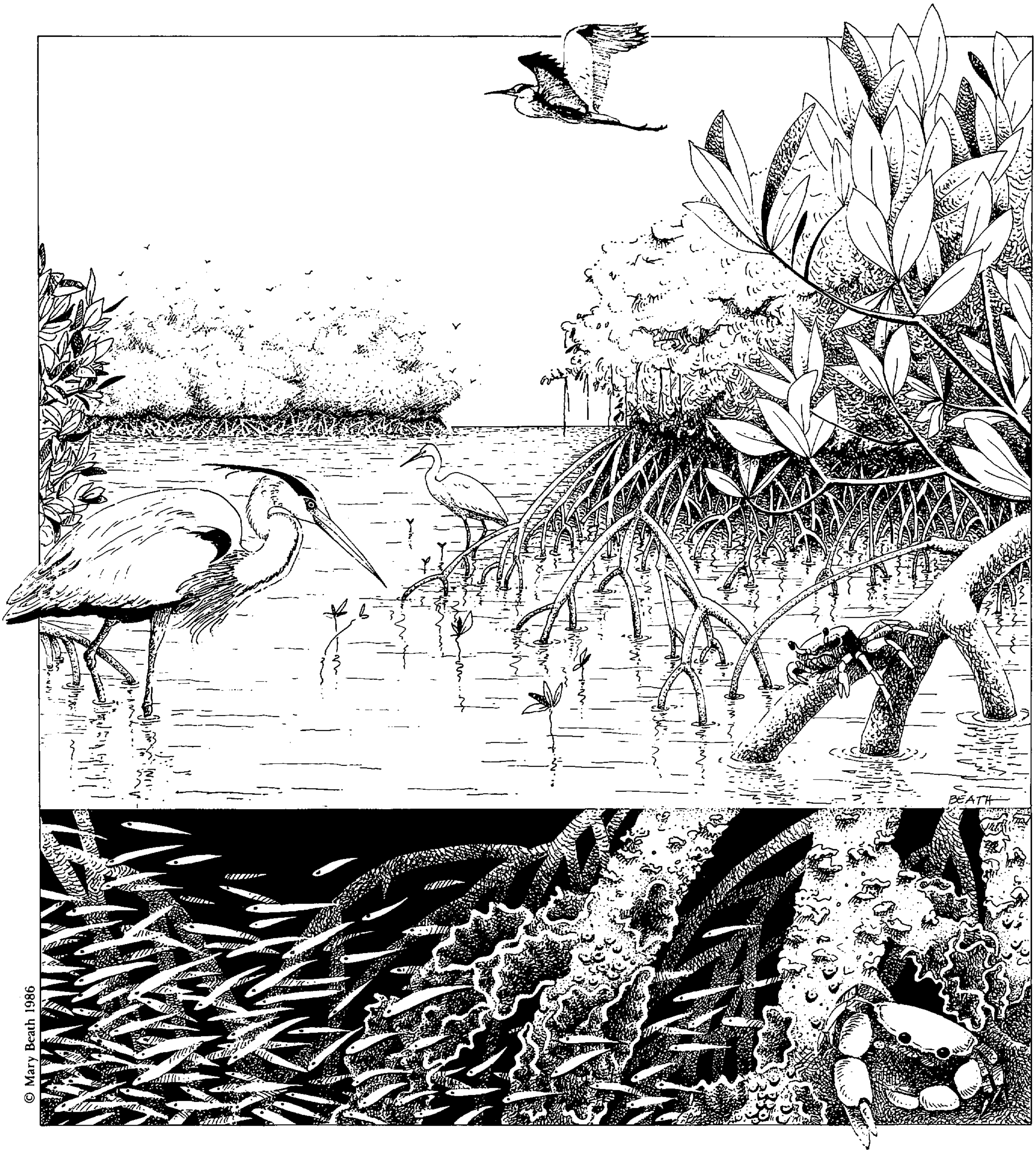


Fig. 6. Prop roots of red mangroves are important nursery areas for fish. Drawing: M. Beath.

Basin forests develop where there are sheet flows of water over areas of very small topographic gradients, such as flat areas where guts reach the coasts, and drainage depressions. Basins receive and store water annually and do not develop strong salinity gradients. Best development occurs in areas of weak but constant flows, whereas forests in stagnant basins have reduced growth. Examples of this type of forest can be found at Mary´s Creek, Reef Bay, or Fish Bay. Cintron (1987) discussed the adaptations of mangroves and other systems to episodes or "pulses" of storms and provided management recommendations for mangrove ecosystems.

Salt Ponds

Most salt ponds are formed when mangroves or fringing coral reefs grow across and isolate a portion of a bay (Fig. 7). Hurricanes and other storms also can pile up coral fragments to create barriers to the sea. St. John has excellent examples of the many stages of this process (Robinson & Feazel 1974). Large ponds include Southside Pond on the southeast end of the island, Francis Bay salt pond, and Mandal Pond. At Newfound Bay a salt pond may form adjacent to the existing one if the reef continues to grow across the mouth of the bay.

Fig. 7. Salt pond on St. John. Photo: L. McLain.

These ecosystems support a specialized biota which varies with fluctuations in pond water salinity. Rapid evaporation results in extremely saline water, and salt crystals sometimes form along the shores of the pond. The most saline ponds support a less diverse fauna than those ponds where storm waves breach the berm and create channels which allow seawater of normal (lower) salinity to rush in. Barracudas, mullets, and crabs can be found in ponds which are open to the sea.

Mangroves frequently fringe the edges of these ponds, and many of St. John's birds are associated with them. Several species of insect-eating and fish-eating birds, including kingfishers, herons, ospreys, stilts, and sandpipers feed on insects, brine shrimp, and fishes in these ponds.

Many salt ponds situated between an upland watershed and its associated bay function as settling or catchment basins, trapping the runoff from the land. Especially in areas where watershed development has occurred, the ponds reduce the amount of silt-laden water which reaches the bay, contributing to maintenance of high water quality. Analysis of salt pond sediments can provide insights into historical land use in a watershed (Nichols & Brush 1988).

Algal Plains and Marine Algae

Algal plains around St. John have not been well-studied. Beets et al. (1986) note this habitat on several of their maps for St. John. In her study of herbivory in Great Lameshur Bay carried out from the underwater habitat Tektite, Earle (1972) listed 154 species of plants and 35 species of plant-eating fishes, many of them associated with the algal plain near the habitat. Earle concluded that herbivorous fish had a greater influence than invertebrates on plant distributions and abundance. In the "Marine Algae of the Danish West Indies" published from 1913-1920, Borgesen described 327 species of algae.

Beaches and Rocky Shores

St. John's beaches are composed primarily of calcium carbonate sands formed from fragments of corals, shells, and algal particles. Some beaches in high-energy environments are composed mostly of large chunks of coral torn loose by the waves. Beach materials of terrigenous origin typically consist of light-colored quartz or feldspar sand, or larger dark-colored gravel, cobbles, and boulders. Terrigenous materials are either eroded from cliffs at the shoreline or from inland soils, and transported to the shore by runoff. Many beaches also have ledges composed of beachrock which run parallel to the beach face, either exposed or buried under a layer of sediment. Beachrock forms fairly rapidly below the beach surface by a natural process in which calcium carbonate precipitates out of seawater, cementing together sediment particles.

Beaches are constantly changing under the driving influence of wind, waves, tides and currents. Seasonal and longer-term changes in these variables significantly affect beach dynamics. High energy storm waves erode beach sediments and produce a steeply sloping foreshore and narrow berm. Beach sediments are transported offshore and may be deposited as a bar at the limit of the outer breakers. When more average waves return, the beach will typically recover to near-original profiles as the less energetic waves transport sand shoreward again. During this exchange of sand between the beach face and offshore storage, some of the sediments will be carried laterally along the coast by longshore currents, some will be lost permanently to deeper water, and some will be blown or washed across the berm to become part of the backshore or beach ridge.

On St. John, most beaches are found along the margins of deeply indented bays, resulting in little exchange of sediment from bay to bay around the enclosing headlands (Fig. 8). Most sediment transport is onshore and offshore within the bay itself,

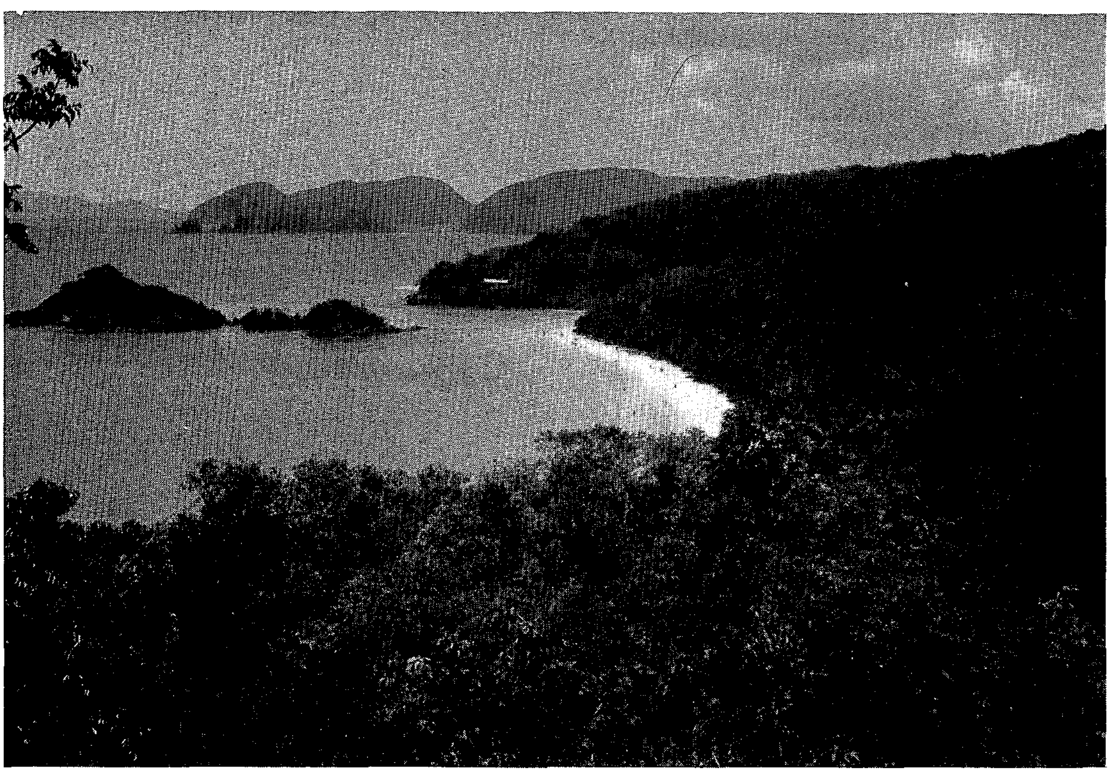


Fig. 8. Trunk Bay Beach on St. John.
Photo: L. McLain.

and the sediment budget is more or less in equilibrium. One exception is the beach at Cinnamon Bay, which is exposed to storm swells from the north in winter and lacks a large headland on the western side to trap sediments within the bay. This bay configuration results in significant losses of sediment by longshore transport, and beach erosion has been and continues to be a problem. Dolan (1973) and Hoffman (1974) studied beach dynamics at Cinnamon, Trunk, and Hawksnest Bays, Young & Young (1968) studied sand movement at Lameshur Bay, and Hubbard (1980) reported a study of storm-related versus seasonal changes at Buck Island beach, St. Croix.

A number of crabs, mollusks, worms, and other invertebrates live in the intertidal zone of St. John´s beaches, and species of ghost crabs (Ocypode) and land crabs (Geocarcinus) make their burrows above high tide. Many shorebirds visit St. John´s beaches, and sea turtles use the beaches for nesting.

Rocky shores are steep slopes, cliffs, or outcrops composed of more or less consolidated rock substrate. They are areas of high wave energy and constitute a severe environment for life. Between the level of the lowest spring tides and the highest elevation normally wetted by spray, they are inhabited by a distinctive assemblage of animals and plants, including the edible topshell or "whelk" (Cittarium pica) discussed below. Some remote rocky shores are used by seabirds (such as the red-billed tropic bird) for nesting and roosting habitat.

STRESSES TO MARINE SYSTEMS

Sedimentation

Sedimentation from dredging and runoff probably constitutes the biggest potential source of reef degradation in the Caribbean. In a recent survey (Rogers 1985), resource managers and scientists in the Caribbean indicated that siltation had caused deterioration of reefs off Florida, Martinique, Guadeloupe, Costa Rica, and elsewhere.

Sediments that settle on coral colonies and cause high turbidity in suspension have sublethal and lethal effects on corals. Dredging near coral reefs and accelerated runoff of eroded soils increase turbidity, thereby cutting down light available for photosynthesis and increasing sediment load on reef organisms. Aside from the localized consequences of removal and cutting of substrate, dredging affects extensive areas by putting fine sediments into suspension where currents carry them to other reef areas. Deterioration of the reef can continue for several years after dredging ceases because of continual resuspension and transport of dredged materials (Brock et al. 1966). Dredging has destroyed large areas of seagrass beds particularly off Florida (Zieman 1985).

Hubbard (1987) reviewed the effects of sedimentation on marine systems, particularly coral reefs in the Eastern Caribbean, and evaluated the current federal and territorial legislation and programs to control sedimentation in the USVI. Rogers (in prep.) reviewed the effects of sedimentation on coral reefs at the organism and ecosystem level and discussed the ways sedimentation can influence fish populations and consequently the fisheries upon which they are based.

Sedimentation studies within VINP/BR

A major environmental concern on St. John is siltation of nearshore marine habitats from accelerated erosion following watershed development. This concern prompted many of the VIRMC II studies. Erosion and runoff are potentially serious problems on St. John because of its extremely steep hillsides and the recent, dramatic increase in development.

Rapid, and in some cases, uncontrolled development on St. John has led to increases in terrigenous runoff. After heavy rains, bays within and outside the park have highly turbid water. St. John residents believe that corals in Hawksnest and Cinnamon Bays on the north shore of the island were killed from siltation following exceptionally heavy rains in April 1983 (457 mm in 24 hr). Development of private lands within the park boundary and development outside the boundary can contribute to turbidity in park waters which encompass 2,286 ha around the island. New subdivision roads continuously being carved into the hillsides are creating the potential for accelerated erosion and runoff.

Using a theoretical approach, Hubbard et al. (1987) calculated peak discharge rates and volumes assuming "natural" conditions of total forest cover for St. John. The distribution of reefs around the island appears to follow a pattern consistent with the assumptions of their model. They concluded that the primary controls of reef development are watershed size, runoff (primarily associated with 10 - 25 yr storms), bay geometry, and exposure and that the recent dramatic increase in the island's development exerts less control. The location of the well-defined "guts" through which runoff flows into the bays strongly influences the distribution of reef organisms.

The most turbid nearshore waters are associated with high runoff and poor flushing ability because of bay geometry and low wave energy, e.g., inner Fish, Coral, Cruz, Great Cruz, and eastern Hawksnest Bays. Greater exposure in western central Reef Bay correlates with higher coral cover than the reefs further east. Hubbard et al. (1987) were primarily examining presence and absence of reefs in their model, and further research on reef structural parameters, e.g., species diversity, in relation to runoff would be worthwhile.

In their comprehensive and detailed study of Hawksnest, Reef, and Fish Bays, Hubbard et al. (1987) briefly describe the reefs and provide profiles showing the different reef organisms. They present grain size characteristics and percent terrigenous material for surface sediments and sediment cores; document growth rates of M. annularis colonies; and provide useful recommendations for future coastal development.

Hawksnest Bay There is less reef cover in Hawksnest than in Fish and Reef Bays. The easternmost patch reef has less than 5% cover, reflecting low wave action and proximity to a large gut.

Examination of annual growth rings for 12 M. annularis heads in Hawksnest revealed a significant short-term decrease in 1981 and 1983 which coincided with heavy rainfall following the construction in 1980 of the clinic in the upper watershed.

Fish Bay The highest concentrations of terrigenous material were found in sediments from inner Fish Bay. Sediment cores from Fish Bay showed higher concentrations of terrigenous matter in the upper layers, possibly the effects of runoff associated with recent bulldozing and road construction. On the other hand, reef development to the southeast may reduce wave energy and trap fine sediment in the inner area of the bay. The best coral cover in Fish Bay occurs along forereef slopes.

Reef Bay Although Reef and Fish Bays have similar watershed and drainage areas, Reef Bay sediments contain less terrigenous matter, presumably because the bay has greater exposure and circulation. As in Fish Bay, the best coral cover was found in sloping lower forereef environments.

Coral growth Cores of large coral heads provide historical information on water quality as smaller growth bands indicate less favorable conditions for growth. Hubbard et al. (1987) hypothesized that reef development (specifically coral growth) would have been greatest following the sugar cane plantation era and less extensive prior to and subsequent to that period, because of adverse effects associated with land clearing.

Although the results of the coring were ambiguous, Hubbard et al. (1987) were able to document a 10 - 20% reduction in growth between the post-plantation era and the present in 5 separate cores through M. annularis colonies. The growth rates were consistent with those found by others (Dustan 1975, Gladfelter et al. 1978, Hudson et al. 1976, Hubbard & Scaturo 1985). The only other coral growth rates for St. John appear to be those for A.

palmata and A. cervicornis reported in Feazel (1975).

For all three bays, Hubbard et al. (1987) found a gradual reduction in coral growth over the last 100 - 200 years (based on limited data from coral heads). They suggest the decrease in growth may be a response to the intensive agriculture of the 1800's, but the growth decline in some cases corresponded to the period following intensive cultivation. Recovery of the forests may have been accompanied by a decrease in the ability of the land to hold and retain sediment and water as more extensive vegetation (e.g., grasses) were shaded out by trees. Breakdown of the terracing systems from the plantation era could also lead to an increase in near shore siltation.

When trying to analyze effects of historical and current land clearing practices it should be remembered that modern practices of clearing land with bulldozers that can remove topsoil down to underlying bedrock and completely uproot trees are potentially far more destructive than past methods.

Effects of sedimentation on coral metabolism Porter & Rogers (in prep.) studied the effects of terrigenous sediments on oxygen production and respiration by A. palmata, D. strigosa, and M. annularis colonies at Henley Cay (west of St. John) using a self-contained chamber equipped with oxygen probes and stirrers. Different concentrations of sediments were applied to coral colonies to determine reduction in photosynthesis and stimulation of respiration resulting from this stress.

Sedimentation rates Nichols & Brush (1988) studied Reef Bay mangrove swamp and Mandal Pond on the south coast of St. John to examine the relationship of land use history in the watershed to natural sedimentation rates from erosion. Using sediment cores, they found that the deposits effectively provided a historical record of sedimentation rates in the two ponds. In spite of extensive clearing of the vegetation in these areas during the plantation era, Nichols & Brush (1988) concluded that human activity had not significantly altered the natural processes of sedimentation. At Reef Bay, in contrast to Mandal Pond, infilling is exceeding submergence.

Recreational Uses

Throughout the Caribbean, tourism and coastal development are exerting severe pressure on the natural resources of many islands and countries. More and more tourists are visiting parks and protected areas in the region. Robinson (1973, 1976) drew attention to environmental damage associated with recreation in VINP in the 1970's prior to the dramatic increase in visitation. Rogers et al. (1988) recently documented the trends in recreational uses of the waters and beaches of VINP and assessed

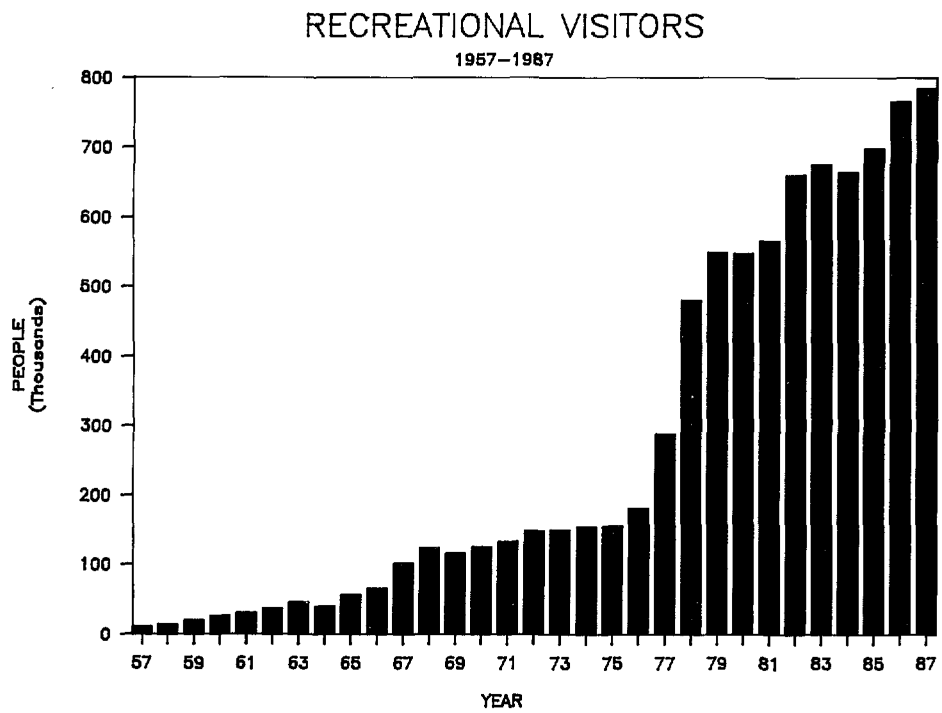


Fig. 9. Recreational visits to Virgin Islands National Park from 1957 - 1987.

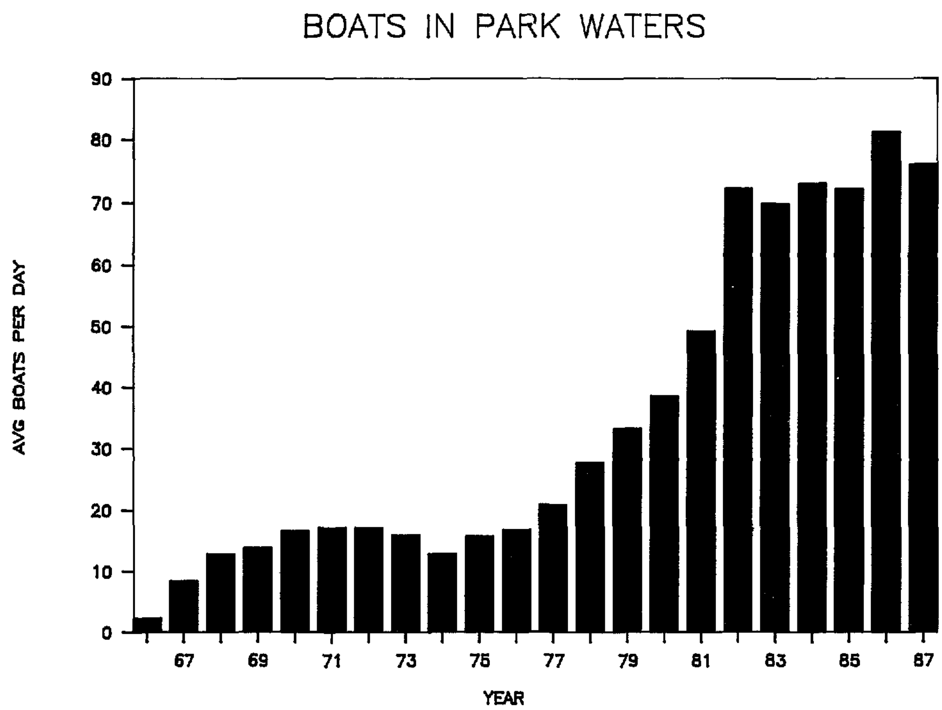


Fig. 10. Boats in park waters from 1966 to 1987.

the degradation of the marine resources attributable to recreational activities (exclusive of fishing).

Recreation in the park has increased dramatically in the last 8 - 10 years. Visits to the park have risen from less than 100,000 prior to 1967 to almost 800,000 in 1987 (Fig. 9). Annual visitation to Trunk Bay beach, the most heavily used beach in the park, has risen from under 20,000 people in 1966 to almost 170,000 in 1986. The average number of boats per day in park waters increased from less than 10 in 1966 to about 80 in 1986 (Fig. 10).

Some of the coral reefs and seagrass beds along the north shore of St. John which receives the heaviest use have suffered degradation. Anchor damage and damage from boats striking or grounding on reefs is evident. Seagrass beds in Francis and Maho Bays have deteriorated (Williams 1988).

Anchor damage

Between January and March 1987, Rogers et al. (1988) examined anchor damage in northern and northwestern bays of St. John, including Francis, Maho and Leinster. Of the 186 boats surveyed, 32% were anchored in seagrass and 14% in coral communities with the remainder on sand, mud, or pavement. In general, the deeper the anchor, the less damage it was causing as sensitive coral and seagrass communities tend to occur near shore in most of the bays surveyed. An estimated 30,000 boats per year anchor in park waters. Mini cruise ships often set 2 anchors, each weighing 1 ton. Anchor chains are often more devastating than anchors themselves because they scour out a large area of the bottom as a boat shifts around with wind and current changes.

Physical damage to Windswept and Hawksnest Reefs

Monthly observations were made at Windswept and Hawksnest Reef from Feb. 86 through April 1987 to record physical damage to these especially vulnerable sites from anchors, boat groundings, careless snorkelers, or other causes. Installation of marker buoys in May 1986 to warn boaters of the presence of these reefs resulted in a marked decrease in damage from boats. While heavy swells can fracture fragile coral branches, boat groundings can do more damage, in some cases even cracking the reef´s framework.

Recognition of the severity of damage associated with increased recreational uses of marine resources in the Caribbean is growing. Tilmant (1987) recently reviewed adverse effects of recreation on coral reefs, citing examples from Australia and Florida. In a survey of stresses affecting Caribbean reefs, many resource managers and scientists reported damage from anchors (e.g., from cruise ships and dive boats), from boat groundings, and from people walking on reef flats and removing corals as souvenirs (Rogers 1985). Construction of marinas and boatyards to support recreational boating have had serious environmental consequences.

Damage from recreational activities is superimposed on destruction from natural causes. VINP Research staff tagged and monitored 50 elkhorn colonies in Hawksnest Bay in July 1987 and found that only 10 of these corals appeared undisturbed 7 months later. Eleven colonies had been completely detached from the substrate apparently during heavy seas. Other tagged corals exhibited breakage, algal growth, or signs of predation.

In response to increased visitation and degradation of the park's marine resources, VINP developed a shoreline use plan in 1987. The plan calls for establishment of mooring buoys to protect sensitive seagrass and reef areas, and seeks to regulate use of park beaches and waters by commercial tour groups. Looe Key National Marine Sanctuary in Florida has a very effective mooring system (Halas 1985). Billy Causey, the Sanctuary Manager, concluded that "the installation of the buoys has been the most beneficial effort that we could have undertaken to protect our reefs". Similar moorings will be installed in VINP.

Oil Pollution

Cintron et al. (1981) reviewed the impact of oil pollution on the structure and function of tropical marine systems. Grounding of vessels often results in release of oil near reefs, mangroves and seagrass beds. The environmental effects can be dramatic, or sublethal and delayed (Birkeland et al. 1976). Further research is required on toxicity of dispersants and oil/dispersant mixtures. Use of dispersants can actually increase damage, especially to reefs and beaches (Cintron et al. 1981).

Corals appear to be more susceptible to detergents used as dispersants and to detergent/oil mixtures than to oil alone (Elgershizen & Kruijf 1976). Chronic low levels of oil pollution endanger coral reproduction (Loya & Rinkevich 1979). In general, oil poses the greatest threat to shallow reef flats where it actually contacts coral colonies. Little is known of the effects of oil pollution on seagrass beds.

Mangroves are especially vulnerable to oil spills as oil can coat the prop roots of red mangroves and the pneumatophores of black mangroves, cutting off oxygen. Death of the trees is inevitable if oil heavily coats the intertidal root areas. Toxic products can remain in the soil resulting in further die off. Lugo et al. (1980) noted sublethal responses, including leaf deformities and partial defoliation.

An environmental sensitivity index atlas was prepared for the USVI coastal areas by Resource Planning Institute with assistance from VIRMC members in 1986 (RPI 1986). Coastal segments for St. John, St. Thomas, and St. Croix were mapped and ranked in order of increasing susceptibility to oil pollution. In general, low energy shorelines with sheltered mangroves are the most vulnerable.

Natural Stresses

Storms

Storms have undoubtedly caused the greatest destruction to coral reefs off the south side of the island. Hurricanes David and Frederic (1979), known to have caused considerable damage to reefs off St. Croix, are most likely responsible for the widespread fragmentation of the dominant branching coral species seen in Fish Bay, Reef Bay, Coral Bay and elsewhere. Tropical Storm Klaus hit the U.S. Virgin Islands on Nov. 6-7, 1984, with winds gusting to 50 knots and very heavy sea swells. About 229 mm of rain fell during the storm, but the damage was primarily from the heavy swells rather than turbidity. Rogers & Zullo (1987) describe the physical damage to corals in Fish Bay.

Coral diseases

Coral diseases are affecting different hard coral species in the waters around St. John. White band disease primarily affects the acroporid corals, *Acropora palmata* and *A. cervicornis*, the same species which are the most vulnerable to storms. *Acropora palmata* is the dominant shallow water coral in the Virgin Islands, and throughout the Caribbean. The disease is characterized by a distinct white strip about 1 cm wide where live coral tissue has been completely removed from the skeleton. It usually kills the entire coral colony. Peters (1983) suggests bacteria may be responsible, but no causal agent has been specifically identified. This disease can have a significant impact on reefs if the coral colonies weaken and eventually collapse because of an increase in carbonate-boring organisms. Decreases in structural complexity of the reef could affect associated fish communities (Gladfelter 1982, Sano et al. 1987).

White band disease has been found on many reefs throughout the Caribbean, although in many cases the impact has been negligible (Gladfelter 1982, Rogers 1985). However, the disease has affected over 5 ha of the *A. palmata* reef at Buck Island Reef National Monument, St. Croix (Gladfelter 1982), and has recently killed large areas of A. palmata on other St. Croix reefs. Davis et al. (1986) photographed the progression of the disease in elkhorn corals at Buck Island and recorded a rate of advance of 4-5 mm/day. Some of the Buck Island corals are regenerating and new colonies have become established (W. Gladfelter, pers. comm.).

Beets et al. (1986) found colonies with white band disease in the following locations around St. John: Brown Bay, Whistling Cay, Cinnamon, Mennebeck Bay, Windswept and Jumbie Bay. A relatively large number of standing dead A. palmata colonies at Jumbie Bay may reflect the presence of white band disease in the past.

Anderson et al. (1986) concluded that white band disease is widespread throughout the British Virgin Islands. They estimated that 0 to 25% of the elkhorn colonies in their study areas exhibited white band disease, with most sites having less than 10% of the colonies affected. It is impossible to determine how severe the disease was in the past, although in some areas a large amount of "standing dead" coral was seen.

Black band disease infects several hard coral species including Montastrea annularis, M. cavernosa, Diploria strigosa, and D. labyrinthiformis and some of the common gorgonian species in the Caribbean (Antonius 1985). The pathogen is the blue-green algae Phormidium corallyticum. Black band disease occurs on corals in VINP and BUIS.

White band and other coral diseases have not been directly correlated with human activities, although Peters (1984) suggests that injuries to corals from snorkelers and divers, and adverse environmental conditions, such as high turbidity and sediment, could increase the frequency of occurrence. National Park Service photographs from the early 1970's at Buck Island Reef and a diagram appearing in Robinson (1973) indicate presence of white band in the Virgin Islands at that time. Gladfelter (1982) studied elkhorn corals with white band in 1976 at Buck Island. It is not known if visitation to Caribbean coral reef areas and damage resulting from recreational activities have been accompanied by increases in coral diseases.

Coral bleaching and other stresses

In the summer of 1987, many corals throughout the Caribbean began to expel their zooxanthellae and lose their normal coloration (Williams et al. 1987). Changes in salinity, turbidity, exposure, and temperature can cause this coral bleaching. Glynn (1984) documents an extreme case in Panama where bleaching was followed by death of the primary framework corals. Scientists suspect warm temperatures were at least partially responsible for the zooxanthellae expulsions in 1987.

This episode was the most severe on record for Florida reefs, but corals which bleached in July had begun to recover by November (Jaap 1988).

VINP staff observed bleaching in several hard coral species and in the zoanthid Palythoa around St. John in October 1987. It was not as severe as that reported for Florida. The brain corals D. labyrinthiformis and D. strigosa were most severely affected although not all colonies of these species turned pale. Bleaching seemed most conspicuous in relatively protected, shallow bays and apparently less extensive in deep areas with strong currents. Agaricia lamarcki colonies as deep as 27 m were bleached. Portions of some affected corals have died and become covered with algae, but other colonies have recovered entirely.

Another Caribbean-wide epidemic occurred in 1983 when over 90% of the population of long-spined black sea urchins (Diadema antillarum) died (Lessios et al. 1984). The die off was followed, at least on some reefs, by extensive growth of algae which the urchins normally feed upon (Hughes et al. 1987). The mass mortality occurred in December 1983 around St. John. Research in Lameshur Bay suggests that although the population is recovering, densities may not return to previous levels for several decades. However, the documented increase in average urchin body size may result in a return to pre-mortality urchin and algal biomass levels much sooner (Levitan 1988).

Witman (1988), also working in Lameshur Bay, found that predation by the fireworm Hermodice carunculata on shallow reefs limited branch growth of the fire coral Millepora complanata and opened up lesions on the colony surfaces. These lesions were rapidly colonized by crustose corallines and other algae. Fire corals only regenerated about 25% of the spaces cleared by predation in one year.

ENDANGERED AND THREATENED MARINE SPECIES

Sea Turtles

In 1980, NPS began monitoring sea turtle nesting activities on St. John and Buck Island, collecting data on seasonality, nesting success, clutch sizes, incubation/emergence, and nest predation. Hawksbill (Eretmochelys imbricata), leatherback (Demochelys coriacea) and green (Chelonia mydas) turtles all nested on USVI beaches in the past (Towle et al. 1978). Hawksbills and leatherbacks are considered endangered, while the green turtle (Fig. 11) is on the federal list of threatened species. Currently, hawksbills nest far more frequently than the other species.

Sandy Point, on the west end of St. Croix, is one of two Caribbean sites where leatherbacks nest in abundance. Greens do not appear to nest on St. John anymore, and only a few greens have nested on Buck Island since 1980 when rangers began keeping records. Four leatherbacks came up on Trunk Bay beach in 1985 and one appeared on Cinnamon in 1984, the first documented observations of this species on St. John since the 1950's.

Mongooses are the primary predator at Buck Island and St. John, preying on eggs and hatchlings. In Small's 1980-81 study they were responsible for destroying an estimated 23% of all turtle eggs on St. John (Small 1982). Extensive trapping of nest sites reduced predation from 15% of nests in 1982 to 6% in 1983. Prior to total eradication of mongooses at Buck Island (completed in 1987), mongooses were destroying up to 55% of all nests on the island. Inundations by heavy sea swells destroys some nests, and poaching is a problem on both islands.

On St. John, nesting of hawksbills generally takes place between June and December with peaks from August through November. At Buck Island, records indicate nesting from April until late December with peak activity from late July through

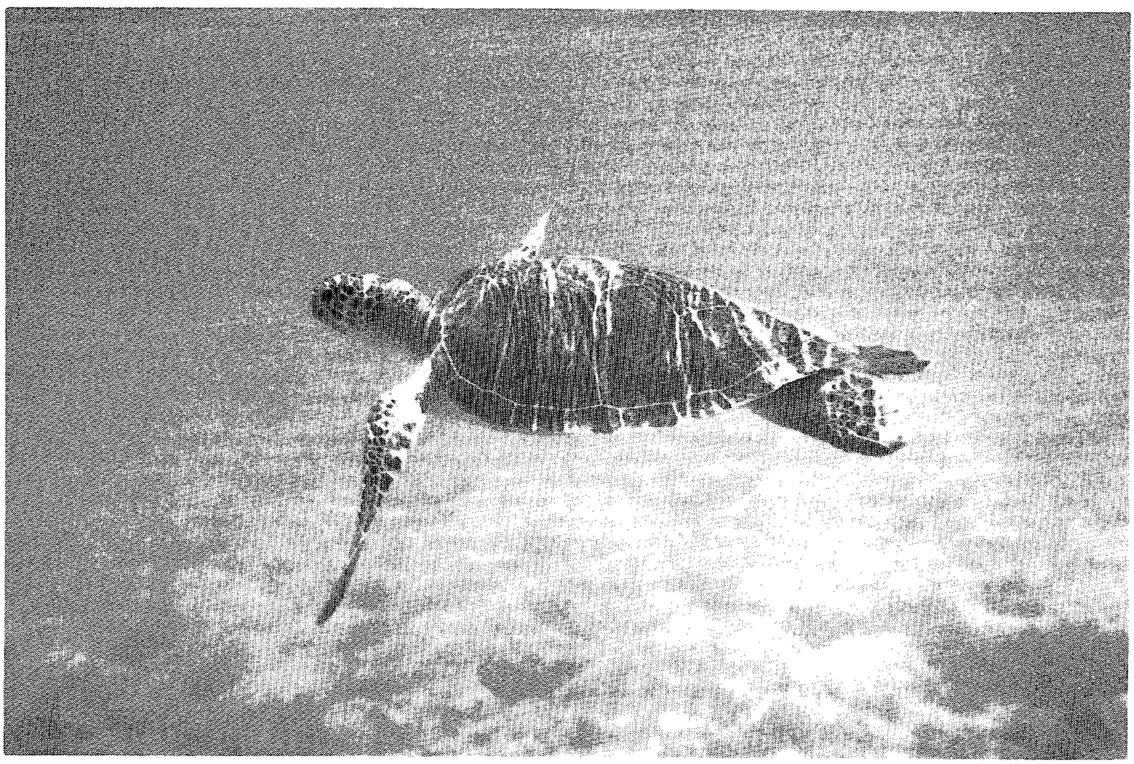


Fig. 11. Green turtle (Chelonia mydas) over seagrass and sand bottom. Photo: L. McLain.

October. Leatherbacks can nest as early as March. Given the 60-70 day incubation period, nesting activity can occur year-round on St. John and Buck Island.

Yearly fluctuations in nesting activity at Buck Island and St. John probably reflect both different levels of monitoring and natural variation in the 2-3 year nesting cycle of sea turtles (Zullo 1986). Although 20 of St. John's beaches supported nesting between 1980-1985, only Cocoloba had nests every year. In spite of its small size (71 ha) Buck Island has more activity than St. John, and the turtles using its beaches deserve special protection. Starting in 1987, NPS staff intensified the monitoring of sea turtle nesting on Buck Island. In 1987, they recorded 120 activities (crawls, nests, aborted nests) and confirmed 65 nests. Most nests were those of hawksbills, although a few leatherbacks and greens also nested.

Marine Mammals

A variety of marine mammals have been seen in USVI waters including bottlenose, spinner, and spotted dolphins, and humpback, killer, pilot, finback, and sperm whales. The National Marine Fisheries Service began keeping statistics on sightings in 1980. Humpbacks travel south to Caribbean waters to mate and bear their young. They are seen in the USVI from November to May. The largest number (about 250 animals) of humpbacks on record were sighted in the 1984-1985 season.

Other Species

Park waters contain limited populations of endangered black corals (Antipatharians), primarily off the northeast coast of St. John in depths over 15 m. Beets (pers. comm.) mapped and measured 35 colonies of three species in Haulover Bay.

FISHERIES

A series of VIRMC fisheries projects done from 1984-1987 had the following objectives: to study the role of fishing in the culture and economy of the VIBR, to assess the fish and shellfish stocks, to determine an ecologically realistic definition of fishery management zones around St. John, to determine if management zones should include the BVI or other areas outside VIBR, to see if fish and shellfish stocks within the VIBR or at Buck Island are declining, and to initiate an effective program for long-term monitoring of fisheries. Lesser Antillean fisheries were also characterized. In this section, these VIRMC studies and other pertinent reports are discussed. Mahon et al. (1986) prepared an annotated bibliography of references on fisheries in the Lesser Antilles.

SOCIOECONOMIC AND CULTURAL ROLE OF FISHING IN VIBR

Studies of fishing on St. John indicate that few people on the island made or make a living from fishing, but it is a very important part of island culture (Dammann 1969, Koester 1986). Most people catch fish for their families and sell or give away the surplus.

Fiedler & Jarvis (1932) interviewed fishermen on St. Thomas and St. John in 1931. At that time 78 out of a total of 405 fishermen were from St. John, and all boats, with the exception of one motorboat, were powered by oar or sail. The island´s population was about 765. Fish sold at 6 cents a pound. Fishermen used whelk, conch, and lobster to bait their traps. Ninety tangle nets were in use for catching turtles. The most extensively fished waters were those between St. Thomas and St. John.

In 1959, there were 11 full-time fishermen and less than 75 part-time fishermen out of a population of about 800 (Idyll & Randall 1959). Idyll & Randall (1959) estimated 500-560 traps were set by local and British Virgin Islands fishermen. Most of the catch was from traps, followed by handlines and beach seines. Apparently, only 5 seines were used around St. John, but these were about 360 feet long and 12 feet deep.

In 1959, demand for fish on St. John was not met. Apparently, most St. Thomas and BVI fishermen fishing around the island took their catch to Charlotte-Amalie, St. Thomas. At the time of this survey, residents did not feel fish populations had declined.

Dammann (1969) estimated about 400 people were involved in commercial fishing in the USVI in 1967, with 120 of them full time. He concluded that the reeffish populations were not being overfished at this time because while the number of fishermen was about the same as in 1930, the number of fish pots had decreased by about half, and the total catch had increased. Clavijo (1984) reported 454 licensed fishermen in 1982-1983. Olsen (1979) described recreational fishing in the USVI and concluded that the estimated combined landings from commercial and recreational fishing probably exceeded the maximum sustained yield.

Koester (1986) described the role of fishing in the economy and culture of St. John based primarily on interviews in March 1984, with 16 fishermen (13 of whom resided on the island) and 7 government agency employees. He estimated a total of 25 to 30 artisanal fishermen lived on St. John, ranging from those who fish parttime for their own families to a few individuals who consider fishing their main occupation and sell their catches. All use relatively low technology methods. At the time of this study, only two people were fishing commercially, and they fished outside park waters.

An unknown number of people from the British Virgin Islands and St. Thomas use the waters around St. John for fishing. Some St. John residents go to the BVI to fish where lobsters, conchs and whelks are more abundant.

Fishermen primarily use fish pots or traps to catch reef fish and lobsters, followed by hook and line methods for pelagic and bottom fish. Trapping has traditionally been the preferred fishing technique (Dammann 1969, Boulon & Clavijo 1986). People also Scuba dive for conchs and lobsters.

The demand for fish on St. John consistently exceeds the supply. Fishermen believe that populations of lobsters, conchs, whelks and reeffish have declined and cite a variety of causes:
1) adverse environmental changes associated with tourism;
2) increased boat traffic, resulting in cutting and dragging of trap lines;
3) theft of fish traps; and
4) restrictions imposed by the park.

It is difficult to assess the magnitude of the impact of park regulations on fishing. Trap fishing and hook and line fishing are still permitted. However, the fishermen are constrained by a variety of restrictions. For example, Title 36 CFR (Code of Federal Regulations) establishes quotas on lobsters, conchs, and whelks, prohibits spearfishing, restricts use of nets to those under 20′ long, and prohibits all fishing in Trunk Bay.

The Federal Endangered Species Act of 1973 prohibits catching of sea turtles. Other regulations, e.g., against cutting of certain plants used in fish trap construction, also limit traditional activities.

The restrictions on the use of gill nets and longer seines for catching baitfish perhaps has had the greatest impact. The relative abundance of baitfish inside and outside park waters is not known.

The tourist industry has provided new employment opportunities, replacing the island's traditional subsistence economy. The park probably has had more of an effect on the island because of its role in increasing tourism and related industries than from its restriction of traditional uses of the land and sea. Koester (1986) recommends integration of fishermen into the management of VINP/BR.

In spite of protective legislation in the USVI and specifically within VINP, and a gradual decrease in the amount of fishing around the island as people have given up fishing for jobs in tourism and elsewhere, fish populations have declined drastically.

ASSESSMENT OF FISH AND SHELLFISH STOCKS

Estimation of most fishery stock parameters is extremely difficult. Stocks are a function of recruitment, growth, natural mortality, and fishing mortality. Stock estimates can be based on 1) estimates of productivity in terms of carbon transfer through trophic levels, 2) length-weight frequencies of individual species, and 3) age, growth, and mortality rates. Fisheries information on catch per unit effort (CPUE) is also useful.

Dammann (1986) notes that although both biological and fisheries data are routinely used in stock assessment, the resulting estimates are often not entirely suitable for tropical shallow-water fisheries. It is especially difficult to assess stocks in shallow tropical seas because of the large number of species and the complex interrelationships of the coral reef, seagrass bed, and mangrove ecosystems which they inhabit.

Large assemblages of species often occur on narrow insular platforms separated from one another by deep ocean passages. In the Eastern Caribbean, each island platform is usually considered to contain its own fisheries stock despite the fact that there is obviously a great deal of gene exchange throughout the region. Most species in the Virgin Islands and Puerto Rico fisheries have pan-Caribbean distributions. There is recent evidence that marine planktonic larvae can maintain their position relative to a particular insular shelf without being swept downstream. Each insular platform apparently recruits new individuals both from within and outside its own system. There are no natural boundaries to the present VIBR, and, in light of daily and seasonal migrations, it is not appropriate to treat the resources within the area as distinct stocks.

Useable fisheries data are derived from the entire geological platform or relatively large sections of it, and at present are not suitable for estimating sustainable yields from such a small arbitrarily defined area as the waters within VINP. It is probably not appropriate to treat the marine resources within the biosphere reserve as distinct stocks.

Fisheries yields from shallow tropical reef, seagrass bed, and mangrove areas perhaps average about 4-5 metric tons/sq. kilometer/yr (Munro & Williams 1985). Larger yields (up to 15 mt/km2/yr) come from well-developed reef areas in the Pacific where fishermen harvest almost all species of living organisms (Munro 1984).

The Caribbean Fisheries Management Council represents the governments of the USVI, Puerto Rico, and the U.S. mainland. It works in cooperation with the BVI government to produce Fisheries Management Plans (FMP) for the local fisheries resources.

An analysis of the data contained in the FMPs of shallow-water reef fish (CFMC 1985) and lobsters (CFMC 1981) reveals that 1) local shallow water resources are heavily, and in some cases over-exploited, 2) fisheries productivity of the shelf is comparatively low (3.3 mt/km2/yr), and 3) maximum sustainable yield (MSY) estimates are low (shallow water reeffish for PR and the USVI, 3500 mt/yr; spiny lobsters for PR and USVI 373.5 kg/yr; conchs, 163.8 kg/yr for St. Thomas-St. John.)

FISH COMMUNITY STRUCTURE

Randall (1968) described 300 common reeffish species from the West Indies. He examined the food habits of 212 species based primarily on specimens from Puerto Rico and the USVI (Randall 1967). For two study sites in St. John, the fringing reef in Lameshur Bay and one at Ram Head Bay, herbivores made up about 24%, omnivores about 16%, and carnivores 60% of the total fish biomass. Randall (1963) installed an artificial reef in Lameshur Bay in 1960 and found that it supported 11 times more fish than a nearby natural reef, probably because of the food provided by a nearby seagrass bed.

Boulon et al. (1986a) studied approximately 50 commercially important species from 20 different habitat types within VIBR using a visual census technique. They recorded number of individuals of each species and minimum/maximum length for each species. Grunts, groupers, goatfishes, snappers, triggerfishes, mackerels, squirrelfishes, and parrotfishes are some of the most important commercial groups they observed.

Variations in the number of censuses done by Boulon et al. (1986) for each habitat type made comparisons difficult. In general, however, high species diversity was correlated with high habitat complexity. Of all habitats sampled, the lower forereef (the seaward extension of most reef systems) stands out because of a high number of species and the relatively larger size of individual fishes. Lobsters are also associated with reef areas with more complex structure, shelter in crevices and overhangs.

Bank pavement areas, often deeper than 20 m, also tend to have larger individuals and may be where they find the principal habitat for lobsters and queen triggerfish. Juvenile fishes tend to be associated with shallow mangrove areas while fish with planktonic eggs reproduce in deeper, offshore habitats. There is some evidence that deepwater algal plains and shallow grass beds serve as nursery areas as well. Migration of coastal pelagic fish species, lobsters, and conchs present sampling and monitoring difficulties. However, most reeffish are non-migratory which allows more management options.

Boulon et al. (1986) selected four long-term monitoring sites for fish: Fish Bay, Lameshur, Hawksnest, and Trunk Bay. Fish Bay was selected because of potential problems from land-based sediment associated with watershed development. Lameshur has little impact from coastal development but has some artisanal fishing pressure. Previous scientific research carried out here can be used for some comparisons. Concern over development of the watershed (particularly building of the St. John clinic) and observation of heavy runoff led to selection of Hawksnest Bay. Trunk Bay was selected in an attempt to study visitor impact. The V.I. Division of Fish and Wildlife and VINP recently signed a cooperative agreement to continue monitoring at Lameshur and Fish Bays.

FISHERIES LANDINGS ON ST. JOHN

Dammann (1969) and Olsen (1979) provide landings data for fish and shellfish in the USVI. More recently, Boulon & Clavijo (1986) looked at 6 months of fishing landings for commercial and subsistence fishermen specifically on St. John. It is impossible to determine the amount of catch landed on St. John that actually comes from within VINP waters. Data came from 28 commercial and 10 subsistence fishermen who landed catch on St. John. (Only 12

St. John fishermen had commercial licenses in 1984.) For the first 6 months of 1984, commercial fishermen landed over 16,000 lbs of fish and shellfish.

About 1400 lbs of lobsters were caught adjacent to or within VINP in a 6 month period in 1984. Fishing for lobsters is concentrated around Fish Bay, Reef Bay and Johnson's Reef (north side). Only 3 fishermen reported conch catches landed on St. John. Most of the conchs came from the south shore where seagrass beds are more extensive. Subsistence fishermen take the same species as found in the commercial catches, with each individual landing less than 50 lbs of fish per month. Most of their fishing takes place outside the park.

Further work on the intensity of trap fishing within park waters and around the island of St. John is necessary. Observations by park staff indicate that the number of traps which lack buoys at the surface and other required identification may exceed those which are marked correctly. Within the park, Lameshur appears to be the the most intensively fished bay.

FISH POISONING

Fish toxicity is a serious marketing concern in the USVI. Over half of the total weight of fish landed and half of the species in the fishery have some risk of carrying the ciguatera toxin which is associated with a benthic dinoflagellate (Olsen et al. 1982). About 3.5% of the species are very likely to contain the poison, including several of the jacks, the dog snapper, and the barracuda (Olsen et al. 1982, Dammann 1969). Toxic fish are apparently unaffected and do not exhibit any signs to indicate they are poisonous. No practical test for toxicity has yet been developed. Ciguatera occurs throughout the Caribbean but most frequently in the islands north of Martinique. One of the areas of highest risk is south of Norman and Peter Islands in the BVI. Doctors in the Marshall Islands (Pacific) have recently found that mannitol, a drug used to reduce swelling of the brain, dramatically and quickly relieves symptoms of ciguatera in some victims.

HABITATS OUTSIDE VINP OF ECOLOGICAL IMPORTANCE TO BIOSPHERE RESERVE FISHERIES

Boulon (1986b) carried out a study to determine which habitats outside VIBR are of ecological importance to fisheries within it. VIBR can not be considered a closed system because of the migration of organisms and the production of planktonic eggs and larvae by most food fishes. The generally westerly flow of the major currents near St. John suggest that planktonic eggs and larvae reach the island from sources "upstream", or to the east.

Boulon (1986b) sampled the following areas: Pillsbury Sound, SW St. John, bank patch reef off Reef Bay, Hurricane Hole, Norman Islands, NE St. John bank pavement, Great Thatch, and Soper´s Hole. Of these, he concluded that only a few could have importance for the VIBR. Coral Bay is the largest and most protected bay on St. John, and the most extensive mangrove communities on the island occur here. This area may serve as a recruitment source for lobsters and fish for many reefs and near shore communities along the south coast of the island. Bank pavement areas northeast of St. John in the Narrows and off SW St. John provide good lobster habitat and support large populations of adult fish. The large bank patch reef off Reef Bay apears to be a good spawning location. Soper´s Hole (Tortola) has suffered from dredging, but may still be an important nursery habitat.

LOBSTER AND CONCH FISHERIES

DuBois (1985) summarized the history of lobster and conch fisheries in the Caribbean, depletion of the stocks, and the constraints on effective management of the fishery. Lobsters and conchs are currently the Caribbean´s most economically important fishery exports. Valencia (1978, cited in DuBois) estimated that the fisheries contributed less than 1% of the Gross National Product of the USVI. However, fishing is an important tradition in the islands, and its cultural and social value should not be overlooked.

In the past, the USVI exported lobsters to other countries. Lobsters were apparently so abundant that they were hard to give away and often served as bait for fish traps. The USVI was exporting lobsters to Puerto Rico as late as 1960 (Caribo 1961). Since the late 1960´s, the USVI has been importing conchs and lobsters, primarily to meet the demands of tourism.

DuBois (1985) noted that attempts to reverse the decline of lobsters and conchs throughout the Caribbean have been largely ineffective. DuBois (1985) states: "Within the region, the USVI perhaps represents the most dramatic example of depletion of stocks due to excessive demand associated with growth and tourism development". He concluded that Belize and Turks and Caicos have been relatively successful in managing lobster and conch fisheries largely because of effective fishermen cooperatives and environmental education. The USVI fishermen are not currently organized into effective cooperatives.

Conchs

Randall (1964) studied the basic biology of the conchs in St. John in the late 1950's and early 1960's. Conchs occur over a large depth range and in a wide variety of habitats including sand, rubble, and seagrass but most often in seagrass beds (Fig. 12). They are herbivores which primarily eat algae but also ingest seagrass. Randall (1964) found that conchs tended to spawn in warm months, ceasing in November or December and

Fig. 12. Queen conch (Strombus gigas) in a seagrass bed in Brown Bay. Photo: L. McLain.

beginning again in January, February, or March. Predators of conchs include spotted eagle rays, lobsters, queen triggerfish, and sharks. While some predators are only capable of consuming the animal after it is removed from its shell, a few species can crush small conch shells to get at the animal inside.

Deterioration of seagrass beds around St. John (Williams 1988) could be partly responsible for the observed depletion of conch populations. Randall (1964) referred to hundreds of conchs in Salt Pond Bay, but populations this large have not been seen there in the last several years.

Boulon (1987) monitored juvenile and adult conch populations in Reef Bay, Outer and Inner Fish Bay, Hawksnest Bay, and Threadneedle Bay monthly in 1985, finding very low numbers of individuals and widely fluctuating population sizes. He also used a diving sled to survey conchs around St. John in 1985, repeating surveys done four years earlier (Wood & Olsen 1983). Numbers of conchs in 1985 were not significantly different than in 1981, although Boulon (1987) suggests caution in drawing conclusions from these results because of small sample sizes. Spot checks at 14 other sites around the island which appeared to be good habitat (e.g., Inner Fish Bay and Reef Bay seagrass beds) revealed 5 sites with no conchs and the remainder with less than 15 each (Boulon 1987). Piles of empty shells were found at several locations.

Absence or low numbers of conchs at sites known to have supported conch populations in the past (Hawksnest, Inner Fish Bay) could reflect migration or harvesting of the animals. The southern park waters, at least above 20 m, have more conchs that northern waters, with Outer Fish Bay having the largest population (Boulon 1987). The number of conchs in this bay were significantly less in the summer months, and Boulon (1987) suggested conchs migrate offshore into deeper water during the summer reproductive season to mate and deposit eggs.

In contrast, Hesse (1979) and Coulston et al. (1985) described migrations in the fall months in the Bahamas and St. Croix, respectively. Coulston et al. (1985) saw reproductive activity from March through November in depths of 15 m to 21 m. Deepwater populations may move inshore into adjacent shallow bays such as Threadneedle. Coulston et al. (1985) and Boulon (1987) agree that deepwater reproductive populations, which escape fishing pressure, may be essential to maintenance of the species in USVI waters. Boulon (1987) suggests that the continuing take of immature conchs around St. John will result in near elimination of local populations. Recent research suggests that the flared lip on conchs may not necessarily indicate reproductive maturity (Wilkins et al. 1985), which means that regulations which only permit taking of conchs with flared lips are not protecting the reproductive populations as intended.

Lobsters

Boulon (1987) surveyed areas in Fish, Reef, and Hawksnest Bays for spiny lobsters (*Panulirus argus*) (Fig. 13) and spotted lobsters (*Panulirus guttatus*) in 1985 and 1986. Alarmingly low numbers of lobsters were found at all sites, although the presence of ledges, overhangs, and holes in these reef areas would appear to provide good lobster habitat. For example, in Reef Bay, only 0 to 4 lobsters were observed in each of 9

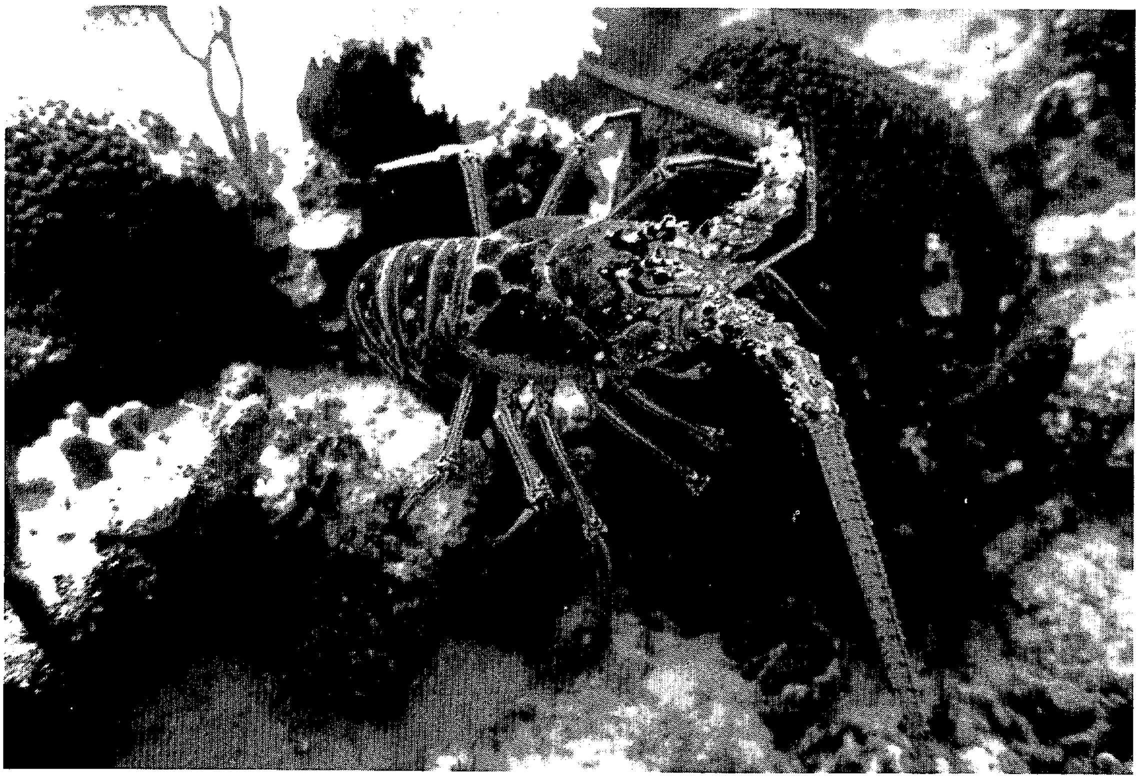


Fig. 13. A spiny lobster (Panulirus argus) on Johnson's Reef. Photo: L. McLain.

censuses, with all of these having carapace lengths less than 3.5 inches (legal size). At Hawksnest, only 1 spiny lobster was seen in 11 monthly surveys. Spot checks for lobsters at 9 additional sites in the summer of 1985, turned up exceptionally low numbers of both species as well.

Knowledge of basic lobster biology is a prerequisite for effective management. Tektite studies provided information on population dynamics (growth and mortality), ecology, and behavior (Cooper et al. 1975, Herrnkind et al. 1975, Olsen et al. 1975, Olsen & Koblic 1975). Olsen et al. (1975) studied lobster distribution around all of St. John using Scuba. In their survey, lobsters were rare from Hawksnest to Francis Bay and on the east end of the island. Mean lobster densities ranged from 0 to 19.4 individuals/ha. This contrasts with an estimated mean density of 64.8 lobsters/ha in the Dry Tortugas in the early 1970's (Davis 1977). Their observations were confined to waters 18 m deep or less, and substantial lobster populations could occur deeper. Lobsters tended to inhabit areas near dropoffs to deep water.

The reproductive period for lobsters appears to be in the spring and fall according to Olsen et al. (1975) or just in the spring according to Davis (1977). The planktonic phase of the spiny lobster's life lasts an estimated 6 to 7 months (Sims & Ingle 1966, cited in Olsen et al. 1975). Mortality may be over 99% (Buesa 1969; cited in Olsen et al. 1975). Juveniles settle in shallow mangrove and seagrass bottoms. The long-spined black sea urchin *Diadema antillarum* commonly provides shelter for young lobsters (Davis 1971). Olsen et al. (1975) suggest most juvenile lobsters in USVI waters occur in mangrove lagoons. Juveniles leave the mangroves after 2 years, after reaching a carapace length of about 80 mm. Some data suggest offshore movement of lobsters during fall and winter out to the reefs.

Olsen & Koblic (1975) found that female lobsters take up to 4 years to reach market size after settlement from the plankton while males take 2 years. Survivorship was estimated at 52 to 66% per year. These authors felt that even within park waters the lobster population showed the effects of fishing.

Herrnkind et al. (1975) studied den occupancy and nocturnal movements of spiny lobsters. One study site in Greater Lameshur had population densities ranging from 4.8 to 15/ha. Lobsters leave dens at night to feed in reefs or sand-algal plains, returning before dawn. These authors suggest resident lobsters have home ranges of 200 to 300 m in diameter. Herrnkind et al. (1975) found indications that intensive handling of lobsters altered their distribution patterns after release (see also Davis 1977).

Gut analysis revealed lobsters eat primarily mollusks (including small conchs) as well as *Diadema*, *Echinometra*, and hermit crabs through scavenging and active predation (Herrnkind et al. 1975). In his study at Dry Tortugas, Davis (1977) also found that lobsters eat mollusks and echinoids, including *Tripneustes* and *Lytechinus.*

Davis (1977) showed the effects of intense recreational harvest of lobsters at Dry Tortugas (Fort Jefferson National Monument). Following prohibition of harvesting for over 2 years, sport fishing for lobsters was permitted for 8 months. Although the control population did not change, the trap catch rate in the experimental area decreased 58% immediately after harvest. One year later, the catch rate had recovered to 78% of its former level. Full recovery could take several years. Davis (1977) documented seasonal movement between shallow and deep waters that appeared to be related to mating and reproduction.

OTHER FISHERIES

The whelk or West Indian topshell, *Cittarium pica*, inhabits rocky coasts a few feet above and below the water line. Randall (1964) studied the general biology of the whelks in Europa Bay, St. John. Boulon (1986, 1987) studied density, seasonal distribution, and size classes of whelks between Windswept Beach and Peter Bay on St. John's north shore. The conspicuous lack of individuals larger than 6.9 cm suggests high levels of harvesting.

Several species of fish are used as bait in local reef and pelagic fisheries, including dwarf herring, redear sardine, false pilchard, flying fish, ballyhoo, and mackeral scad. The Division of Fish and Wildlife surveyed baitfish in the USVI from 1984 to 1987. In St. Thomas and St. John fishermen primarily use haul seines to catch bait, while St. Croix fishermen generally use cast nets. Some species of baitfish may show seasonality in abundance.

FISHERIES OF BUCK ISLAND REEF NATIONAL MONUMENT

Tobias et al. (1988) studied lobsters, conchs and reeffish at Buck Island from November 1985 to June 1986 to determine the effectiveness of NPS regulations in protecting fish and shellfish populations and to assess the impact of commercial trap fishing. Censuses similar to those carried out previously by Gladfelter et al. (1977) and Simpson (1979) at the same locations led them to conclude that reeffish are decreasing in abundance. Park rangers and concessioners feel there has been a severe decline. The average density of conchs in seagrass beds west of the island was 0.14 individuals/m2 which compares to a density of 0.17/m2 reported by Boulon et al. (1986) for VINP. Less than 2% of the animals censused were adults. The mean density of lobsters at 3 small reef areas was only 0.008/m2.

Fewer species and fewer fish overall were caught at Buck Island in experimental traps than at Teague Bay, an unprotected area south of Buck Island. Commercially important reef fishes do not appear to be any more abundant than at Teague Bay or elsewhere around St. Croix.

LESSER ANTILLEAN REGIONAL FISHERIES

Goodwin (1986) provides information on regional trends in Lesser Antillean fisheries and the implications of these trends for management of the VIBR and other protected areas in the region. Sustainable conservation of regional ecosystems requires effective inter-institutional and international cooperation.

Few data exist on the abundance and sustainable yields of Lesser Antillean fishery resources. Shallow-water reeffishes are apparently overfished in most of the Lesser Antilles (Goodwin et al. 1985). Habitat destruction associated with coastal construction will become an increasingly important threat to fisheries. However, current landings could be moderately increased through attention to underexploited resources (deep water snapper-grouper stocks, migratory pelagic fishes). Management of the resources is presently secondary to considerations of improved local income, employment and nutrition. Biosphere Reserves could benefit fisheries by 1) including protected breeding and nursery areas, 2) managing zones to increase local availability of fish, and 3) developing strategies for use of underused resources.

The Organization of Eastern Caribbean States has drawn up a draft set of fishery regulations which provides for the establishment of marine reserves, thereby providing a legal foundation for designating components of a multi-site reserve. Strategies which involve the participation of local people have been successful in the BVI, Dominica, St. Lucia, and elsewhere and may provide a valuable starting point for development of a regional biosphere reserve network. Case studies of successful marine resource management strategies and research projects which result in clear benefits are needed. The Draft Fisheries Regulations include specific management measures for fish, lobsters, conchs, sea turtles and coral.

FISHERIES REGULATIONS IN THE USVI

The Division of Fish and Wildlife in the Dept. of Planning and Natural Resources has responsibility for managing the fisheries in the USVI. Territorial Act 3330, in 1972, established many regulations, including minimum size of lobsters and gear restrictions. The Territorial Government also adopted federal regulations in the Exclusive Economic Zone (EEZ), 3 to 200 miles offshore, which, (beginning in 1982), established a minimum size limit of 8 inches for yellowtail snappers (with a one inch per year increase to 12 inches) and 12 inches for Nassau grouper (with a one inch per year increase to 24 inches). There is also a closed season each year for Nassau groupers from January 1 to March 31 to protect spawning individuals.

"Fisheries in Crisis" was the title of a conference held by the Division of Fish and Wildlife in St. Thomas in Sept. 1987. This conference provided momentum for the creation of Fishermen´s Committees of Overseers. The St. Thomas-St. John Committee submitted a proposal to the Governor to declare a 5 year moratorium on the taking of all conchs and a size limit and closed season for whelks. With the Governor's signature, these regulations went into effect February 1988. A size limit of 2 and seven-sixteenth inches (6.2 cm) for whelks became effective on Feb. 1, 1988 as well as a closed season from April 1 to Sept. 30 of each year. Prior to this, there had been no regulations at all on conchs or whelks, with the exception of those inside VINP. Inside the park, people were allowed to take 2 conchs and 1 gallon of whelks per person per day. The National Park Service and the local government have concurrent jurisdiction over park waters, and the park has adopted the more restrictive regulations.

In addition to regulations discussed above, the park prohibits seines longer than 20', allows use of traditional design fish traps, permits the taking of 2 lobsters per person per day, and prohibits all fishing within Trunk Bay (Title 36 CFR).

RECOMMENDATIONS FOR FUTURE RESEARCH AND MANAGEMENT OF MARINE RESOURCES

Effective long-term assessment programs must be established for the marine ecosystems of St. John. The National Park Service is providing funds for long-term monitoring of coral reefs at Virgin Islands National Park, Buck Island Reef National Monument, Biscayne National Park, and Fort Jefferson National Monument (Dry Tortugas). Routine gathering of data on environmental parameters, such as temperature, will be combined with tracking of benthic reef organisms using photographic and transect methods at permanent study sites (Rogers 1988). Fish censuses will also be carried out. The new Cooperative Agreement between the NPS and the V.I. Divison of Fish and Wildlife should help to facilitate cooperative research, particularly on local fisheries.

Conch and whelk populations should be systematically monitored to determine the effectiveness of recent regulations. Fish and lobster populations should be monitored to determine the need for further management actions, for example, area closures, gear restrictions, or increase in minimum size at harvest (see Boulon 1987). Data must be collected in a statistically rigorous way.

Local fishermen must be an integral part of the management process and the decisions which are made. Numerous people have pointed out and emphasized not only the desirability but the necessity of bringing fishermen into the process of research, information exchange, and management (e.g. DuBois 1985, Goodwin 1986, Koester 1986).

DuBois (1985) points out the critical need for research on the linkages between habitat degradation (such as destruction of mangroves) and fisheries (stock depletion). Overfishing has also depleted lobster and conch populations in many Caribbean nations (DuBois 1985).

The lack of sufficient information on the coastal and inshore currents off St. John impedes research regarding dispersal of larvae, sediment transport, and transport and dilution of pollutants such as oil, nutrients and toxic materials. Effective management of fisheries requires more knowledge of larval dispersal patterns. As Munro & Williams (1985) point out, "Effective management strategies will vary greatly depending on the extent to which recruitment to a reef is derived from within the fished population (self-recruiting) or was spawned outside the system". Other research needs include: migration patterns of coastal pelagics; seasonality of fish and shellfish populations; and the population dynamics/habitat requirements of baitfish.

Implementation of specific management recommendations for the marine systems and fisheries of VINP could help to reduce the pressure on these resources and perhaps reverse the deterioration of benthic areas and the decline of fish and shellfish populations.

The Shoreline Use Plan should be implemented as soon as possible by installing mooring and marker buoys in critical bays and near vulnerable reefs. Minimum depth or minimum distance from shore requirements for anchoring should be considered in areas where anchoring is allowed. Zoning of park waters for fishing or other activities should be evaluated as a means of reducing conflicts among resource users (see Kelleher 1985 on zoning for Great Barrier Reef, Australia; see Putney 1987 on resource users in VINP).

The water quality monitoring program started by the park's research staff in 1988 to look at basic parameters (oxygen, turbidity) should be continued and expanded to include collection of data to help determine if sewage, oil, and fuel from boats are causing deterioration of water quality in park waters.

TERRESTRIAL SYSTEMS

HISTORY OF RESEARCH: FLORA AND VEGETATION

The Virgin Islands were among the first Caribbean islands to be explored by botanists. Several early floras (West 1793, von Eggers 1879, Millspaugh 1902) dealt mainly with St. Croix. Borgeson (1898, 1909, 1923) described the vegetation of the Danish (later, United States) islands in a series of papers. Britton published annotated systematic lists of plants of Anegada (1916), the USVI (1918), and a narrative of collecting on Puerto Rico and the USVI (1923). Britton & Wilson (1923-1930) prepared a flora of the vascular plants of Puerto Rico and the Virgin Islands, covering the area from Mona to Anegada and St. Croix. Liogier (1965, 1967) made nomenclatural changes and additions to Britton & Wilson's flora, and Fosberg (1976) revised the flora of St. Croix.

Beard (1945) described the flora of the BVI. D'Arcy prepared annotated checklists of the flora of Tortola (1967) and Anegada (1971). Little (1969) studied the trees of Jost van Dyke, and Little et al. (1976) treated the flora of Virgin Gorda. Little & Wadsworth (1964) and Little et al. (1974) produced a comprehensive two-volume guide to the identification and distribution of the trees of Puerto Rico and the US and British Virgin Islands. Oakes & Butcher (1962) discussed the poisonous and injurious plants of the Virgin Islands. Woodbury & Little (1979) prepared a flora of Buck Island Reef National Monument.

The works of Beard (1944, 1949, 1955) constitute the basic references on tropical American vegetation, including the Windward, Leeward, and the British (but not the US) Virgin Islands. The plant ecology of Puerto Rico was studied by Gleason & Cook (1927). Velez (1957) described the herbaceous angiosperms of the Lesser Antilles. Ewel & Whitmore (1973) mapped the ecological life zones of Puerto Rico and the USVI and described their plant associations. Howard (1973) discussed the vegetation of the Antilles, including biogeographical aspects. Lugo et al. (1981) and Brown (1982) provide an overview of the status of Caribbean forests in the early 1980's. Many other references on the plant ecology of the West Indies can be found in Rundel (1974). Mosquera & Feheley (1984) provided a bibliography of forestry in Puerto Rico and the USVI.

While the above references contain much valuable information, few works deal exclusively with the botany and plant ecology of St. John. Woodworth (1943) prepared an annotated list of the economic plants of the island. Robertson (1957) prepared a preliminary map of plant formations as part of an initial biological survey for the National Park. Forman & Hahn (1980) gave a quantitative description of the spatial patterns of trees in the Reef Bay forest. A list of vascular flora in VINP is contained in the NPS NPFLORA computerized data base. Teytaud (1988) mapped environmental factors and potential natural vegetation in St. John. Woodbury & Weaver (1987) described and mapped the existing vegetation types of St. John and Hassel Island, provided a species listing by vegetation type, and collected herbarium specimens to be deposited at the Virgin Islands Biosphere Reserve Center.

Weaver & Chinea-Rivera (1988) established sixteen long-term monitoring plots in the Cinnamon Bay watershed in 1983 to explore species-site relationships and structural characteristics of the vegetation at different elevations. Stem density, mean height and diameter of stems, basal area, number of species, and diversity indices were calculated. The trees in these plots were remeasured in 1988. Earhart et al. (1988) and Matuszak et al. (1987) describe a long-term monitoring study, begun in 1984, of vegetation on three plots in the Reef Bay, Hawksnest Bay, and Fish Bay watersheds.

DESCRIPTION OF TERRESTRIAL SYSTEMS

Flora and Vegetation

According to the life zone system of Holdridge (1967) most of St. John has a subtropical climate which is transitional between dry forest and moist forest (Ewel & Whitmore 1973, Teytaud 1988). A true moist forest life zone occurs only in a small area on the highest and wettest parts of the island, and a true dry forest life zone occupies only the driest areas at the eastern end and some points of land along the shorelines. In Beard´s (1955) system of vegetation classification, upland areas with this type of climate would normally support "climax" plant formations consisting of semi-evergreen forest in the moist forest life zone, and deciduous seasonal forest elsewhere. In St. John the "normal" climatic factors are overridden by the effects of steep topography, shallow non-zonal soils, and drying tradewinds. These conditions shift the potential natural vegetation to Beard´s dry-evergreen formation-series, with dry evergreen forest in the moist forest life zone and dry evergreen woodland and thicket in other areas (see Teytaud 1988).

Recurrent hurricanes, human disturbances (chiefly vegetation clearing and development, Tyson 1984), and the presence of exotic feral animals such as pigs, goats, and donkeys have all had an effect on the vegetation of St. John (Lazell 1980, Nellis et al. in prep). Existing vegetation is almost entirely secondary and therefore difficult to relate to Beard´s descriptions of climax formations. Harris (1963), Lazell (1980) and Byrne (1980) provide comparative data from other West Indian islands subjected to similar kinds of human disturbance.

Woodbury & Weaver (1987) mapped and classified the existing vegetation of the uplands as follows: (a) moist forest; 10 to 30 m tall, with 2 or 3 tree strata (layers); trees over 70% evergreen; has characteristics of both Beard´s seasonal and dry evergreen formation-series but not typical of either type; subdivided into upland, gallery, and basin types; (b) dry evergreen woodland (described by some authors as deciduous type); 5 to 10 m tall with two tree layers; leaves small; (c) dry evergreen thicket or scrub 0 - 3 to 5 m tall; with small leaves; (d) thorn and cactus, less than 5 m tall; dominated by tree cacti and other thorny species; (e) recently disturbed secondary vegetation in various stages of recovery; and (f) pasture (Fig. 14). The most advanced seral stages occur in some moist upland forests (e.g., Bordeaux Mountain summit) and gallery forests (e.g., Reef Bay Gut and Battery Gut) but still contain introduced species. The dry forests between the littoral and the summit forests are made up of a mixture of secondary species and show no pronounced altitudinal zonation.

Woodbury and Weaver listed nearly 800 species of plants in 116 families from St. John. Eighteen species were considered rare and endangered, and six of these may be new to science (Table 1). Of the 750 species of trees of Puerto Rico and the Virgin Islands which were described in Little & Wadsworth (1964) and Little et al. (1974), 547 (73%) are native and 203 (27%) were introduced. Matuszak (1985) lists 14 endemic species for the Virgin Islands. Woodbury & Weaver (1987) note that the areas of vegetation under Park Service jurisdiction are unique because similarly protected areas in these vegetation types do not exist elsewhere in the Caribbean.

Table 1. Rare and endangered species of plants from St. John (From: Woodbury & Weaver 1987)

Machaonia sp. (new)	*Erythrina eggersii*
Malpighia sp. (new)	*Galactia eggersii*
Eugenia sp. (new)	*Malpighia linearis*
Byrsonima sp. (new)	*Malpighia woodburyana*
Psidium sp. (new)	*Zanthoxylum thomasianum**
Apocynaceae (new, vine)	*Ilex urbanii*
Peperomia myrtifolia	*Calyptranthes thomasianum*
Schoepfia schreberi	*Solanum mucronaturm*
Cypselia humifusa	*Tillandsia lineatispica*

* On the Federal endangered species list.

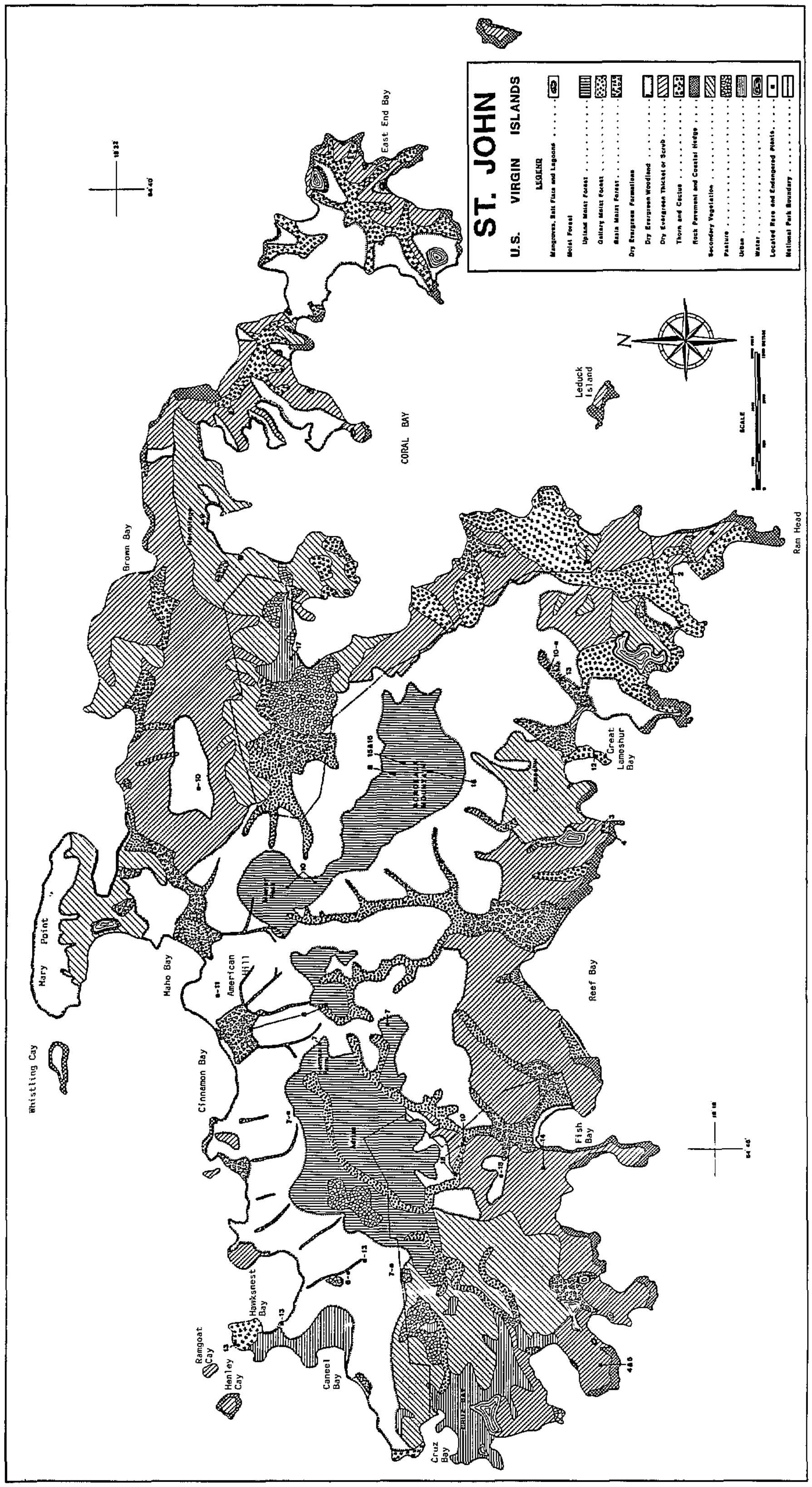


Fig. 14. Vegetation map of St. John. (From: Woodbury & Weaver 1987).

Earhart et al. (1988) established three permanent plots in the forest of St. John in the Reef, Fish, and Hawksnest Bay watersheds. They identified and measured all plants having a diameter at breast height (dbh) greater than or equal to 5 cm, measured a sub-sample of tree heights, mapped stem locations, and determined the distribution of each species within each plot. For each species, they calculated basal area and relative density, dominance and frequency values.

The Bordeaux plot (1.0 ha), in upland moist forest, has 62 species in 33 families. Farming probably ceased on this plot 100 years ago. Located in gallery moist forest, the L´Esperance plot (0.5 ha) has 39 species in 26 families and has been recovering for an estimated 60-70 years. The Hawksnest plot (0.5 ha), in dry evergreen woodland, has 54 species in 26 families and was abandoned more recently than the other plots. The regenerating forest in these 3 plots are composed of native and exotic species. Matuszak et al. (1987) provide interesting historical and ethnobotanical data on eight of the most important species in the plots.

Tyson (1987) reported on land use in the Reef, Fish and Hawksnest Bay watersheds during the period from 1718-1950. Agriculture in all three watersheds peaked between 1755 and 1780 but continued at a relatively high level until 1820 and then declined during the 19th century. Tyson delineates areas which were subjected to intensive use, as well as some areas which may have remained free from direct human impact.

Sage Mountain in Tortola supports a vegetation type that is similar to the upland moist forest in St. John in some respects but unique in others (see Little & Wadsworth 1964). Beard (1949) classified this forest as "xerophytic rain forest," thus giving it an undeserved reputation for wetness (Bowden et al. 1970). In his revised classification scheme Beard (1955) placed this type in dry evergreen forest; it represents merely a somewhat wetter example of the moist forest life zone found on St. John. Although the Sage Mountain forest is nominally protected by the BVI Government, the relatively "natural" portion of it has shrunk steadily over the years. Efforts should be made under the aegis of the Biosphere Reserve to help the British Virgin Islands to protect the remaining forest, both as a valuable resource in its own right and because of its importance for comparative research.

At the time Beard published his 1949 paper on the vegetation of the Lesser Antilles, he could not find a single undisturbed example of either dry evergreen or seasonal vegetation in the dry forest and moist forest life zones of those islands. Very little is known about the structural or functional characteristics of natural vegetation in these life zones. Lugo et al. (1978) studied the structure, productivity, and transpiration of Guanica Commonwealth Forest, a subtropical dry forest on the southwest coast of Puerto Rico characterized by secondary growth with scrub forest, deciduous forest and semi-evergreen forest types. Data on nutrient dynamics (Lugo & Murphy 1986) and biomass (Murphy & Lugo 1986) for this forest are also available. This site is somewhat drier than St. John and is underlain by shallow limestone-derived soils, but is similar enough that the results of these studies may serve as an approximation of the functional characteristics of St. John's secondary dry forest. Lugo et al. (1978) reported that productivity of the Guanica forest is low compared to that of other tropical ecosystems. As in Cruz Bay (Teytaud 1988), soil moisture deficit occurs for ten months of the year and low soil moisture availability is the dominant factor controlling forest productivity, growth, litter decomposition, water loss, and physiognomy.

Soils

Rivera et al. (1966, 1970) described and mapped the soil types of the USVI and provided information on suitability of soils for various uses. Most of St. John is covered by soils belonging to the Cramer series; other soils are generally found only in valleys and along the coasts (Rivera et al. 1970). Cramer soils occur on steep mountainsides, and the surface layer is gravelly or stony clay loam. Between 50% and 70% of the surface may be covered with rock outcrops, boulders and stones. These soils were formed in place from basic volcanic rocks and are red or reddish-brown and moderately permeable. They are well-drained, slightly acidic to neutral in the surface layer, clayey, moderately fertile, shallow, and dry. The subsoil may be at or below the wilting point for 3 to 6 months per year. Runoff is excessive, permeability and infiltration are moderate, and erosion hazard is severe. Most St. John soils fall in the U.S. Department of Agriculture's hydrologic group D, indicating that they have a high potential for runoff.

Buck Island is almost entirely covered with soils belonging to the Southgate Rockland Complex (Rivera et al. 1970). These soils formed in place on steep slopes from "granitic" rocks. They are greyish-brown to dark brown clay loams that are 50% to 70% rock outcrops, with soil material less than 13 cm thick between the outcrops. Loose stones and boulders are common on the surface. These soils are well-drained, slightly acidic in the surface layer, clayey, moderately fertile, very shallow and have a low water-holding capacity. Collins & Craft (1988) note that the classification of Rivera et al. (1966, 1970) should be modified to reflect the conditions which prevail on tropical islands with complex geological history.

Soils near the periphery of each of the long-term plots established by Earhart et al. (1988) in the Fish, Reef, and

Hawksnest Bay watersheds were sampled in 1986 (Matuszak et al. 1987). Samples were analyzed for macronutrients (P, K, Ca, Mg, and S) and micronutrients (Zn, Fe, Cu, Mn). Organic matter, texture, sodium content, and pH were also examined.

Brown & Scheffel (1985) investigated the recovery of soil organic carbon during forest succession on St. John. They found that conversion of forest to agriculture results in almost a three-fold decrease in soil carbon. However, recovery of soil carbon in the moist forest life zone of St. John is relatively fast and seems to occur within 50-60 years, a rate similar to that found for dry forest and wet forest life zones in Puerto Rico. The carbon content of the mature forest in St. John is high and more typical of sites in wetter climates.

Groundwater

A reconnaissance survey of groundwater was carried out by McGuinness (1946). Cosner (1972) prepared a more extensive report, including alternatives of water supply.

About 1 to 3 inches of water per year enters the soil and stream-channel deposits. The most important aquifer is the fractured volcanic rocks throughout most of the island. The depth to the water table averages less than 50 feet in the hills of St. John, but it is close to the land surface along the shoreline. Some of the groundwater may enter the sea, but much of it is used by the vegetation in the valleys and along the shore (Cosner 1972).

Jordan (1972) presents evidence which indicates that the base flow of streams on the three main islands of the USVI has diminished. Streams that were once perennial now dry up in the dry season, except for a few spring-fed pools in the stream channels that are sustained except in severe drought. Jordan attributes this decline mainly to changes in land use, i.e., reversion of land from crops and pasture to dense brush and forest. Recharge to the aquifer has been reduced because rainfall that once infiltrated below the shallow root zone of crops and grasses has been increasingly intercepted and transpired by deep-rooted secondary brush and trees. A contributing factor to the decline in base flow appears to be a long-term decrease in rainfall since the early 1900's.

HISTORY OF RESEARCH: FAUNA

Much of the literature on the terrestrial fauna of the Virgin Islands appears in works on biogeography and systematics of various taxonomic groups. More information exists on birds, reptiles, mammals, and amphibians than on invertebrates.

The volumes of the New York Academy of Science's Scientific Survey of Puerto Rico and the Virgin Islands, issued at irregular intervals from the 1920's to the present, are a basic reference including many citations of earlier zoological work. Highfield et al. (1985) produced a preliminary bibliography of holdings in the Virgin Islands National Park libraries which contains pertinent references. Work is continuing on a very comprehensive annotated bibliography of the Virgin Islands (Highfield et al, in prep.). The endoparasites, arachnida, insects, brochyuran crabs, fresh water fishes, and mammals of St. Croix, were catalogued by Beatty (1944). Philibosian & Yntema (1977a) published an annotated checklist of the birds, mammals, reptiles and amphibians of the Virgin Islands and Puerto Rico. MacLean (1982) gives keys and species accounts of the reptiles and amphibians of the Virgin Islands. Lazell (1980, 1983a, 1983b) gave an account of the terrestrial fauna and the biogeography of the herpetofauna of the British Virgin Islands. Riley's (1975) Field Guide to the Butterflies of the West Indies is the basic reference for this group. Raffaele's Guide to the Birds of Puerto Rico and the Virgin Islands (1983), is more specific to the Virgin Islands than the earlier standard, Bond's Birds of the West Indies (1979), and contains information on endangered species. Chace & Hobbs' (1969) systematic account of the freshwater and terrestrial decapod crustaceans of the West Indies includes the species present in the Virgin Islands.

Invertebrates and Aquatic Fauna

Muchmore (1987) investigated the invertebrates of St. John, establishing many new distribution records and discovering a considerable number of new species. Until recently only a few records have existed in the literature of onychophora, isopods, millipedes, scorpions, spiders, ants and a scattering of other insects from St. John. Before Muchmore's work there were apparently no records of snails, annelids, freshwater crustacea, centipedes, most arachnida, and most groups of insects, though some of these have been reported from St. Croix, St. Thomas, and Tortola (Muchmore 1982). Curry (1970) prepared an entomological checklist for the Virgin Islands Ecological Research Station at Lameshur Bay and collected many specimens. Her checklist includes more than 75 taxa in 10 orders, Coleoptera being the best represented. Curry & Curry (1971) studied the Chironomids (midges) in the USVI and on Anegada. Coleopterans (beetles) and other insects from the USVI are described by Ivie (1983, 1985a, 1985b), Ivie & Miller 1984, Ivie & Triplehorn (1986), and Ivie & Nickle (1986).

The freshwater stream habitat has apparently not been well investigated in St. John. Besides insects and frogs, at least 8 native species of fishes, 9 shrimps and several kinds of crabs are known to inhabit freshwater streams in St. Croix (Beatty 1944, Clavijo et al. 1980). Woodbury & Weaver (1987) found very small areas of freshwater swamp vegetation in a few places on the leeward side of St. John where there were large inputs of fresh water. Typical tree species here are the pond apple (Annona glabra), escambron (Machaerium lunatum), and Enallagma latifolia. Examples of this uncommon habitat occur at Fish Bay and Coral Bay.

An interesting and not uncommon freshwater habitat occurs in the leaf axils of various species of bromeliads, which retain moisture after rainfall. Miller (1971a, 1971b) investigated the invertebrate communities living in leaf axils and found scorpions, cockroaches, isopods, centipedes, two species of frogs, various dipteran larvae, algae and protozoans. He studied dipteran larvae in two species of bromeliads, Tillandsia urtriculata from the xerophytic vegetation near the coast and Aechmea lingulata from the moist highlands of Bordeaux Mountain. The bromeliad leaf axil micro-habitat represents one of the most widely distributed freshwater sources on the island, and it enables dipterans to successfully inhabit areas which would otherwise be too dry to support their larvae.

Amphibians and Reptiles

Of the 45 living and 6 extinct terrestrial species of native amphibians, reptiles, mammals and birds listed by Philibosian & Yntema (1977a) as breeding on St. John, none are endemic to that island alone, but 11 of the non-flying forms are endemic to the Puerto Rico Bank. These authors list a total of 111 species of living vertebrates on St. John, including introduced and non-breeding species (but not accidental birds or freshwater fishes).

Four species of frogs, a land tortoise, 2 geckos, 3 Anolis lizards, the common tree iguana, an Ameiva ground lizard, an Amphisbaena worm lizard, and a Typhlops worm snake are found on St. John today (Philibosian & Yntema 1977a, MacLean 1982). The systematic literature on Virgin Islands amphibians and reptiles is growing (Williams 1969; MacLean 1982; Nellis et al. 1983; Lazell 1980, 1983a, 1983b). Philibosian & Yntema (1976, 1977, 1978) along with MacLean et al. (1977) provide recent herpetological summaries for the USVI. Philibosian (1975) studied the territorial behavior and population regulation of Anolis acutus in St. Croix and A. cristatellus in St. John.

Birds

St. John plays an increasing role as a research site in the tropics. One of the earliest lists of birds from St. John may be found in Oldendorp's monumental cataloging from 1732 to 1768 of life on St. John during the influence of the Moravian Church (Oldendorp 1770). Successive lists of birds and new additions to the bird fauna (Ridgway 1884) of the Virgin Islands, and St. John in particular, have been published (Newton 1860; Nichols 1943; Mortenson 1909, 1910). Bond's Supplements to the Check-list of Birds of the West Indies (1940) and the revised field guide (Bond 1985) specifically mention St. John as site locations of range extensions. The 6th edition of the American Ornithologists Union's Check-list of North American Birds (1983) included an expanded geographical range, including Central America, and the West Indies. Again, St. John is frequently mentioned for its range extensions for migrant avifauna. Norton (1983, 1986) has prepared checklists for VINP, and Leck and Norton (in prep.) are working on an updated checklist. Wauer (1988) recently produced an illustrated guidebook to the more common birds in the USVI.

Lamb (1957) and Kepler (1971) provided information on endangered species and their habitats. The Brown Pelican (<u>Pelecanus occidentalis</u>) gained attention on St. John because of sufficient numbers and accessible colonies for research (Boulon et al. 1982, Collazo & Agardy 1982, Coblentz 1986). This endangered species nests, roosts and feeds adjacent to and within park boundaries. The recent listing of the Roseate Tern (<u>Sterna dougallii</u>) as threatened (Federal Register, Nov. 2, 1987) in the West Indies can in part be attributed to work on colonies near St. John (Halewyn & Norton 1984, Norton 1988).

For example, the Puerto Rican (Stolid) Flycatcher (<u>Myiarchus stolidus</u>) on St. John played a role in describing the status and speciation of the <u>Myiarchus</u> group in the West Indies (Hall 1965, Seaman 1957, Lanyon 1967). The type locality of the Caribbean (American) Coot was St. John (Ridgway 1884), and the recent discovery of the Lesser Antillean Bullfinch on St. John (Raffaele & Roby 1977) illustrates that the bird life of St. John is dynamic. New data may be expected as a result of the island's location in the West Indian archipelago and because of its regenerating habitats (Norton & Hobbs 1987).

International concern for the role of forest habitats as wintering areas for migrant and resident birds in the tropics is focusing on the island of St. John. Comparative studies conducted on St. John and St. Thomas (Askins et al. 1987) are expected to provide insight on the importance of forest habitats on developed and relatively undeveloped islands in the West Indies. Annual Christmas bird counts conducted on St. John for the last 10 years and other islands in the Caribbean also provide a data base for further comparative work (Norton in prep. a).

St. John has 24 living and 2 extirpated breeding species of land birds (Leck & Norton, in prep; Norton 1986). Land birds are here considered to be those in the families of vultures and raptors, and pigeons through passerines (Bond 1979). There are 19 living and 3 extirpated (no longer breeding in the Virgin Islands) native breeding water birds, seabirds, waders and shorebirds. One hundred nineteen (119) species are listed as migrants or visitors not known to breed, of which 3 introduced species may be found on St. John. The total list of avifauna as of 1988 is 170 species.

Robertson (1962) laid the foundation of serious modern ornithological study in St. John and gave a summary of previous work. He investigated the quantitative distribution of landbirds in relation to moist and dry forests. The heavy second growth forest on St. John is especially attractive to non-breeding, wintering wood warblers (Askins et al. 1987). Worm-eating, Black-throated Blue, and Hooded Warblers were widely distributed in the moist forest habitat in St. John (Robertson 1962).

The Virgin Islands lack most Greater Antillean species of birds. Fourteen species of St. John´s breeding land birds are widely distributed in the Caribbean and 10 species reach range limits in the eastern Greater Antilles. Of the latter, 5 apparently reached the Virgin Islands from the Lesser Antilles and 5 from Puerto Rico and the Greater Antilles. The Mocking bird has recently extended its range to the Virgin Islands from Puerto Rico; the other Greater Antillean species are rare and appear to be relict. The Lesser Antillean species seem to be a more recent and more aggressive element in the Virgin Islands avifauna, and all except the Bridled Quail Dove are common and extending their ranges (Robertson 1962).

Robertson noted that he had no satisfactory explanation for the absence from the northern Virgin Islands of 22 out of the total of 53 species in the native land avifauna of Puerto Rico. Judging from the vegetation of St. John, he assumed that habitat (i.e., heavy forest) suitable for many of the missing species was available in the Virgin Islands under original conditions, and a land connection to Puerto Rico is generally thought to have existed during glacial periods in the Pleistocene. Only two species of birds in St. John are now more or less restricted in distribution to the heavier (moist) forest areas. Robertson speculated that forest obliteration early in the historical period may partially account for the present impoverishment of forest birds, but admits that evidence to support this view is lacking since the earliest information on Virgin Islands birds dates from the 1850´s, long after forest destruction and near the close of the plantation era.

Only a few of the forest-adapted birds in the West Indies, including the two found on St. John, are good overwater dispersers. On St. John, poor overwater dispersal ability alone is probably not a sufficient mechanism to account for the paucity of forest species, because a land connection to Puerto Rico would have afforded a direct route during the Pleistocene. According to Pregill & Olsen (1981) however, dry scrub and savanna were the predominant vegetation types on the emergent portions of the Puerto Rico Bank whenever sea level was lowered by glaciation. Species narrowly adapted to mesic conditions would have been confined to reduced windward upland habitats on the higher mountains of Puerto Rico. Most forest birds would have been prevented from colonizing the Puerto Rico Bank by lack of habitat during glacial eras and by water barriers during interglacials. Thus, contrary to Robertson's speculations, the present poor representation of forest species in the Virgin Islands may not be a consequence of forest destruction by man.

Small, low islands tend to have fewer species than larger and/or higher ones, since the size of the species pool is to some extent a function of both the total area of the island and the number of habitats available. With 24 extant breeding species of land birds and 2 extinct, St. John has slightly more species than the average for an island of its size and number of habitats, as can be determined from Terborgh & Faaborg's (1980a) regression analysis of species number on area and habitat diversity.

Terborgh & Faaborg (1980a) also found a striking difference in the trophic organization of West Indian bird communities compared to the mainland: in the Antilles the largest guilds (in terms of biomass) are of frugivores rather than gleaning and hovering insectivores. Since insects as a resource can be partitioned in many more ways than fruit, communities low in insectivores and high in frugivores will necessarily contain fewer species than those in which the reverse is true. A partial explanation for the paucity of insectivores in the Antilles might be the finding that insect densities appear to be lower on Caribbean islands than on the mainland, but paradoxically, the biomass of insectivorous birds is greatly increased every winter by large numbers of migrant North American warblers (Terborgh & Faaborg 1980b). As many of its forested watersheds recover under the protection of the National Park, St. John could become an important site for the testing of theories on insular land bird ecology (see Abbott 1980, Strong et al. 1984).

Seaman (1949-1963) authored a series of reports on his studies of Virgin Islands wildlife, including various species of birds. He studied the food habits of the Bridled Quail Dove (Geotrygon mystacea) (Seaman 1966). A study of the biology of this species in the Virgin Islands, including field work in St. John, is presently in preparation by Nellis et al. Another study of G. mystacea on Guana Island in the British Virgin Islands, using radio tracking techniques, is in progress (Chipley in prep.). Leck (1973) studied dominance relationships among nectar-feeding birds (2 hummingbirds and bananaquit) in St. Croix. LaBastille & Richmond (1973) gave an account of the birds of Anegada, with descriptions of habitat and comparisons to records from the USVI. Mirecki (1976) reported the results of the Cambridge ornithological expedition to the British Virgin Islands. Philibosian & Yntema (1977b) discussed the status of endangered, threatened, and extinct birds of the Virgin Islands.

Norton (1979, 1981) reported several new records of birds for the Virgin Islands, and has annually edited the West Indies region seasonal summaries of American Birds (1980-1988), including data from the Virgin Islands. Norton has reported on the status of Pelecaniformes (Norton in press) and Sterninae (Norton in prep. b) in the Virgin Islands. Norton (1984) noted the expansion of the Cayenne Tern in the British and USVI and on the Puerto Rico Bank (Schaffner et al. 1986).

Norton et al. (1986) discuss some aspects of distribution and ecology of Virgin Islands anatids. Norton & Seaman (1985) described the status of fledgling white-crowned pigeons banded in the Virgin Islands. Nellis et al. (1984) discussed the population status of Zenaida Doves and other Columbids in the Virgin Islands. Lazell (1980, 1983) reported on the status of endangered birds in the British Virgin Islands.

Mammals

The only native mammals now known from St. John are five species of bats (fruit bat, *Artibeus jamaicensis*; fisherman bat, *Noctilos leporinus*; red fruit bat, *Stenoderma rufum*; cave bat, *Brachyphylla cavernarum*; velvety free-tailed bat, *Molossus molossus*). The Brazilian free-tailed bat is present but not known to breed (Philibosian & Yntema 1977a). Hayward (1969) made brief notes on species of bats collected at Lameshur Bay. Nellis (1971) and McManus & Nellis (1972a, 1972b) studied bats found on St. John, although their work was done in other locations. An extinct Capromyid rodent, the Antillean Hutia (*Gsolobodon portoricensis*), is known from bones in aboriginal kitchen middens.

Five other species of wild mammals found on St. John today were introduced by man. These are the roof rat (*Ratus rattus*), the Norway rat (*Rattus norvegicus*), the house mouse (*Mus musculus*), the white-tailed deer (*Oedocoilus virginianus*), and the Indian mongoose (*Herpestes auropunctatus*). These animals have all established breeding populations on the island, and the mongoose in particular has attained large population sizes and ubiquitous distribution. In addition there are feral populations of a few domestic animals such as pigs, cats, and burros. Of these the burros have by far the largest numbers. Other publications dealing with Virgin Islands mammals are Lazell (1980, 1983b), Seaman (1949-1963), Philibosian & Yntema (1977b), and LaBastille & Richmond (1973).

Coblentz (1983) studied the impact of exotic animals in VINP and reported that the abundant burros and mongooses clearly exert a significant influence on the island's biota. Burros have a detrimental impact on vegetation and increase erosion through their trail-forming activities. Mongooses are destructive to many small ground-dwelling native vertebrates and invertebrates (Coblentz & Coblentz 1985a, Seaman 1952, Seaman & Randall 1962, Nellis 1979, Nellis & Small 1983), and also prey on eggs and hatchlings of the endangered hawksbill turtle (Small 1982). Lazell (1980) also discusses the impact of feral and domestic goats on vegetation.

Coblentz & Coblentz (1985b) studied the reproduction of the mongoose in St. John. Seaman (1952) and Seaman & Randall (1962) discussed mongoose predation on wildlife in the Virgin Islands, as did Nellis (1979) and Nellis & Small (1983). Nellis & Evarard (1983) presented a monographic treatment of the biology of the mongoose in the Caribbean. A study of the distribution, home ranges, behavior, physical adaptations, food habits, and population biology of feral burros in St. John, including management options, was recently carried out by biologists from the Virgin Islands Division of Fish and Wildlife. A population size of about 300 was estimated by these workers (Nellis et al. in prep.), and exclosures were used to assess impact on vegetation. Radio tracking techniques were employed to monitor movements.

Coblentz & Coblentz (1985a) tested the feasibility of short duration (5 day) high-intensity trapping to control mongooses in localized sensitive areas, in particular near sea turtle nesting beaches. They estimated that an average of 86-87% of the trappable mongooses in localized areas could be removed in 5 days, and stated that hawksbill turtles nesting at beaches where trapping was done experienced no known loss of eggs or young, compared to as much as a 23% loss to mongooses previously (Small 1982). They recommended such a trapping program as a satisfactory alternative to complete eradication of mongooses, which is preferable but difficult and costly. VINP Resource Management staff are currently trapping mongooses near park beaches.

STRESSES TO TERRESTRIAL SYSTEMS

Originally, St. John was almost completely forested, but approximately 90% of the forests were removed during the plantation era in the 1700's and 1800's. As slavery was abolished, large plantations gave way to small-scale intensive farming and grazing. As this agricultural phase came to a close, the natural vegetation began to recover. Virgin Islands National Park now protects many of the resultant secondary forests which are representative of an ecosystem in which humans have had significant impact (Tyson 1987). St. John entered a new development phase in the late 1960's and 1970's. At the present time, many areas outside park boundaries (and some private lands within the authorized boundary) are again being cleared of vegetation to accommodate the increasing demands of development.

Soil Erosion and Runoff

As discussed previously in the section on "Stresses to Marine Systems", sediments from upland watersheds can have adverse impacts on the three major Caribbean coastal ecosystems--coral reefs, seagrass beds, and mangroves. The steep topography of most Caribbean islands, plus the high clay, slow-infiltration capacity of many soils, can cause very high natural erosional losses even under forested conditions (Liegel 1985). While it appears to be true that Caribbean islands in general have a higher population density, higher intensity of land use, lower forest cover, and higher rates of sediment yield than continental areas either in the Caribbean or the United States, understanding of tropical watershed function remains relatively incomplete, and quantitative information is scarce. Land use and the intensity of rainfall seem to be the most important variables controlling variations in sediment yield (Lugo 1985). Williams & Hamilton (1982) have recently reviewed the literature on the behavior of tropical watersheds, and Dissmeyer (1985) discusses practical techniques for watershed management in the Caribbean.

An excellent general presentation of the theoretical and practical aspects of soil erosion and sedimentation, as well as a proposed sediment control program for the Virgin Islands, is given in CH2M Hill (1979a). This report contains useful background information on climate, soil characteristics, major causes of erosion, and effects of sedimentation. Detailed topographic maps showing major watersheds and nearshore marine communities, as well as major tidal flooding areas and water resources facilities, are included. In another report, CH2M Hill (1979b) discuss the use of the Universal Soil Loss Equation (USLE), developed by the U.S. Soil Conservation Service for agricultural applications, in predicting soil erosion in the

Virgin Islands. Attempts (e.g., U.S. Department of Agriculture, undated) have been made to adapt the USLE for tropical conditions, but in this form it is useful mainly as a crude indicator of relative erosional impact rather than an accurate predictor of actual soil loss.

Virgin Islands soils tend to have high percentages of clay and silt, and to be coarsely granular when dry. The soils are highly permeable until saturated, after which they swell up and become poorly permeable, with the result that runoff then increases dramatically. The clayey topsoil has a high percentage of colloidal-sized soil particles which are difficult to dislodge from the soil matrix, but once dislodged, they will remain in suspension for a very long time before settling out. Such particles are an important factor in causing turbidity of stream and coastal waters of the Virgin Islands (CH2M Hill 1979a).

High-intensity rainfall events in the Virgin Islands occur in association with easterly waves, polar air, or tropical storms and hurricanes, mostly between the months of September through November (Bowden et al. 1970). Information on the maximum 24-hour rainfall (both observed and calculated), the probability of occurrence for rainfalls of various intensities, and some data on recorded stream flow are available for St. John (CH2M Hill 1979b, Cosner 1972, Jordan 1972, Robison et al. 1973). Due to rainfall variability, small watershed area, actual evapotranspiration-to-rainfall ratio near unity (Teytaud 1988), and low groundwater storage capacity, streamflow on St. John is generally meager, variable and intermittent (CH2M Hill 1979b). There are often long periods between flows in major watercourses, broken by periods of short and sometimes very high flows. This large variability in streamflow causes high variability in erosion and sediment transport to the sea. Most watercourses on St. John are free of undergrowth indicating that while stream flow is periodic, it is frequent enough and violent enough to prevent the growth of an understory.

Man's land-use activities in a watershed tend to increase the natural variation in suspended sediment by creating new sediment sources and increasing runoff. Several studies indicate that land use is the single most important factor affecting sediment losses in tropical watersheds (Gottfried & Ingles 1985). Most states have adopted water quality standards which include limitations on the amount of sediment, usually expressed as turbidity, that a land-use activity can add to a stream. Virgin Islands law prohibits discharge without a permit of any pollutant into streams but provides no standards; the definition of "pollutant" does not specifically refer to soil or suspended sediment, although the definition of "pollution" includes "changes" in turbidity of any waters (Virgin Islands Department of Conservation and Cultural Affairs 1979, pp. 17-23).

Concentrations of dissolved nutrients in streams draining undisturbed watersheds are generally quite low. Nutrient inputs come mainly from surface runoff, sub-surface percolation, and the atmosphere; outputs are in the form of streamflow, groundwater seepage, and losses to organisms and burial of organic sediments. As in the case of suspended sediment, nutrient concentrations tend to vary widely for different runoff events and for adjacent watersheds with similar land uses. Other factors being equal, nitrogen and phosphorus concentrations correlate best with land use and cover, in particular to the proportion of agricultural and urban land in a watershed (Marsh 1983).

Purcell (1980) studied the effects of nutrient and sediment inputs on the plankton populations of two relatively undeveloped bays in St. John. Two VIRMC projects have addressed the fate of sediments after they enter the sea. As mentioned previously, Hubbard (1987) reviewed the literature on sedimentation in tropical marine environments and made recommendations on watershed management and priorities for future research on sedimentation. He lists the following land-use activities as major causes of erosion and/or sedimentation in the Virgin Islands: road construction, land clearing, agriculture, alteration of watercourses, filling in of coastal ponds or opening them to the sea, and urban development. Hubbard et al. (1987) studied the effects of runoff on the marine environment by calculating theoretical values for peak discharge rates and volumes under "natural" conditions of total forest cover.

The vital role of watercourses in providing a linkage between the upland and marine components of a coastal ecosystem, and the importance of preserving their integrity and natural function has been discussed by many authors (e.g., Clark 1977). Streamside buffer strips reduce erosion, preserve the stream channel´s stability, retard runoff, trap sediments and nutrients, maintain suitable water temperature for aquatic life, and provide habitat for birds and other wildlife. The optimum width for a streamside buffer zone varies with stream width, topography, soil type, type of impact, and other factors. Title 12 of the Virgin Islands Code (Virgin Islands Department of Conservation and Cultural Affairs 1979, pp. 3-4) prohibits the cutting or injury of any vegetation within 30 feet from the center or 25 feet from the edge of any natural watercourse. Recent research has shown that this may not be a sufficient width of buffer area to protect a stream from the effects of sedimentation when adjacent land is cleared, especially on steep slopes. Several studies in the United States (cited in Brinson et al. 1981) recommend a minimum buffer width of 75-100 feet on each side. For the temperate U.S., Dissmeyer (1985) gives widths varying from 25 feet at 0% slope to 105 feet at 40% slope and 185 feet at 80% slope. Lugo (1985) gives a recommended width of at least 165 feet for tropical watersheds. Since most of St. John has slopes in excess of 40% (Teytaud 1988), and is at times subject to more intense rainstorms than many temperate areas, it seems clear that a 165 feet (50 m) width is not excessive. In addition to adopting this standard within the park, cooperative agreements should be sought with local government to observe the same standard outside park boundaries whenever sedimentation might impact park lands or waters.

Development

The impact of the explosively growing human population of St. John may very soon become the overriding ecological force in many of the island's ecosystems, as it once was during the days of plantation agriculture. The purpose of this section is to briefly review some of the pertinent literature on terrestrial resource management in small islands, emphasizing an interdisciplinary "human ecology" approach.

Towle (1985) recently reviewed the environment/development dilemma of small islands, giving a number of case histories. He discusses various conceptual models and methodologies developed over the years to deal with the problems of island systems and to bridge the gap between the natural and social sciences in minimizing human-environment conflict. Coulianos (1980) researched concepts for ecodevelopmental tourism for small Caribbean islands. Towle & Teytaud (1982) prepared a useful annotated bibliography of source materials on Caribbean island resource management, focusing on the USVI. Clark (1977) prepared a comprehensive general work on coastal ecosystem management, and McEachern & Towle (1974) and Odum (1976) discuss ecological guidelines for island development in the tropics. Westman (1985) provides an excellent synthesis of ecology and planning.

McElroy (1978) reported on economic and social impacts of the Virgin Islands' coastal zone management program, and Pflaum (1980) gives data and historical trends on population, economy, and social characteristics. Posner et al. (1981) analyzed the economic impact of VINP on St. John and developed an economic assessment methodology for insular areas.

Many studies have attempted to transfer the concept of carrying capacity from animal ecology to environmental planning and resource management, but most efforts have met with limited success. There are a number of difficulties connected with such use of carrying capacity concepts. First, lack of theoretical or empirical knowledge about the interactions among the multiple factors involved requires many value judgments and simplifying assumptions, which are not always clearly specified. Secondly, in human systems, many limits to growth can be technologically circumvented, albeit at ever-increasing economic, environmental and social costs. Finally, planners must consider at least four different kinds of carrying capacity: ecological, relating to human impact on the ecosystem; physical, relating to available land area and/or scope of facilities; psycho-social, relating to human satisfaction and societal function; and recreational, relating to some combination of the preceding or to the lowest threshold of any one. In each case the estimation of thresholds of overload is essentially the process of making an intelligent guess as to the allowable level of human use, based on the goals, policies and objectives of the managed area. In zones where the goal is resource protection, the thresholds will differ from those in zones where the goal is maximization of recreational opportunities. Since the limits to growth will be set by the lowest threshold point, conflicts inevitably arise in multiple use areas (Yapp & Barrow 1979).

Lewsey (1978) studied the environmental effects of tourism development on the carrying capacity of small island systems, using Barbados as a case study. Brookfield (1980) edited a report on a UNESCO/MAB study of the carrying capacity of the small islands of Eastern Fiji, using a complex simulation model. The government of Hawaii (Anonymous 1979) prepared a research plan with valuable discussions of procedures and problems in the use of carrying capacity concepts in growth management of islands. A planning study for a workshop on Caribbean island resource management and carrying capacity, based on the adoptive environmental assessment and management approach of Holling (1978), was carried out for U.S. MAB by Towle et al. (1982).

As Westman (1985) has pointed out, so far most attempts to use the carrying capacity concept in environmental planning have been theoretically flawed. Some studies have simply attempted to establish appropriate levels of use given different perceptual and economic constraints, with no attempt to determine the true ecological carrying capacity. Other studies have used mathematical manipulations which are not empirically justified, have disregarded fundamental ecological concepts, or have failed to use detailed ecological data. Nevertheless, the application of carrying capacity concept to environmental management remains an important goal worthy of further research. One recent study, by Shelby and Heberlein, published in 1986 and entitled "Carrying capacity in Recreation Settings" is especially useful in the context of St. John and has some useful "lessons" for management. Future efforts will require similar but broader empirical studies of the nature of the interrelationships between variables, and must take into account all different kinds of carrying capacity in various ecological and developmental contexts and under a wide variety of impacts affecting the "system".

RECOMMENDATIONS FOR FUTURE RESEARCH AND MANAGEMENT OF TERRESTRIAL RESOURCES

The works of Earhart et al. (1988) and Matuszak et al. (1987) serve as the basis for a long-term study of St. John's forest dynamics. The New York Botanical Garden has made a commitment to maintain their plots and carry out intensive investigations over a 30-year period with some logistical support from VINP. The long-term objectives include:

1. analysis of secondary forest development (including data on recruitment, growth and mortality);
2. analysis of the influence of exotic species on forest development;
3. evaluation of the role of major storms and other disturbances;
4. assessment of the effects of historical land use on forest regeneration; and
5. identification of management actions which will preserve endangered species and promote conservation of biological diversity.

The New York Botanical Garden also initiated work on a Flora of St. John in 1987. Researchers will conduct a thorough botanical survey of the entire island and prepare a manual of the plants. The manual will include keys and illustrations of about 300 species, vegetation maps, descriptions of the ecological characteristics of the island, a brief land use history and a section on indigenous use of native plants. Researchers from the University of Wisconsin have recently initiated studies of the dry forests of St. John and plan to study regeneration, germination of native and exotic species, influence of soil moisture on germination, and the role of grazing animals in forest dynamics (Brown 1988).

Studies of the terrestrial plant communities in St. John have begun to move beyond the initial phase of cataloging and classification into studies of ecosystem function, development/regeneration, and response to natural and human disturbance. Much interest has been aroused within the last 10 to 15 years by the shift from the older paradigm of the natural environment as relatively benign, free of disturbances and supporting mainly steady-state ecosystems, to the present viewpoint of nature as a shifting landscape of mostly non-equilibrium patches. Such patches originate from a wide range of natural disturbances and typically incorporate a variety of mechanisms for recovery (Reiners 1983, Lugo 1978, Pickett & White 1985, Forman & Godron 1981, Holling 1985). One important consequence of this change in viewpoint is that the focus of research is no longer on comparisons between disturbed and undisturbed ecosystems, but rather on the effects of natural versus human-caused disturbances.

In general, human-induced disturbances contrast sharply with natural ones in terms of kind, scale, intensity, and frequency. Functional studies need to be carried out for each major vegetation type in St. John as a baseline against which to judge successional changes and the effects of different kinds of disturbance on the whole ecosystem (Lugo 1978, Odum 1985, Sprugel 1985, Reiners 1983). Careful studies are necessary to determine whether there are any differences in ecosystem response to natural disturbances versus human disturbances. The importance of such studies lies in increasing our ability to recognize symptoms of stress and manage ecosystems in ways that recognize their holistic nature (Risser 1985).

At the organism and population levels, detailed information on life histories, reproduction and mortality needs to be collected for dominant, rare and endangered species. Observations of successional sequences initiated by various kinds and intensities of disturbance, both human and natural, should be made. Given enough information of this type, predictive models of forest succession can be constructed which incorporate variable succession pathways depending on a stand's age and species composition when disturbed (Ewel 1980).

More information is needed on the adverse effects of careless watershed development and their mitigation, including practical information on stabilization of cleared hillsides and other means of erosion control. Hubbard (1987) presents many excellent recommendations and guidelines for development. He notes that the following activities have severe consequences and should be prohibited or discouraged: dredging in nearshore waters, filling of salt ponds, removal of seagrasses and mangroves, and development in major water courses.

GEOLOGY

St. Thomas and St. John, the two large northern islands of the USVI, are composed of stratified volcanic and volcaniclastic rocks with minor limestone of Early Cretaceous (Albian) to possible Late Cretaceous age (Donnelly 1966). These rocks are intruded by a wide range of dikes and plutons of gabbroic to granitic composition, some of which may be as young as Tertiary (Kesler & Sutter 1979).

The oldest rocks on St. John are submarine lavas (keratophyre and spilite), beds of volcanic debris and chert and associated intrusive rocks of the Water Island Formation (Donnelly 1966) which underlie the southeastern half of the island including the East End. Fossils in cherts of the Water Island Formation on St. Thomas indicate that the unit is of Early Cretaceous (Albian) age. The Water Island Formation is overlain by andesitic volcanic and volcaniclastic rocks of the Louisenhoj Formation (Fig. 15) which underlies much of northwestern St. John. Donnelly (1966) suggested that the Louisenhoj Formation was deposited unconformably on the Water Island Formation after a period of emergence, tilting and erosion, on the slopes and environs of a subaerial volcanic island located roughly between St. Thomas and St. John, an area now occupied by Pillsbury Sound. Recent work by D. Rankin (written communication, 1988) suggests that the Louisenhoj Formation is conformable on the Water Island. A period of quiescence followed, and limestones and calcareous shales and sandstones of the Outer Brass Limestone were deposited on the Louisenhoj. This unit is relatively thin (a few tens of meters thick) and forms a band of rock underlying the lowland from Maho Bay to Leinster Hill.

The youngest layered deposits on St. John are volcaniclastic rocks of the Tutu Formation (Fig. 16) which make up Whistling Cay and much of Mary Point. Fossils contained in the Tutu Formation on St. Thomas suggest that those deposits are of Early Cretaceous (Albian) age (Donnelly et al. 1971). Thus the volcanic and volcaniclastic rocks of St. John all appear to have been deposited in a relatively short period of time spanning perhaps 10 to 15 million years about 100 million years ago (D. Rankin, written communication, 1988).

Following deposition of the Tutu Formation, the layered rocks of St. John were folded, faulted and intruded by dikes and plutons of gabbroic to granitic composition. The plutons are prominent along the north coast of St. John where their heat has recrystallized the surrounding strata. The layered rocks now form a monocline dipping to the north with the steepest dips along the north shore of St. John. The monocline is in turn warped into a broad north plunging anticline whose form is more or less indicated by the broad curve of the north shore of St.

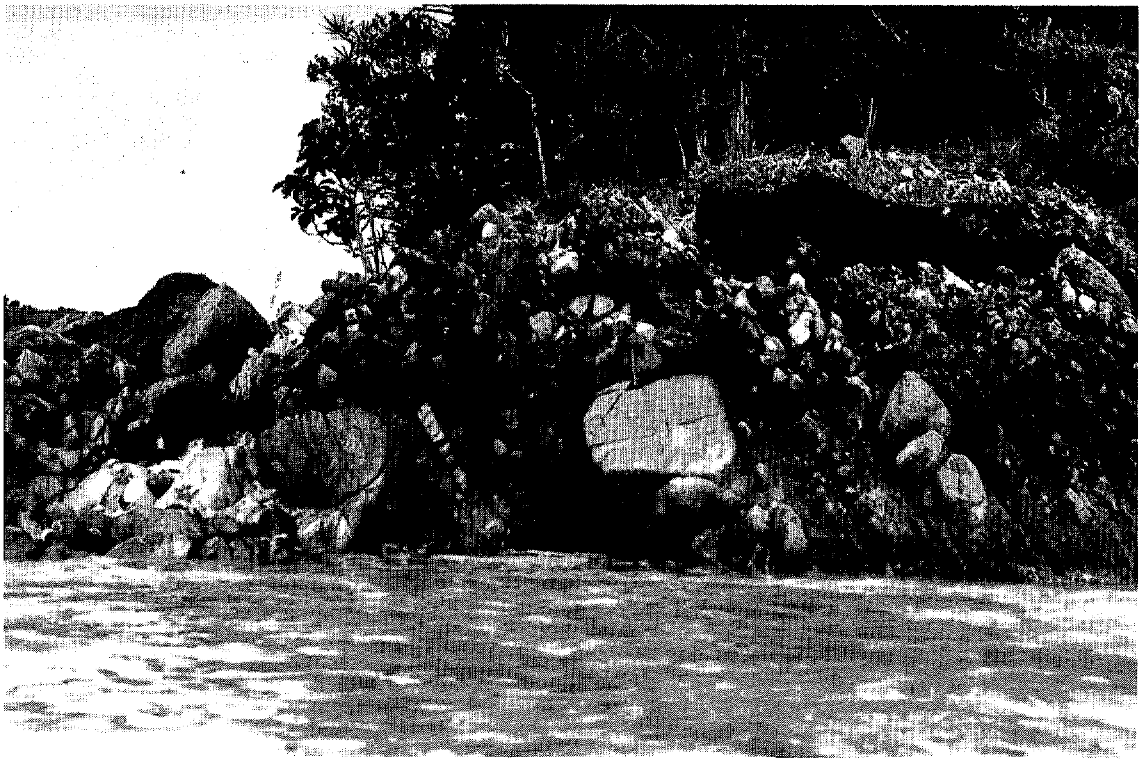


Fig. 15. Example of the Louisenhoj Formation, south end of Trunk Bay. Photo: D. Rankin.

Fig. 16. Bedded siltstone of the Tutu Formation, point between Francis and Maho Bays. Photo: D. Rankin.

John from Hawksnest Bay to the East End (D. Rankin, written communication, 1988).

The geology of the British Virgin Islands is essentially similar to that of St. Thomas and St. John, although some Tertiary volcanic and volcaniclastic rocks are exposed and plutonic rocks are prominent (Helsley 1960). Anegada is a low sandy spit formed of carbonate reef sediments.

St. Croix lies on a somewhat isolated, submerged ridge separated from the Puerto Rico Bank by the Virgin Islands Basin. Geologically it is related to the islands of the Puerto Rico Bank. If St. Croix was ever connected to the northern Virgins, it may have been separated from that group by either block (Meyerhoff 1927, Whetten 1966) or shear faulting (Adey 1977, Turner 1971).

The oldest rocks exposed on St. Croix are epiclastic volcanic sandstone and mudstone of the Caledonia Formation (Whetten 1966). These weakly metamorphosed, uplifted, folded and faulted rocks were derived from volcanic and other narrow-trench sediments originally deposited by turbidity currents on the deep ocean floor about 70 to 80 million years ago (Adey 1977). Buck Island is an emergent part of the St. Croix shelf.

Somewhat later in the Cretaceous, one or more volcanoes formed on the sea floor to the south or southeast of St. Croix. Volcanic debris was shed northward to form the Judith Fancy formation, composed of tuffaceous sedimentary rocks, which occur on St. Croix but not on Buck Island.

St. Croix was uplifted above sea level in the Oligocene (Whetten 1974), originally as two islands. The East End Range (including proto-Buck Island) and the Northside Range were separated by a trough several miles wide. The trough was subsequently filled in by the deposition of the Kingshill marl formation. There then followed a period of mild deformation, post-Miocene uplift, and erosion to form the present-day topographic features.

The Virgin Islands are near the northeastern corner of the present Caribbean Plate, a relatively small trapezoidal-shaped plate which is moving eastward relative to the North and South American continents carried on the American Plate. The arc of the Lesser Antilles is an active volcanic arc above a subduction zone in which Atlantic oceanic crust of the American Plate is carried downward under the Caribbean Plate. The closest volcano to the Virgin Islands of this presently active arc is Saba, about 160 km to the east. The Caribbean Plate is sliding past North and South American plates along east-west trending northern and southern boundaries (an extreme oversimplification) (see Dillon et al. 1987). The western boundary is a subduction zone in which the Cocos Plate is being driven northeastward and down under the edge of the Caribbean Plate west of Central America.

The deep basins of the Caribbean Plate, the Colombian and Venezuelan basins, are probably floored by oceanic crust, that is, crust formed at a spreading ridge. Two hypotheses dominate current thinking for the origin of the Caribbean (Dillon et al. 1987). One suggests that a branch of the Atlantic spreading system extended to the Pacific Ocean through the Caribbean area. By this hypothesis new oceanic crust formed between North and South America as the two continents separated during their westward migration from the Mid-Atlantic ridge. The other hypothesis is that the Caribbean oceanic crust formed in the Pacific Ocean and was carried eastward between North and South America as they separated. According to Dillon et al. (1987) the latter hypothesis has had the most adherents in recent years, but the first hypothesis of ocean-opening in place, seems to simplify many Caribbean geologic problems and is gaining support.

The present northern boundary of the Caribbean Plate extends from the Gulf of Honduras, along the Cayman Trough and the north coast of Hispaniola to the Puerto Rico Trench. Thus the Greater Antilles straddle the present plate boundary. Cuba lies to the north and the rest of the Greater Antilles lie to the south within the Caribbean Plate. The origin of the Greater Antilles is closely tied to the site of origin of the Caribbean oceanic crest.

One group of authors believes that the Greater Antilles evolved as a mid-Caribbean archipelago which never had any close connections with Central America (Pregill 1981). These islands are thought to have resulted from volcanism due to subduction of oceanic lithosphere along a broad arc extending from western Central America east to Puerto Rico, beginning in the late Cretaceous. The islands became fully uplifted and continuously emergent sometime in the late Oligocene or early Miocene (about 23 million years ago). The Lesser Antilles formed much more recently by volcanism at the eastern plate boundary.

In contrast, another group of authors believes that the Greater Antilles are the remnants of a "proto-Antillean" archipelago which originated as a series of volcanic islands between southern Mexico and South America during the first half of the Cretaceous, 135 to 90 million years ago (Coney 1982, Rosen 1975). Beginning about 90 million years ago this archipelago was rafted eastward with the relative movement of Caribbean lithosphere. The northernmost islands became the backbone of Cuba, the central ones other parts of the Greater Antilles, and the southernmost elements became the coastal range of Venezuela and the islands of Aruba, Bonaire, and Curacao. Some fragments may also have been displaced to the region of the Lesser Antilles. By the Eocene (40 million years ago) the core of the Greater Antilles had reached their present positions and a new archipelago, the backbone of present-day Central America, had formed along the trailing edge of the Caribbean plate. An arc of new volcanic islands -- the forerunners of the Lesser Antilles -- had appeared at the leading edge of the Caribbean plate as it dived under the adjacent plate. During the last 40 million years these original Lesser Antilles were consumed in the adjacent trench. A new volcanic arc, the present-day Lesser Antilles, has been created (Brown & Gibson 1983, Pielou 1979). At the present time it is not clear which hypothesis on the evolution of the Greater Antilles is most nearly correct, but the question has important implications for the Virgin Islands.

BIOGEOGRAPHY

The different interpretations of Caribbean plate tectonic history have spawned a lively controversy regarding the reality of the hypothesized "proto-Antilles" and their role in the distribution of the Greater Antillean biota. Some authors (e.g., Pregill 1981) argue for continued acceptance of the classical view that all organisms which colonized these islands did so by some form of long-distance overwater dispersal. Others (e.g., Rosen 1975) attribute the origin of the entire biota to transport from the region of central America aboard the drifting islands of the "proto-Antilles."

MacFadden (1980, 1981) emphasizes that the two "opposing" biogeographic models may actually be complementary. The present biota of the Antilles could be the result of an early plate tectonic rafting event "over-printed" with numerous events of later overwater dispersal to, and among, Caribbean Islands. A critical, and at present unresolved issue in the controversy is whether large land masses in the Greater Antilles have been continuously above sea level and capable of sustaining a flora and fauna (Pregill 1981, MacFadden 1981). Few geological studies have been directly concerned with just when the islands were above water, and caution is necessary in using plate tectonic reconstructions to support biogeographic hypotheses (Hedges 1982, Khudoley & Myerhoff 1971).

At the time of the Wisconsinan glacial maximum (24,000 to 17,000 years ago), eustatic sea level was lowered by as much as 120 m and the Caribbean climate was drier than at present (Bonatti & Gartner 1973). During the previous interglacial of 65,000 years ago, however, sea level was 8-10 m above the present level and the climate was wet. The successive glaciation events which were responsible for cyclic sea-level fluctuations as well as alternating wet (interglacial) and dry (glacial maximum) climatic periods throughout the Pleistocene have greatly influenced the distribution of species and the composition of Caribbean biotas. During glacial periods, grasslands, savannas, and scrub forests predominated in the lowlands of Puerto Rico and the emergent bank to the east (Pregill & Olson 1981). All the islands on the Puerto Rico Bank were connected to each other by dry land at such times, facilitating the exchange of species especially those adapted to the widespread xeric conditions.

The Puerto Rico Bank became fragmented by rising sea levels about 7,000 years ago, at which time the Virgin Islands were isolated from each other and from Puerto Rico (Heatwole & Mac Kenzie 1967). The rise in sea level was accompanied by a return to more mesic conditions, which led to the formation of isolated relict populations of such formerly widespread species as the iguana Cyclura pinguis on Anegada and the endemic toad Peltophyrne lemur in xeric areas of Puerto Rico and possibly Virgin Gorda (Pregill & Olson 1981). Many land vertebrates became extinct in the Greater Antilles at this time, presumably as a result of climate and habitat changes in conjunction with the shrinking areas of islands. The ranges of various vegetation types would also have been affected, with an increase in mesic formations at the expense of xeric types.

The Pleistocene glaciations caused sea-surface temperatures to drop by at least 3-4 degrees Celsius (Pregill & Olson 1981). This cooling of the Caribbean and the accompanying lowering of sea level would have resulted in a contraction of the coral reef communities. Seventeen thousand years ago the shoreline was at least 120 m lower, and the broad flat island shelves of today were dry land. The new shorelines consisted of the very steep slopes that surround most islands today at 120 m depths. The area suitable for reefs during these glacial periods was probably 10% or less of that available today (Colin 1978).

Pregill & Olson (1981) conclude that because the Wisconsinan glaciation had such a profound effect on the distribution of West Indian biota, it can be assumed that earlier glacial/interglacial cycles in the Pleistocene had similarly drastic effects. Repeated events of faunal and floral isolation, speciation, and extinction would have occurred, with the result that relict distributions would be superimposed on one another through time, complicating many aspects of Antillean biogeography. Even farther back in time, the exceedingly complex tectonic history of the Greater Antilles adds yet another layer of intricacy to distributional patterns. These authors therefore caution that any attempt to interpret the biogeography of individual organisms or the species composition of islands without accounting for their history is bound to have limited success. This warning is mainly directed towards the many ecological studies inspired by MacArthur & Wilson's (1967) Theory of Island Biogeography, which attempts to explain the numbers of species on islands in terms of immigration/extinction equilibria. Recent summaries of biogeographic theory, including island biogeography can be found in Brown & Gibson (1983), Pielou (1979), Williamson (1981), and Endler (1982).

RECENT GEOLOGICAL RESEARCH IN ST. JOHN

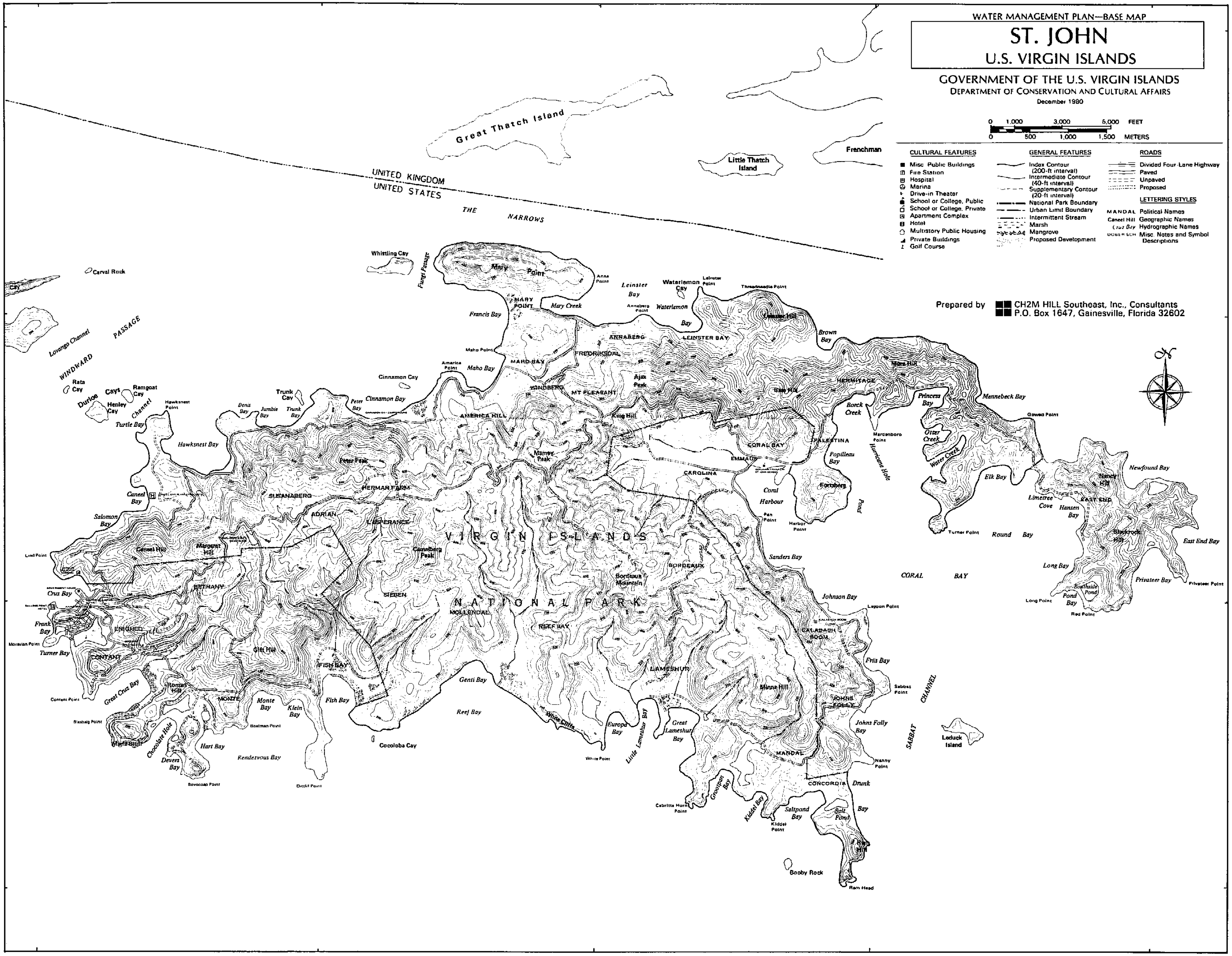
Rankin (1984, 1985a, 1985b, and work in progress) has recently conducted geological fieldwork in St. John in connection with a U.S. Geological Survey project to produce geologic quadrangle maps of the USVI at a scale of 1:24,000. Chemical analyses have been performed on rock samples from St. John to characterize the igneous activity that formed the rocks and to determine the tectonic setting in which they formed. Rankin's field work confirms the stratigraphic succession up through the Tutu formation and the general distribution of units as worked out by Donnelly (1966), but he has found that a considerable revision of the geological contacts and structural trends portrayed by Donelly may be necessary.

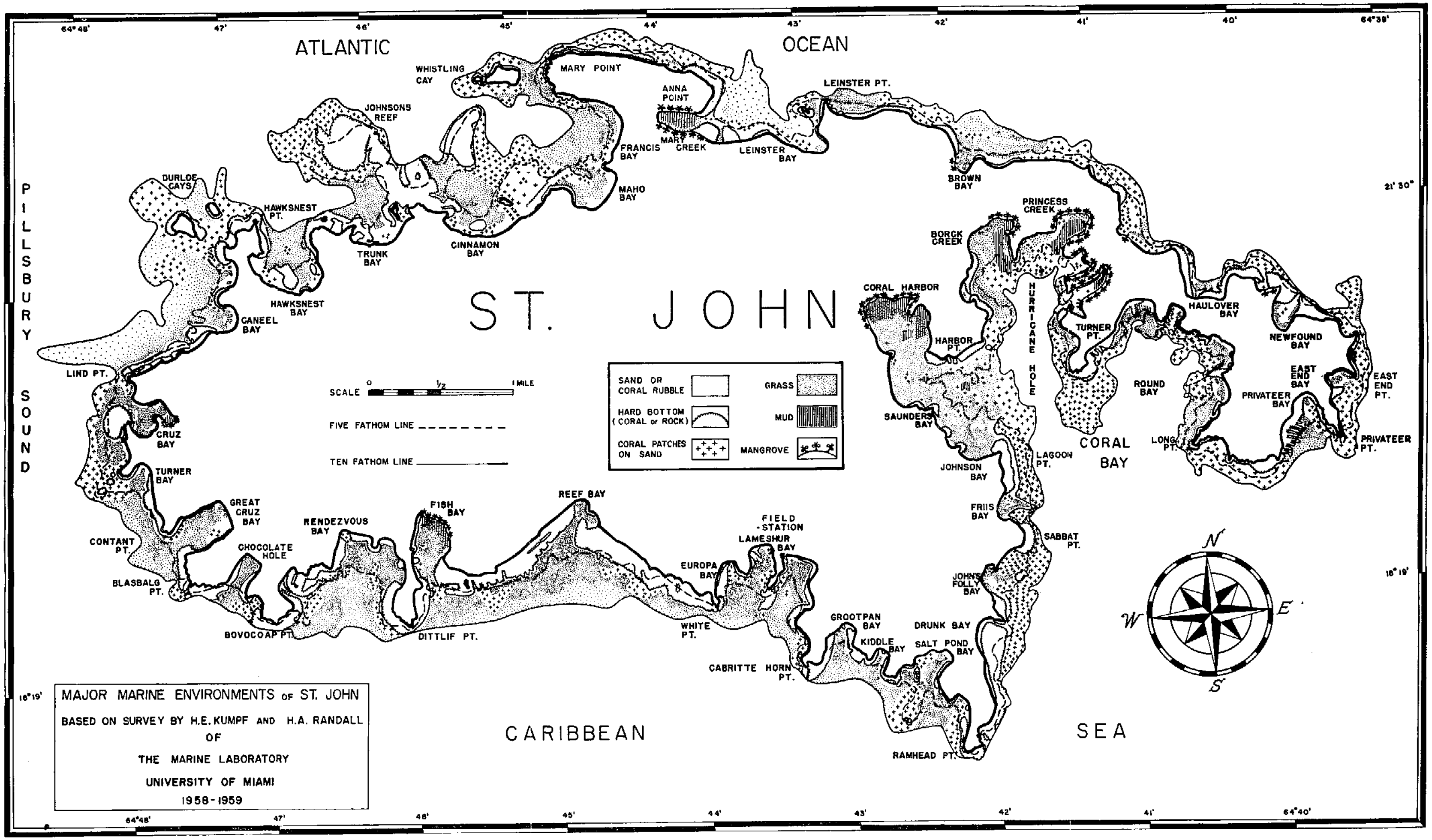
Results of the geochemical analyses on St. John done as part of a mineral resource appraisal of the USVI by the U.S. Geological Survey (Tucker et al. 1985) indicate an unusual concentration of heavy metals in some rocks. Concentrations of copper, lead, iron, tin, barium, zinc, and precious metals were locally anomalously high. This finding has raised questions about the concentrations of these potentially toxic substances in runoff and their possible effects on marine systems. Trace metals enter surface waters as a result of bedrock weathering. They are toxic to marine organisms above a certain level although some are essential for metabolic processes at lower concentrations. The natural erosion of rocks would not be expected to adversely affect marine organisms. However, man's activities could accelerate rates of erosion and/or add pollutants to runoff. Ramos-Perez et al. (1988) analyzed saltwater, stream water and marine sediments from Fish, Greater Lameshur, Bordeaux, Coral and Reef Bays for iron, manganese, magnesium, copper, chromium, nickel and zinc. The objective of their baseline study was to determine the contribution of heavy metals to near-shore marine ecosystems. All water and sediment samples showed low metal concentrations typical of unpolluted environments.

CONCLUSIONS

The National Park Service has the responsibility and the obligation to manage Virgin Islands National Park not only as a national park but as a biosphere reserve. The UNESCO Action Plan for Biosphere Reserves (1984) lists several objectives including establishment of research facilities and a research program; establishment of monitoring procedures; compilation of baseline inventories; preparation of a history of research; development of a training/education program; and preparation of a management plan specifiying steps to be taken in fulfilling biosphere reserve functions.

The National Park Service has made a strong commitment to the biosphere reserve program, particularly in its support of research by VIRMC. However, much remains to be done in developing a fully functioning biosphere reserve. The challenge is to take the information which is available and apply it to achieve a successful balancing of the increasing pressures from the island´s rapid development and tourism on the natural resources with conservation of these resources. Local residents must be integrated into management of the biosphere reserve. The General Management Plan for VINP should be revised or updated to identify a core area for the biosphere reserve which would include the Lameshur and Reef Bay watersheds. This core area would be strictly protected. Awareness of park regulations and environmental concerns should be increased through continuation of the series of seminars at the Virgin Islands Biosphere Reserve Center which began in 1987 and through further development of interpretive programs (snorkel trips, evening programs). Additional fliers on protection of natural resources, such as the new one on anchoring and snorkeling, could be developed. Research by VIRMC has focused attention on the degradation of marine and terrestrial ecosystems in VINP. VIRMC and VINP should work more effectively with the Coastal Zone Management Division to help control development of St. John and its consequences for the marine and terrestrial systems, for example in developing comprehensive land and water use plans which are still lacking for the islands.


WATER MANAGEMENT PLAN—BASE MAP
ST. JOHN
U.S. VIRGIN ISLANDS
GOVERNMENT OF THE U.S. VIRGIN ISLANDS
DEPARTMENT OF CONSERVATION AND CULTURAL AFFAIRS
December 1980
0 1,000 3,000 5,000 FEET
0 500 1,000 1,500 METERS
CULTURAL FEATURES
Misc. Public Buildings
Fire Station
Hospital
Marina
Drive-in Theater
School or College, Public
School or College, Private
Apartment Complex
Hotel
Multistory Public Housing
Private Buildings
Golf Course
GENERAL FEATURES
Index Contour (200-ft interval)
Intermediate Contour (40-ft interval)
Supplementary Contour (20-ft interval)
National Park Boundary
Urban Limit Boundary
Intermittent Stream
Marsh
Mangrove
Proposed Development
ROADS
Divided Four-Lane Highway
Paved
Unpaved
Proposed
LETTERING STYLES
MANDAL Political Names
Caneel Hill Geographic Names
Fish Bay Hydrographic Names
Misc. Notes and Symbol Descriptions
Prepared by CH2M HILL Southeast, Inc., Consultants
P.O. Box 1647, Gainesville, Florida 32602
Great Thatch Island
Little Thatch Island
Frenchman
UNITED KINGDOM
UNITED STATES
THE NARROWS
Whistling Cay
Fungi Passage
Mary Point
Carval Rock
WINDWARD PASSAGE
Lovango Channel
Durloe Cays
Rata Cay
Henley Cay
Ramgoat Cay
Cinnamon Cay
Trunk Cay
Trunk Bay
Cinnamon Bay
Maho Bay
Francis Bay
Mary Creek
Leinster Bay
Waterlemon Cay
Waterlemon Bay
ANNABERG
LEINSTER BAY
FREDRIKSDAL
MAHO BAY
MT PLEASANT
AMERICA HILL
Brown Bay
Mennebeck Bay
Princess Bay
Otter Creek
Water Creek
Borck Creek
HERMITAGE
PALESTINA
CORAL BAY
EMMAUS
CAROLINA
Coral Harbour
Hurricane Hole
Elk Bay
Newfound Bay
Nanny Hill
EAST END
Limetree Cove
Hansen Bay
Round Bay
East End Bay
Long Bay
Privateer Bay
Privateer Point
CORAL BAY
Hawksnest Bay
Turtle Bay
Caneel Bay
Salomon Bay
SUSANABERG
HERMAN FARM
ADRIAN
L'ESPERANCE
Caneel Hill
Margaret Hill
VIRGIN ISLANDS NATIONAL PARK
Camelberg Peak
BETHANY
Cruz Bay
Frank Bay
Turner Bay
ENIGHED
CONTANT
SIEBEN
MOLLENDAL
REEF BAY
BORDEAUX
Bordeaux Mountain
Sanders Bay
Johnson Bay
CALABASH BOOM
Friis Bay
LAMESHUR
Minna Hill
JOHNS FOLLY
Johns Folly Bay
SABBAT CHANNEL
Leduck Island
Great Cruz Bay
Roman Hill
MONTE
Monte Bay
Klein Bay
Fish Bay
FISH BAY
Genti Bay
Reef Bay
Cocoloba Cay
Chocolate Hole
Hart Bay
Rendezvous Bay
Devers Bay
White Cliffs
Europa Bay
Little Lameshur Bay
Great Lameshur Bay
MANDAL
CONCORDIA
Drunk Bay
Grootpan Bay
Kiddel Bay
Saltpond Bay
Salt Pond
Booby Rock
Ram Head



Source: Kumpf and Randall (1961)

APPENDIX III

TECHNICAL PUBLICATION SERIES

Beets, J., Lewand, L. & Zullo, E. 1986. Marine community descriptions and maps of bays within the Virgin Islands National Park/Biosphere Reserve. Report #2.

Beet, J. & Lewand, L. 1986. Collection of common organisms within the Virgin Islands National Park/Biosphere Reserve. Report #3.

Anderson, M., Lund, H., Gladfelter, E. & Davis, M. 1986. Ecological community type maps and biological descriptions for Buck Island Reef National Monument and proposed marine park sites in the British Virgin Islands. Report #4.

Lund, H., Anderson, M., Gladfelter, E. & Davis, M. 1986. Trends in recreational boating in the British Virgin Islands: A preliminary assessment of impact from human activities on anchorages and development of a monitoring program for safe anchorages. Report #5.

Davis, M., Gladfelter, E., Lund, H. & Anderson, M. 1986. Geographic range and research plan for monitoring white band disease. Report #6.

Gladfelter, E., Anderson, M., Lund, H. & Davis, M. 1986. Marine ecosystems of the Lesser Antilles: Identification of representative sites. Report #7.

Boulon, R. 1986. Map of fishery habitats within the Virgin Islands Biosphere Reserve. Report #8.

Boulon, R. 1986. Fisheries habitat of the Virgin Islands region of ecological importance to the fishery resources of the Virgin Islands Biosphere Reserve. Report #9.

Dammann, A. 1986. Assessment of fish and shellfish stocks produced in the biosphere reserve. Report #10.

Boulon, R. & Clavijo, I. 1986. Utilization of the Virgin Islands Biosphere Reserve by artisanal fishermen. Report #11.

Koester, S. 1986. Socioeconomic and cultural role of fishing and shellfishing in the Virgin Islands Biosphere Reserve. Report #12.

Boulon, R., Beets, J. & Zullo, S. 1986. Long-term monitoring of fisheries in the Virgin Islands Biosphere Reserve. Report #13.

Goodwin, M. 1986. Characterization of Lesser Antillean fisheries. Report #14.

Putney, A. 1987. Data synthesis and development of a basis for zoning of the Virgin Islands Biosphere Reserve. Report #15.

Putney, A. 1987. Conceptual framework for the management of the Virgin Islands Biosphere Reserve. Report #16.

Rogers, C. & Zullo, E. 1987. Initiation of a long-term monitoring program for coral reefs in the Virgin Islands National Park. Report #17.

Knausenberger, W., Matuszak, J. & Thomas, T. 1987. Herbarium of the Virgin Islands National Park: Consolidation and curation of a reference collection. Report #18A.

Matuszak, J., Craft, E. & Knausenberger, W. 1987. Establishment and soil characterization of long-term forest monitoring plots in the Virgin Islands Biosphere Reserve. Report #18B.

Tyson, G. 1987. Historic land use in the Reef Bay, Fish Bay and Hawksnest Bay watersheds, St. John, U.S. Virgin Islands, 1718-1950. Report #19.

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Hubbard, D., Stump, J. & Carter, B. 1987. Sedimentation and reef development in Hawksnest, Fish and Reef Bays, St. John, U.S. Virgin Islands. Report #21.

Boulon, R. 1987. A basis for long-term monitoring of fish and shellfish species in the Virgin Islands National Park. Report #22.

Nichols, M. & Brush, G. 1988. Man's long-term impact on sedimentation: Evidence from salt pond deposits. Report #23.

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Williams, S. 1988. Assessment of anchor damage and carrying capacity of seagrass beds in Francis and Maho Bays for green sea turtles. Report #25.

Tobias, W., Telemaque, E. & Davis, M. 1988. Buck Island fish and shellfish populations. Report #26.

Earhart, J., Reilly, A. & Davis, M. 1988. Initial inventory of three permanent forest plots in the Virgin Islands National Park. Report #27.

Ramos-Perez, C. & Gines-Sanchez, C. 1988. Geochemistry of St. John and influence on marine systems. Report #28.

Rogers, C. & Teytaud, R. 1988. Synthesis of selected resource management information for Virgin Islands National Park and Biosphere Reserve. Report #29.

APPENDIX IV

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