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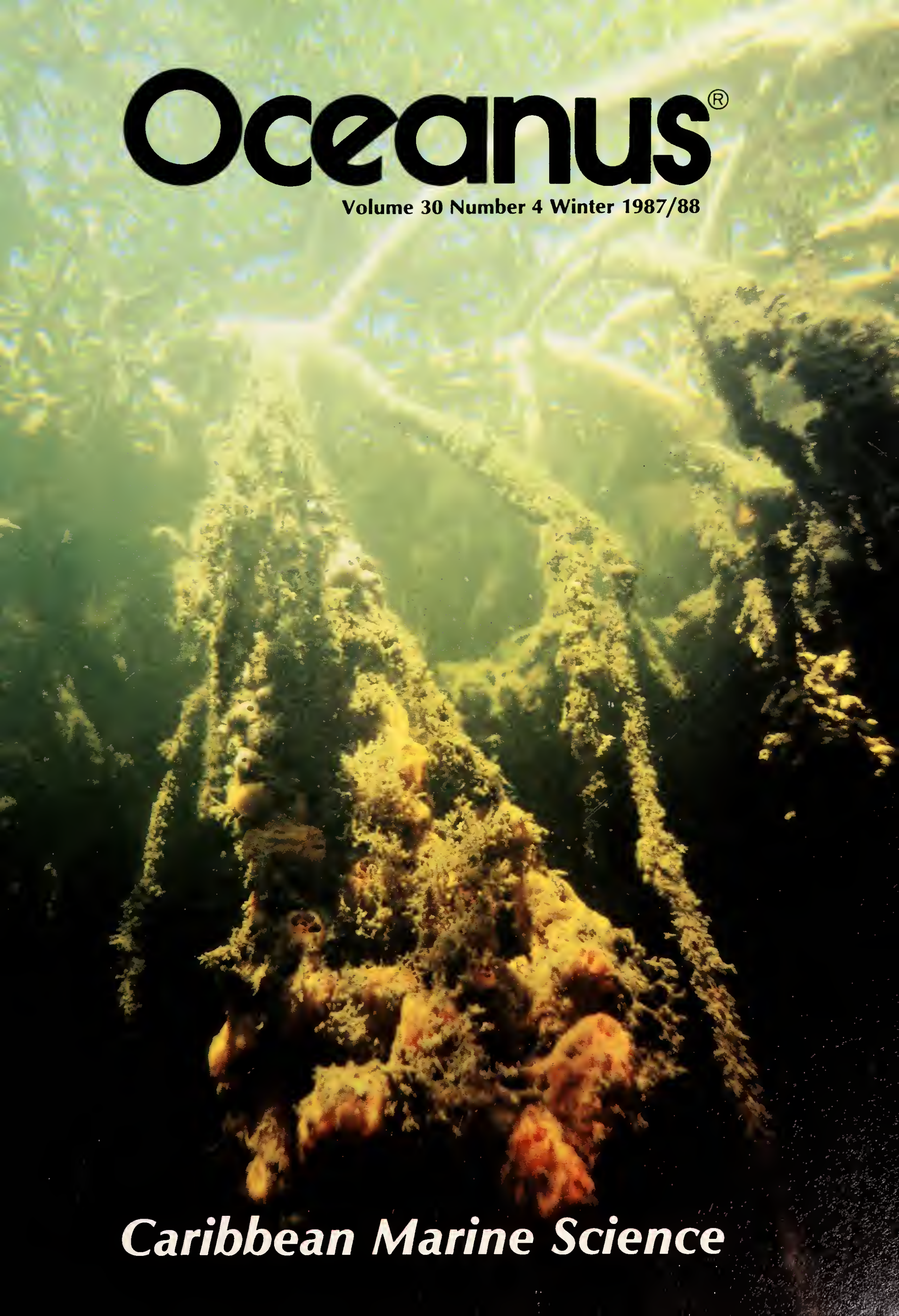

Caribbean Marine Science

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COVER: Underwater view of red mangrove. The red sponge growing on the arching prop roots is the Caribbean fire sponge, *Tedania ignis*. (Photo by Chip Clark)

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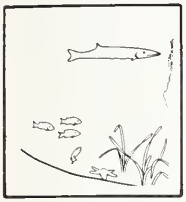

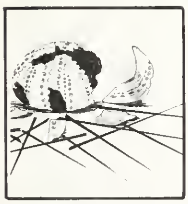

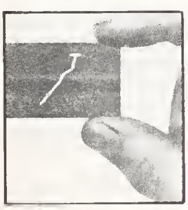

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El Salvador
Nicaragua
Caribbean Sea
Costa Rica
Panama
Columbia
27°
24°
21°
18°
15°
12°
9°
87°
84°
81°
78°
75°

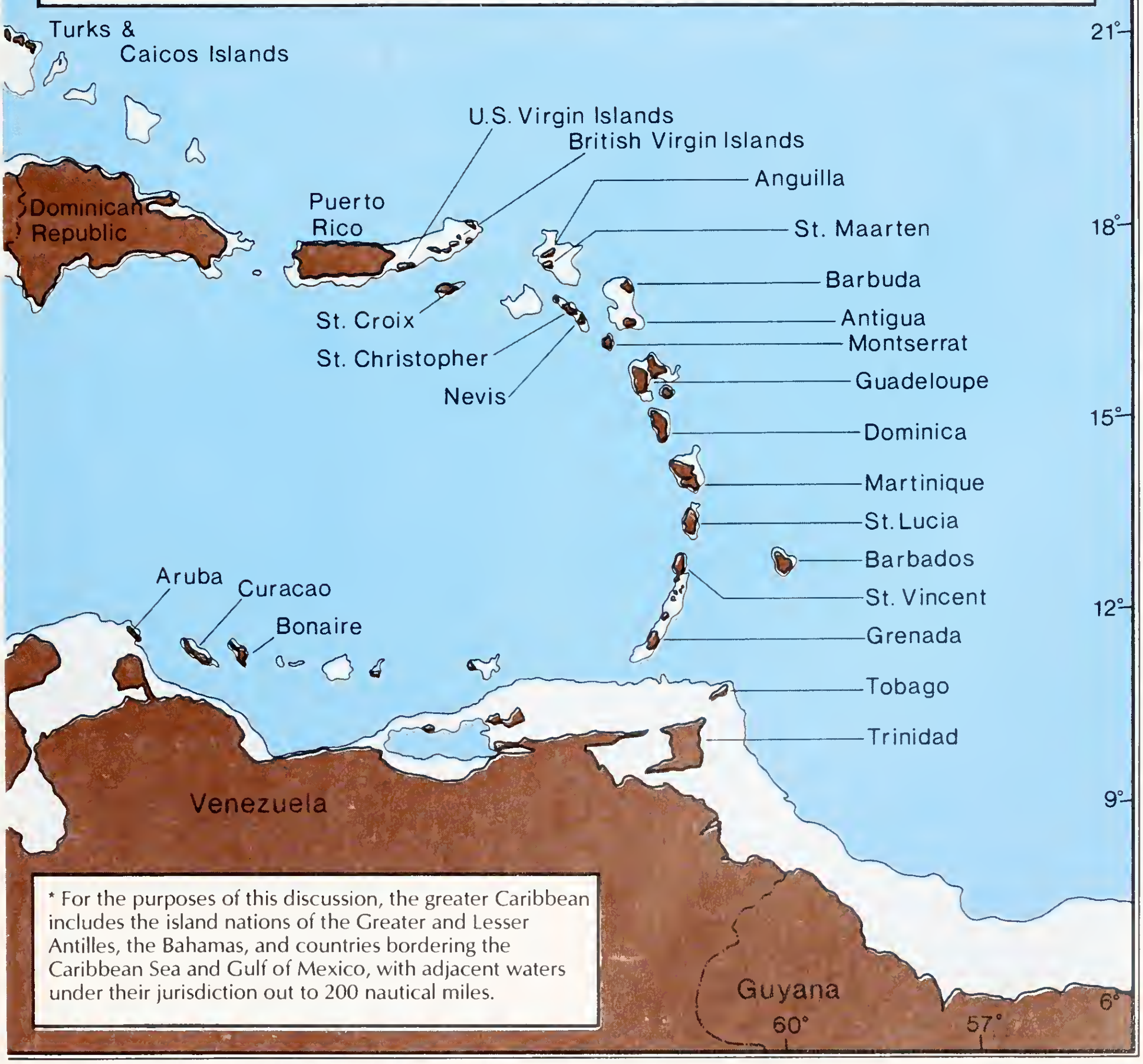
Introduction

Caribbean Marine Science

by John D. Negroponte

Assistant Secretary of State for Oceans and International Environmental and Scientific Affairs

As you review the impressive body of marine scientific work described in this special issue of *Oceanus*, keep in mind that the United States is very much a member of the greater Caribbean* family of nations. We are linked by maritime boundaries with seven



* For the purposes of this discussion, the greater Caribbean includes the island nations of the Greater and Lesser Antilles, the Bahamas, and countries bordering the Caribbean Sea and Gulf of Mexico, with adjacent waters under their jurisdiction out to 200 nautical miles.

Caribbean nations in addition to Mexico. Puerto Rico and the U.S. Virgin Islands play a large role in everyday regional affairs. Our Gulf states, and Florida in particular, figure prominently in Caribbean banking and commerce. Much of our oil passes through the region on its way to refineries around the Gulf of Mexico, or bound for our West Coast via the Panama Canal.

By and large, our Caribbean neighbors share our democratic traditions of political and intellectual freedom. We share historical affinities and backgrounds, and in some cases, common colonial origins and language. Millions of Americans visit or live in the region. Many of us are of Caribbean origin, beginning with Alexander Hamilton and continuing to the present.

Scientific interactions can do much to build the regional ties and collegial spirit important to our mutual economic well-being and security. Even during the most strained periods of our relations with some of our Caribbean neighbors, the exchange of information on meteorological conditions, hurricane predictions, and air traffic control was never interrupted.

Aside from being a very agreeable place to live or visit or work, the region is of substantial and growing scientific interest to

Marine scientific research and Law of the Sea in the Caribbean.

	Law of the Sea Treaty		Max. Maritime Claim (nm = nautical miles)	Research Restrictions (see Note[1])
	Signed	Ratified		
*Anguilla (UK)	—	—	200 nm Fisheries Zone (UK)	X
Antigua & Barbuda	02/07/83	—	200 nm EEZ	X
*Aruba (Neth.)	12/10/82	—	200 nm Fisheries Zone (Neth.)	X
Bahamas	12/10/82	07/29/83	200 nm Fisheries Zone	
Barbados	12/10/82	—	200 nm EEZ	X
Belize	12/10/82	08/13/83	3 nm Territorial Sea	
Brazil	12/10/82	—	200 nm Fisheries Zone	X
*Brit. Virgin Islands (UK)	—	—	200 nm Fisheries Zone (UK)	X
*Cayman Island (UK)	—	—	200 nm Fisheries Zone (UK)	X
Colombia	12/10/82	—	200 nm EEZ	X
Costa Rica	12/10/82	—	200 nm EEZ	
Cuba	12/10/82	08/15/84	200 nm EEZ	X
Dominica	03/28/83	—	200 nm EEZ	X
Dominican Republic	12/10/82	—	200 nm EEZ	X
El Savador	12/05/84	—	200 nm Territorial Sea	
*Fr. Guiana (Fr.)	12/10/82	—	200 nm EEZ (Fr.)	X
Grenada	12/10/82	—	200 nm EEZ	X
*Guadeloupe (Fr.)	12/10/82	—	200 nm EEZ (Fr.)	X
Guatemala	07/08/83	—	200 nm EEZ	X
Guyana	12/10/82	—	200 nm EEZ[2]	X
Haiti	12/10/82	—	200 nm EEZ	
Honduras	12/10/82	—	200 nm EEZ	X
Jamaica	12/10/82	03/21/83	12 nm Territorial Sea	
*Martinique (Fr.)	12/10/82	—	200 nm EEZ (Fr.)	X
Mexico	12/10/82	03/18/83	200 nm EEZ	X
*Montserrat (UK)	—	—	200 nm Fisheries Zone (UK)	X
*Netherlands Antilles (Neth.)	12/10/82	—	200 nm Fisheries Zone (Neth.)	X
Nicaragua	12/09/84	—	200 nm Territorial Sea	X
Panama	12/10/82	—	200 nm Territorial Sea	
*Puerto Rico (U.S.)	—	—	200 nm EEZ	
*St. Barthelemy (Fr.)	12/10/82	—	200 nm EEZ (Fr.)	X
St. Christopher & Nevis	12/07/84	—	200 nm EEZ	
*St. Croix (U.S.)	—	—	200 nm EEZ	
St. Lucia	12/10/82	03/27/85	200 nm EEZ	
*St. Martin (Fr. & Neth.)	12/10/82	—	200 nm EEZ (Fr.)	
	12/10/82	—	200 nm Fisheries Zone (Neth.)	X
St. Vincent & Grenadines	12/10/82	—	200 nm EEZ	
Suriname	12/10/82	—	200 nm EEZ	X
Trinidad & Tobago	12/10/82	04/25/86	200 nm EEZ[2]	X
*Turks/Caicos Islands (UK)	—	—	200 nm Fisheries Zone (UK)	X
United States	—	—	200 nm EEZ	
*U.S. Virgin Islands (U.S.)	—	—	200 nm EEZ	
Venezuela	—	—	200 nm EEZ	X

* Indicates territory or dependent of country shown in parentheses.

[1] Legislation or decree stipulating scientific research jurisdiction.

[2] Enabling legislation only.

Reference: Ross, David A. and Therese A. Landry, *Marine Science Research Boundaries and the Law of the Sea*. Woods Hole, MA: Woods Hole Oceanographic Institution, International Marine Science Cooperation Program, 1987. Table prepared by Judith Fenwick.

U.S. marine researchers. To put that into perspective, one fifth of all U.S. marine scientific projects requiring research vessel clearance from foreign governments are conducted in the waters of the greater Caribbean. The actual number of projects has doubled in the last five years. Because no part of the Caribbean Sea is beyond 200 nautical miles of land, all of it falls within some coastal nation's potential jurisdiction over marine scientific research. Although the United States does not choose to exercise this right, most other Caribbean countries do.

Thus, any single research cruise will likely involve multiple clearances—requiring interaction with government officials and participation of scientists in as many as a dozen countries. Although this bureaucratic maze can be difficult to negotiate, it also provides opportunities for establishing institutional and individual working relationships. These are essential to developing an indigenous marine science infrastructure adequate to address the region's needs in marine research and environmental resource management.

There are about 60 ongoing internationally sponsored cooperative projects or programs dealing primarily with marine resources, pollution assessment, and environmental management in the Caribbean. A number of them are described in this issue. Some are small-scale bilateral arrangements, while others are long term and multilateral or regional. Despite this large number of programs, a 1983 survey by the United Nations Education, Scientific, and Cultural Organization (UNESCO) counted only 117 marine scientists in the island nations of the Caribbean, of whom fewer than half are in the small island countries. In Latin American countries bordering the region, UNESCO lists 583 marine scientists, but only 63 of them are in the small Central American countries. It is difficult for these individuals, who usually have full-time responsibilities in their own institutions, to find the time or energy to participate fully in cooperative programs. Clearly, in the smaller countries, the resources of the Caribbean scientific community are being spread very thin.

If we really want to do cooperative research, it would seem prudent to place a very high priority on building education and training opportunities into ongoing programs to develop new scientific talent in the region. I would argue that these opportunities should be made available by strengthening institutions within the region as much as possible. The classic "brain drain" scenario is all too real in the smaller countries of the Caribbean—enthusiastic young marine scientists studying abroad, but never going back because there is no science infrastructure to support work in their field, although their skills are sorely needed. I commend the academic institutions that are engaged in cooperative programs at the institutional level, however modest. They are wisely investing in the long-term future of regional marine science collaboration by strengthening the research capabilities of their institutional counterparts.

Institution building is a slow process, but there is much that governments can do in the near term. While the State Department's primary role in international scientific affairs is policy guidance and coordination, we advocate, when possible, research with practical applications. In the Caribbean region, marine science bears importantly on both income generation and environmental protection. We encourage all nations to treat these two objectives together, and the Caribbean countries recognize that tourism, fisheries, and mariculture depend on a clean and healthy marine environment.

In this connection, the United States encouraged the recent establishment in Kingston, Jamaica, of the Regional Coordinating Unit (RCU) of the United Nations Environmental Programme's (UNEP's) Caribbean Environment Program. The National Oceanic and Atmospheric Administration (NOAA) has offered to make available a full-time scientific advisor to the RCU. We also supported the Intergovernmental Oceanographic Commission's IOCARIBE Secretariat in its first seven years, and are pleased that it now has a permanent office in Cartagena, Colombia. Both the IOCARIBE office and the RCU can play useful roles in coordinating regional marine research and its application to environmental management problems.

The United States also participated in the UNEP-sponsored negotiation of the 1983 Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region (Cartagena Convention—see page 6) and the related Oil Spill Protocol. We were an original signatory and one of the first to ratify these instruments, which entered into force earlier this year. Additional protocols are envisioned to give substance to the Cartagena Convention's broad aim of marine environmental protection. The First Meeting of Parties, held in October 1987, decided to call a meeting of experts to draft a Protocol on Specially Protected Areas and Wildlife, and also agreed to actively pursue the development of a Protocol on Marine Pollution

The Cartagena Convention

On March 24, 1983, the United States, 16 other nations, and two economic organizations meeting at Cartagena de Indias, Colombia, adopted an international agreement pledging cooperation among Caribbean nations to control pollution and guide the development of the region's marine resources in a manner that protects the quality of the environment (see Oceanus, *Vol. 27, No. 3, page 85).*

The Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region (the Cartagena Convention), calls upon nations in the region to assume the responsibilities to control marine pollution from land-based sources, atmospheric sources, dumping, seabed activities, and vessels. It announces a common commitment to principles of sustainable development and environmental stewardship to guide exploitation and protection of the region's marine resources.

The Cartagena Convention entered into force in October 1986, after winning formal approval by nine nations in the region. The United States played a leading role during the negotiations and was one of the first nations to ratify the treaty. In transmitting the treaty to the Senate for its advice and consent, President Reagan called it "an important step in creating, in the region, marine pollution standards which are generally higher [than current standards]." To date, the following countries have ratified the Convention and its associated protocol on cooperation in combating oil spills: France, the United States, Britain, Antigua and Barbuda, Barbados, the Netherlands, Trinidad and Tobago, Jamaica, Mexico, and Venezuela. Grenada and Saint Lucia have ratified the Convention (document containing the broad principles) but have not ratified the protocol (addendum agreement setting forth more specific obligations).

The Cartagena Convention, like others developed under the Regional Seas Program of the United Nations Environment Programme (UNEP), was designed to be an "umbrella" agreement articulating general principles. During the years ahead, additional protocols will be developed under the "Cartagena umbrella" to spell out in more detail legal duties to be undertaken in connection with the treaty's announced principles. By negotiating broad principles first, differing interests and perspectives were accommodated. It is hoped that over time, governments will be able to accept increasingly specific obligations as set forth in additional protocols.

The first meeting of nations that have deposited instruments of ratification to the Cartagena Convention was held October 26 to 28, 1987, on the French island of Guadeloupe. At the first meeting, parties to the treaty agreed to defer the adoption of rules of procedure until the next meeting, in 1989. Parties also agreed to further pursue additional protocols to be developed under the Convention, including one on specially-protected areas and wildlife, and one on land-based source pollution.

The Wider Caribbean region defined in the Cartagena Convention encompasses the marine environment of the Caribbean Sea and the Gulf of Mexico, including the waters of the United States Exclusive Economic Zone (within 200 miles of U.S. shores) south of 30 degrees North latitude (approximately 50 miles south of the Florida-Georgia border). The 27 countries located in the Wider Caribbean region are linked by certain shared living resources, and similar coastal development and resource management dilemmas.

Vast differences in wealth among nations in the region have led to unequal abilities to actively participate in solving regional problems. Given the economic difficulties facing many nations in the Caribbean, it is vital that the United States follows through on President Reagan's recommendation in 1983 that the United States play a "leading role in the effective implementation of the Convention."

—Miranda Wecker,
Council on Ocean Law,
Washington, D.C.

Acknowledgment

Support for a joint project by the Council on Ocean Law and the Coastal States Organization has been provided by The William H. Donner Foundation. The goal of the project is to bring this regional treaty process to the attention of the U.S. states and affiliated islands in affected areas, and identify priorities to be addressed at meetings of the Cartagena Convention.

from Land-based Sources. Both are potentially valuable, and we expect that scientists familiar with these problems will be willing to contribute to their framing and implementation.

While we look forward to working with other signatories within the provisions of the Convention, we also have initiated a number of region-wide activities on our own. The President's Caribbean Basin Initiative, enacted by Congress in 1983, is intended to provide special incentives for U.S.-Caribbean trade, balance of payments support, and development assistance, thereby promoting the

The Caribbean Basin Initiative

The Caribbean Basin Initiative (CBI) is a program to promote economic development and political stability in Central America and the Caribbean Islands through private sector initiative. The goal is to attract foreign and domestic investment to these countries in new industries, diversifying the economies, and expanding exports.

The major elements of the program are:

- Duty-free entry to the United States for a wide range of products manufactured in CBI countries, as an incentive for investment and expanded export production.
- Increased U.S. economic aid to the region to promote trade, investment, and private sector growth. Aid has more than tripled during 1981–1986 and is being used to finance critical imports from the United States, establish development banks, provide project financing, fund market research and other technical assistance for exporters, to train management and labor, and build free trade zones.
- Caribbean Basin country self-help efforts to improve the local business environment and eliminate excessive bureaucratic red-tape for investors and traders.
- A deduction on U.S. taxes for conventions and business meetings held in qualifying CBI countries, to stimulate tourism.
- A wide range of U.S. Government, state government, and private sector business-support programs, including trade and investment financing, technical assistance, and business development missions.
- Multilateral support from other trading partners, and from such development institutions as the Inter-American Development Bank and World Bank. For example, Canada is implementing Caribcan, providing duty-free entry to Canada for products from the Commonwealth Caribbean.

The 22 participating Caribbean Basin countries are: Antigua and Barbuda, Aruba, Bahamas, Barbados, Belize, British Virgin Islands, Costa Rica, Dominica, Dominican Republic, El Salvador, Grenada, Trinidad and Tobago, Guatemala, Haiti, Honduras, Jamaica, Montserrat, Netherlands Antilles, Panama, St. Christopher-Nevis, St. Lucia, and St. Vincent and the Grenadines. Countries eligible, but not participating in the CBI, are Anguilla, Cayman Islands, Guyana, Nicaragua, Suriname, and Turks and Caicos Islands.

CBI Progress

Although U.S. imports from CBI countries decreased 22 percent during the first two years of the CBI program, this decline can be accounted for entirely by the substantial drop in the value of petroleum imports from the region.

The good news is U.S. imports of nonpetroleum products from the region grew more than 12 percent in 1984–85. High growth rates were registered for a variety of nontraditional products, such as apparel, fruits, and vegetables. The seafood sector performed even better.

There is strong interest among U.S. investors. Between September 1983 and November 1986, the Overseas Private Investment Corporation provided $168 million in financial support for 59 projects in the CBI region, and insured 129 investments totaling $193 million.

The CBI is having an impact, but there is no dramatic difference yet in living standards in the Caribbean Basin. Real Gross Domestic Product (GDP) growth in the CBI region was around 2 percent in 1986. This is encouraging when compared to the declines in GDP experienced by many of these countries in the recent past, but is still below population growth.

For further information, contact the CBI Center at (202) 377-0703. The Center is located in Room H-3020, U.S. Department of Commerce, 14th Street and Constitution Avenue, N.W., Washington, D.C. 20230.

economic development and political stability of Basin nations through private sector initiatives.

The United States Agency for International Development (USAID) is supporting the development of promising agriculture and mariculture activities in the Caribbean. Two new multipurpose marine parks are being created with USAID funding in Belize and Haiti to promote sustainable use of marine resources. The Ocean Studies Board of the National Academy of Sciences, at my request, developed a scientific plan for a resource-oriented marine science initiative in the region. This plan has already served as a catalyst for scientific activities in the region, such as the proposal prepared by the Association of Island Marine Laboratories of the Caribbean (see page 13). Elsewhere in this issue (page 33) is a summary of an Inventory of Caribbean Marine Resources produced by the National Oceanic and Atmospheric Administration in collaboration with USAID and the Intergovernmental Oceanographic Commission.

The list could go on, but I think I have made my point. The Caribbean is important to us, and cooperative marine science activities serve vital U.S. interests in the region in improving international relations, in enhancing environmental quality, and in promoting mutual economic interests. I am pleased to have the opportunity to introduce this special issue of *Oceanus*, and I commend the scientific community for its contributions to the region, as reflected in the articles that follow. Keep up the good work!

John D. Negroponte was confirmed as the Assistant Secretary of State for Oceans and International Environmental and Scientific Affairs in July 1985. From November 1981 to June 1985 he was U.S. Ambassador to Honduras. Since this article was prepared, the author has been appointed Deputy Assistant to the President for National Security Affairs.

Acknowledgment

Oceanus magazine would like to thank the Woods Hole Oceanographic Institution's Sea Grant Program for its support of this issue.

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AIMLC Meeting

The 21st Annual Meeting of the Association of Island Marine Laboratories of the Caribbean will be held May 24-27, 1988 at Mote Marine Laboratory in Sarasota, Florida. Sessions on marine biology, chemistry and toxicology, geology, fisheries, underwater park management, seagrasses, mangroves, and coral reefs will be highlighted as special areas of study. For more information, contact Linda Franklin at Mote Marine Laboratory 1600 City Island Park, Sarasota, Florida 34236. Phone (813) 388-4441.

Cooperative Coastal Ecology at Caribbean Marine Laboratories

by John C. Ogden

The Caribbean is a microcosm of tropical coastal seas throughout the world, containing political, economic, and environmental problems common to similar areas in the Pacific and Indian oceans. Its waters, from Central America north to the Bahamas and east to the Lesser Antilles, are shared by many nations of various sizes. So the Caribbean, more than any other sea except perhaps the Mediterranean, offers ecologists a challenge, an opportunity, and even an obligation for cooperative international marine research and resource management.

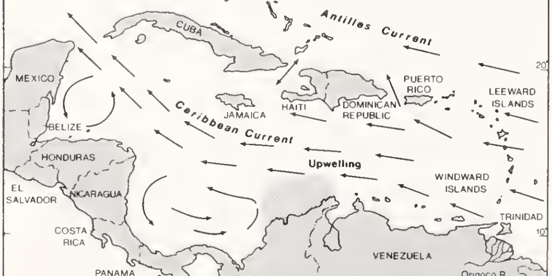
During the next decade, the region will undergo significant changes. Population is exploding, and lands are being developed at an ever-increasing rate. We are expecting to see more cases of over-exploited fisheries; on Jamaica's north coast this situation has already virtually emptied the reefs of many species of demersal, or bottom-feeding, fish. Agriculture, industry, and tourism are responsible for poor land-use practices near large and small rivers on practically every coast in the Caribbean. The increasing population, and hillsides stripped of vegetation, send large volumes of sediment into the coastal zone, destroying mangrove forests, and smothering seagrass beds and coral reefs under a load of silt and sewage—reminding one of the similar ecological disaster at Kaneohe Bay on the Hawaiian island of Oahu.

Governments are aware of the need for information on their own marine environments, but until now have been reluctant to pool their respective resources and address the problems on a regional basis. However, through the efforts of the United Nations Educational, Scientific, and Cultural Organization (UNESCO) Coastal Marine Program (COMAR), and the Intergovernmental Oceanographic Commission (IOC), the political groundwork has been laid for international cooperation in marine science and resource management. Marine scientists in the Caribbean, for their part, have begun networking among themselves to establish procedures that will build a regional body of knowledge. One example of such cooperation is the Caribbean Pollution Research and Monitoring group, CARIPOL (see article, page 25), formed as a specialized venture of the IOC.

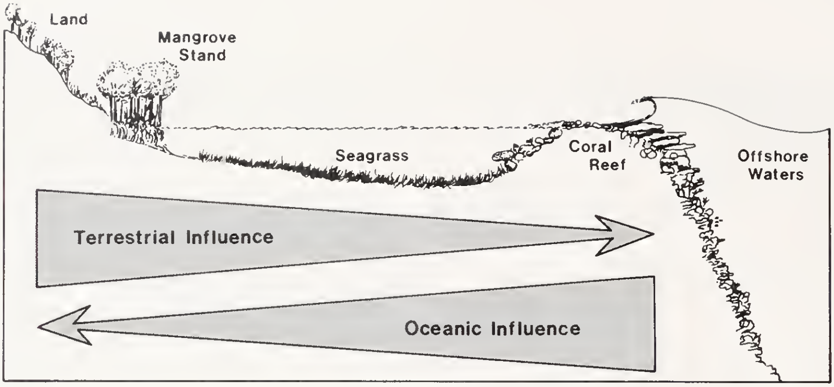
A Unified System

The Caribbean measures approximately 500 miles by 1,200 miles—a relatively small area, oceanographically speaking—and is swept from east to west by the Caribbean current, with coastal countercurrents and several large gyres. Because most of the marine plants and animals in the Caribbean have a planktonic larval phase that lasts from several weeks to more than a year, and the propagules are carried long distances by the east-west current, the homogeneity of species associations in these waters is striking.

The homogeneity of the Caribbean was dramatized in 1983–84 by a mass mortality, killing 95 to 99 percent of the long-spined black sea urchin, *Diadema antillarum* (see article, page 69). Haris A. Lessios, a biologist at the Smithsonian Tropical Research Institute in Panama, believes the mass



The surface currents of the Caribbean Sea.



The Caribbean coastal seascape, showing the relationships of coral reefs, seagrasses, and mangroves. The arrows show generalized gradients of terrestrial and oceanic factors that influence the distribution, structure, and productivity of these coastal ecosystems.

mortality was caused by a pathogen such as a virus, protozoan, or fungus. The mortality was remarkably species-specific, and spread without loss of severity along surface current patterns. The disappearance of the heretofore abundant plant-eating urchin in turn caused an eruption of algal growth, destroying corals and other reef-dwelling organisms.

Most island and mainland coastlines drop precipitously to depths of more than 2,000 meters within a few kilometers of shore, so the total area of the coastal zone—the shallow water (less than 200 meters deep) that man is most dependent on for food, and the zone most susceptible to the influence of man—is small. Typical of tropical seas, however, is the fact that the warm surface waters of the Caribbean rarely mix with the nutrient-rich, cold waters below. Nutrients, particularly inorganic nitrogen and phosphorus, are regenerated from decaying plant and animal material by bacteria, and are the fertilizers of the plant growth that supports all other forms of life. Because these nutrients remain locked away in the deep, cold waters offshore, the primary productivity, or the *rate* at which plant material is produced in photosynthesis, of the open sea is low. Most fisheries and renewable marine resources are located in the coastal zone where nutrients are concentrated from other, land-based, sources and primary productivity is high.

Given its range of island sizes, the size of their coastal zones, and the uniformity in distribution of many of its plants and animals, the Caribbean presents marine biologists with a unique opportunity to discover the factors that control the distribution and abundance of organisms, and those that control the productivity of coastal ecosystems. As the foundation of this basic regional information becomes more firmly established, critical resource management problems can be addressed more effectively.

The Caribbean Coastal Seascape

The coastal seascape of the Caribbean supports a complex interaction of three distinct ecosystems: mangrove stands, seagrass beds, and coral reefs. Distinct in their solutions to the ecological "problem" of obtaining the nutrients lacking in warm surface waters, these tropical marine ecosystems are among the most productive in the world. In terms of biomass production per unit time, they exceed even intensively cultivated crops such as sugar cane.

Lush mangrove forests, consisting of several species of trees, are found in river basins, coastal floodplains, and estuaries. In these and other protected areas, their root systems collect the abundant nutrients from runoff and river discharge. There appears to be a gradient in the size of mangrove stands in the Caribbean, with the most impressive forests along the coasts of the Greater Antilles with their extensive river systems, and a virtual absence of mangroves on the smaller islands of the eastern Caribbean.

Similarly, the most productive seagrass beds, dominated by turtle grass, *Thalassia testudinum*, occur where their roots take advantage of the nutrient enhancement from river runoff or outwelling from coastal mangrove lagoons. During times of highest tides and during storms, the nutrients collected in these lagoons get flushed out into the open water, fertilizing the rooted plants growing there. In a gradient that mirrors that of mangrove stand sizes, the seagrass beds become increasingly diverse, with turtle grass decreasing in importance in favor of seagrasses with lower nutrient requirements, as one moves from larger to smaller islands.

Corals contrast with both seagrass and mangroves by regenerating nutrients internally, rather than collecting them through roots. In their association with unicellular algae called zooxanthellae, corals are able to thrive in the warm and shallow, but nutrient-poor waters at the edge of the coastal shelf. Algal turfs, containing nitrogen-fixing blue-green algae, are responsible for a large component of the high productivity of coral reefs.

Interaction of Caribbean Coastal Ecosystems

The dynamics of nutrient exchange, and other basic aspects of how mangrove, seagrass, and coral ecosystems interact in the Caribbean are only now beginning to be understood. The Smithsonian Institution's National Museum of Natural History is helping this effort by sponsoring a regional program of research known as Caribbean Coral Reef Ecosystems (CCRE), headquartered in Belize, but with additional research sites planned for elsewhere in the Caribbean (see box, page 11).

Coral reefs buffer the impact of the ocean on

Caribbean Coral Reef Ecosystems (CCRE)

The Caribbean Coral Reef Ecosystems (CCRE) program has its roots in a collaborative field research project conceived by six National Museum of Natural History scientists more than 15 years ago. This initial group of Smithsonian researchers represented several major disciplines that are essential in the study of reef ecology: zoology, botany, carbonate geology, and paleobiology. The immediate aim was the synoptic investigation of Caribbean coral reefs. Since it was expected that comparative studies would eventually be carried into other littoral (shoreline) environments, the original program was named Investigations of Marine Shallow Water Ecosystems (IMSWE).

Program logistics and financial constraints made it advisable to establish a field station in one representative location, rather than travel as a group to different places to carry out studies. After a number of dive surveys conducted by us and colleagues from other institutions, we chose the barrier reef of Belize (then British Honduras). This reef complex turned out to be the most diverse in structure, habitat types, and animal and plant species of all locations examined. It could also be considered the most pristine system, with only minimal disturbances from the distant land mass, such as silting and run-off of nutrients and pollutants, and only moderate fishing activities by natives and a few tourists.

In February 1972, Carrie Bow Cay, a 0.4 hectare (1 acre) sand island on top of the southern Belize barrier reef was chosen as the site for our field laboratory. During the following decade, some 65 scientists and graduate students worked at the station, and more than 100 research papers were published on the fauna, flora, and geology of the Carrie Bow reef tract, culminated by the multidisciplinary volume entitled The Atlantic Barrier Reef Ecosystem at Carrie Bow Cay, Belize, I: Structure and Communities *(K. Rützler and I. G. Macintyre, eds., 1982; Smithsonian Contributions to the Marine Sciences, 12).*

Grants from the Exxon Corporation's Public Affairs Department (Central and South America) aided the program soon after its inception and, in the early 1980s, stimulated a new focus: ecological study of Caribbean mangrove swamp communities. This new program became known as the Smithsonian Western Atlantic Mangrove Program (SWAMP) and, in addition to the Exxon support, earned a 2-year Smithsonian Scholarly Studies Program award for its 18 staff scientists. Carrie Bow Cay continued to serve as logistical base, with nearby Twin Cays chosen as the model mangrove system.

Beginning in Fiscal Year 1985 (October 1984) the National Museum of Natural History, strengthened by the research experience derived from the IMSWE and SWAMP programs, received an increase to its budget base for the study of Caribbean Coral Reef Ecosystems. This "umbrella" program, now known by its acronym CCRE, encompasses reef, mangrove, seagrass meadow, and plankton community studies, and maintains its primary focus on the Carrie Bow Cay, Belize, region. To date, about 50 scientists a year have conducted studies there. In addition, comparative studies in other places in the Caribbean basin have been initiated or are planned. Sites under consideration are: Yucatan (Mexico), Venezuela, St. Vincent, Barbados, Martinique, Guadeloupe, Jamaica, Bermuda, and coastal Florida. The possibility of conducting deep-water studies along the fore-reef slope of the Belize barrier reef is under review. A modest sub-program of fellowship support is augmenting Smithsonian staff research under this program.

—Klaus Rützler, and Marsha Sitnik

the coastal zone, creating lagoons and protected waters that favor the growth of seagrasses and mangroves. Mangrove forests and seagrass beds buffer coral reefs from contact with land, and promote reef growth offshore by trapping sediments, removing excessive nutrients, and interrupting freshwater discharge, thus stabilizing the salinity of the coastal zone. Because their environmental requirements are so different, coral reefs and mangroves rarely occur next to each other. It follows then, that some of the most productive coasts are those where broad seagrass meadows are interposed between mangroves and coral reefs.

An example of nutrient exchange among these ecosystems is related to the daily or seasonal migration of animals from one ecosystem to another. Judy L. Meyer, an ecologist at the University of Georgia, found that schools of juvenile reef-dwelling grunts, *Haemulon* spp., act as nutrient transporters; they forage by night among the seagrass beds and defecate by day in the reefs, measurably increasing the nutrient concentrations over coral colonies. Corals with resident grunt schools, carrying these additional nutrients, grew faster than those lacking schools.

Seagrass beds and mangroves have been recognized as important nursery areas for many species of reef fishes and invertebrates. Numerous studies at the West Indies Laboratory on St. Croix have shown that the planktonic larvae of the French grunt, *Haemulon flavolineatum*, preferentially settle in seagrass-covered lagoons where they spend the first few months of their life, moving gradually to coral reefs as small juveniles.

As previously mentioned, there seems to be a relationship between the form that mangrove stands and seagrass beds take, and the size of the land mass they are associated with. Research into varying properties of coastal ecosystems in relation to land-mass sizes is an important program, and one that demands international cooperation throughout the Caribbean. By comparing one site to another over a long period of time, the observed differences and similarities may be correlated with particular factors. The insular nature of marine biological research in the Caribbean until now has made comparison between sites difficult because of differing objectives and methods. For this reason, generalizations developed at one site may not apply to other sites.

For example, the population density of the common striped parrotfish, *Scarus iserti* varies directly with the gradient of decreasing land influence from Panama to St. Croix. Its behavior also changes dramatically along the gradient. In Panama, striped parrotfish show an elaborate territorial behavior in addition to group foraging behavior. In St. Croix, territories are not found, and the fish forage over a wide area in small groups. The hypothesis is that territorial behavior in striped parrotfish is possible only where productivity is enhanced and food resources are concentrated. In St. Croix, productivity is depressed and food resources are more widely distributed. The parrotfish adopt a foraging strategy to match their resources. Other relatively simple measures of community structure and function made over long periods of time, along geographical gradients, could resolve important pathways of interaction and tell us a great deal about the factors influencing the structure and productivity of coastal communities.

A Cooperative Network

There are more than 17 marine laboratories in the Caribbean region, many of which have a long tradition of sharing research results. This is fortunate because many of them—such as the Bellairs Institute of McGill University in Barbados—are just field stations with facilities for about 10 scientists. Individually, their small sizes limit their ability to carry out large research projects independently; but spread out over the Caribbean as they are, together they can take on the sort of regional research necessary for crucial resource management issues.

The Association of Island Marine Laboratories of the Caribbean (AIMLC) (page 13), with 24 member laboratories including Florida and Bermuda, was founded in 1957, and hosts a meeting at a member laboratory nearly every year. At several workshop meetings of Caribbean marine scientists, held at the West Indies Laboratory in St. Croix and the Discovery Bay Marine Laboratory in Jamaica in 1982 and 1985, under the sponsorship of the National Science Foundation (NSF) and UNESCO, a program of sustained ecological research, involving a cooperating network of Caribbean marine laboratories was designed. The program, called Caribbean Coastal Marine Productivity (CARICOMP), will establish research sites; map the distribution of coral reefs, seagrasses, and mangroves; and collect monitoring data using standardized methods and techniques. For example, one of the most simple yet useful measures that integrates many aspects of the environment is the growth rate of principal coral, algae, seagrass, and mangrove species. This information, combined with basic physical and chemical data, will be centrally processed and incorporated into regional models of coastal productivity.

This developing data base from sites surrounding the Caribbean will suggest further specialized research projects. Research of a regional character, directed at an understanding of the factors controlling coastal ecosystem structure and function, will be the result.

The training of Caribbean scientists and technicians in the application of modern techniques in marine science is central to the network. This training should include remote sensing, manned submersibles, remotely operated vehicles (ROVs), and the latest diving technology—exemplified by the National Oceanic and Atmospheric Administration's (NOAA's) new underwater laboratory, *Aquarius* (see box, page 15). The network will make the best information available for management of marine resources on a regional scale, while stimulating basic research in areas where information is lacking.

Research on Various Timescales

The network of Caribbean marine laboratories will be able to anticipate and study regional events on short and intermediate timescales, such as hurricanes, larval distribution patterns or mass mortalities, and make real-time maps on a region-wide scale. For example, hurricanes regularly traverse the Caribbean, and may be involved in fish kills caused by phytoplankton blooms stimulated by storm-driven upwelling of nutrients from deep water. Hurricanes destroy the dominant coral species on shallow reefs at intervals, opening space that is re-colonized by a variety of species, and promoting biological diversity. The potential for long-distance distribution of larvae by currents presently makes identification of fisheries stocks difficult, and single-point management of fisheries resources impossible. New techniques involving genetic markers may identify points of origin of larvae and track distribution patterns, providing a rational basis for regional fisheries management.

As an example of an event taking place on a longer time scale, "white band disease" of elkhorn coral, *Acropora palmata*, the principal reef-building coral of the Caribbean, has killed more than 90 percent of this species at Buck Island Reef National Monument in St. Croix, managed by the National Park Service as one of the nation's first underwater parks. The cause of the disease is unknown, but it is found through the islands of the eastern Caribbean and may move to mainland coasts to the south and west. The network could rapidly assemble a picture of such events; relate them to micro- and meso-scale

Association of Island Marine Laboratories (AIMLC)

The Association of Island Marine Laboratories of the Caribbean (AIMLC) represents 24 member marine laboratories, primarily in the greater Caribbean basin, and more than 500 individual members with interest in Caribbean marine science.

The Association advances Caribbean marine science by arranging meetings; fostering personal and official relations among members; assisting or initiating cooperative research programs; and publishing a journal (Proceedings of the Association of Island Marine Laboratories of the Caribbean), *a newsletter* (Caribbean Marine Sciences), *and an address and specialty list of Caribbean scientists. Lucy Bunkley Williams is the editor of the newsletter. Contributions may be submitted to her, or copies obtained from her at: Department of Marine Sciences, University of Puerto Rico, Mayaguez, PR 00708. Below is a list of member laboratories.*

Bellairs Research Institute of McGill University
St. James
Barbados

Bermuda Biological Station
St. George's West
Ferry Reach 1–15
Bermuda

Bitter End Field Station, Virgin Gorda
Fisheries Research Laboratory 6-22406
Southern Illinois University at Carbondale
Carbondale, IL 62901

Caraibisch Marien Biologisch Instituut
Piscadera Baai
P. O. Box 2090
Willemstad, Curaçao
Netherlands Antilles

Caribbean Marine Research Laboratory
Lee Stocking Island
Bahamas

Center for Energy and Environmental Research
University of Puerto Rico
Mayaguez, PR 00708

Centro de Investigaciones de Biologia Marina
Presa de Tavera # 302
Ciudad de los Millones
Santo Domingo
Republica Dominicana

Centro de Investigacion y de Estudios Avanzados del IPN—Unidad Merida
Carretera Antigua a Progreso KM 6
Apartado Postal 73—Cordemex
97319 Merida, Yucatan
Mexico

Centre Universitaire Antilles—Guyane
B. P. F-97167, Pointe-A-Pitre, Cedex
Guadeloupe (F. W. I.)

CCFL Bahamian Field Station
San Salvador, Bahamas
College Center of the Finger Lakes
270 Southwest 34th Street
Fort Lauderdale, FL 33315

Department of Marine Sciences
University of Puerto Rico
Mayaguez, PR 00708

Discovery Bay Marine Laboratory
P. O. Box 35
Discovery Bay
Jamaica

Estacion de Investigaciones Marinas de Margarita
Fundacion La Salle de Ciencias Naturales
Apartado 144, Porlamar
Nueva Esparta, Venezuela

Laboratorio Investigaciones Pesqueras
Corporacion para el Desarrollo y Administracion de los Recursos Marinos
P. O. Box 3665, Maina Station
Mayaguez, PR 00708

Fundacion Cientifica Los Roques
Apartado 61248
Caracas
Venezuela

Institute of Marine Affairs
P. O. Box 3160
Carenage Post Office
Port of Spain
Trinidad and Tobago, W. I.

Instituto de Investigaciones Marinas de Punta de Betin
Apartado 1016, Santa Marta
Colombia

Instituto Oceanografico
Universidad de Oriente
Apartado 94
Cumana
Venezuela

Marine Science Center
College of the Virgin Islands
Charlotte Amalie, St. Thomas
U.S. Virgin Islands 00802

Mote Marine Laboratory
1600 City Island Park
Sarasota, FL 33577

Port Royal Marine Laboratory
Department of Zoology
University of the West Indies
P. O. Box 12
Mona, Kingston 7
Jamaica

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Rosenstiel School of Marine and Atmospheric Sciences
University of Miami
4600 Rickenbacker Causeway
Miami, FL 33149

Smithsonian Tropical Research Institute
Balboa, Panama
APO Miami, FL 34002

West Indies Laboratory
Fairleigh Dickinson University
Teague Bay
Christiansted, St. Croix
U.S. Virgin Islands 00820

The fore reef at Discovery Bay, Jamaica, in 1983, three years after Hurricane Allen destroyed most of the shallow water branching corals, Acropora spp.*, leaving only mounding corals. By periodically destroying the dominant shallow water corals, hurricanes promote biological diversity on coral reefs.*

The Antillean fish trap is used in the eastern Caribbean subsistence fishery. Traps are commonly set in seagrass beds near coral reefs.

circulation patterns; and suggest causes, needed research, and management strategies.

On a still longer time scale, sea level is projected to rise rapidly during the next 100 years, potentially interfering with the wave buffering capacity of coral reefs in the coastal zone. A systematic program of coral cores at the network sites will help define the climatic factors and events that have led to the establishment and growth of coral reefs in the Caribbean. Corals, just like trees, have growth rings that are used to infer past conditions (see *Oceanus*, Vol. 29, No. 2, page 31). Good baseline data will be needed to track sea level, study the growth responses of coral reefs, and anticipate management problems associated with increased wave action in the coastal zone (see article page 53). A coral coring program directed by Peter J. Isdale at the Australian Institute of Marine Science tracked the influence of river flow during the last few hundred years on coral growth.

In addition to providing a window on the past, the Caribbean is an ideal intermediate-scale region in which the global system may be modeled. The network of marine laboratories would serve to provide "ground truth" for the new technology being applied to study global change. Data gathered in a coordinated regional program could be used to tune the capabilities and sensitivity of remote sensing technology, and will provide the key to linking the past with the future in our understanding of the tropical coastal zone.

John C. Ogden is Professor of Biology at Fairleigh Dickinson University, and Director of the University's West Indies Laboratory on St. Croix in the U.S. Virgin Islands. He is also the co-chairman of the Steering Committee of CARICOMP.

Acknowledgment

The steering committee of CARICOMP, along with a large group of cooperating Caribbean scientists, are responsible for much of the material presented in this article.

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Aquarius:
The Dawning of a New Age in Caribbean Marine Science

Aquarius, NOAA's new underwater research station.

The National Oceanic and Atmospheric Administration's National Undersea Research Program (NURP) is poised to launch the most advanced undersea laboratory available to the scientific community—a habitat-based, manned saturation system known as* Aquarius. *The laboratory/habitat is designed to accommodate up to six scientists at depths reaching 37 meters for as long as a month.* Aquarius *was recently deployed at Salt River Canyon—less than a kilometer from the mouth of the Salt River, on the north coast of St. Croix—and is currently undergoing final preparation and safety checks for its first science missions, sponsored by NURP at Fairleigh Dickinson University's West Indies Laboratory (NURP-FDU).*

The value of saturation diving in marine research was proven by Hydrolab, *a four-person habitat that was used by NURP-FDU to conduct 85 research projects from 1978 to 1985. Habitats allow scientists to work at depths requiring long decompression times for extended periods. Prolonged stays on the ocean floor permit scientists to establish and monitor in situ experiments using the newest methods, hastening the evolution of undersea science from an observational to an experimental mode.*

The Aquarius *system has four parts: the 81-ton research habitat; a life-support buoy (LSB); a launch, recovery, and transport vessel; and a 118-ton baseplate that holds the habitat on the ocean floor. The LSB is a reinforced 13-meter enclosed boat hull modified for unattended operation. It is connected to the habitat by a 38-meter long, 20-centimeter diameter umbilical that provides the habitat with air, power, water, and communication lines. The larger transport vessel will be able to carry the baseplate and habitat to any number of sites, enabling comparative study of various Caribbean—indeed global tropical—ecosystems. The surface support personnel of NURP/FDU will provide diver training, operational expertise, and safety standards.*

Aquarius *will expand the productivity of saturation diving for scientific research, for in addition to being a comfortable underwater home, the* Aquarius *could rightly be called a* **lab***itat, since it is equipped with modern experimental facilities. The onboard equipment includes video monitoring and recording capability, a computer network, environmental data-logging system, and wet lab.*

The science missions scheduled for 1988 will address the general topics of nutrient cycling and recruitment processes in marine organisms. Specifically, the projects will examine:

- *The effect of water movement on the feeding behavior of corals.*
- *The oxygen dynamics and anaerobic metabolism of reef sediments.*
- *The structural patterns and processes of algal communities along a depth gradient.*
- *The energetics of sediment removal and zooplankton feeding in reef-building corals.*
- *Nutrient fluxes in the benthic microflora of coral reef sediments.*
- *Biological and physical processes affecting larval settlement and early recruitment of marine organisms.*

Results from this research will help our understanding of relationships between primary productivity, energy and material flow through ecosystems, and the potential availability of this energy and material to higher trophic levels, such as fishes and man.

For further information on Aquarius *and the NURP-FDU Caribbean Science Program, contact Dr. Robert C. Carpenter, Science Director, West Indies Laboratory, Teague Bay, Christiansted, St. Croix, U.S. Virgin Islands 00820.*

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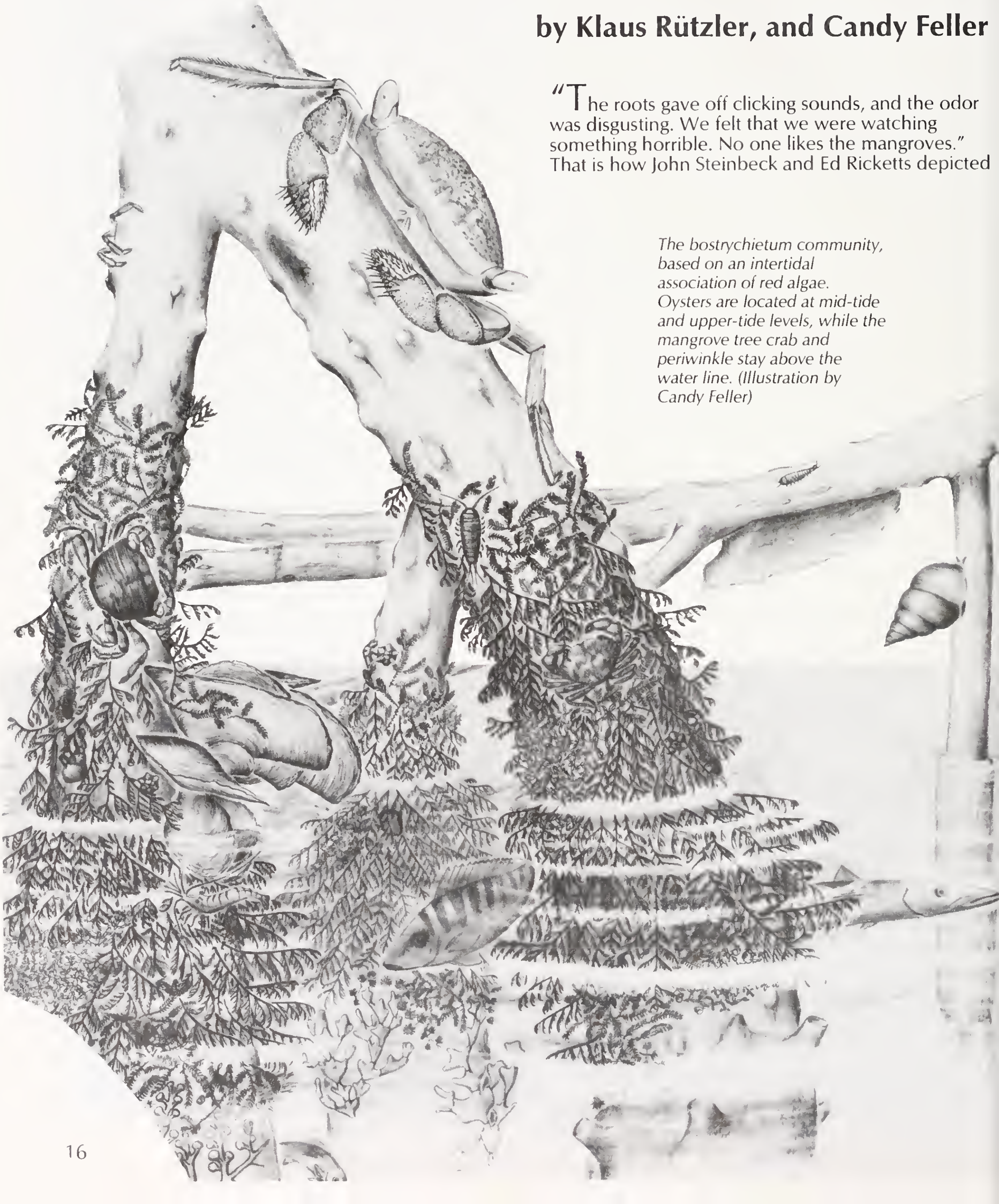
* "Saturation" in the context of diving means that the maximum amount of gases possible are dissolved in a diver's blood at a particular depth. "Decompression" is necessary when a diver's blood contains a greater quantitiy of gases than can normally be eliminated from the blood without the formation of bubbles.

Mangrove Swamp

by Klaus Rützler, and Candy Feller

"The roots gave off clicking sounds, and the odor was disgusting. We felt that we were watching something horrible. No one likes the mangroves." That is how John Steinbeck and Ed Ricketts depicted



The bostrychietum community, based on an intertidal association of red algae. Oysters are located at mid-tide and upper-tide levels, while the mangrove tree crab and periwinkle stay above the water line. (Illustration by Candy Feller)

Communities

the mangroves in 1941 in the *Sea of Cortez*. Many people agree with them. So why have two dozen scientists from the Smithsonian Institution, primarily from the National Museum of Natural History, and twice as many colleagues from American and European universities and museums devoted a decade of exploration to one square kilometer of "black mud, . . . flies and insects in great numbers . . ., impenetrable . . . mangrove roots . . .," and ". . . stalking, quiet murder"?

The study started in the early 1980s, and focuses on an intertidal mangrove island known as Twin Cays, just inside the Tobacco Reef section of the barrier reef of Belize, a tiny Central American nation on the Caribbean coast (see article page 76). The principal purpose of this research is to document the biology, geology, ecological balance, economic importance, and aesthetic value of a prominent coastal ecosystem using the example of a diverse and undisturbed swamp community.

Properties of Mangrove Swamps

Mangrove swamp communities dominate the world's tropical and subtropical coasts, paralleling the geographical distribution of coral reefs. Mangroves on the Atlantic side of the American coasts occur between Bermuda and almost to the mouth of the Rio de la Plata (Argentina), and throughout the West Indies. Like reefs, mangrove swamps are environments formed by organisms, but unlike most coral communities, they thrive in the intertidal zone and endure a wide range of salinities.

"Mangrove" refers to an assemblage of plants from five families with common ecological, morphological, and physiological characteristics that allow them to live in tidal swamps. Worldwide, at least 34 species in nine genera are considered to be true mangroves. P. B. Tomlinson's recent book, *Botany of Mangroves*, defines this group of plants by five features: 1) they are ecologically restricted to tidal swamps, 2) the major element of the community frequently forms pure stands, 3) the plants are morphologically adapted with aerial roots and viviparity (producing new plants instead of seeds), 4) they are physiologically adapted for salt exclusion or salt excretion, and 5) they are taxonomically isolated from terrestrial relatives, at least at the generic level. "Mangrove swamp" or "mangal" refers to communities characterized by mangrove plants.

Mangrove trees are used for water-resistant timber, charcoal, dyes, and medicines. They resist coastal erosion during storms and possibly promote land-building processes by trapping sediment and producing peat. The protective subtidal root system of the red mangrove serves as nursery ground for many commercially valuable species of fishes, shrimps, lobsters, crabs, mussels, and oysters. An assorted fauna of birds, reptiles, and mammals is also at home in the mangrove thickets and tidal channels.

Human disturbances have made a heavy impact on many mangroves near populated areas as a result of dredging and filling, overcutting, insect control, and garbage and sewage dumping. The intertidal environment of mangroves is endangered by pollutants in the water, air, and soil. Accidental oil spills appear to be particularly damaging. Oil and tars not only smother algae and invertebrates, but also disrupt the oxygen supply to the root system of the mangrove trees by coating the respiratory pores of the intertidal prop and air roots.

A Mangrove Laboratory in Belize

Belize (formerly British Honduras), boasts the longest barrier reef of the Northern Hemisphere, extending 220 kilometers from the Mexican border in the north to the Gulf of Honduras in the south. Behind this barrier lies an enormous lagoon system averaging 25 kilometers between the mainland and open ocean. Mangroves border most of the coastline, extend upstream from countless river mouths, and fringe or cover most lagoon cays.

One of these is Twin Cays (Figure 1)—an island divided into two by an S-shaped channel. Twin Cays has become our study site and experimental field laboratory. Although we usually spend the nights and conduct laboratory bench work on nearby Carrie Bow Cay—site of the National Museum's coral reef field station for the last 15 years—most days and many nights are spent in the mangrove channels, lakes, ponds, mud flats, and even the trees. A self-contained weather station established on one of the mud flats transmits data on wind, sun, rain, temperatures, and tides to a portable computer on Carrie Bow Cay.

The bibliographies on mangroves show that during the last 200 years more than 6,000 papers have been published describing biological and geological details from almost as many different swamps over the world. Our ongoing study aims to

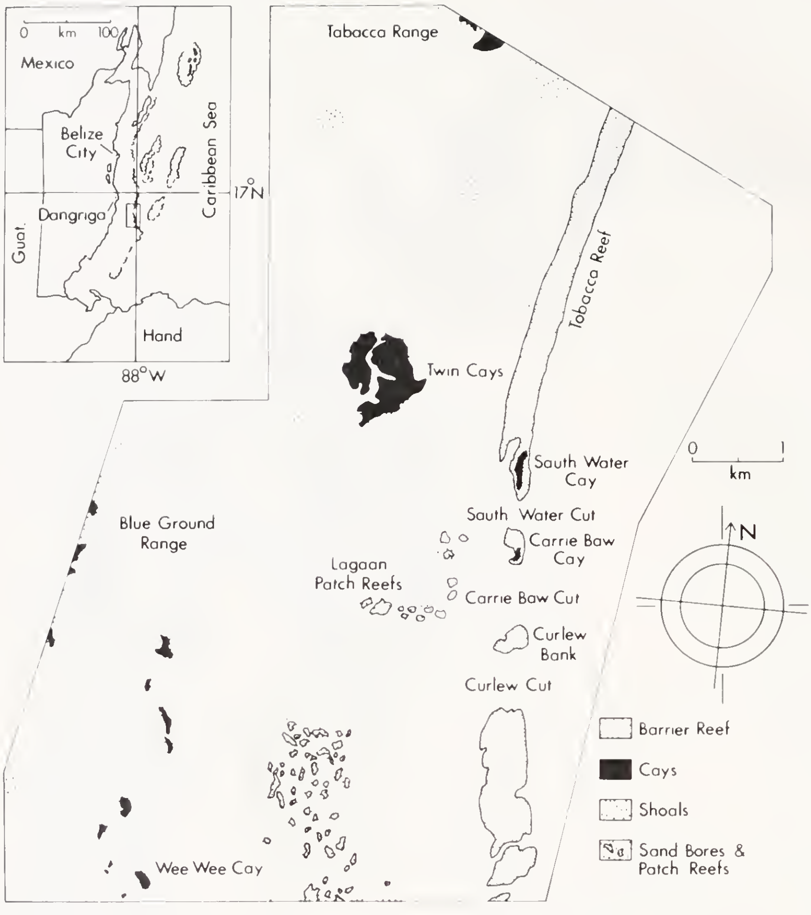


Figure 1. Mangrove ecosystem study area, Twin Cays, Belize. The National Museum of Natural History's coral reef field station is located on Carrie Bow Cay, about 4 kilometers southeast. (From Rützler and Macintyre, 1982, Smithsonian Contributions to the Marine Sciences 12*)*

analyze as many components as possible of a single mangrove swamp and, ultimately, assemble them to a mosaic reflecting structure as well as function of this unique ecosystem.

Geological History of Twin Cays

A popular theory holds that mangroves are builders of land because they trap and hold fine sediments. Early on in our study we discovered that this is not necessarily true. We tried to reclaim nearby Curlew Cay, which had been lost to a hurricane (it is now known as Curlew Bank), by planting an assortment of young red mangroves, but were unsuccessful. So the question arose, if islands are not built by mangroves, how do they get started?

To learn more about the Holocene (recent time—back to 18,000 years before present) stratigraphy under the present island, Ian G. Macintyre of the Smithsonian Department of Paleobiology, along with Robin G. Lighty and Anne Raymond of Texas A&M University, drove pipes 8 meters into the sediment, down to the Pleistocene level (marks the beginning of the Holocene), and retrieved sediment cores that date back 7,000 years.* They also collected rock cores below this level. What they found below the mangroves was a carbonate substrate consisting of a dense limestone formed mostly by finger corals (*Porites*) with abundant mollusk fragments, indicating an environment of deposition similar to today's calm-water patch reefs. The sequence of peat, algal-produced sand, and mangrove oysters in the sediment cores indicates that this mangrove was apparently established on a topographic high formed by a fossil patch reef, and kept pace with the rising sea level. However, there is also evidence that the island repeatedly changed its size and shifted position, generally building with lagoon sediments on the windward coasts, while eroding at the leeward edge, which is characterized by shallow-water bottoms formed by stranded peat deposits.

The mangrove community itself can be thought of as being composed of three components: the above-water "forest," the intertidal swamp, and

* Although the Holocene can date back as much as 18,000 years, there are only 7,000 years of sediment accumulation in this particular area, as sea level did not flood the Belize lagoon until the upper Holocene.

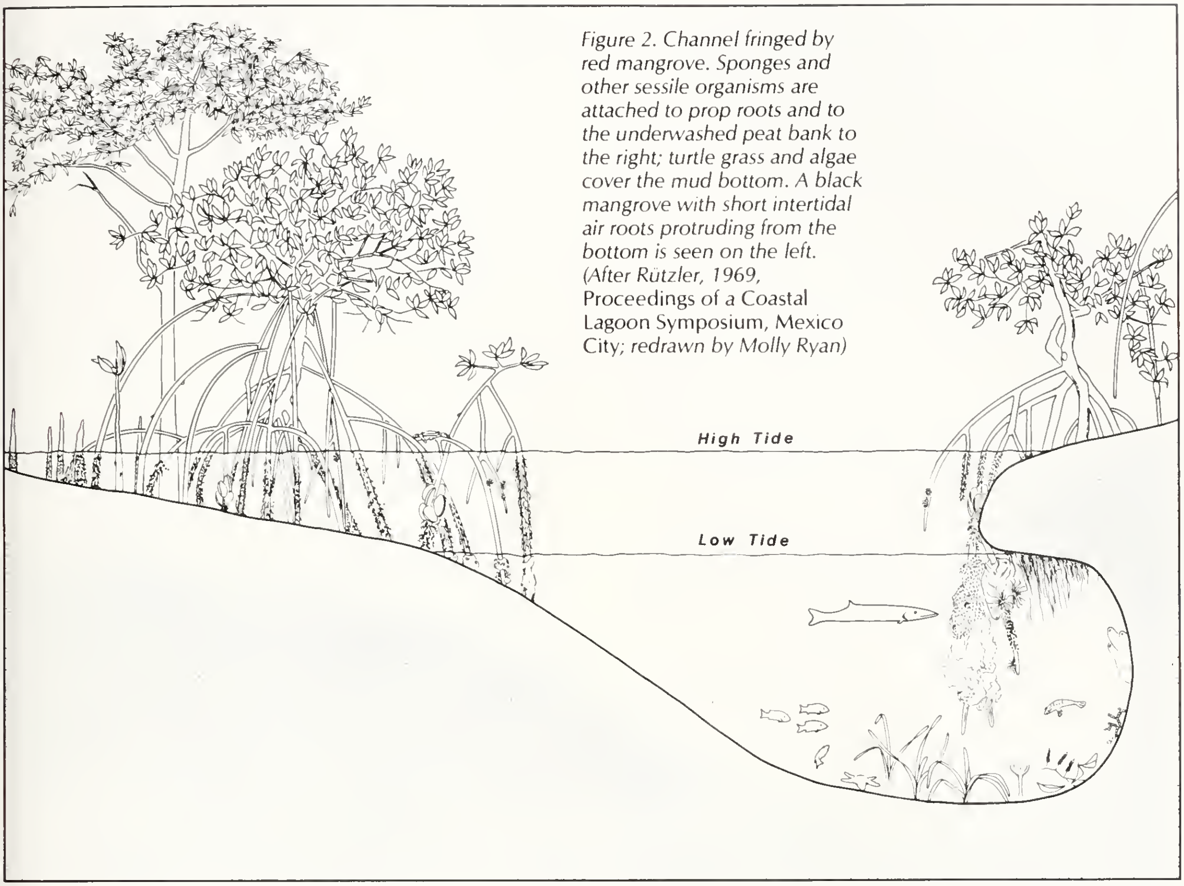


Figure 2. Channel fringed by red mangrove. Sponges and other sessile organisms are attached to prop roots and to the underwashed peat bank to the right; turtle grass and algae cover the mud bottom. A black mangrove with short intertidal air roots protruding from the bottom is seen on the left. (After Rützler, 1969, Proceedings of a Coastal Lagoon Symposium, Mexico City; *redrawn by Molly Ryan)*

the underwater system (Figure 2). In our descriptions, we will start from the bottom and work up.

Environments Below the Tides

The bottom of the mangrove from the intertidal to 3 meters, the greatest depth of the main channel, is composed of what most people would call muck. To us, it displays many varieties, such as carbonate silt, mud, and sand with varying amounts of mucus, organic detritus (products of plant and animal decay), peat, and silicious skeletons derived from diatom algae and sponges. Many fine-grained limestone sediments are produced by physical and biological erosion on the nearby reef and carried into the mangrove by water currents. Sands, on the other hand, are primarily produced within the community by digestion or decay of calcareous green algae (*Halimeda*).

The most abundant and ecologically important plant on the submerged mangrove bottoms is the turtle grass (*Thalassia*). It stabilizes the muddy bottom, offers substrate for egg cases and many small sessile organisms, and provides food and shelter to animal groups ranging from microbes to 2-meter manatees. Jörg A. Ott, a seagrass ecologist from the University of Vienna, determined that turtle grass in the Twin Cay mangrove is more dense, and grows 3 times faster than *Thalassia* in the nearby open lagoon, resulting in an almost 10-fold net leaf production.

Red mangrove stilt roots line all channels, creeks, and ponds and, below tide level, support spectacularly colored clusters of algae, sponges, tunicates (sea squirts), anemones, and many associates. They also provide hiding places for many mobile animals, such as crabs, lobsters, sea urchins, and fishes.

Algae without the ability to root in mud bottoms abound on the stilt roots. Mark Littler, from the Smithsonian Department of Botany, and co-workers Diane Littler and Philipp Taylor found that, curiously, fleshy algae seem to prefer roots that had penetrated the water surface, but had not yet reached the bottom of the channel or lake. Calcifying algae (such as the sand-producing *Halimeda*), on the other hand, are common on the submerged parts of anchored roots and along the channel banks. Experiments demonstrated that the hanging roots offer palatable plants protection from benthic (bottom-living) herbivores such as sea urchins and many fishes, whereas *Halimeda* has its own skeletal protection.

Certain algae and many sessile invertebrates on the subtidal mangrove roots are protected from predators by toxic substances stored in their tissues and produced by their own metabolism. Sponges are particularly well-known for their antibiotic and feeding-deterrent properties. The sponges, in turn, are used by many smaller organisms, such as anemones, polychaete worms, shrimps, crabs, amphipod crustaceans, gastropod mollusks, and brittle stars as an effective physical and chemical shelter. Collaborating with our Smithsonian colleagues, Kristian Fauchald, Gordon Hendler (now at the Los Angeles County Museum), and Brian Kensley, we extracted up to 40 species and 400 specimens of endozoans (species living within another) larger than 2.5 millimeters from, as an example, a 1-liter fire sponge (*Tedania*), a species that causes burning, itching, and even severe dermatitis in humans.

Sponges are among the most common, massive, and colorful invertebrates in the submerged mangrove. To settle and metamorphose, their larvae need solid substrate with low exposure to sedimentation, although we observed grown specimens surviving for months buried in light mud after they had fallen from their place of original attachment. Only two kinds of firm substrate are available to such settlers, red mangrove stilt roots, and vertical or overhanging banks composed of a felt of peat and mangrove rootlets and flushed by tidal currents.

In both locations, the competition for space is fierce, not only among sponges, but also between sponges and other sessile organisms, such as algae, hydroids (the polyp-generation of many medusae), corals, anemones, bryozoans (moss animals), and tunicates (sea squirts). With our colleagues Dale Calder, Royal Ontario Museum, Ivan Goodbody, University of the West Indies, and Jan Kohlmeyer, University of North Carolina, we are analyzing the sequence of settlement of species at different seasons, following their growth and methods and hierarchies of competition.

We have found that within days new substrates (wood, plastics) are colonized by ubiquitous bacteria, fungi, and lower algae. Next to arrive are coralline algal crusts, sponges, hydroids, scyphozoan polyps (the polyp stage of the upside-down jellyfish *Cassiopea*), anemones, serpulid and sabellid worms, bryozoans, and ascidians (the latter two are colonial, encrusting organisms). After 3 to 6 months, substrates are fully covered by a spectrum of organisms. This spectrum varies greatly, and depends on the season in which the experiment was started, the habitat position of the substrate, and the environmental endurance of the settlers.

Not all subtidal mangrove life is restricted to the bottoms and roots. Fishes of all size and age classes hide or feed in the water column around the red mangrove roots and along the banks. Many of these depend on plankton, such as copepods and other small crustaceans (shrimp-like animals), for food. Members of both groups form characteristic swarms during the day. Smithsonian's Frank Ferrari teamed up with Julie Ambler, Texas A&M University, Ann Bucklin, University of Delaware, and Richard Modlin, University of Alabama, to study the systematics, ecology, and genetics of the swarms and found population densities much greater than expected. They counted more than 2,000 copepods per cubic meter of water in a small bay at night, and estimated 100 million individuals congregated during the day in a band of swarms along a 1,000-meter stretch of channel bank.

The Intertidal Mangrove Swamp

Although the tidal range in the Caribbean is small, in shallow coastal areas it can strongly influence current flow and distribution of organisms. At Twin Cays, the mean tidal range is only 15 centimeters, yet a combination of astronomical, geomorphologic, and meteorologic factors can cause a range of more than a half meter.

Red mangrove (*Rhizophora*) prop roots, black mangrove (*Avicennia*) pneumatophores,* peat banks, and mud flats are the typical substrates of the intertidal zone supporting distinctive communities. Barnacles (*Chthamalus*), wood boring isopods (*Limnoria*), oysters (*Crassostrea*), and "mangrove oysters" (*Isognomon*, not a true oyster) are the best known indicators of intertidal hard substrates, while fiddler crabs (*Uca*) are typical for the mud flats. Green algal mats (*Caulerpa, Halimeda*) are found exposed on peat-mud banks during low tide. The most abundant and characteristic intertidal mangrove community, however, is called the bostrychietum, named after the principal components of an association of red algae (*Bostrychia*, with *Catanella* and *Caloglossa*).

The bostrychietum (see page 16) has a remarkable water-holding capacity, which allows the plants and their associated animals to survive extended dry periods. We measured water loss rates in two of the substrate species and found evidence of two different methods of water retention. *Bostrychia* is a delicate, tufted plant that holds water primarily interstitially (between the branches). *Catenella* is more fleshy and less elaborately branched, and holds water intracellularly (within the cells), in its tissues.

Loren Coen, Dauphin Island Sea Lab, examined the animal associates of the bostrychietum, particularly in respect to grazing. He found that amphipods (*Parhyale*) become concentrated in the algal mats in high numbers during receding tides, and that their grazing on *Bostrychia* can match or exceed the algal growth. The mangrove tree crab, *Aratus*, and other crabs from the low-tide level were also found with large quantities of *Bostrychia* in their guts.

Desiccation and related problems of increased temperature and salinity in organisms subjected to exposure at low tide became particularly apparent during an extreme low tide in June 1983. A 20-centimeter zone below mean low-tide level became exposed during noon hours under a clear sky.

Large communities of low intertidal (rarely exposed) and subtidal (never exposed) organisms,

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* A feature of many mangroves is that some part of the root system is exposed to the atmosphere. In an oxygen-poor substrate, oxygen is absorbed directly from the atmosphere. In the black mangrove, these aerial roots, termed pneumatophores, occur as direct upward extensions of the subterranean root system.

such as occupants of seagrass meadows (including the turtle grass itself), and mangrove mud banks and stilt roots, were killed during the long exposure to desiccation. Estimates indicate that more species of algae and invertebrates, and much more living matter (biomass), were destroyed during those days of June than during two hurricanes combined (Fifi, 1974; Greta, 1978).

Collaborating eco-physiologist Joan Ferraris, Mt. Desert Island Biological Laboratory, is examining a number of organisms (sponges, sipunculan worms, shrimps, crabs) that are exposed to strong salinity-temperature stress in their natural environment. Results so far show a fine correlation between experimental tolerances in the animals and range of variability of stress factors in their natural habitat. In the case of sponges, regulatory mechanisms controlling water-ion balances are still unknown, but in the absence of organs, they must take place inside individual cells.

Unfortunately, the intertidal swamp is not only an exciting biological study zone, but also a gallery of pollutants. Even in this remote location every imaginable piece of floating debris discarded by man can be found, washed in by currents among the mangrove roots and deposited by the receding tides.

Mangrove Forest Above the Tide

Unlike the adjacent marine systems, the above-water flora and fauna of the mangrove-covered islands appear less complex and diverse. From the water, an unbroken, monotonous barrier of red mangrove trees confronts, and frequently intimidates, the casual explorer.

The species composition of the above-water plant community around Twin Cays is relatively simple. Three halophytic* tree species, known collectively as mangroves, dominate the natural vegetation on most of the islands: Red mangrove (*Rhizophora*), black mangrove (*Avicennia*), and white mangrove (*Laguncularia*). On cays with slightly higher ground, additional woody and herbaceous (soft-stemmed) halophytes are associated with the mangrove, such as buttonwood (*Conocarpus*), saltwort (*Batis*), and sea purslane (*Sesuvium*).

In general, mangrove forests have well-defined horizontal zonation. On these mangrove islands, the seaward and channel margins typically are fringed by dense, 4- to 10-meter-tall stands of red mangrove. Behind this fringe, the red mangrove is usually more open and shorter, with black and white mangroves intermixed. The zonation is easily recognized: dull gray-green spires of black mangrove, and flattened, yellow-green crowns of white mangrove stand slightly above and behind the dark green dome of the fringing red mangrove.

The interiors of some of the larger islands off Belize, like Twin Cays, have several extensive, unvegetated mud flats and shallow ponds. Numerous stumps throughout the mud flats are evidence that the trees that once grew there fell victim to some environmental stress. The red mangrove trees growing around the margins of the mud flats and in the ponds are severely stunted and widely spaced. Over the years, these natural bonsai have been distorted and pruned by their environment into fantastic forms, seldom more than 1.5 meters tall.

The above-water fauna on the cays is considered by most investigators to be introduced from the Belizean mainland. Even on the largest mangrove islands, most of the "land" is intertidal; therefore, the only environments available to terrestrial animals are arboreal. The fauna is limited to birds, lizards, snakes, snails, and arthropods, such as land crabs, spiders, and insects. These animals probably reached the cays from the mainland by flying, or rafting on or in pieces of wood and other floating debris.

A few land bird species have established permanent breeding populations on the mangrove islands. Warblers, vireos, hummingbirds, cuckoos, grackles, and white-crowned pigeons are among the permanent residents. Several of the islands also provide nesting sites for ospreys. These birds frequently build their nests atop tall snags of black mangrove.

At Twin Cays, the green-back heron is the most commonly observed wading bird. It breeds on the island, and builds its twig nest in the red mangrove fringe along the channels. It is frequently seen diving for small fish in the shallow, interior ponds. The most conspicuous birds of the area are the brown pelican and frigatebird, which fly overhead or perch in mangrove trees.

Insects are, by far, the most diverse and abundant group of above-water animals inhabiting the Belizean mangrove cays. Ants, in 28 or so species, are clearly the most abundant. Termites, because of their huge nests and extensive covered walkways, are the most conspicuous. Some major groups of insects, such as bees, are poorly represented in mangrove fauna. As is other tropical ecosystems, a large percentage of the insect species that we have found associated with mangroves are undescribed.

Conclusions

The red mangrove fringe, the specialized vegetation, the physical environment, and the associated fauna and flora form a complex and diverse island community above water as well as below. We have learned that mangroves produce fine sediments and organic detritus, and stabilize them by modifying the wave and current regime of the open lagoon. The inventory of species has yet to be completed, but already we have shown that most phyla are represented by species of which 10 to 25 percent, and in some cryptic (having a hidden or concealed lifestyle) microscopic-sized groups, up to 60 percent, are undescribed. The mangrove swamp is rich in recycled nutrients and high in production rates, but its occupants are severely stressed by factors such as

text continued on page 24

* A plant growing in salty soil or salt water, termed a halophyte, has unique physiological characteristics that enable it to obtain fresh water, excrete salt, and reduce fresh water loss.

A Gallery

"Boston Bay," Twin Cays. In the foreground are prop roots of red mangroves (Rhizophora). *(Photo by K. Rützler)*

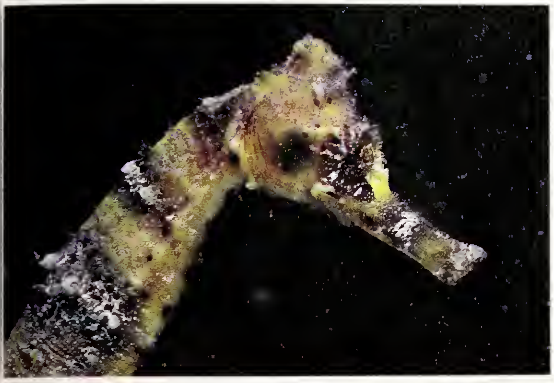
Stinging sea anemone (Bunodeopsis) *on turtle grass. (Photo by G. Miller)*

Black mangrove (Avicennia) *pneumatophores. (Photo by M. Parrish)*

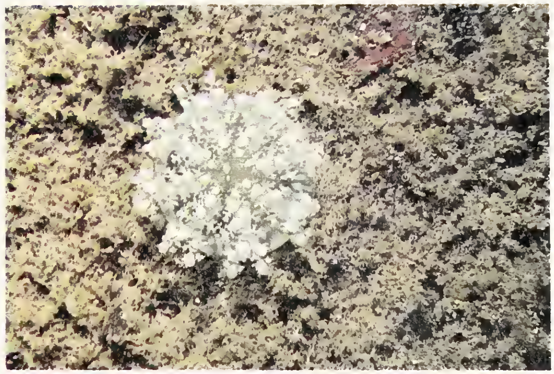
Sponges, ascidians, and anemone on a submerged root. (Photo by K. Rützler)

Clapper rail. (Photo by S. Canupp)

# of Mangrove Life



Seahorse (Hippocampus). *(Photo by G. Miller)*



Young upside-down jellyfish (Cassiopea) *on mud bottom. (Photo by K. Rützler)*

Mangrove oysters (Isognomon). *(Photo by K. Rützler)*

Starfish (Oreaster). *(Photo by K. Rützler)*

Drift goods deposited by the tides under black mangroves. (Photo by M. Parrish)

Carrie Bow Cay Field Station

A small field station located just behind the barrier reef in Belize has served as a base for research by the Smithsonian Institution and other scientists since 1972. The facility has been made possible largely through the generosity of the Bowman family, whose members have lived in the Stann Creek District of Belize for several generations. Being naturalists in their own right, the Bowmans were easily convinced to dedicate part of the island to research on the biology and geology of Belize's barrier reef.

Since its founding in 1972, the National Museum of Natural History's coral reef field station has undergone continuous improvements. Some changes were necessitated by research requirements, others by the devastating effects of hurricanes Fifi (1974) and Greta (1978). The original buildings on the small island of Carrie Bow (at present, about 0.4 hectares, or 1 acre), consist of an old plantation house, carried disassembled across from the mainland, and two smaller cottages. During most of the 1970s, the small cottages and parts of the big house provided sleeping space for only six persons, and necessitated combining the laboratory and workshop into a single room. A small kitchen provided cooking space. Electricity supplied by a small portable generator was limited to short periods during the day and evening.

After damage from hurricane Greta in 1978, the laboratory cottage had to be rebuilt. It was enlarged by adding a second story, thus providing additional sleeping space and allowing the research laboratory and workshop areas to be separated. The old outdoor aquarium system with low-volume seawater flow was improved by increasing capacity and enclosing the area with wood siding and windows to protect it from the weather.

In 1985, a new agreement with the Bowman family allowed expansion of living and laboratory space to the upper level of the big house. The resulting renovations added badly needed dry space for instruments, library, and computer. At the same time, the smallest cottage was replaced by a better designed, larger building serving as a dormitory, and a new, separate, and sound-isolated compressor and generator house was built. Other renovations include boat moorings, water tanks and showers, kitchen, and replacement of all electric wiring and fixtures. Some new equipment was added, such as a 4-kilowatt diesel generator, two new 5-meter dive boats, two microscopes, a centrifuge, an electronic balance, air and water filtration systems, and two propane-gas refrigerators. To improve safety, the boats were provided with radiophones compatible with the station's main radio, and a radio-telephone line was established to the Royal Air Force Helicopter Detachment in Belize City, who helped develop logistics for emergency evacuation in case of a diving accident. Plans for 1988 call for an increased seawater capacity with larger pumps, a solar power system, and a 6,000-liter storage tank, and for improved water quality by extending the water intake pipe to the fore reef.

Finally, in step with the upscaled mangrove study, we established a self-contained weather station in Twin Cays, 4 kilometers to the northwest. Meteorological and oceanographic sensors are automatically scanned every half hour, and data sent via radio to a portable computer on Carrie Bow Cay. By mid-1988, transmitted data will also be received at the International Airport, Belize, for evaluation and use by the Meteorological Office.

—Klaus Rützler, and Mike Carpenter

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salinity and temperature fluctuations, desiccation potential, abundance of fine sediments, and shortage of firm substrates. Space, from the sea bottom to the tree tops, is distinctly partitioned by the animals that exploit this specialized plant community. These intertidal islands, because of their isolation from the Belizean mainland, provide us with ideal locations to study pure mangrove communities in the Caribbean.

Klaus Rützler is Curator of Lower Invertebrates and Program Director of Caribbean Coral Reef Ecosystems (CCRE), National Museum of Natural History, Smithsonian Institution, Washington, D.C. Candy Feller is a freelance scientific illustrator, presently based in McAlester, Oklahoma.

Acknowledgment

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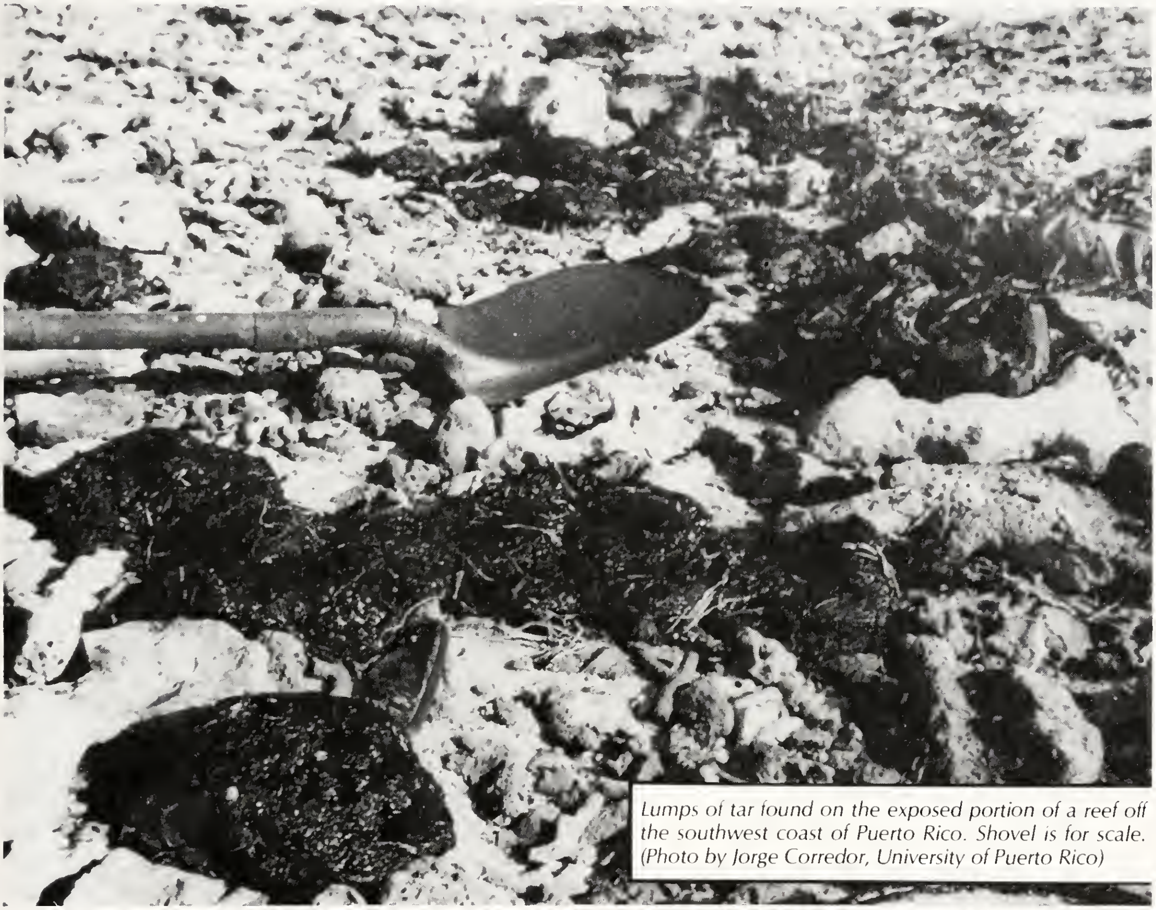
Petroleum Pollution



Lumps of tar found on the exposed portion of a reef off the southwest coast of Puerto Rico. Shovel is for scale. (Photo by Jorge Corredor, University of Puerto Rico)

in The Caribbean

by Donald K. Atwood, Fred J. Burton, Jorge E. Corredor, George R. Harvey, Alfonso J. Mata-Jimenez, Alfonso Vasquez-Botello, and Barry A. Wade

The title for this article, by its very existence, presumes a problem. That is, if one writes about petroleum pollution in the Caribbean, there must be some. Such a presumption contradicts perceptions of the Caribbean as an area of idyllic islands surrounded by clear, warm seas and beautiful, fringing reefs. Does such pollution exist? If so, where does it come from, what effects does it have, and what were the reasons for investigating its existence in the first place?

We will answer the last of these questions first, and because of its obvious oceanographic connection, we will include the Gulf of Mexico in our considerations.* In 1976, the Intergovernmental Oceanographic Commission (IOC) in Paris, the United Nations Environment Programme (UNEP) in Nairobi, Kenya, and the United Nations Food and Agriculture Organization in Rome, all of which have interests in the Caribbean/Gulf of Mexico (or "American Mediterranean," as this area is often called), convened a meeting of scientists from that region in Port of Spain, Trinidad, to discuss what needed to be done regarding a growing concern over marine pollution. Although this group recognized numerous local pollution problems in the region (for example, lack of sewage treatment facilities for coastal urban centers, and agricultural runoff), their report, as published by the Intergovernmental Oceanographic Commission (IOC) in Paris (see Selected References), noted that petroleum pollution was of region-wide concern, and recommended that the organizations present initiate a research and monitoring program to determine the severity of the problem and monitor its effects.

CARIPOL

Two of these agencies, the IOC and UNEP, followed up on this recommendation. The IOC worked cooperatively with a Steering Committee of regional scientists to design a program that would 1) provide necessary information, and 2) allow laboratories from throughout the region to participate without expensive, sophisticated equipment. UNEP provided funds to train participants, and for symposia to present, discuss, and publish the results. The program was named CARIPOL, for CARIbbean POLlution research and monitoring, and the Steering Committee designed a program to monitor three parameters related to petroleum pollution:

- **Tar on beaches.** Tar to be collected from the water line to the back of the beach along 1-meter transects, weighed, and reported as grams of tar per meter of beach front.
- **Floating tar.** One-meter-wide neuston nets (designed to skim the ocean surface, sampling the upper few centimeters) to be towed from a vessel outside the vessel wake for a known time and vessel speed. The tar collected to be weighed and reported as milligrams of tar per square meter of sea surface.
- **Dissolved/dispersed petroleum hydrocarbons (DDPH).** One-gallon samples to be collected in carefully cleaned, small-mouth bottles suspended on a 1-meter tether from a surface float. The petroleum to be extracted from this sample using nanograde (ultrapure) hexane, and the amount extracted to be estimated using a technique called ultraviolet spectrofluorescence. A compound called chrysene (similar to the most toxic constituents in petroleum) to be used as the standard for this measurement.

In the summer of 1979, some of the region's worst fears regarding petroleum pollution were realized when a well drilled by the Mexican government's national petroleum company (PEMEX IXTOC–1) blew out in the southern Bay of Campeche (in the southern Gulf of Mexico), and became the greatest single oil spill in history. In September of that year, and in the face of the IXTOC disaster, governments in the region, which had agreed to participate in CARIPOL, sent scientists and technicians to the University of Costa Rica in San Jose to be trained in making the standard CARIPOL observations. Training was conducted in both English and Spanish, and detailed method manuals were published in both languages. By 1980, the program was operational, and data were being reported to a central facility operated by the U.S. National Oceanic and Atmospheric Administration (NOAA) in Miami, Florida. Figure 1 shows the region throughout which data were collected, as well as the countries that participated.

During the following six years, CARIPOL participants provided data on more than 9,000 observations throughout the region. Participants varied from national park rangers in Bonaire who sampled beaches to university professors in Costa Rica, Cuba, Jamaica, Mexico, Trinidad, the United States, and Venezuela to naval personnel in Colombia. The data set collected was the largest and most complete in the world, and allowed some significant conclusions regarding the status of petroleum pollution in the Wider Caribbean and its effects.

Tar on Beaches

CARIPOL participants provided significant amounts of beach tar data from throughout the region (Figure 2). Although the scale in Figure 2 prevents good resolution of the data in many locations (especially for more than 5,000 data points in Trinidad and Tobago), the figure clearly indicates that 1) there are substantial data through much of the region (there is a noteable lack in the northern Gulf of Mexico), and 2) the problem of beach contamination by tar is serious in many locations, with numerous beaches having average concentrations in excess of 100 grams per meter of shore front.

Experience throughout the region indicates that when beach tar values reach 10 grams per meter, persons using the beaches commonly get tar on their feet. At values approaching 100 grams per meter, the beach becomes virtually unuseable for tourist purposes. Given the fact that many of the region's economies depend extensively on tourism, the high incidence of contamination in excess of 100 grams per meter is a serious problem. The high concentrations of tar on beaches in the southern Bay

* Throughout this issue of *Oceanus*, "the Caribbean" is defined as the waters and countries of the Caribbean Basin—the Lesser Antilles, Greater Antilles, countries bordering the western and southern rim, and the Caribbean Sea. In this article, because of oceanic and geographic links, the scope is expanded to what is sometimes termed the "Wider, or Greater Caribbean"—a designation that includes the Gulf of Mexico and parts of Florida.

Figure 1. The Caribbean pollution research and monitoring (CARIPOL) area, with participating countries identified.

of Campeche and the east coast of Yucatan in Mexico, the southeast coast of Florida, the Cayman Islands, the area near Kingston Harbor in Jamaica, Curacao, and beaches on the windward side of islands such as Barbados, Grenada, Trinidad, and Tobago are of special concern. In fact, windward coasts are seriously contaminated throughout the region as evidenced in Figures 3 (Trinidad and Tobago), and 4 (the Florida Peninsula). In each of these cases, beaches exposed to the prevailing southeast trade winds are significantly more contaminated than beaches on the leeward side of the landmass. This is interpreted as evidence that the source of much of the tar is upwind throughout the region, and clearly the result of factors beyond the control of the individual governments involved. Beach contamination is particularly serious in Grand Cayman, where there is no domestic petroleum activity. However, this island is located in an area adjacent to heavy tanker traffic that moves through the Yucatan Strait and Windward Passage.

In several areas, beach pollution levels have been serious for many years. In Florida, for example, a comparison of recent results to studies by the

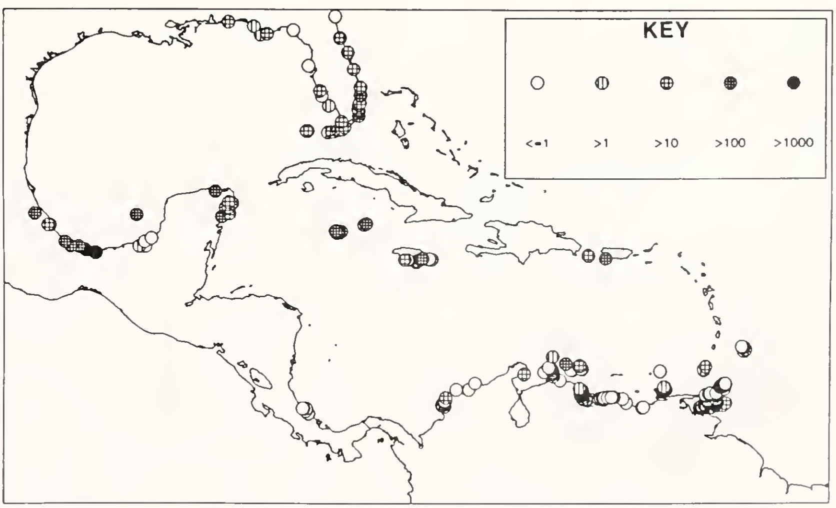


Figure 2. Average concentrations of beach tar in grams per meter of beach front for each site sampled in the CARIPOL petroleum pollution monitoring program. The average concentration at each sample site is shown as a shaded circle.

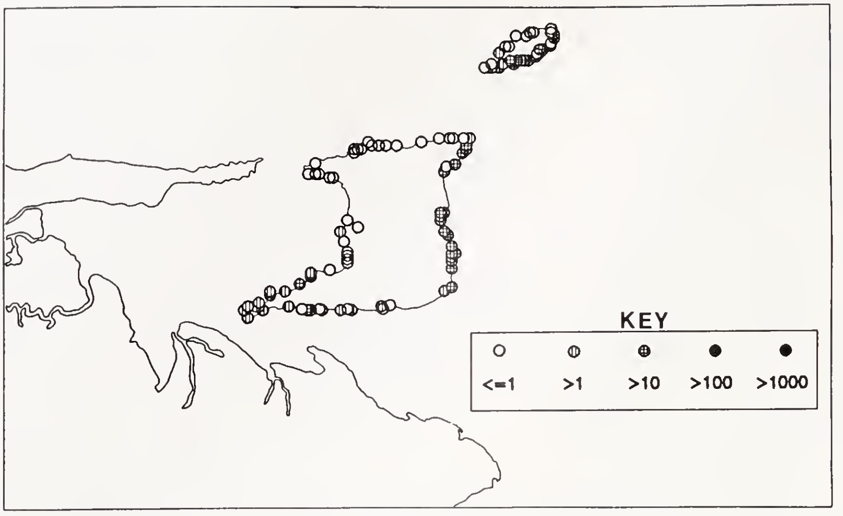


Figure 3. Average concentrations of beach tar at sampling sites in Trinidad and Tobago. Concentrations are depicted by shaded circles.

American Petroleum Institute in 1959 and 1974, indicates that the level of contamination on southeast Florida beaches has been about the same since 1958. Thus, despite continuing concerns, as expressed in continuing newspaper accounts in southeast Florida, levels of beach tar contamination have changed very little during the last 30 years.

Floating Tar

The CARIPOL data base on floating tar, with 681 records, is the smallest of the three parameters measured. The major portion of these data were taken in the Gulf of Mexico in programs conducted by Mexico (Universidad Autonoma de Mexico) and the United States (University of South Florida and NOAA) (Figure 5). Some very pertinent points can be made using these data when considered in the light of regional current patterns. Figure 6 is a composite plot of satellite-tracked buoy trajectories in the Caribbean Sea and Gulf of Mexico in 1975 and 1976 (as measured by a group headed by Robert L. Molinari of NOAA's laboratory in Miami). Superimposed on the buoy tracks is a schematic depiction of the average position of the major flow through the system. This flow enters through the southeastern passes of the Lesser Antilles arc, moves through the Caribbean as the Caribbean Current, traverses the Eastern Gulf of Mexico as the Gulf Loop Current, or Loop Intrusion, and exits through the Straits of Florida (between Florida and Cuba) as the beginnings of the Gulf Stream.

At times the Loop Current "pinches off" just north of the Straits of Yucatan and becomes an eddy that moves westward through the Gulf while the major flow exits directly through the Straits of Florida until the Loop Current is "rebuilt." Floating-tar concentrations are higher in the Loop Intrusion and southern Straits of Florida than in adjacent areas. Similar high concentrations exist in the Eastern part of the Caribbean coincident with the average

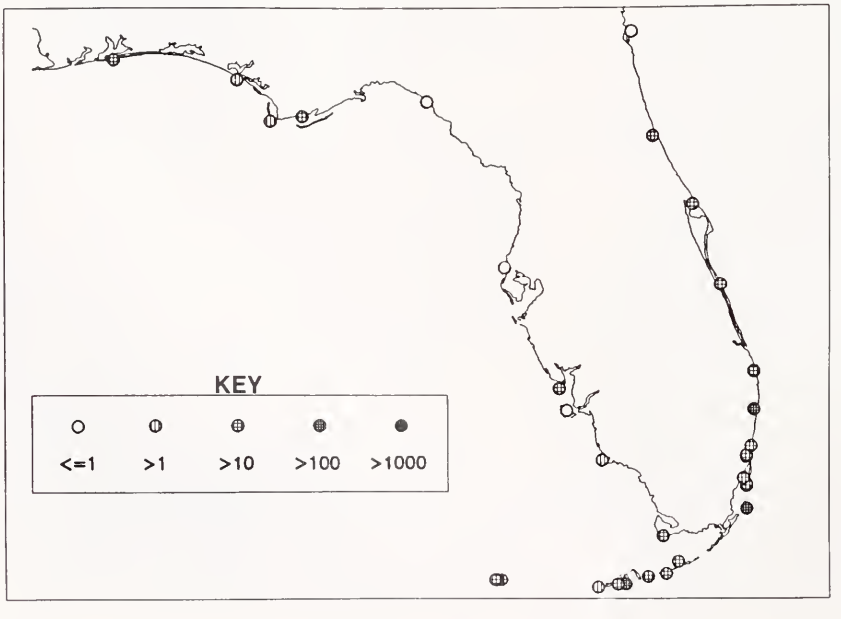


Figure 4. Average concentrations of beach tar at sampling sites along the coasts of the U.S. Florida peninsula. Concentrations are depicted by shaded circles.

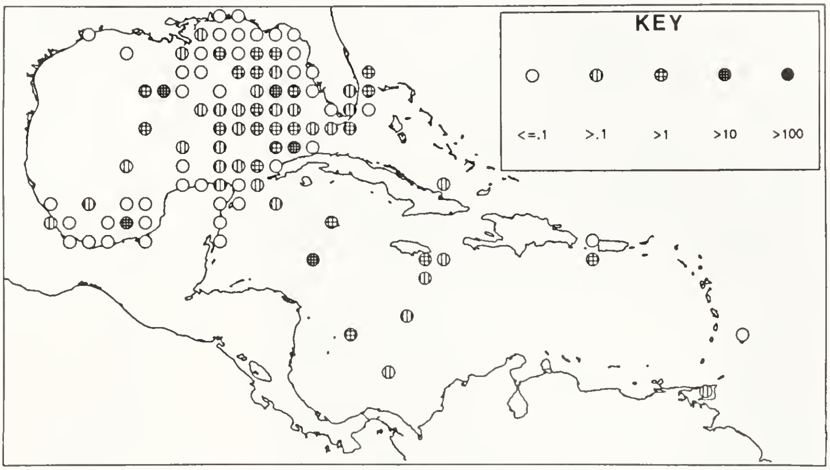


Figure 5. Average concentration of floating tar in milligrams per square meter for each 1-degree square for which CARIPOL data exist. The average concentration for each square is shown as a shaded circle in the middle of that square (thus, some circles appear on land).

position of major east-west flow in that area. Scientists at NOAA's Miami laboratory analyzed floating tar data collected by the United States in the Gulf of Mexico and Straits of Florida and similarly concluded that floating tar concentrations are significantly higher within the Loop Instrusion and the Southern Straits of Florida.

Comparison of floating tar concentrations in the CARIPOL data base to those observed in the 1970s in global IOC program on petroleum pollution monitoring, called Marine Pollution Monitoring Program for Petroleum (MAPMOPP), show that where overlap occurs between the CARIPOL data and the relatively sparse MAPMOPP data in the region, average concentrations are very similar. This demonstrates that 1) data from the two programs compare very well and 2) the situation probably has not changed significantly during the last decade.

Dissolved/Dispersed Petroleum Hydrocarbons

The CARIPOL data base contains 1,464 records for dissolved/dispersed petroleum hydrocarbons (DDPH). The data are plotted in Figure 7. The results of a careful intercalibration exercise, held at the Bermuda Biological Station in St. George's, Bermuda, in 1985, indicate that values greater than 0.1 microgram per liter can be considered significant. Based on experience within the Wider Caribbean, including experience in the Bay of Campeche during the 1979 IXTOC-1 oil well blowout, the background level for DDPH in the Gulf of Mexico seems to be best stated as 1 to 10 micrograms per liter.

This is borne out by Figure 7, where the majority of the values shown are greater than 1.0 micrograms per liter, with many values near Yucatan and in the Gulf of Mexico greater than 10.0 micrograms per liter. This Gulf of Mexico background level is more than an order of magnitude higher than the 0.1 to 0.2 micrograms per liter observed during the 1970s MAPMOPP program for areas that were not obviously contaminated, and for which a reasonable statistical sampling existed—for example, the Western Pacific and parts of the Mediterranean.

If we accept the MAPMOPP data as correct, and there is no reason not to, we must conclude that the Gulf of Mexico is significantly contaminated with DDPH relative to "clean" areas sampled in the

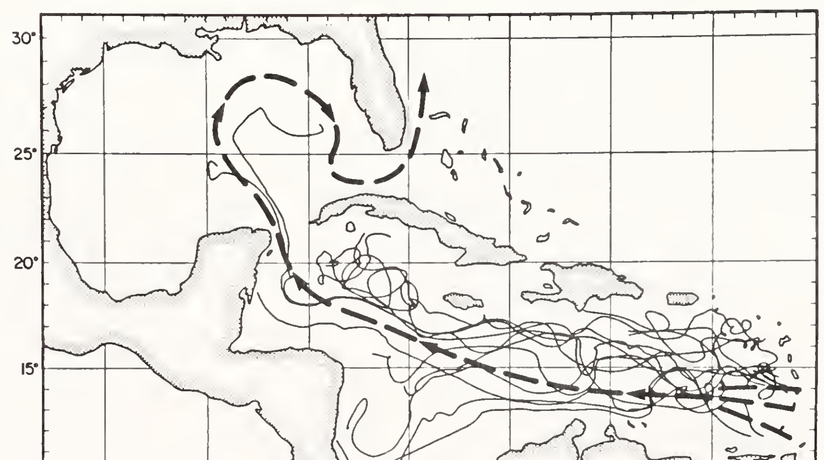


Figure 6. Composite plot of satellite-tracked buoy trajectories collected in the Caribbean Sea and Gulf of Mexico from October 1975 to June 1976. The heavy dashed line represents the major flow through the system when the Gulf Loop Current is intact in the Gulf of Mexico.

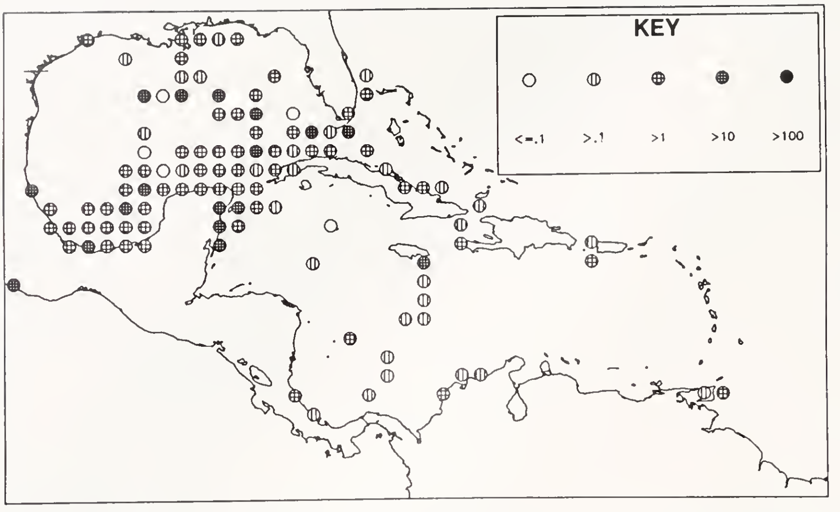


Figure 7. Average concentration of dissolved/dispersed petroleum hydrocarbons (DDPH) in micrograms per liter for each 1-degree square for which CARIPOL data exist. The average concentration for each square is shown as a shaded circle in the center of that square (thus, some circles appear printed on land).

MAPMOPP study. This is particularly true in the numerous locations where average values exceed 10 micrograms per liter. Contamination is not obvious for the Caribbean Sea itself from the CARIPOL data set, except for the east coast of Yucatan, and the area near Kingston Harbor in Jamaica. However, the extent of CARIPOL sample coverage for DDPH in the Caribbean is sparse.

NOAA/Miami scientists during their analysis of floating tar and DDPH data for the Gulf of Mexico and Straits of Florida, as part of this CARIPOL study, showed significantly higher DDPH values for the Southern Straits of Florida—just as they had for floating tar. They also showed that, for the regions they examined, the average values of DDPH and floating tar covaried—that is, when one was high for a region, so was the other.

Ocean waters contain populations of bacteria capable of metabolizing petroleum, which, when presented with quantities of petroleum, rapidly grow and consume the oil. Thus, the high level of DDPH contamination in the Gulf of Mexico is an indication that these bacteria are not able to remove it faster than it is replenished. This in turn indicates that there is a constant, fresh input of DDPH to this area.

Sources of Petroleum Contamination

In an effort to identify probable sources of the petroleum contamination documented above for the Wider Caribbean, it is beneficial to review major observations made in the regional monitoring of beach tar, floating tar, and DDPH. They are as follows:

- Windward exposed beaches throughout the region from Barbados to Florida are heavily contaminated with tar relative to leeward exposures.
- Surface waters of the major east-to-west flow in the region, that is, the Caribbean Current, the Gulf Loop Intrusion, and the Straits of Florida contain significantly more floating tar than adjacent areas.
- Waters of the Gulf of Mexico and those south of the Yucatan Strait are chronically contaminated with DDPH at a level an order of magnitude higher than that measured in uncontaminated areas during the 1970s MAPMOPP project. This chronic, high level of DDPH is an indication that there is a constant, fresh input of petroleum to these waters.
- Highest levels of petroleum contamination in the region exist within, and adjacent to, waters with extensive petroleum tanker traffic, for example, the Cayman Islands and the Straits of Florida.

In addition to these regional observations we can add some very pertinent findings from individual country programs as reported at the CARIPOL Petroleum Pollution Monitoring Symposium held in La Parguera, Puerto Rico, in December 1985. These are as follows.

Julio Morell and Jorge Corredor of the University of Puerto Rico reported a time series of floating tar observations off the Southwest coast of Puerto Rico in which the level of contamination dropped significantly as tanker traffic from a nearby petroleum refining complex declined. These scientists concluded that at least 50 percent of the variability in their data can be explained by variations in tanker traffic.

Fred J. Burton of the Mosquito Research and Control Unit on Grand Cayman reported the high levels of contamination on and near Grand Cayman, Cayman Brac, and Little Cayman Islands, which are all adjacent to major tanker routes. Studies using sophisticated techniques called "ultraviolet fluorescence excitation/emission," and "glass capillary gas chromatography" in examination of tar found on beaches of these islands indicated that 80 percent of the samples examined had a crude oil source with spectra similar to Arabian and/or Alaskan crudes.

In cooperation with local airline pilots, Burton also documented the existence of slicks near the Cayman Islands. Twelve such slicks were documented. All were narrow (about 0.5 kilometers wide) and long (up to 100 kilometers). In three cases, these slicks were observed as being released from ships, two of which were tankers either cleaning tanks (February 1982), or discharging ballast (October 1985). All 12 slicks were sighted in the early hours of daylight, indicating that releases were occurring at night. Additionally, a decline of beach contamination on Cayman Brac and Little Cayman was noted when oil transshipment operations near these islands virtually ceased in 1982.

Barry A. Wade and graduate students at the University of the West Indies, Kingston, Jamaica, campus used techniques similar to those used by Burton. They demonstrated that most contaminating oil found on the South coast of Jamaica was similar to Venezuelan crude oil, which is the crude most commonly imported into Jamaica. Interestingly, oil on Jamaican beaches with a northeast exposure did not exhibit these characteristics, indicating that oil on these beaches had a different origin. The rate of tar arrival on south coast beaches was estimated at 1.4 grams per meter per day, but at times of "documented near-shore tanker washing," this could reach 400 grams per meter per day. The authors concluded that the principal source of tar contamination was illegal ballast washing and discharge from tankers.

Edward Van Vleet of the University of South Florida in Tampa demonstrated that pelagic tar levels in the eastern Gulf of Mexico and Straits of Florida were substantially higher than in most other areas of the world, and that as much as 50 percent of this tar entered these areas from the Caribbean through the Yucatan Strait. Gas chromatographic analyses of this pelagic tar showed that 50 percent of the floating tar had chemical characteristics diagnostic of tanker ballast washings. This lead to the conclusion that 50 percent of the pelagic tar in these areas was from tanker discharges.

Given the above observations, we conclude that as much as 50 percent of the floating tar and beach tar throughout the Wider Caribbean region comes from the adjacent North Atlantic gyre system, and is carried to and through the region by the prevailing winds and currents. The fact that the 1970s MAPMOPP data show high floating tar concentrations in the adjacent North Atlantic supports this conclusion.

However, there is obviously significant fresh input of petroleum directly in the region, as evidenced by the chronically high DDPH levels. Correlation of high floating tar and beach tar levels with petroleum tanker operations, and the unique gas-chromatography profiles of 50 percent of the floating tar in the eastern Gulf of Mexico and Straits of Florida, shows that most of this fresh input is from petroleum tanker ballast washings. The remainder is probably from petroleum drilling and production operations, for example the PEMEX operations in the Bay of Campeche, as well as from natural seeps. As noted previously, the southeast Florida level of beach tar contamination has been about the same for 30 years. There are a number of possible explanations for this. One is that despite increasing success at controlling release of petroleum from tankers, tanker traffic in the area has increased so much that the level of pollution is still the same. Another, less plausible explanation is that beach

CARIPOL scientists recovering a neuston net towed at the sea surface to sample for floating tar. (Photo by Jorge Corredor, University of Puerto Rico)

contamination in the late 1950s was the result of ships sunk during World War II (1940 to 1945), which were still breaking up, thus releasing the petroleum trapped in their hulls. In this scenario, the present high pollutant levels result from existing tanker traffic.

Effects of Petroleum Contamination

There are clearly adverse effects from the petroleum contamination existent in the Wider Caribbean. One obvious effect is the serious soiling of beaches in an area where tourist use of these beaches is important to state economies. This is a problem throughout the region. In southeast Florida, beaches are continually cleaned to allow tourist usage—with a secondary result of increased beach erosion. It is clear that any tourist development on windward exposed beaches in the region will have a significant tar problem.

Floating tar has adverse effects other than when it is blown ashore on beaches. University of South Florida scientists, Edward Van Vleet and G. Pauly, in results presented in a CARIPOL Symposium in 1985, analyzed internal organs and feces from threatened and endangered marine turtles collected around Florida. Results indicate that these turtles feed on floating oil, and that this oil may remain in the turtles' digestive tracts for several days. Tar scraped from the mouths of many of these turtles had the same chemical characteristics as that of tanker ballast washings. They also noted that the highest incidence of stranding of dead sea turtles in Florida is along the southeast Florida coast, an area adjacent to the heavily contaminated Florida Straits, and coincident with the highest concentrations of beach tar in the entire Florida Peninsula.

The effects of DDPH are not as readily documented. The IXTOC-1 blowout experience showed that the gross contamination from that event was largely assimilated by the system through such processes as bacterial degradation and chemical degradation as the result of sunlight. However, then, as now, it was observed that the Gulf of Mexico background of DDPH was in the range of 1 to 10 micrograms per liter, that is at least an order of magnitude greater than that observed in uncontaminated areas during the 1970s MAPMOPP study. This chronic exposure to the most toxic portion of petroleum, polycyclic aromatic hydrocarbon (PAH) is probably affecting marine life. For example, numerous studies have been made on an enzyme system response to PAH exposures in marine organisms. One recent study conducted by J. M. Davies, J. S. Bell, and C. Houghton (as reported in *Marine Environmental Research* in 1984) examined fish caught at various distances from North Sea oil drilling operations, where oil-base muds were used, and drill cuttings discarded over the side at the drilling sites. Sediments within 1.0 kilometer of these sites had total PAH concentrations of about 10,000 nanograms per gram, which we estimate would cause water column exposures no greater than that observed in the Gulf of Mexico. Their results show a statistically significant enhancement of enzyme oxidation of ingested hydrocarbons in two fish species (cod and haddock) caught in sediment contaminated areas, as opposed to clean areas. The authors interpret this result as evidence that the contaminating oil is biochemically available to these fish, resulting in a response of the fish enzyme systems. They point out that such enzyme response has been inversely correlated with reproductive success in flatfish along the coast of California.

Summary

- A significant level of petroleum pollution exists throughout the Wider Caribbean. Manifestations of this pollution include serious tar contamination of windward exposed beaches, high levels of floating tar within the major currents system, and very high levels of dissolved/dispersed hydrocarbons in surface waters.
- The sources of petroleum pollution in the region include oil entering from the adjacent North Atlantic (50 percent) and tanker ballast washings (50 percent).
- Effects of this petroleum pollution include:
  1) tar levels on many beaches that either prevent recreational use, or require expensive clean-up operations,
  2) probable distress and death to marine organisms, such as endangered turtles who feed on floating tar; and
  3) responses in the enzyme systems of marine organisms that have been correlated with declines in reproductive success.

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Caribbean Marine Resources:

A Report on Economic Opportunities

by A. Meriwether Wilson

Marine resources in the Caribbean Basin are being overlooked, undervalued, and even destroyed at an alarming rate. Historically, these resources have provided a livelihood for many people in the region, as well as revenue to the islands whose shores are surrounded by this complex body of water. But today, as many of these resources are in jeopardy, information, particularly about the economic potential, is needed—as all Caribbean nations face important policy decisions on the use and development of their marine resources.

Recognizing the urgent need for a balanced and sustainable development of Caribbean marine resources, the U.S. Agency for International Development (USAID) and the U.S. National Oceanic and Atmospheric Administration (NOAA) recently completed a joint study entitled "Caribbean Marine Resources: Opportunities for Economic Development and Management." The report from the study, summarized in this article, gives projections for potential marine resources that could support economic advancement of the Caribbean Basin countries. It also reports on the present status of known resources.

Regional Overview

Nearshore Marine Habitats. The Caribbean Sea and many other tropical marine areas are a study in complex relationships. Coastal waters generally contain some of the world's most diverse and productive ecosystems, including coral reefs, seagrass beds, and mangrove forests. Through internal energy recycling mechanisms, these ecosystems manage to overcome the nutrient limitations of the relatively sterile tropical offshore waters.

One example of the complex relationships in tropical environments is that of the stony coral animals, which are responsible for building the limestone (calcium carbonate) reefs. These reefs form major parts of the bases, or platforms, of many of the Caribbean islands. The secretion of calcareous materials by these coral animals is enhanced by a unique symbiotic relationship between the host animal and a microscopic algae (zooxanthellae), which lives in the coral itself. Being plants, the latter algae require sunlight, and therefore clear waters, for growth. Mangroves (see article page 16) and seagrass beds are dependent on nutrient sources from in situ organic decay and nearby rivers.

It is this delicate physical, chemical, and biological linkage that creates and maintains these ecosystems, which in turn become resources for human use. Mangroves are nursery and breeding grounds for invertebrates, fishes, and birds; reefs are sources of sand for tourism, and also act as protective barriers during storms. Too often the importance of understanding these linkages and maintaining these habitats in their entirety is overlooked when assessing a marine habitat for its economic value and resource development potential.

These marine habitats are under constant stress from the very development activities that, ironically, form the crux of the economic opportunities for developing these resources. For this reason, a balanced approach is needed for determining human impacts on ecosystems, and in turn, the impacts of resulting environmental change on human health. Tourism, fisheries, shoreline and harbor construction, upland forestry, and agricultural activities are some of the major factors that affect nearshore habitats. When these activities are carried out without ecological consideration and caution, chemical pollution, sediment loading, and coastal erosion occur, which in turn may lead to loss of species, including humans, and entire habitats.

Opportunities for developing ecologically and economically sound nearshore resource activities include tourism (discussed here as a separate resource), marine protected areas, endangered species, harbor and port development, and fisheries enhancement. To manage resources based on ocean, coastal, and upland development projects, there needs to be a framework of governmental and institutional support.

Capture Fisheries and Mariculture. Fisheries resources include conch and lobster (exportable at high prices), offshore game fish, and mariculture opportunities—such as crabs, clams, and seaweeds. Most Caribbean fishery activities take place in nearshore areas, are small-scale in nature, and are carried out by local people for daily subsistence.

There are nearly 200 species of different reef finfish in some nearshore areas, presenting a multi-species resource with capture and management requirements that are different from the single-species resources that dominate open-ocean and temperate environments. Tropical fisheries vary greatly between environments. The small volcanic islands with narrow submarine shelves have limited nearshore fishery resources, while the Central and South American coasts, with wide continental shelves and increased nutrient resources from river runoffs, have more potential for higher yields.

The nature of a fishery industry in the Caribbean is closely related to the type of technology available. Many subsistence fishermen use canoes or sailboats with outboard motors. While there are increasing recommendations to advance the technology for locating and capturing fishery resources, this is often what creates the demise of a particular resource. The overexploitation of targeted species—for example, lobster, conch, and tuna—and the lure of higher paying jobs in the service sector have turned fishing into a part-time activity for most Caribbean fishermen. There are a few large-scale operations that exploit offshore species. These, however, are generally capital intensive, require larger vessels, and have extensive marketing and processing needs. These needs include being near urban ports or centers—a condition that is limited in the Caribbean (see articles pages 57 and 65).

As the nearshore fisheries are depleted through inadequate ecological knowledge, poor management, coastal and seaborne pollution, and habitat degradation, the need for high-quality protein for both the local and tourist markets continues to create pressure to expand offshore fisheries and increase fish imports. Yet these "new" underdeveloped resources will suffer the same fate of inshore fisheries stocks if management controls are not implemented.

The overriding constraints on developing fisheries in a sustainable manner include: limited knowledge of fish populations; inappropriate gear and technology; lack of marketing and processing facilities; poor infrastructure; few trained staff at all levels; and low priority in the governmental arena. Ciguaterra, a poison to the human nervous system found in some reef fish, is an increasing problem for both the local and tourist populations. It needs immediate monitoring and research efforts.

The culture of marine organisms—mariculture—is being considered as a solution to overfished waters, protein needs, and the need to reduce imports. Those countries with nutrient-rich estuarine bays, lagoons, and mangrove areas are

Distribution and status of threatened Caribbean coastal and marine animal species.

Species (Common Names)	Status	Country
Monachus tropicalis (Caribbean Monk Seal, West Indian Seal)	E	Mexico, Bahamas
Trichechus inunguis (Amazonian Manatee, S. American Manatee)	V	Col., Ven.
Trichechus manatus (Caribbean Manatee, N. American Manatee)	V	Mex., Bah., Cuba, D. Rep., Haiti, Jam., P. Rico, Trin./Tob., Belize, C. Rica, Guat., Hond., Nica., Pan., Col., Ven.
Pterdroma hasitata (Black-capped Petrel, Diablotin)	V	Haiti
Caretta caretta (Loggerhead Turtle, Tortuga de mar, Cares, Tartaruga domar, Uruana, Suruana)	V	Mex., Antig./Barbud., Bah., Cuba, D. Rep., Jam., Ne. Ant., P. Rico, Trin./Tob., C. Rica, Guat., Hond., Nica., Pan., Col., Ven.
Chelonia mydas (Green Sea Turtle, Tortuga Verde del Atlantico and Pacifico, Tortuga Blanca)	E	Mex., Antig./Barbud., Bah., Cay. Isl., Dom., D. Rep., Gren., Guad., Haiti, Jam., Mart., Ne. Ant., P. Rico, St. Luc., St. Vin., Trin./Tob., USVI, Belize, C. Rica, Guat., Hond., Nica., Pan., Col., Ven.
Eretmochelys imbricata (Hawksbill Turtle, Carey, Tortuga Carey, Tartaruga verdaderia and de Pente)	E	Mex., Antig./Barbud., Bah., Cay. Isl., Cuba, Dom., D. Rep., Gren., Guad., Haiti, Jam., Ne. Ant., P. Rico, St. Luc., St. Vin., Trin./Tob., USVI, Belize, C. Rica, Guat., Hond., Nica., Pan., Col., Ven.
Lepidochleys kempii (Kemp's Ridley, Atl. Ridley Sea Turtle, Tortuga Lora)	E	Mex.
Lepidochelys olivacea (Olive Ridley Turtle, Pacific Ridley Turtle, Tortugaverde, Parlama)	E	Mex., Cuba, P. Rico, C. Rica, Guat., Hond., Nica., Pan., Col., Ven.
Dermatemys mawii (Central American River Turtle)	V	Mex., Belize, Guat., Hond., Pan., Col., Ven.
Dermochelys coriacea (Leatherback, Leathery Turtle, Luth, Tortuga Tora, Barriguda, Tarataruga)	E	Mex., D. Rep., Grenadines, Guad., P. Rico, Trin./Tob., BVI, USVI, Belize, C. Rica, Nica., Pan., Col., Ven.
Caiman crocodilus crocodilus (Spectacled Caiman)	V	Trin./Tob., Col., Ven.
Caiman crocodilus fuscus (Brown caiman)	V	Mex., Cuba, Nica., Pan., Col., Ven.
Crocodylus acutus (Amer. Crocodile, Crocodilo, Lagarto Negro)	E	Mex., Bah., Cay. Isl., Cuba, D. Rep., Haiti, Jam., Ne. Ant., Belize, C. Rica, Guat., Hond., Nica., Pan., Col., Ven.
Ameiva polops (St. Croix Ground Lizard)	E	USVI
Family Anthipathidae (Black Corals)	CT	Caribbean Region
Strombus gigas (Queen Conch)	CT	Caribbean Region
Panilurus argus, P. guttatus (Spotted Spiny Lobster)	CT	Caribbean Region

Status Key: E—Endangered; V—Vulnerable; CT—Commercially Threatened; Source: International Union for the Conservation of Nature and Natural Resources/Cambridge Monitoring Centre, 1987—as cited in Goodwin and Wilson, 1987 (see Selected References).

Existing marine parks and protected areas in the Caribbean region.

Country	Protected Area Name	Estab.	Hectares	(Marine %)
Antigua	Diamond Reef Marine Park	1973	2,000	—
	Palaster Reef Marine Park	1973	500	—
Bahamas	Inagua National Park	1965	74,000	(10)
	Exuma Cays Land and Sea Park	1958	45,000	(80)
	Conception Island Land and Sea Park	—	810	(80)
	Union Creek	1965	1,813	—
Barbados	Barbados Marine Reserve	1980	—	(100)
Belize	Half Moon Cay Natural Monument	1982	4,144	(95)
	Hol Chan Marine Reserve	1987	—	—
British Virgin Islands	Wreck of the Rhone Marine Park	1983	323	(96)
Colombia	Parque Nacional Corales del Rosario	1977	18,700	—
	Parque Nacional Natural Tayrona	1969	15,000	—
	Parque Nacional Natural Isla de Salamanca	1969	21,000	—
	Santuario de Fauna Los Flamencos	1977	7,000	—
Costa Rica	Cahuita National Park	1970	2,000	(35)
	Tortuguero National Park	1970	18,947	(16)
Dominican Republic	Parque Nacional del Este	1975	43,400	—
	Samana Bay—Silver Banks Marine Sanctuary	—	—	—
Honduras	Rio Platano Biosphere Reserve	1980	350,000	—
Jamaica	Montego Bay Marine Park	1959	—	—
	Ocho Rios Marine Park	—	278	—
Martinique	Parc Naturel Regional de la Martinique	1975	—	—
Mexico	Isla Mujeres	—	—	—
	La Blanquilla	—	—	—
	Cancun-Nizuc-Isla Mujeres	—	—	—
	Arrecifes de Cozumel	1980	—	—
	Isla Contony	1960	—	—
	Ria Celestrum	1979	59,000	—
	Rio Lagartos	1918	47,840	—
Netherlands Antilles	Bonaire Underwater Park	1983	—	(100)
	Curacao Underwater Park	1983	—	(100)
Puerto Rico	Jabos Bay/Mar Negro	—	—	—
Saint Lucia	Maria Islands	1985	—	—
	Pigeon Island	1982	—	—
Trinidad and Tobago	Buccoo Reef and Bon Accord Lagoon	1970	—	(100)
	Caroni Swamp	1982	7,900	—
US Virgin Islands	Virgin Islands National Park, St. John	1963	6,073	(33)
	Buck Island Reef, St. Croix	1961	356	(80)
Venezuela	Parque Nacional Archipelago Los Roques	1972	225,143	—
	Parque Nacional Mochima	1973	94,935	—
	Parque Nacional Morrocoy	1974	32,090	—
	Laguna de Tacarigua	1974	18,400	—

Sources: International Union for the Conservation of Nature and Natural Resources, 1982, 1985; M. E. Silva, et al., 1986; Van'T Hoff, 1985—as cited in Goodwin and Wilson, 1987 (see Selected References).

potentially suitable sites for the development of commercially viable mariculture species, such as shrimp, crabs, conch, finfish, and seaweeds. While mariculture at first appears to be a cure-all, there are numerous constraints that have generated a poor success rate for many mariculture projects in the Caribbean. Mariculture requires a high initial investment of time, land, and money. There is a general lack of many of the elements that make up a successful mariculture project. These include adequate biological information on the cultured organisms, sufficient variability of seed and brood stocks, suitable culture sites, and adequate government support. Mariculture projects must also overcome the problems associated with introducing exotic species, new diseases in cultured animals, and numerous import/export regulations. Despite these seemingly overwhelming deterrents, the potential benefits from mariculture strongly support the continued development of projects on a cautious, pilot-scale basis.

Geological Resources. Hard minerals (sand, gravel, metal, phosphate, limestone, and salt) and oil reserves are the primary marine geological resources throughout the Caribbean region. The hard mineral resources are important potential low-cost resources, yet there is insufficient information and local technology available to acquire detailed information on their location, quantity, and quality. Petroleum resources are extensive in specific areas of the Caribbean. They are exploited primarily by national and international companies.

Although sand and limestone may appear to be ubiquitous resources, the mining techniques and removal of these resources cause some of the most severe impacts on marine resources. Limestone and sand come from the coral and algal banks that form much of the base of most Caribbean islands. As these minerals are dynamited and dredged for construction, there may be damage to adjacent reef habitats through loss of substrate for organisms to grow on. The resulting sedimentation in the water column reduces the amount of penetrating sunlight needed for coral growth.

Metal resources include high-value minerals, such as gold, platinum, titanium, and chromium, which are deposited on shelf areas by stream and beach processes.

Excavation studies are needed for all of these minerals, to identify source locations, current dynamics, and impacts on adjacent habitats. There also is a need for low-cost, high-resolution seismic profiling studies in those areas of the Caribbean with extensive continental shelves.

The Caribbean Action Plan of the United Nations Environment Programme (UNEP) considers petroleum pollution to be a major regional concern (see article page 25). Numerous beaches are polluted from oil spills, and covered with tar, thus making them undesirable for tourism. The impact of oil on marine turtles, birds, and coral reefs is an area of active research.

Radar and remote-sensing technologies can provide information on tracing a variety of pollutants such as sediment runoff, sewage, and petroleum. There need to be cooperative programs for information exchange and technological assistance between the regional, academic, and government agencies of developed and underdeveloped countries in the region.

Educational Resources. The need for appropriate education, training, and technical support in the Caribbean underlies the development of every resource mentioned in this article. Although there is increasing interest in the marine world, there is too often a focus on the short-term economic benefits rather than long-term resource values. Education is in itself a long-term resource, but one that has immediate opportunities at all levels of schooling and training. Many public and private marine research institutions suffer from a lack of funding, which often results in inadequate instrumentation and poor libraries. Educational opportunities suffer because of the low priority assigned to this resource by governments.

The Rosenstiel School of Atmospheric and Marine Sciences at the University of Miami in Florida is in the process of developing a computerized data base and electronic mail network for all published and non-published articles on Caribbean marine resources and environments. This effort should aid countries with limited library facilities.

Tourism. The seductive images of surf, sand, and sun have created a multi-faceted tourism industry in the Caribbean. This industry is having an effect on the gross domestic product (GDP) of individual countries, local employment opportunities, and foreign exchange earnings. Yet the development of tourism resources is also producing dire consequences for both the natural environments and the people who use them. The very resources that make up the attractions are being destroyed: examples include coral reefs, sand beaches, and clear waters. All these are subject to intense development pressure from construction activities, sewage pollution, and overfishing.

There also are numerous social consequences to a rapid expansion of tourism. Often social values of the local people are restructured and undermined by the financial lures of service-oriented positions. Visitor preferences may change over time as different trends in recreation come into vogue.

There are many types of marine-related tourism in the Caribbean, just as there is an array of users to support them; these activities include snorkeling and diving, yachting, tennis and golf, and nature experiences, such as bird and whale watching. There is an increasing interest in the "nature" types of tourism that have a potential to require less intense infrastructure—camping facilities, for example, rather than high-rise hotels. Many countries, however, are not immediately interested in low-tech, smaller-scale recreation projects, as they do not appear to bring in immediate high revenues.

There needs to be a balance between what environments have to offer, and what kind of income and employment generation a country wishes to develop. Each beach or scenic area that is being considered for development needs to be studied for its long-term ability to maintain a fresh water supply, to meet sewage requirements, and to sustain adjacent coastal ecosystems. It is generally felt that the average tourist uses twice as much water a day as the average island resident. Oil spills, sewage, and anchor damage from boats have harmful impacts on adjacent beaches, reefs, and seagrass beds.

Marine parks and protected areas are examples of tangible efforts to integrate resources and economic opportunities. These parks exist on a spectrum from strict conservation to intense recreation areas, each targeted to different audiences and resource management goals. The Organization of American States (OAS), Division of Regional Development, is presently conducting a study on the potential economic benefits of legally established marine protected areas. While many of these parks exist on paper, most do not have operational budgets, management plans, enforcement capabilities, or educational and recreational facilities. Endangered species legislation also can be a tourism opportunity in terms of developing awareness and preservation of a resource.

Tourism projects of any scale and style need to be evaluated in terms of sustainability of the environment, the users, financing options, infrastructure, and management needed to maintain the project. There needs to be an integration of public and private concerns throughout all project phases. It is only through such integration that tourism can continue to be a mechanism to expose and explore the marine resources the Caribbean is so fortunate to have.

Country Specifics

The following list of Caribbean nations is not comprehensive. Omission of a country does not imply a reduced importance. The following country-specific descriptions are designed only to provide general trends of marine resource needs and opportunities.

This presentation focuses on coastal uses, as this is the area most in demand for human settlement needs. Many countries have similar problems based on their common ecologies or development stages. The countries are grouped in an ecological orientation to identify common resource constraints and opportunities. Small islands generally have limited shelf areas and intense pressure on the coastal zone, while larger islands and continental areas have more rivers and other land-use opportunities to diversify economic resources.

SMALL ISLANDS

Antigua/Barbuda

Population/Land Area: 80,000/443 square kilometers.

Ecological Features: low flat volcanic island on coral platforms and narrow submarine shelves; white sand beaches, seagrass bays, fringing reefs.

Economic Resources: artisanal fishing (conch, lobster); traditional wooden boat building; sand mining to U.S. Virgin Islands; offshore oil leasing.

Tourism Elements: economic mainstay, 12 percent GDP, 25 percent labor force; government supports tourism infrastructure (roads, water) and marketing; yacht anchorages, historic and archaeological sites, beaches and reefs.

Resource Problems: excessive sand removal destroying reefs; overexploitation of lobster population; resort building on beaches.

Recommendations: enforce sand mining laws; establish one ministry for all coastal zone matters.

Protected Areas: Diamond Reef, Palaster Reef, Green Island.

Barbados

Population/Land Area: 240,000/431 square kilometers.

Ecological Features: low flat volcanic island on coral platforms, narrow submarine shelves; white sand beaches, mangroves, seagrass bays, fringing reefs.

Economic Resources: pelagic, demersal finfish; oil and gas production.

Tourism Elements: tourism service sector increased with decline in sugar production, 10 percent GDP, economic mainstay; attractions include beaches, caves, historical sites, and reefs.

Resource Problems: nearshore fisheries overexploited; coastal erosion from dredging and construction stressing reefs, changing water circulation patterns and quality; pollution from sewage, wastes, fertilizers.

Recommendations: need comprehensive coastal development plan; planning for water treatment and storage requirements.

Protected Areas: Barbados Marine Reserve.

Research Institutions: Bellairs Research Institute of McGill University; University of West Indies.

British Virgin Islands

Population/Land Area: 12,000/153 square kilometers.

Ecological Features: small clusters of low, hilly volcanic islands; mangroves, seagrasses, salt ponds, coral reefs.

Economic Resources: finfish, mangrove nurseries, turtle nesting sites.

Tourism Elements: 70 percent GDP, primarily yacht charters and cruise ships; primary basis for island development plans; sailing, beaches, reefs, and historic sites.

Resource Problems: mangroves cleared for tourism development causing loss of habitats and increasing sedimentation in seagrass and reef areas; boat anchors damaging reefs; domestic sewage problems.

Recommendations: legislation and planning to address mangrove clearing and sewage capabilities.

Protected Areas: Wreck of the Rhone Marine Park.

Dominica

Population/Land Area: 87,000/751 square kilometers.

Ecological Features: high rugged volcanic mountains, no coastal plain, numerous rivers and rain forest cover.

Economic Resources: hydroelectric power for all needs; artisanal fishing.

Tourism Elements: limited due to lack of beaches, potential focus on island's terrestrial natural resources, wildlife and historical features.

Resource Problems: hurricane devastation to reefs; maintenance of primary coastal road encouraging shoreline erosion, oil and ship wastes pollution.

Recommendations: use inland rock sources for beach and road stabilization; coastal setback policy and tourism planning needed.

Grenada

Population/Land Area: 115,000/344 square kilometers.

Ecological Features: numerous steep volcanic islands; mangroves, seagrasses, reefs.

Economic Resources: fisheries include nearshore and pelagic finfishes, lobster and conch; turtle nesting and breeding areas.

Tourism Elements: one major white sand beach, rainforests, historic sites, and shipwrecks.

Resource Problems: overexploitation of all fisheries; beach erosion near tourism centers and airport, coastal tree removal and sand mining increasing erosion; seaborne and solid waste pollution.

Recommendations: increase fisheries utilization management; survey sand resources; develop coastal setback policy; have coastal management under one ministry; develop environmental awareness of marine resources.

Montserrat

Population/Land Area: 12,000/98 square kilometers.

Ecological Features: high, rugged, volcanic island, rainforests.

Economic Resources: artisanal fisheries for lobster, conch, finfish; steel and traditional wooden shipbuilding industry.

Tourism Elements: 77 percent GDP, year-round retirement resort of stayover visitors; tax incentives for tourism projects.

Resource Problems: overexploitation of fisheries.

Recommendations: improve fisheries management, marketing, and infrastructure.

Netherlands Antilles

Population/Land Area: 270,000/960 square kilometers.

Ecological Features: two island groups—leeward (Curaçao, Bonaire, Aruba), low hills and bays with mangroves, seagrasses, fringing reefs; windward (St. Maarten, St. Eustatius, Saba), high, rugged, volcanic with coral reefs and seagrass areas.

Economic Resources: oil highest revenue earner for leeward islands; pelagic and nearshore fisheries.

Tourism Elements: largest employer; well-educated labor force; natural beauty, pristine reef areas.

Resource Problems: marine habitats suffering from industrial and recreational uses; depletion of fisheries off Saba bank; sewage pollution and dumping.

Recommendations: enhance public education; regulate fishing access; develop mariculture potential.

Protected Areas: underwater parks on Bonaire, Curaçao, and Saba.

Research Institutions: Foundation Carmabi.

St. Kitts/Nevis

Population/Land Area: 44,000/204 square kilometers.

Ecological Features: high volcanic, narrow coastal shelves.

Economic Resources: traditional nearshore fisheries and shipbuilding.

Tourism Elements: 11 percent GDP, tourism in infancy, growth and marketing encouraged by government, primarily stay-over guests; dive sites, historic attractions, and rain forests.

Resource Problems: nearshore fisheries exploited; coastal erosion from sand removal; sewage pollution from tourism activities; inadequate port facilities.

Recommendations: develop offshore fisheries, marketing and management structure; investigate mariculture resources; regulate sand mining.

St. Maartens. (Courtesy St. Maarten, Saba, St. Eustatius Tourist Office)

St. Lucia

Population/Land Area: 120,000/616 square kilometers.

Ecological Features: high, rugged, volcanic island with extensive seagrasses, coral reefs, few beaches.

Economic Resources: pelagic fisheries; seagrasses, coral reefs, few beaches.

Economic Resources: pelagic finfisheries.

Tourism Elements: third largest commercial activity; attractions are historic and archaeological sites, and wildlife.

Resource Problems: erosion from forest clearing and sand mining affecting reef and seagrass habitats; tourism construction stressing habitats.

Recommendations: integrate authority of coastal management sectors; use interior sources of rock for construction; increase environmental awareness of tourism impacts and planning.

Protected Areas: Maria Islands, Pigeon Islands, Savannes Bay.

Research Institutions: Caribbean Environmental Health Institute.

St. Vincent/Grenadines

Population/Land Area: 101,000/389 square kilometers.

Ecological Features: volcanic, mountainous, no seagrasses, reefs, black sand beaches; Grenadines have largest shelf area in Lesser Antilles.

Economic Resources: finfishes, lobster, conch; primary sea transport area.

Tourism Elements: sailing, beaches, and reefs primarily in the Grenadines.

Resource Problems: seaborne tar pollution on beaches; excessive sand mining for construction; waste from yachts.

Recommendations: use sand from dune areas; restore tourist beaches.

Trinidad/Tobago

Population/Land Area: 1.1 million/5,130 square kilometers.

Ecological Features: tropical forests, swamps, white sand beaches, reefs.

Economic Resources: artisanal fisheries, export trade of fish and shells; oil production revenues.

Tourism Elements: second major source of foreign exchange, primarily in Tobago; charter boat industry.

Resource Problems: pollution pressure and recreation misuse of Caroni Swamp; coastal zone resource use conflicts; overcollecting turtles and shells.

Recommendations: develop adequate marketing for fisheries; need comprehensive coastal development plan and authority; enforce collecting laws.

Protected Areas: Bucco Reef/Bon Accord Lagoon, St. Giles Island, Saut 'd Eau, Soldado Rock, Kronstadt Island.

Research Institutions: Institute of Marine Affairs.

Stony coral animals require clear, sunlight-filled waters to build the limestone reefs that form large portions of the base of many Caribbean islands.

LARGE ISLANDS

Dominican Republic

Population/Land Area: 5.5 million/49,986 square kilometers.

Ecological Features: mountainous, extensive mangrove areas.

Economic Resources: subsistence fishing, agriculture, and bauxite mining.

Tourism Elements: high government priority; increased infrastructure and employment activities.

Resource Problems: dependence on fishery imports; new tourism development without environmental assessments; mangrove destruction for fuelwood; ciguatoxic reef fish; overfishing of lobster; illegal collecting of corals, birds, and turtles; sewage from tourism development.

Recommendations: develop high priority waste disposal; protect ornamental fishes and birds; increase information on fisheries stocks and critical habitat locations; develop tourism assessment mechanisms.

Protected Areas: Silver Banks Humpback Whale Sanctuary, Parque Nacional de Este, Parque Nacional Jaragua, Parque Nacional Montecristi.

Research Institutions: Centro de Investigaciones de Biolgia Marina.

Haiti

Population/Land Area: 6 million/27,700 square kilometers.

Ecological Features: western third of Hispaniola Island, low mountains, numerous beaches, bays, mangroves, seagrasses, coral reefs.

Economic Resources: minimal marine activities.

Tourism Elements: local lack of interest in marine habitats has maintained pristine protected quality; tourism potential growing in recreational marine sector; diving.

Resource Problems: few inventories of marine resources; pollution near urban centers; mangrove destruction for fuelwood; overexploitation of fish, invertebrate and shell export trade.

Recommendations: need assistance and training in fisheries.

Jamaica

Population/Land Area: 2 million/960 square kilometers.

Ecological Features: large mountainous island with coastal plain areas; mangroves and coral reefs.

Economic Resources: scientific marine research, subsistence fisheries, bauxite.

Tourism Elements: second largest source of foreign exchange; high-density tourist areas of international visitors for culture and marine recreation.

Resource Problems: extreme overfishing; domestic and industrial pollution; high sediment loading from bauxite mining; coastal erosion from sand removal; dredge spoils into mangrove areas; unregulated coastal activities including tourism and collecting of reef curios.

Recommendations: need comprehensive coastal planning; enforcement of collecting and protected areas legislation; need fisheries development plans; need national permitting agency; increase public awareness of coastal uses.

Protected Areas: Montego Bay Marine Park, Ocho Rios Marine Park.

Research Institutions: Discovery Bay Marine Laboratory and Port Royal Marine Laboratory of the University of the West Indies.

CENTRAL AMERICA

Belize

Population/Land Area: 154,000/22,962 square kilometers.

Ecological Features: 2nd largest barrier reef in the world, extensive flat swampy coast, cays and offshore atolls.

Economic Resources: oil and gas, artisanal fisheries; barrier reef resources.

Tourism Elements: increasing slowly, diving and boating on offshore islands and reefs.

Resource Problems: poaching of turtles, lobster and conch by foreigners; saltwater intrusion into freshwater wells; unregulated coastal activities; seaborne pollution; sewage dumping in mangroves.

Recommendations: evaluate freshwater limitations; enforce poaching laws.

Protected Areas: Half Moon Cay National Monument; Hol Chan Marine Reserve.

Costa Rica

Population/Land Area: 2.6 million/51,022 square kilometers.

Ecological Features: rugged mountains, extensive streams and rivers, wide coastal plain, fewer reef and mangrove areas than Pacific coast.

Economic Resources: subsistence fisheries; oil.

Tourism Elements: undeveloped as coast is remote from urban centers, yet potential due to unspoiled nature of environments.

Resource Problems: mangrove clearing for fuel and shrimp ponds; fewer disturbances than Pacific side; some siltation and pollution from pesticides and oil.

Recommendations: need information on fishery resources.

Protected Areas: Chauita National Park Tortuguero National Park.

Research Institutions: Centro de Investigacion en Ciencias del Mar y Limnologia, Universidad de Costa Rica.

Guatemala

Population/Land Area: 8.4 million/198,779 square kilometers.

Ecological Features: coast dominated by beaches, mangroves, estuaries.

Economic Resources: artisanal fisheries, lobster export, estuarine mariculture.

Tourism Elements: needs development to utilize extensive beach areas.

Resource Problems: oil spills; inadequate training in marine resources.

Recommendations: improve fisheries marketing infrastructure; inventory marine resources and establish national policy for updating of marine and fisheries legislation.

Research Institutions: Centro de Estudios del Mar y Acuacultura, Universidad de San Carlos de Guatemala; Direccion Tecnica de Pesca y Acuicultura.

Honduras

Population/Land Area: 4.3 million/110,074 square kilometers.

Ecological Features: mountainous, long coast with wide submarine shelves; mangroves abundant; coral reefs and seagrasses in outlying island areas.

Economic Resources: least developed resources in the Caribbean; minerals, commercial fishing exports.

Tourism Elements: growing and national priority to develop island recreation areas.

Resource Problems: tourism activity without prior environmental assessments; fragmentation of coastal authorities; tourist related sewage; overfishing.

Recommendations: increase knowledge and training base for tourism and fishing activities; develop plans to protect island areas; develop local fisheries.

Mexico

Population/Land Area: 78 million/1.9 million square kilometers.

Ecological Features: few mangroves; wide lagoons with undisturbed seagrass and reef areas.

Economic Resources: lobster, conch, shrimp fisheries.

Tourism Elements: marine recreation and diving rapidly developing with planned centers of Cancun and Cozumel; unspoiled resources.

Resource Problems: extent of marine resources needs investigation.

Recommendations: encourage balanced tourism development.

Protected Areas: La Blanquilla, Cancun-Nizuo-Isla Mujeres, Arrecifes de Cozumel, Isla Contay, Rio Celestrum, Rio Lagartos.

Research Institutions: Centro de Investigacion y de Estudios Avanzados del Instituto Politeonico Nacional; Centro de Investigacion y Entrenamiento para Control del la Calidad del Agua; Instituto de Biologia, Universidad Nacional Autonoma de Mexico; Centro de Ciencias del Mar y Limnolgia; Instituto Nacional de Pesca; Universidad Autonoma Metropolitana, Department de Zootecnica, Division Ciencias Biologicas y la Salud; Instituto Tecnologico y de Estudios Superiores de Monterrey.

Nicaragua

Population/Land Area: 2.5 million/148,004 square kilometers.

Ecological Features: large continental shelf; coastal areas uninhabited due to extensive jungles, rivers and swamps.

Economic Resources: shellfish exports, turtle breeding habitats.

Tourism Elements: currently no tourism or industry development.

Resource Problems: extent of marine resources needs investigation.

Recommendations: inventory marine resources.

Panama

Population/Land Area: 1.8 million/75,548 square kilometers.

Ecological Features: mountainous, long coast, wide shelf, sparse mangroves.

Economic Resources: world trade port, financial center; shrimp mariculture.

Tourism Elements: tourism integrated with service and banking oriented economies; early stages of development with marine resources.

Resource Problems: overfishing and collecting of turtles; limited information on coastal resources.

Recommendations: develop local fisheries; upgrade technical training; develop coastal resource plans.

Research Institutions: Centro de Ciencias del Mar y Limnolgia; Smithsonian Tropical Research Institute.

SOUTH AMERICA

Colombia

Population/Land Area: 27 million/1.1 million square kilometers.

Ecological Features: extensive coastal areas influenced by major rivers; island archipelagos offshore.

Economic Resources: oil and gas; minerals; minimal local fisheries.

Tourism Elements: undeveloped coastal tourism except for island areas, government priority to increase.

Resource Problems: few marine inventories; water and oil pollution; sedimentation; collecting of endangered turtle species; mangrove filling.

Recommendations: need data to develop marine resources; implement existing plans; develop underutilized fisheries through increasing information on stock assessment, management and infrastructure.

Protected Areas: Parque Nacional Corales del Rosario, Parque Nacional Natural Tayrona, Parque Nacional Natural Isla de Salamanca, Santuario de Fauna Los Flamencos.

Research Institutions: Centro de Investigaciones Oceanograficas e Hidrograficas; Facultad de Biologia Marina, Fundacion Universidad de Bogata, Jorge Tadeo Lozano; Facultad de Ingenieria Pesquera, Universidad Technologica de Magdalena; Instituto de Investigaciones Marinas de Punta de Betin; Laboratorio del Instituto Nacional de los Recursos Naturales Renovables y del Ambiente.

Venezuela

Population/Land Area: 17.8 million/912,000 square kilometers.

Ecological Features: extensive coast that is one-quarter mangroves.

Economic Resources: oil industry; commercial fishing.

Tourism Elements: increasing international coastal tourism but still only 1 percent GNP; potential development of island and beach areas for recreation and protection.

Resource Problems: conflicting demands on coastal areas; destruction of natural habitats; construction causing coastal erosion; filling in of mangrove swamps; overfishing of turtles and lobster; river dams altering hydrologic regimes causing sedimentation of lagoons.

Recommendations: increase public awareness of coastal resources; need effective legislation for pollution, endangered species and fisheries regulations; policy for coastal conflicts.

Protected Areas: Parque Nacional Archipelago Los Roques, Parque Nacional Mochima, Parque Nacional Morrocoy, Laguna de Tacarigua.

Research Institutions: Centro de Investigaciones Biologicas, Universidad de Zulia; Estacion de Investigaciones Marinas de Margarita, Fundacion La Salle de Ciencias Naturales; Instituto Oceanografico; Instituto para el Control y la Conservacion de la Cuena del Lago Maracaibo.

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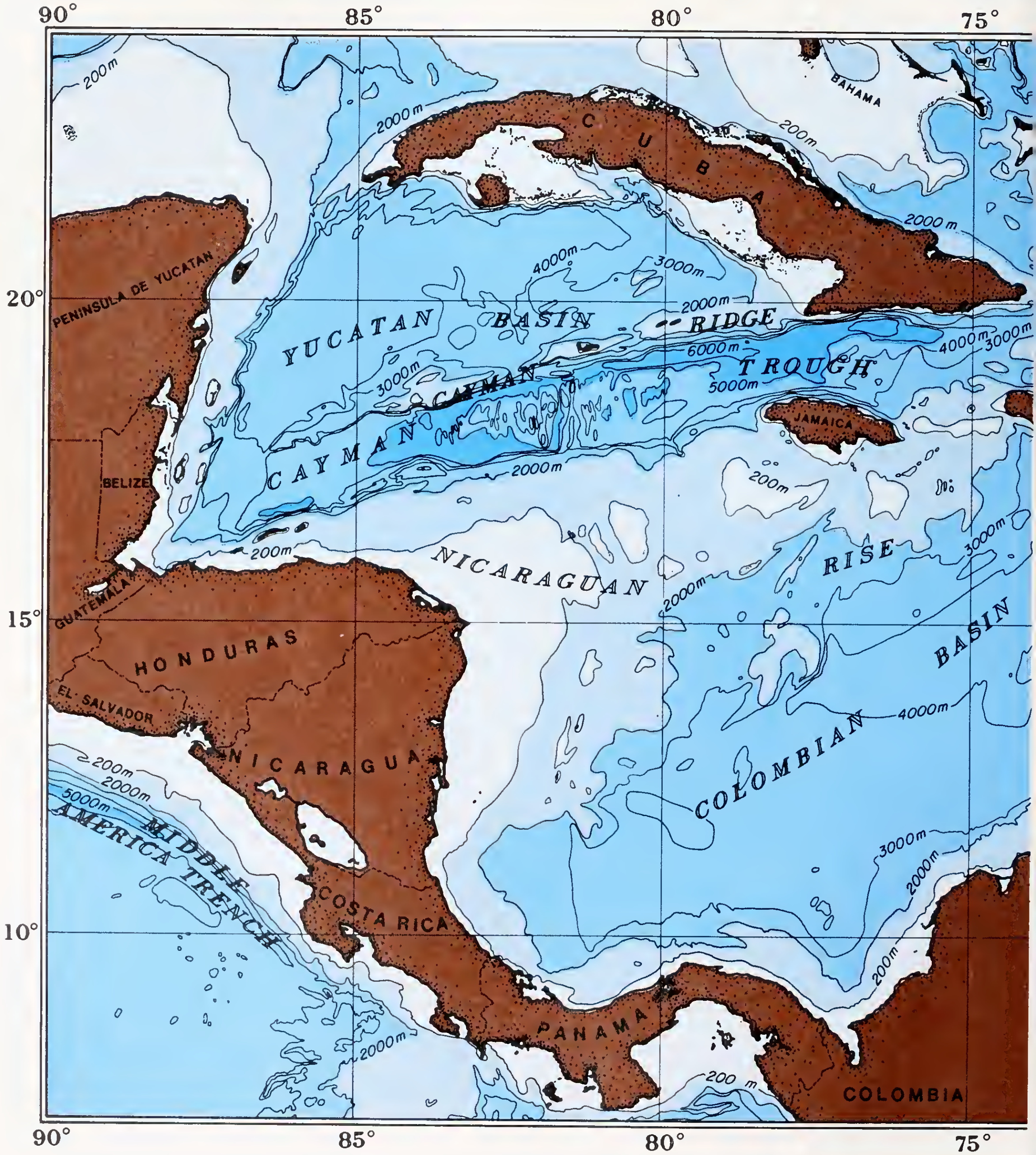
Geology of the Caribbean

—New techniques, including broad-range swath imaging of the seafloor that produces photograph-like images, and satellite measurement of crustal movements, along with plans for new scientific drilling, have excited geologists, and promise to explain the complex geology of the region.



by William P. Dillon, N. Terence Edgar, Kathryn M. Scanlon, and Kim D. Klitgord

The Caribbean Sea (Figure 1) often seems to be a distinctive place—geographically and culturally. Whether that is true or not, the Caribbean, most certainly, is a distinctive place geologically. The geological Caribbean is a separate plate of the Earth's surface, moving semi-independently of the other plates that surround it. This movement causes the plate to grind against the surrounding plates, and thus, its boundaries are disclosed by a band of earthquakes that extends around the plate's

Figure 1. Geography and bathymetry of the Caribbean region.

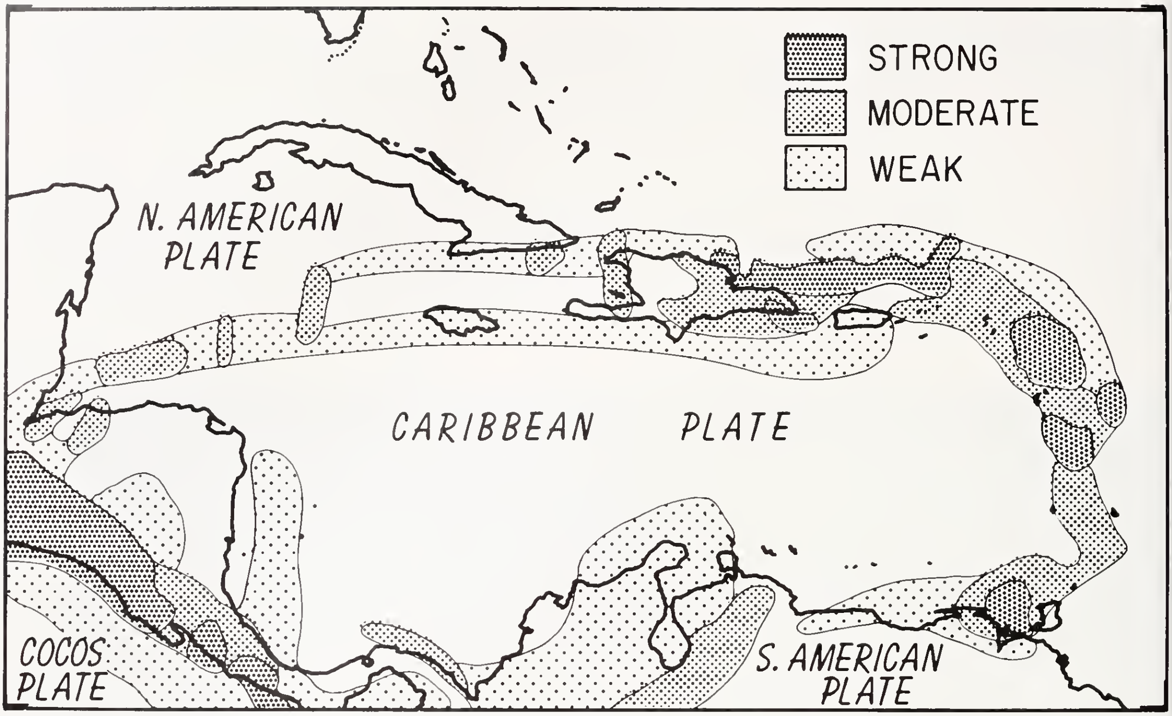


Figure 2. Relative earthquake activity of the Caribbean. The Caribbean is a separate plate of the Earth's outer shell, and its boundary is defined by a band of earthquakes that are caused by the grinding of one plate against another, and the stresses within the plate boundary zones caused by plate movements.

periphery (Figure 2). Some places that usually are considered part of the Caribbean—the Bahamas, Cuba, and Mexico's Yucatan Peninsula—lie outside the band of earthquakes (therefore, off the plate), and so are not part of the geological Caribbean. Of the three main basins of the Caribbean region, the Yucatan, Venezuelan, and Colombian basins, only the latter two are included in the Caribbean Plate.

Presently, the Caribbean Plate—flanked by the North American and South American plates—moves eastward, or possibly slightly north of eastward. As the Caribbean Plate moves, the American plates are driven under it on its eastern side, a process known as subduction. Along the east-west trending northern and southern boundaries, the Caribbean Plate is sliding past the American plates—an extreme oversimplification, which we will consider more extensively. Finally, on the west, the Cocos Plate is being driven northeastward, and is being subducted beneath the Caribbean. Since the boundaries of the plate are where the activity is, we will look at each one.

The Boundaries of the Caribbean Plate

The Northern Boundary. The northern boundary of the Caribbean Plate is aligned east-west, essentially parallel with the direction of movement of the plate. The basic movement of the faults at the boundary is strike-slip, that is, the movement on the faults (slip) is parallel to the trend of the faults (strike). Thus, a very simple fault system could exist if the plate boundary were straight, but it is not. The northern plate boundary has two major deflections (Figure 3). Moving west along the boundary, there is a northward bend at the island of Hispaniola (the Dominican Republic/Haiti), and a southward jog between Jamaica and the Yucatan Peninsula. Because the Caribbean Plate is moving relatively eastward, the Hispaniola bend creates a protuberance that is being crushed against the North American Plate. The result is the formation of folds and thrust faults that grow continuously over time as the plates move, such as those shown in one of our recent profiles (Figure 4). These are found both offshore and on land in Hispaniola.

The abrupt jog in the plate boundary between Jamaica and Yucatan creates an ever-widening gap, or spreading center, as the Caribbean Plate moves relatively eastward. As the spreading center has opened, the potential gap has been filled by molten material that has welled up from below the rigid outer shell of the Earth. The process is similar to that occurring at normal ocean-opening spreading centers, like the Mid-Atlantic Ridge, and the new crust that is formed is essentially the same as normal oceanic crust. The result of the opening, then, is the formation of the Cayman Trough, the floor of which is a narrow band of new ocean crust that is being formed along the northwestern edge of the Caribbean Plate. This probably is the smallest actively developing ocean basin in the world.

Stresses along the northern plate boundary have caused uplift in many of the islands, and subsidence in some other areas. This has resulted in exposure on land of marine limestones, reefs, and marine terraces in many areas. Upraised limestone strata (layers) on a fault block create the spectacular cliffs of Mona Island, between Puerto Rico and Hispaniola (Figure 5). Upraised limestone strata on Puerto Rico's north coast have been weathered and eroded into steep pits and peaks, known as karst topography. Figure 6 shows karst near Arecibo, where a karst sinkhole has been adapted to make it a reflector for one of the world's largest radio telescopes.

The Southern Boundary. The motion at the straight, eastern part of the southern plate boundary is dominantly strike-slip (refer back to Figure 3). The western part of the boundary forms a great curve from western Venezuela to western Colombia. This shape, in conjunction with the movement of the Caribbean Plate and the plate collision and subduction that extends along the entire west coast of South America, creates compression that causes major faults and uplifts here, at the northern end of the Andes. Some subduction of the Caribbean may be occurring north of Colombia, according to some researchers.

Motion between the North and South American plates appears to be slow, but what there is seems to put the Caribbean Plate into a vise, slowly crushing it in a north-south direction. This has resulted in folding of sediments south of Puerto Rico and Hispaniola, and north of western Venezuela and Colombia.

The Eastern Boundary. The eastern boundary of the Caribbean Plate is a subduction zone, in which the American plates are driven under the Caribbean (refer again to Figure 3). An idealized cross-section of this boundary, extending east-west through Barbados (Figure 7), shows that the Caribbean Plate, moving relatively eastward, is scraping off the sediments that lie on the South American Plate and is forming an accretionary sediment pile. The sediments have been derived mostly from the erosion of South America. New sediments on the seafloor arrive at the convergence on the westward-moving basement conveyor belt (the South American Plate). These sediments initially are shoved under the pile, and eventually are crumpled and faulted up into a thick ridge of sediment where the plates converge. In one place, this ridge of deformed sediment extends above the sea surface to form the island of Barbados. Thus, Barbados is formed of folded sediments with a cap of reef limestone (Figure 8), unlike all of the other Lesser Antilles, which are volcanic.

Where the American plates bend over and start to descend, earthquakes occur (refer again to Figure 2). The earthquakes are as shallow as 10 to 20 kilometers near the bend, and extend in a dipping band to more than 150 kilometers beneath the Lesser Antilles island arc. The crust of the descending Atlantic plates begins to melt as it descends into the hot rocks of the mantle. The molten material, or magma, thus created rises to form volcanoes that become the Lesser Antilles island arc. The spectacular pitons (twin peaks) on St. Lucia (Figure 9) have formed from volcanic vents that were filled with magma that solidified, then had the surrounding rocks eroded away. Nearby, on southern St. Lucia, the boiling water springs of Soufrieres give evidence that these volcanoes still are active. The volcanoes of the Lesser Antilles are famous for their large, explosive eruptions, such as

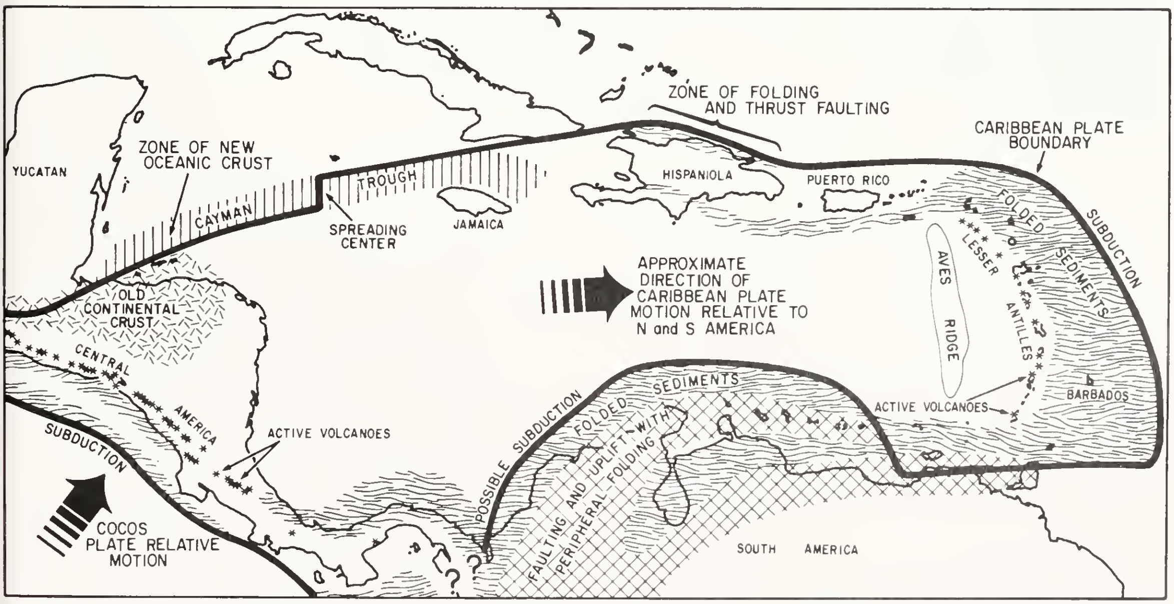


Figure 3. Geological features of the active boundary zone of the Caribbean Plate. (Figure adapted from Case, J. E., and T. L. Holcombe, 1980)

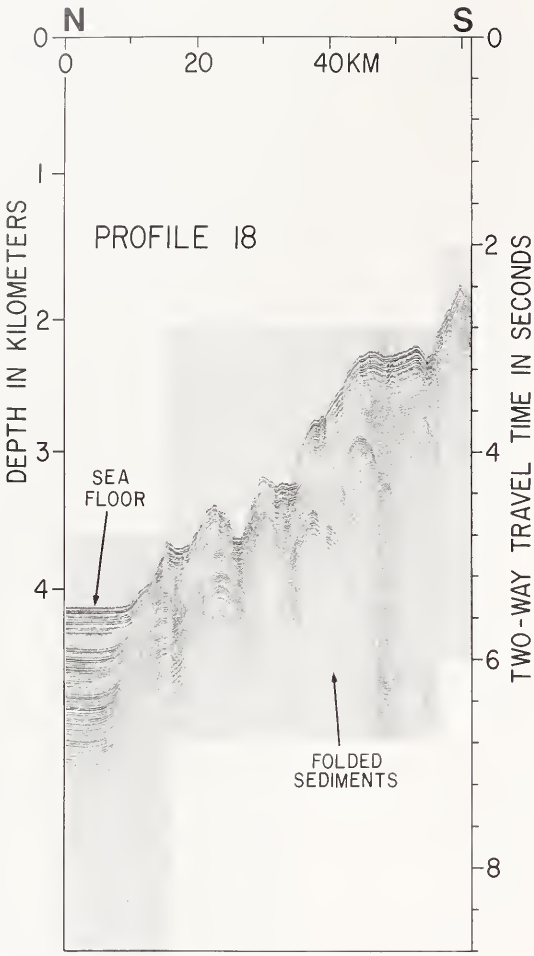


Figure 4. A seismic profile recently collected by the U.S. Geological Survey north of Haiti off the island of Hispaniola. Here, at a compressional zone created by an irregularity in the plate boundary, sediments north of the Caribbean Plate are crumpled. The folds continually grow, and new folds are created as a result of the continuous movement of one plate relative to the other.

the 1902 eruption of Mt. Pelée on Martinique. In the first three quarters of this century, they killed nearly 30,000 people—more than those killed during that period by all other volcanoes in the world.

The present arrangement of volcanoes is quite recent, geologically. Prior to about 5 million years ago, the island arc was straighter, and the arc included the islands of St. Barthelemy, Antigua, and the eastern part of Guadeloupe, as well as the islands to the south. The western part of Guadeloupe and the active volcanic islands to the northwest are younger. An even older island arc, probably inactive for more than 15 million years, is represented by the submerged Aves Ridge.

At the northern end of the subduction zone, as the plate boundary swings around to the west toward Puerto Rico and Hispaniola, diagonal subduction continues to drive the North American Plate beneath the Caribbean Plate. Because little sediment is available here to form an accretionary sediment pile, a great deep is formed instead. This is the Puerto Rico Trench, and with depths greater than 8,200 meters, it is the deepest area in the Atlantic Ocean.

The Western Boundary. The western boundary of the Caribbean Plate, where the Cocos Plate is being thrust beneath the Caribbean, is a subduction zone similar to that along the eastern boundary. The trench formed by the plate boundary here, however, is not filled by a ridge of deformed sediment scraped from the downgoing plate, as it is at the eastern boundary. Sediments on the Cocos Plate are thin, and there is little sediment input from Central America, and therefore the 6-kilometer-deep trench remains unfilled, as in the Puerto Rico Trench.

The northern part of Central America (parts of Guatemala, Belize, and Honduras) is formed of a block of very old (more than 300-million-year-old) continental crust that has been deformed and faulted more recently. The remainder of the land along the western plate boundary consists of volcanic rocks and bands of folded sediment—all related to the subduction process.

Origin of the Caribbean Crust

Most of the Caribbean area—the Venezuelan, Colombian, and Yucatan basins—is floored by crust that apparently is oceanic rather than continental in origin. Oceanic crust is formed at a spreading ridge from molten material that wells up from the interior of the Earth as two plates move apart. As determined by acoustic studies, oceanic crust worldwide is remarkably uniform in thickness and structure, and it is much thinner than continental crust (7 to 10 kilometers versus 30 to 40 kilometers thick). It is characterized by a "spreading" topography, or lineations that originated as a result of its formation, and, commonly, by a clearly identifiable striped pattern of magnetic anomalies. Remarkably, none of the above characteristics apply to much of the crust in the Venezuelan Basin and part of the Colombian Basin, which is thicker and smoother than normal oceanic crust, and has a very poorly defined magnetic anomaly pattern. The differences have attracted a bevy of imaginative hypotheses to explain why the seafloor here is different—among them the idea that widespread eruptions occurred about 80 million years ago, creating molten flows of volcanic rock that covered the original topography and left an atypically smooth surface. The cover of volcanic rock also may be responsible for subduing the magnetic anomaly field.

Numerous hypotheses on the origin of the Caribbean have been proposed, but with the acceptance of plate tectonics, two have dominated the current thinking. One assumes that a branch of the Atlantic crustal spreading system extended through the Caribbean region to the Pacific Ocean, and that new oceanic crust was created between the North and South American plates as the two

Figure 5. Cliffs, 60 meters above sea level, at Mona Island between Puerto Rico and the Dominican Republic. Mona Island is a fault block on the northern side of the Caribbean. The marine limestones that form the island have been shoved up above sea level in response to stresses at the plate boundary. (Photo by W. Dillon, USGS)

separated during their westward migration (see box, page 49). The other proposes that the crust formed in the Pacific Ocean, and that it was wedged between the North and South American plates as they separated. Smooth crustal surfaces and weak magnetic anomaly patterns do characterize the crust in parts of the western Pacific Ocean, lending support to a Pacific-origin. Of the two hypotheses, the latter has had the most adherents in recent years. However, new ideas on ocean-opening in place, the first possibility (above), seem to simplify many Caribbean geological problems, and are gaining credence.

Search for Marine Geologic Resources

The need for economic development in the Caribbean caused the U.S. State Department to recently ask the oceanographic community to hold two workshops. These have resulted in reports that include major sections on the development of marine geologic resources in the region. The first report was the outgrowth of a request to the National Research Council, Ocean Studies Board, which called a meeting in January 1986 of U.S. scientists interested in Caribbean problems. This request attracted more than 115 written responses and proposals, and a report was prepared by David A. Ross (Woods Hole Oceanographic Institution) and Harris Stewart (an independent consultant). The second report, which stemmed from a State Department, Agency for International Development (USAID), request to the National Oceanographic and Atmospheric Administration, resulted in a workshop held in September 1986, which was attended by scientists from the United States and many Caribbean countries. This is discussed by A. Meriwether Wilson in this issue of *Oceanus* (page 33). The meetings considered a broad variety of topics, but the conclusions and recommendations for geological work were quite similar.

Figure 6. Irregular topography in uplifted marine limestones on the northern coastal plain of Puerto Rico at Arecibo. The pits and steep round-topped peaks are created by solution of the limestone along cracks by rainwater and groundwater, creating a topography known as karst. One of the pits shown here has been used to create the dish reflector for one of the world's largest radio telescopes. Note the four-story building in the foreground for scale. (Photo by W. Dillon, USGS)

Aside from petroleum, which will be developed by industry, the most important marine geologic resources in the Caribbean probably will be sedimentary, and therefore an understanding of the sedimentary processes, present and past, is imperative.

Perhaps the most valuable nonpetroleum geological resource of the marine realm is sand and gravel, needed for construction and beach replenishment. Onshore deposits of these materials commonly are inadequate and, in the Caribbean, the mining of beaches for these resources has begun. Such activity can be very unwise—because it can aggravate shore erosion, and can destroy features attractive to tourists, an important source of income in many Caribbean countries.

Studies, such as those done by the U.S. Geological Survey in Puerto Rico, where the problem of illegal mining of beaches is severe, show that mining of offshore sand and gravel can be done safely, if we understand how underwater streams of sediment move. In some places, such flows of sediment are lost from the shelves to the deep sea. These areas are ideal for mining. In other locations, flows of sand on the island shelves appear to nourish the beaches, so these flows should not be disturbed. Knowledge of the locations of sand and gravel deposits, and the dynamics of underwater sediment migration, are the key to safe and effective use of these resources.

The knowledge needed to use offshore sand and gravel resources is essentially identical to that needed to locate and extract other sedimentary mineral deposits in the offshore region, known as placer deposits. These accumulations of dense minerals have been concentrated by the action of waves or currents. The deposits of greatest interest are those with economically valuable minerals such as gold, platinum, and minerals containing titanium, chromium, and rare earths.

Both reports to the State Department agree that studies needed to understand the sedimentary deposits and safe extraction of resources include side-scan sonar and seismic-profiling surveys, extensive core sampling, current measurements, and biological surveys. The geological surveys need to be done on at least two scales. On the regional scale, side-scan sonar and other broad geophysical surveys of the entire continental or insular margins of a country should be carried out, as the U.S. Geological Survey has done around Puerto Rico and the U.S. Virgin Islands. This allows general mapping to identify potential resource sites and understand broad geologic problems. On the local scale, high-resolution surveys can identify economic deposits, and give the details of sedimentary processes.

The search for offshore oil and gas resources in the Caribbean has been affected recently by economic conditions that have slowed the petroleum industry worldwide, but the sites of future resources probably will follow the pattern of the past when exploration resumes. Most petroleum resources have been found in the southern

continued on page 50

The Opening of The Caribbean

How the Caribbean ocean basin formed remains the subject of great deal of speculation. One explanation is given by the adjoining diagrams, which represent several stages in a recent conceptual model of how the Caribbean and North Atlantic formed.

Diagram A shows the North Atlantic and future Caribbean as it is thought to have appeared 150 million years ago, 25 million years after North America and Africa started to drift apart. Very little of the Caribbean crust had formed at this time, but South America and Central America were about to break apart. The broad, open arrows indicate directions of plate drift relative to North America, which for the purpose of illustration, is imagined as remaining fixed.

Diagram B shows locations of the continents 118 million years ago. At this time, 32 million years of drift had resulted in formation of part of the Caribbean crust.

Diagram C shows the Caribbean at the end of its opening phase, 80 million years ago. At that time the active spreading center died, and floods of molten volcanic rock flowed across the seafloor of most of the Caribbean Basin.

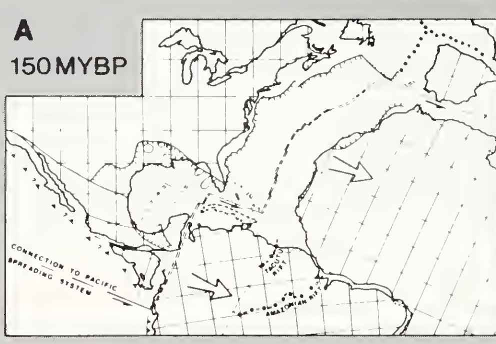
Diagram D shows that, by 36 million years ago, a reorganization of plate boundaries had occurred. The northern boundary of the plate had become a strike-slip plate margin that cut off the Yucatan Basin as it does now, but at that time the northern boundary was located south, rather than north of Hispaniola and Puerto Rico. A subduction zone, which eventually became the Aves Ridge, was the beginning of subduction in the eastern Caribbean.

In Diagram E, we show that, at 10 million years ago, the northern boundary of the Caribbean was approximating its present configuration. It had jumped northward, so that Hispaniola and Puerto Rico were now on the Caribbean Plate, and they were drifting relatively eastward—as they do today. Furthermore, a jog in the plate boundary west of Hispaniola had begun to create the present Cayman Trough. The subduction on the eastern plate boundary had jumped eastward to its present position at the Lesser Antilles island arc. On the west, northern Central America had drifted to a location south of Yucatan from its previous location, south of central Mexico (note its location on the three diagrams on the left). Also on the west, the present subduction zone pattern had developed. The present situation is, of course, as shown in Figure 3 (page 42).

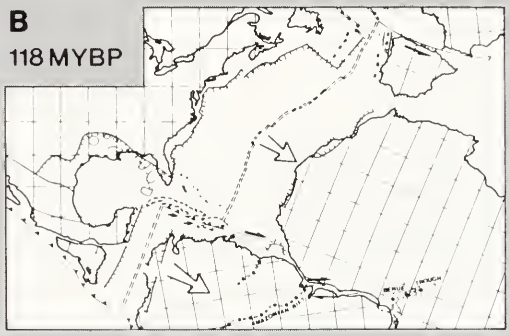
This summary of Caribbean development

continued on page 50

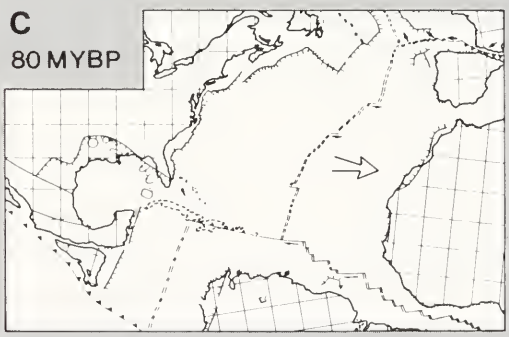
A
150 MYBP

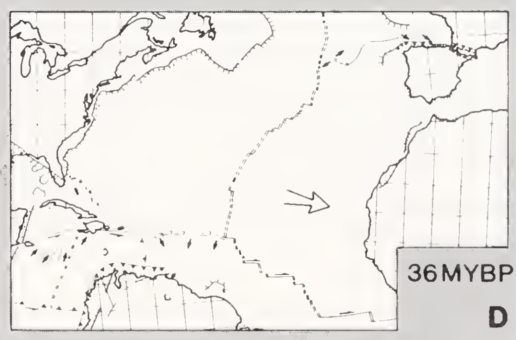


B
118 MYBP



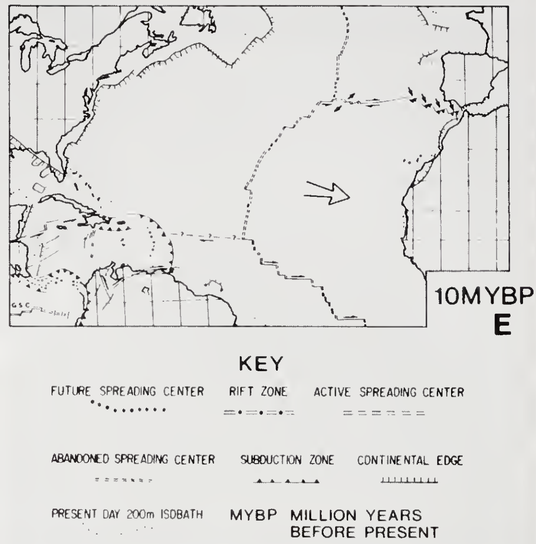
C
80 MYBP





36 MYBP
D

Continued from page 49
is taken from a 12-step model created by Kim Klitgord of the U.S. Geological Survey and Hans Schouten of Woods Hole Oceanographic Institution (Klitgord, K. D., and H. Schouten, 1986, Plate kinematics of the central Atlantic, In *Vogt, P. R., and B. E. Tucholke, eds., The Geology of North America, Vol. M, The Western North Atlantic Region, Geological Society of America, pp. 351–378). Although this is one of the most recent models of Caribbean development, it must be considered as one of a series of competing hypotheses, some of which are very different.*



Caribbean—Colombia, Venezuela, and Trinidad and Tobago. These resources occur in the thick folded and faulted sediments of northern South America. Petroleum exploration in Central America has been disappointing, and generally, little oil has been found in the Caribbean islands.

In the Greater Antilles, oil exists in Cuba and one former field in the Dominican Republic. Barbados, the sedimentary island in the accretionary sediment pile of the eastern Caribbean, does have oil and gas production. This may bode well for future exploration in the folded sediments of the eastern Caribbean. The rest of the Lesser Antilles, being volcanic islands, probably have little potential for petroleum.

New Directions in Research

Because of the wide variety of geologic activities in the Caribbean area, such as earthquakes, volcanism, and various other plate boundary interactions, there has been a continuing interest in the area by scientists from the Western Hemisphere, and from Europe. Two exciting newer approaches currently being applied in the Caribbean are techniques for broad-range swath imaging of the seafloor, and the direct measurement of the movement between plates. New proposals for drilling in the region are also generating interest among scientists.

Swath imaging is of two types: multibeam bathymetry systems that generate swath contour maps of the bottom, and side-scan sonar systems that generate swath images of the seafloor that look like aerial photographs taken over land. Side-scan sonar actually is very much like photography, because it provides information on the shape as well as the reflectivity of objects it images; of course it uses sound rather than light to create the image. Such a photograph-like image is exciting to marine geologists, who until recently had to satisfy themselves with two-dimensional, cross-sectional profiles.

The broadest range swath device (as much as a 60-kilometer swath) is the GLORIA side-scan-sonar system; its towed sending and receiving unit, or "fish," is shown in Figure 10. GLORIA (Geologic Long Range Inclined Asdic) surveys in the Caribbean Sea have been carried out by the system's builders, the British Institute of Oceanographic Sciences (IOS) on the eastern Caribbean Plate boundary region, and by the U.S. Geological Survey, in cooperation with IOS, on the northern plate boundary around Puerto Rico and in the Cayman Trough. The survey in the folded sediments of the eastern plate boundary region disclosed previously unknown, volcano-like features from which pressurized mud (possibly charged with gas) had erupted on the seafloor. The Puerto Rico and Cayman Trough GLORIA surveys provided continuous coverage across the northern plate boundary. At Puerto Rico, we can now, for the first time, identify where the strike-slip motion between plates occurs. The Puerto Rico survey also disclosed linear patterns of submarine canyons north of the island, formed by sediment derived from rivers and shore erosion that spilled off the edge of the shelf during storms and flowed down the slope (Figure 11). Figure 11 also shows a huge amphitheatre, created by the slumping away of 4,000 cubic kilometers of rock. Such a slump can generate a large and destructive seismic sea wave (tsunami), so the likelihood of such events is a matter for concern. At the Cayman Trough spreading center, GLORIA was used to locate the actively spreading ridge, and to reveal the sea-floor volcanoes that complicate the floor of the trough.

In the Cayman Trough, and in the deep basin within the Virgin Islands, GLORIA images have been interpreted along with data from a swath-bathymetry device (measures water depth). The photograph-like quality of GLORIA and the precise bathymetric maps created by swath-bathymetry devices, such as Sea Beam, are mutually supportive for purposes of data interpretation, so the combination is especially valuable. French scientists have been very active in collecting Sea Beam data in the Caribbean.

The relative motion across the northern plate boundary of the Caribbean, which has been deduced indirectly, soon will be measured by precise location of ground stations over several

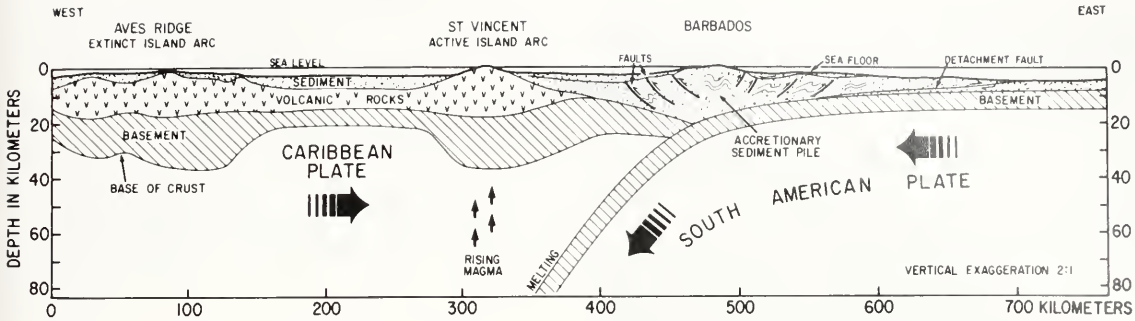


Figure 7. The eastern margin of the Caribbean plate at the location of Barbados and St. Vincent. (Figure adapted from Westbrook, G. K., and W. R. McCann, 1986. Subduction of Atlantic lithosphere beneath the Caribbean, In *Vogt, P. R., and B. E. Tucholke, eds., The Western North Atlantic Region, The Geology of North America, Vol. M, pp. 341–350. Boulder, CO: The Geological Society of America)*

years, using Earth-orbiting satellites. Presently, this direct measurement technique is being used between Hispaniola and the Bahamas by Carl O. Bowin, a Senior Scientist at the Woods Hole Oceanographic Institution. Plans for other similar measurements are being made.

Many of the geological mysteries of the Caribbean, such as the problem of whether the crust drifted in from the Pacific or formed in place, can best be solved by actually sampling the sediments and basement of the deep basins. Two scientific drilling cruises were carried out by the National Science Foundation's (NSF's) Deep-Sea Drilling Project ship *Glomar Challenger* in 1969 and 1972. This drilling, at 11 sites, sampled the rock beneath the sediments of the Caribbean, and showed that molten flows of volcanic rock had covered the sea floor about 80 million years ago. This volcanic episode may have caused the basement rock of the Caribbean to be different from normal oceanic crust, as discussed previously. Age of these volcanic flows was determined by paleontologic dating of microfossils obtained in the drilled cores. Dates of gaps in sedimentation in the cores—gaps produced by deep-sea erosion—also helped to determine when the volcanic barrier of Panama was erected, which cut off the Caribbean from the Pacific.

After a 15-year hiatus, a large group of scientists have recently met, in mid-November in Jamaica, to plan a new drilling cruise. The NSF's new Ocean Drilling Project vessel *JOIDES Resolution* will be used, perhaps by 1991. With our present greater understanding of the Caribbean region and the deeper drilling capability of the *JOIDES Resolution*, we should be able to bring this new sampling to bear on a fascinating set of geological problems—such as the evolution of plates and basins, the development of convergent accretionary margins, and the pattern of changing environments over geologic time caused by the rearrangements of drifting plates. One of the prime targets will be an area of the southeastern Venezuelan Basin, which seismic profiles show was not covered by the floods of molten volcanic rock that covered the rest of the Colombian and

Figure 8. Barbados—a view of part of the contorted sediment pile that forms the island. The sediments are scraped off the South Atlantic Plate and crumpled as that plate is thrust under the Caribbean Plate. (Photo by K. Scanlon, USGS)

Figure 9. Les Pitons of St. Lucia in the Lesser Antilles probably are the remains of volcanic vents that were filled with molten magma that solidified. The surrounding volcanic rocks were eroded away. These spines are about 800 meters high. (Photo courtesy of the St. Lucia Tourist Board, through Hill and Knowlton Inc., New York)

Figure 10. Testing the GLORIA launching system in San Juan harbor, Puerto Rico. The GLORIA "fish" is the torpedo-like object held in the gantry cradle that rotates and slides out across the ship's stern to allow a safe launching. The fish, towed 300 meters behind the ship, carries the devices that send sound pulses out to the side of the ship's track and receive the returning echoes, thus allowing an image of a broad swath of seafloor to be created as the ship steams along. (Photo by Dann Blackwood, USGS)

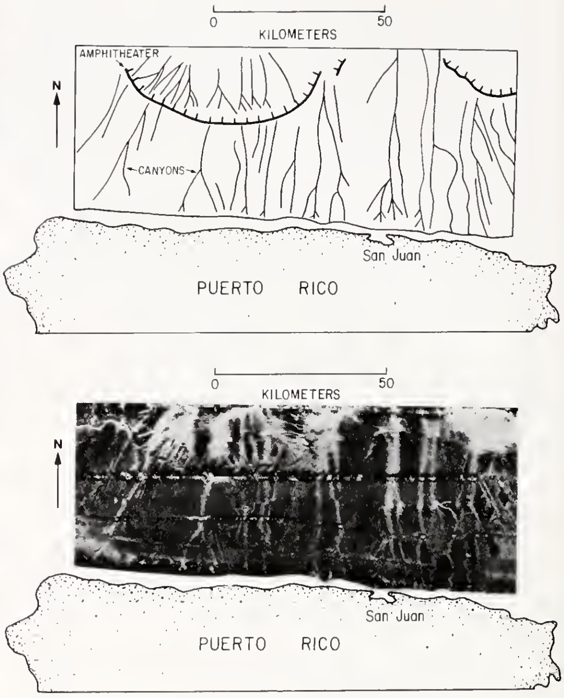


Figure 11. A small portion of the GLORIA side-scan sonar image of the region around Puerto Rico. This is a mosaic of four east-west side-scan tracks that shows the straight submarine canyons on the northern slope of Puerto Rico. A large amphitheater apparently was created by slumping that could have been triggered by earthquakes in this area of high earthquake frequency. If this large area of rock and sediment slid as a single mass, large and destructive sea-surface waves (tsunamis) would have been generated. Part of a second, smaller amphitheater is visible at the right edge of the image.

Venezuelan basins. The age of the basement rocks and latitude at which they were formed (which can be determined from their magnetic characteristics) will be important information in judging competing hypotheses of Caribbean formation.

The brief listing of research topics here only scratches the surface of present geological research in the Caribbean. Geologists have been fascinated and mystified by the Caribbean for generations, and, although we now understand the region far better than our grandfathers, there are still major questions unanswered in this region of very complex geology.

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Acknowledgments

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Changing Climate and Caribbean Coastlines

by Frank Gable

Tourism is a major source of income in the Caribbean. This fact, coupled with a rapidly increasing population and its accompanying demand for space and resources, means that any rise in relative sea level will have severe repercussions. Such a rise has been documented, and it appears likely that it will continue for the foreseeable future.

The Caribbean is particularly vulnerable to a projected increase in sea level because it is made up largely of island nations that have far more coastal zone per unit of land area than do continental nations. Furthermore, many government and international funding agencies have made, and continue to make, important economic and environmental decisions without considering the possibility of a rising sea level.

Causes for the Sea-Level Rise

Rise in sea level has been substantiated by recent data, and by reinterpreting older data, and is due to several causes:

Atmospheric Warming. Since 1880, the global atmosphere has warmed by 0.6 degrees Celsius (1 degree Fahrenheit). This warming trend is at least partially because of the measured increase of carbon dioxide and trace gases in the atmosphere—the so-called "greenhouse effect" (See *Oceanus*, Vol. 29, No. 4, pp. 2–8). Although the Earth was about as warm in the 1930s and '40s as it is today, the earlier warming was confined mostly to the higher latitudes of the Northern Hemisphere. Recent warming is more dispersed globally, and thus is likely to have more effect on the Caribbean. This warming trend acts in two ways to increase sea level: First, it causes an increase in ocean volume through thermal expansion; and second, it causes the melting of land-bound ice.

In October 1985, a conference was held at Villach, Austria, on atmospheric gases and climatic change. This conference, sponsored by the United Nations Environment Programme (UNEP), the World Meteorological Organization (WMO), and the International Council of Scientific Unions (ICSU), arrived at the conclusion that a projected global warming of 1.5 to 4.5 degrees Celsius (2.7 to 8.0 degrees Fahrenheit) during the next century would lead to a sea-level rise of from 20 to 140 centimeters (0.65 to 4.60 feet).

Other estimates for the projected rise in sea level vary: The United States National Academy of Sciences (NAS) forecasts a 70-centimeter (2⅓ foot) global rise in the next century, with a rise of 28 centimeters by the year 2025. The United States Environmental Protection Agency (EPA), sees a global rise of 137 centimeters (4½ feet) during the next 100 years, with a rise of 38 centimeters (1¼ feet) by the year 2025.

The consensus is that global sea levels will rise from 61 to 183 centimeters (2 to 6 feet) during the next century, with a rise of 30 centimeters (1 foot) during the next 40 years. However, for part of the Caribbean region, the rise during the next 40 years is expected to be 15 to 20 centimeters greater than the average global rise, because of a simultaneous subsidence of the land.

Natural Subsidence. The Caribbean region is very active, geologically. It is on a separate tectonic plate, caught, as if in a vise, between the North American and South American plates (see page 42). Consequently, it is subject to frequent earthquakes and volcanic activity. The coastlines of the region contain topographic evidence of changes in land level, both up and down, with no discernible trend in either direction. This fact, coupled with the paucity of long-term tide-gauge data (as opposed to Europe, where some tide gauges have been in operation since the 19th Century), makes planning for the region even more difficult. But, there are other natural factors, such as the compaction of fine-grained deposits due to the weight of overlying sediments, and the oxidation of highly organic soils—such as peat—which contribute to subsidence.

Man-Made Subsidence. Human intervention can induce subsidence or accelerate naturally occurring subsidence. Examples of these activities that have been seen in the Caribbean are the pumping of ground water for agriculture, municipalities, or industry; and the extraction of crude oil and natural gas (a subsidence of 3.4 meters—11 feet—was measured in Venezuela's Lagumillas oil field in the period 1926 to 1954). Also, there is compaction of sediments caused by vibration, and by buildings and other engineering works. Other major causes of subsidence in the islands are the mining of sand and gravel, and land reclamation and drainage projects.

A Wild Card. Hurricane formation requires sea-surface water temperatures of 27 degrees Celsius (81 degrees Fahrenheit) or higher. The Caribbean Sea is about 25 to 26 degrees Celsius (77 to 79 degrees Fahrenheit) in winter, and 28 to 29 degrees Celsius (82 to 84 degrees Fahrenheit) in summer; thus, a global warming trend may well cause an extension of the hurricane season. It also may lead to hurricanes forming at higher latitudes within the Caribbean region. In general, an increased frequency of severe storms will tend to flatten the typical beach profile and cause increased shoreline destruction in the area.

Record storm surges of greater than 7 meters (23 feet), with associated winds of 200 kilometers per hour (124 miles per hour), have been recorded within the last 20 years. In 1961, hurricane Hattie produced a storm surge of 4 meters (13 feet) on the coast of Belize, with significant island flooding and erosion.

Impacts

Preliminary estimates of tide-gauge trends in the Caribbean region suggest that, in recent years, relative sea level has risen at the rate of 32 millimeters (⅛ inch) a year. The "Bruun Rule," first promulgated by Per Bruun in 1962 in the *Journal of the Waterways and Harbors Division*, and considered to be a benchmark in the field, states that a 1 centimeter (0.39 inch) rise in sea level will generally result in a 1 meter (39.37 inches) shoreline retreat.

Beach resorts provide important revenues to coastal areas throughout the Caribbean, and relatively few of the most intensively developed resorts have beaches broader than about 30 meters (98 feet) at high tide. The projected rise in relative sea level of 30 centimeters (12 inches) during the next 40 years will inundate up to 20 to 50 meters (66 to 164 feet) of beach, which, in many cases, will be the entire beach.

The major tourism area on Grenada is Grand Anse; most of the hotels are situated on or near this 2-kilometer-long beach, which has eroded at the rate of 70 centimeters (2⅓ feet) per year between 1970 and 1982. The causes of this erosion are mining of offshore sand, and possible relative sea-level rise.

Another place where the mining of sand and aggregate is creating serious problems is Vigie Beach, on the island of St. Lucia. A typical crescent-shaped pocket beach, it is about 1.5 kilometers (5,000 feet) long and 20 to 30 meters (66 to 98 feet) wide. Because of its proximity to the St. Lucia capital of Castries, it has served as the primary source of sand and aggregate for building in that city. In an analysis of Vigie Beach, using aerial photographs taken from 1940 to 1970, regression of the beach averaged 60 centimeters (2 feet) per year. An estimated US$10 million of real estate was at risk by 1970. By 1973, the beach front of the Red Lion Hotel at the southern end of the beach had eroded to just pebbles and cobble stones, resulting in a reduction of tourism and lost revenues.

Mining of bottom sand, and most dredging, generally eliminates a natural breakwater that acts to reduce wave energy falling on a shoreline. Modification of tidal inlets also can have an effect on the erosional and depositional pattern of abutting beaches. With projected sea-level rise, and the prospect of even more tropical swells from storms, this should be of great concern. The countries of Dominica, Grenada, Jamaica, St. Christopher and Nevis, St. Lucia, and St. Vincent appear to be in the most jeopardy from these hazards because of their sand-mining activities.

Over time, a 1- to 2-meter rise in sea level will be likely to inundate wetlands, accelerate erosion, and exacerbate coastal flooding—threatening coastal structures and increasing the landward penetration of saline waters in estuaries and freshwater aquifers. Wetlands, consisting for the most part of mangrove swamps, along undeveloped coastlines are expected to migrate readily into adjacent lowlands. Yet, because most coastal lowlands have steeper gradients, the net result will be a reduction in these natural storm barriers, and a reduction in their role in erosion control. Coral reefs—prominent formations in the Caribbean—also are endangered by a rise in relative sea level. These reefs provide a barrier for the shores behind them.

Other potential problem spots are urban areas located in low-lying coastal areas, such as Belize City, Belize, where about 28 percent of that country's population of 150,000 live. Today, it is only 15 centimeters (6 inches) above sea level, with a tendency toward destruction from the hurricanes which impact there, dead-center, on an average of once every 30 years.

Another example is Georgetown, Guyana's capital and largest city, with a population of about 200,000. It is located on the coast, and built on drained marshland protected by dikes. Fully 90 percent of Guyana's total population of almost 800,000 live on the narrow coastal plain, often on land reclaimed from tidal marshes and mangrove swamps.

Paramaribo, Suriname's main port and capital, with a population of 182,000, has many wooden buildings built on stilts to protect them from tidal action. Also, Cayenne, the capital and main port of French Guiana, with a population of 38,000, is situated on a low-lying island in the Cayenne River estuary.

Responses

How have the nations of the Caribbean responded to existing or potential natural hazards (including a possibly accelerated rise in relative sea levels) along their coastal zones? One example is Costa Rica, where permits from the Tourism Institute and the Ministry of Public Works and Housing must be secured in order to develop within 200 meters (656 feet) from mean sea level along 75 percent of that country's shoreline. Another example of special policies for land-use planning within a shore area is in Guatemala. Although not as refined a policy as in Costa Rica, the coastal area of Guatemala has been treated as a separate situation with regard to zoning. The coastal area stretches inland 3 kilometers (1.86 miles) from the shore. Barbados, since April of 1984, has maintained a coastal conservation project unit, whose tasks include the monitoring of natural phenomena such as hurricanes, winter swells, and sea-level rise. Further, there is now a building setback requirement of 30 meters (98 feet) from the high tide mark.

Grenada, in 1983 had a Physical Tourism Development Plan funded by the Organization of American States. From this study, a coastal monitoring program was begun in August 1985. One of the four major tasks of the program, if funding is received, will be to set up additional tide gauges, and initiate long-term sea-level measurements. It is further hoped that a recommended 50-meter (164-foot) development setback policy will be legislated and implemented in the near future.

Gustavia, St. Barthelemy, French West Indies, representative of the low-lying coastal towns found throughout the Caribbean. (Photo by the author)

Tide-Gauge Stations

A network of tide-gauge stations is essential to the monitoring of Caribbean sea-level change. The list below includes many of the existing tide gauge stations in the Caribbean and those proposed by a workshop on Physical Oceanography and the Climate of the Caribbean Sea and Adjacent Regions, held in Cartagena, Colombia, in August 1986, under the auspices of the United Nations Intergovernmental Oceanographic Commission.

EXISTING

Port Isabel, Texas
Miami Beach, Fla.
Key West, Fla.
Havana, Cuba
Cape San Antonio, Cuba
Tampico, Mexico
Tuxpan, Mexico
Veracruz, Mexico
Alvarado, Mexico
Coatzacoalcos, Mexico
Carmen, Mexico
Progreso, Mexico
Chetumal, Mexico
Port Cortes, Honduras
Port Castilla, Honduras
Limon, Costa Rica
Cristobal, Panama
Cumana, Venezuela
Chaguaramas, Trinidad
Port of Spain, Trinidad
San Juan, Puerto Rico
Magueyes, Puerto Rico
Port Plata, Dominican Republic
Port au Prince, Haiti
Port Royal/Kingston, Jamaica
Guantanamo Bay, Cuba

PROPOSED

Port Morelos, Mexico
Carapachibe, Cuba
Grand Cayman
Cape Cruz, Cuba
Montego Bay, Jamaica
Savanna-La Mar, Jamaica
Swan Isle, Honduras
Morant Cay, Jamaica
Pedro Cay, Jamaica
Serranilla, Colombia
San Andres Isle, Colombia
Colon, Panama
Cartegena, Colombia
Riohacha, Colombia
La Orchila, Venezuela
Toco, Trinidad
Crown Point, Tobago
Charlotteville, Tobago
Kingston, St. Vincent
Georgetown, Grenada
Bridgetown, Barbados
Castries, St. Lucia
Fort de France, Martinique
Roseau, Dominica
Basse Terre, Guadaloupe
St. Croix, U.S.V.I.
Mona Is., Puerto Rico
Isla Saona, Dominican Republic
Cape Du Mole, Haiti
Cape Maisi, Cuba

Caribbean Research Agenda

As a response to the concern expressed in the Caribbean region about the implications of expected natural and man-induced climatic changes for the marine and coastal environment, the United Nations Environment Programme has initiated a study to review the situation in the Caribbean through their Regional Seas Program. Some of the intended objectives of the study include an examination of the possible effects of sea-level changes on the coastal ecosystems, including but not limited to, deltas, estuaries, coral reefs, beaches, and wetlands. Another objective is to determine areas or systems that appear most vulnerable to the projected climate changes and related effects.

A meeting held at Kingston, Jamaica, on July 30 to August 1, 1987, established a Task Team on Implications of Climatic Changes in the Caribbean Region. The author and other researchers at the Woods Hole Oceanographic Institution are involved in this Task Team, which will prepare a report on the expected effects and associated areas of climatic changes in the region. Recommendations for policy development also will be forthcoming for preparation of legislation, and for organizational development. With many countries in the Caribbean, these recommendations will not be easy to implement.

Other studies are being conducted in the Caribbean Sea and adjacent areas. The United Nations Educational, Scientific, and Cultural Organization (UNESCO) Lesser Antilles Coastal Zone Management and Beach Stability Program, which began in February of 1985, covers Antigua, Dominica, Grenada, St. Lucia, St. Vincent, and St. Christopher and Nevis. The aim of this project is to assist in developing internal capabilities to manage and conserve, for socio-economic benefits, the beach and nearshore resources. One of the recommendations put forth was to implement a system of tide gauges at each island in the Caribbean. About two or three tide gauges per island are believed to be required to determine local relative sea-level changes.

Another project, under the auspices of the United Nations Intergovernmental Oceanographic Commission (IOC), held a workshop on Physical Oceanography and the Climate of the Caribbean Sea and Adjacent Regions in Cartagena, Colombia, in August, 1986. The goal of the workshop was to convene a small working group of physical oceanographers from the Caribbean region for the purpose of designing a research agenda. One of the projects proposed was an open-sea and coastal network of sea level and weather stations to contribute data on both an island scale and basin scale. The interests of many area states were primarily in the economic and applied aspects of shelf and coastal processes, and a sea-level project was felt to be essential to these interests.

Management of Caribbean coastal areas has been hindered by the general lack of knowledge about coastal ecosystems, and by the shortage of expertise in coastal management issues and policy. To address these problems, the United Nations is taking the initiative to alert countries in the Caribbean to the possible implications of sea-level changes through various workshops and meetings. Funds are initially needed to implement coastal research studies in order to improve coastal management programs in the region. Hopefully the United Nations effort will lead not only to an improved understanding of the problems caused by sea-level rise, but also the allocation of much-needed resources to assist the Caribbean nations in their management efforts.

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Changing Times for Caribbean Fisheries

by Mel Goodwin

It's 2:00 A.M. in the Grenadines, and 'Joe Bah Koe'—his mother named him Herbert Adams—is just leaving the island of Carriacou in his 18-foot fishing boat. His is one of the better boats in the fleet, and the 40-horsepower outboard pushes the wooden hull steadily toward Sail Rock. Baitfish are plentiful this morning. By dawn Joe Bah Koe has begun trolling for the dolphinfish, kingfish, and wahoo that are abundant during the first half of the year. Fishing is good today; two dolphinfish and one kingfish are brought ashore around noon.

Ninety miles to the north, a slender canoe arrows toward the shore of Vieux Fort, St. Lucia. The gunwales of the hollowed log hull are only inches above the water, and the sea is rough, but *the 55-horsepower outboard is at full throttle. Despite the weather, the 15-mile excursion into the Atlantic has produced nearly 100 pounds of dolphinfish. Still, the boat's three occupants are concerned by what may await them on shore. Five other boats are already drawn up on the beach, and are selling their catch to an eager public. If customers are hard to find, it may be necessary to reduce prices or find transportation to carry the fish to other parts of the island.*

"Rasta Willy," pulling his boat ashore on St. Kitts, is not troubled. There are plenty of eager hands dragging the heavy dory across the beach stones, and more people already crowding in to buy a pound or two of fish. Ten fish traps and 3 hours of seining with a heavy net have produced about 50 pounds of reef fish and ocean gar. Most of the reef fish are small and the gar are very bony, but the catch will sell for nearly 200 Eastern Caribbean (EC) dollars (US$75.00).

Winds of Change

From Grenada to the British Virgin Islands, the tools and techniques of artisanal fishermen have changed little in the last 300 years. Even though outboard engines, synthetic lines, and metal hooks have replaced sail, natural fiber, and bone, the target species, fishing grounds, and techniques remain virtually the same. Innovations have often brought mixed benefits. Outboard engines are more expensive to operate than sails, and boats without sails become helpless when engines fail. Replacing woven wicker with wire mesh initially increased trap catches, but led to overexploitation of traditional fishing grounds. Now the fish are smaller and fewer than in the past.

Eastern Caribbean fisheries may have changed little in three centuries, but today, the winds of change blow through the islands. Many of the 21 island nations in the Greater and Lesser Antilles have been independent for less than 20 years. In earlier times, colonists emphasized agriculture as the primary industry, but recent independence has been accompanied by problems of rising import costs and declining prices for traditional agricultural exports. It would appear that islands in a vast ocean could turn to the sea to offset an eroding agricultural base, but making the switch from land to water is not so simple. With few exceptions, residents have been raised to farm, not fish, and awareness of the importance of marine resources is slow to take hold. Fishermen who have traditionally worked day-to-day for short-term gains are now being asked to consider long-term resource management. While they might welcome the results of improved fish stocks and habitats, they often see management activities as limiting their fishing practices and territories.

Meanwhile, as potential food and export commodities go untapped, economic and social problems mount. Most Caribbean islands are net importers of food: In Dominica and St. Kitts local demand for fish exceeds supply by more than 250 percent, while imports of fish to St. Lucia were valued at more than EC$2 million in 1982. This trade imbalance has a ripple effect, reflected in inadequate nutrition and widespread unemployment. Because such circumstances are often interpreted as an inability of the government to provide for its citizens, political stability is jeopardized, along with the well-being of the people.

Availability of Fish

While need and concern for fisheries development are growing in response to these conditions, a fishing industry also requires that there be fish available to harvest. Too often, fisheries development projects have demonstrated that technology and capital resources are more abundant than the fishery resources they target. From 1965 through 1971, the United Nations Development Programme, together with the Food and Agriculture Organization, undertook a major exploratory fishing program. The project concluded that fishery resources in the Eastern Caribbean were not sufficient to support large-scale commercial development.

A satellite view (Figure 1) of the region shows why: production of single-celled algae, a critical link in marine food chains, is low for much of the region. Though warm temperatures and abundant sunshine favor algal growth, they also cause the ocean water column to become stratified. Consequently, there are no regular upwellings to bring nutrients from deep water to the surface, and without nutrients, algae cannot grow.

As a result, commercial fisheries in the Caribbean have developed only around the larger island and continental land masses. Groundfish (croaker, sea trout, catfish, and porgy) dependent upon estuaries and broad, muddy bottoms are harvested off Yucatan (Mexico), Cuba, Hispaniola (Dominican Republic), Jamaica, and in the Orinoco (Venezuela) and Magdalena (Colombia) river deltas. Small coastal pelagic fishes (herring, anchovy, and sardine) are the largest single group of fishes landed in the region, but the commercial harvest is confined to Cuba, Colombia, and Venezuela. Shrimp are harvested along the coasts of Cuba, the Dominican Republic, and Central and South America; but Eastern Caribbean islands have neither the shelf area nor the estuarine habitat to support a commercial harvest.

Present hopes for Eastern Caribbean fisheries development center on pelagic fishes (tuna, dolphinfish, kingfish, billfish, and flyingfish). Although exploitation of these stocks by Eastern Caribbean fishermen has been limited by small fishing boats and inadequate cold storage, development assistance programs to remove these constraints are underway in Grenada, St. Vincent, St. Lucia, Dominica, and Antigua.

Still, there is a certain nervous restraint about these preparations: the actual potential for expansion is unknown for most species. While the present harvest by Eastern Caribbean fleets is relatively small, the same stocks are targeted by numerous other nations; commercial fishing vessels from Taiwan, Korea, Japan, Scandinavia, the French West Indies, and the United States operate within the Exclusive Economic Zone (see *Oceanus*, Vol. 27, No. 4) of the Eastern Caribbean countries. In the last three years, for example, the area has seen a sharp increase in

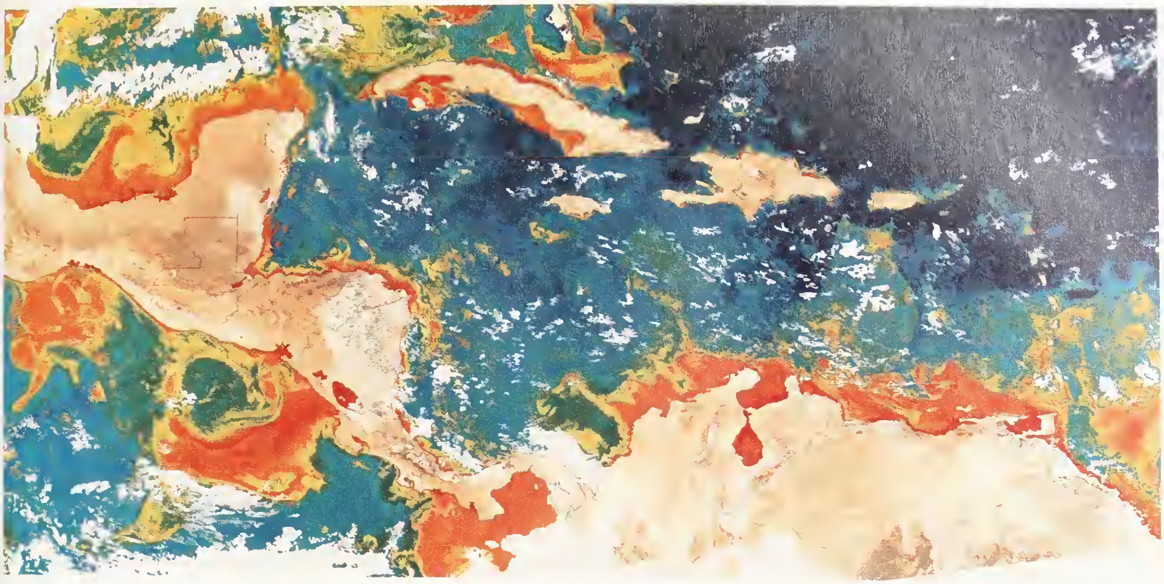

Figure 1. Composite satellite imagery of the Caribbean Basin from the Nimbus-7 Coastal Zone Scanner, February and March, 1980. Phytoplankton pigment concentrations are coded from low (blue), to high (red). Note low concentrations in the upper right, in the vicinity of the Eastern Caribbean Islands. (Courtesy Dennis K. Clark, NOAA, NESDIS, Washington/RSMAS, University of Miami)

fishing activity by U.S. vessels in pursuit of swordfish. In some cases, permission has been sought, but more often than not, the vessels operate without the knowledge or consent of Caribbean governments.

The swordfishing issue was the subject of a special workshop at the 39th Gulf and Caribbean Fisheries Institute last year in Bermuda. Fisheries ministers from five Caribbean nations met with fisheries biologists and industry representatives to review information on swordfish stocks and options for management. Island governments had not previously recognized the potential value of the fishery (at least US$2.2 million), or the willingness of many longlining vessels to cooperate with local authorities. Perhaps the most important outcome was the realization that these shared stocks require management on a regional basis. The next important step toward such management was taken in November 1987, when the Organization of Eastern Caribbean States met to define a policy for allocation of shared fisheries resources.

Time for Decision

Fisheries development in the Caribbean has reached a crossroads—or perhaps a precipice. One option is to take a laissez-faire approach to fisheries management, as has happened previously in many fisheries throughout the world. The expectation underlying this approach is that fishing effort will increase until it is no longer profitable, and in this way the natural limits of fishery resources will "automatically" constrain the industry to appropriate levels. This expectation is reasonable for businesses in which the cost of raw materials increases as the materials become more scarce and in greater demand, but fishery resources are "free," and there is no direct economic constraint to increased investment in harvest capacity as these resources dwindle. The usual result of this approach is a sequence that moves from underutilization to overexploitation, while investment in fishing capability steadily increases. The sequence very often concludes with collapse of the fishery.

The fishery resources of the Caribbean, however, are not large enough to provide the buffer capacity needed to replenish depleted areas, nor are local economies so healthy that they can easily accommodate a serious decline in an important food- and income-producing sector. An unregulated approach to fisheries development in the Caribbean is likely to create serious social and political problems for countries of the region.

Alternative

The alternative is to adopt an approach that addresses all the components of the fishery sector: harvest, processing, marketing, and especially the natural production processes that make a harvest possible in the first place. In the past, many efforts to develop Caribbean fisheries have concentrated on single aspects of this sector, and have been marginally successful at best. Now, there is growing support within the region for a more integrated approach targeted to a variety of needs and opportunities:

Underutilized Resources. Traditional Caribbean fisheries continue to be overexploited because fishermen see no alternative. While there is little fishing in deep water, snappers, groupers, and crabs could probably be harvested from these areas. The available quantities are not likely to be large enough to interest commercial investors, but could make a significant difference on a local scale. Together with squid, octopus, shark, and other pelagic fishes, these resources offer potential for increased landings as well as a means for reducing pressure on nearshore fisheries.

In all cases, the actual harvest that these resources can support is unknown. Rather than delay development until resource assessments are carried out, an alternative approach has been adopted in St. Kitts. Here, pilot fishing operations are directed toward underutilized species, so that information needed to assess the stocks can be obtained in the course of actual fishing. Another alternative for pelagic fishes is to grant a few short-term licenses to foreign fleets for limited operations. This provides a means of obtaining information on available resources (as well as a modest revenue from license fees) without investing in expensive—and possibly inappropriate—fishing vessels.

Improved Technology. Increased fisheries production in the Caribbean requires a variety of improvements to artisanal fishing fleets. Harvest of deepwater bottom fishes and crabs requires depth sounders and mechanical hauling devices. Vessel safety has been a chronic problem in the Eastern Caribbean, and will become increasingly serious as fishing activities move farther from shore. Similarly, the use of more expensive equipment will increase the need for vessel insurance, the availability of which will depend on the economic viability and technical competence of the fishing operations. But none of these factors demand direct transfer of highly sophisticated technology from commercial fisheries in developed countries. The fact that conch, spiny lobster, and reef fish stocks have already been overexploited with artisanal techniques suggests that, in general, the absence of modern technology is not a primary problem.

In some cases, relatively simple technology can be most appropriate. The harvest of pelagic fishes, for example, may be significantly improved through the use of fish aggregating devices (FADs). These are objects that float at or below the surface in deep water and provide a visual reference point in an otherwise relatively featureless environment. FADs may be free-floating or anchored, and may be a simple bundle of palm fronds, or complex rafts costing several thousand dollars. The U.S. Agency for International Development (USAID) recently sponsored an evaluation of commercial and locally constructed FADs. They found a significant increase in catch by artisanal fishermen in the vicinity of such devices. Suitably installed FADs can improve the economic return from small-scale fishing by reducing the amount of time and fuel spent searching for fish, as well as increasing the actual catch. The same devices contribute to recreational fisheries that can be important money earners in the tourism sector of the economy.

Processing and Marketing. During the season for migratory pelagic fish, fishermen often restrict their catch to quantities that can be sold immediately. The absence of cold storage and organized market facilities frequently cause some villages to be glutted with a surplus of fish, while others have none at all. Successful development of pelagic fisheries will increase the need for on-board as well as shore-based cold storage; spoilage of large tunas and mackerels can result in severe cases of food poisoning.

Again, facility needs vary with local conditions. A large central market with walk-in freezers may be less appropriate than small ice makers and insulated boxes that would allow fishermen to hold their catch overnight. An increasing number of consumers are willing to pay a higher price for a regular supply of iced and cleaned fish in preference to crowding at a beach in uncertain hopes of obtaining a "fresh" fish that, in fact, may have been lying ungutted in the sun for several hours. An incremental approach to marketing and processing facilities can provide a solution to immediate problems without making large investments that may prove to be unsuitable for local conditions. At the same time, regional collaboration on market opportunities can help make the best use of available resources.

Management. A viable fishing industry obviously depends on something to catch, yet fisheries development efforts typically consider resource management as secondary to harvest and post-harvest processes. Perhaps management is often viewed as antagonistic to development—because traditional management tools are based largely on restricting the activity of fishermen. Some restrictions are undoubtedly necessary, but there is another equally important challenge for management: to develop means for enhancing these resources and the natural processes on which they depend.

Montserrat has been engaged in one form of resource enhancement for the last six years. An artificial reef has been constructed from scrap automobiles with assistance from the Caribbean Conservation Association and the Canadian government. Since its construction, local fishermen report substantially increased catches from the area, and are in favor of expanding the project. Similar potential seems to exist for increasing the production of spiny lobsters by providing suitable artificial shelters. The question of "attraction versus enhancement" continues to be debated by fisheries biologists, but there is no question that the prospect should be explored.

Mariculture. Artificial culture is another means for enhancing natural production. Numerous projects have been proposed to culture shrimp, spiny lobsters, oysters, crayfish, conch, spider crabs, and a variety of fishes. Some projects are wildly impractical, while others hold promise—but none have demonstrated long-term economic benefits for local economies. A recent report produced by the U.S. National Oceanic and Atmospheric Administration concluded that "the primary recommendation for mariculture development is to proceed with caution." Despite the high-risk nature

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Caribbean Conch Culture

The queen conch (Strombus gigas) *has been a high-protein staple in the West Indian diet since pre-Columbian days, and, until as recently as the 1960s, was a major export of 16 Caribbean countries. Today, these stocks are seriously over-fished and depleted. There remain only two marginal exporters—Belize, and the Turks and Caicos Islands. Of the many mariculture projects tried, involving various species, the one for conch is the most promising in the Caribbean—and Trade Winds Industries, Ltd. (TWI), of the Turks and Caicos is the pioneer in this effort.*

Nature can be harsh, even in what appears to be a tropical paradise. It can be particularly harsh to the larval stage of marine invertebrates, such as the queen conch, which suffers larval mortalities of greater than 99 percent. But what if the conch could be protected from predation in its early developmental stages, and brought to maturity in a protected environment?

To answer this question, several staff members of PRIDE (Foundation for the Protection of Reefs and Islands from Degradation and Exploitation), a non-profit organization in the Turks and Caicos Islands created by Virginia native and Annapolis graduate Chuck Hesse, founded TWI as a potentially profit-making adjunct. Since its inception in 1984, TWI has developed and operated a commercial conch hatchery, based on research begun under the auspices of PRIDE in 1980, when six conch larvae were successfully brought through metamorphosis (one survived to maturity). Today, it is a well-rehearsed routine.

The crescent-shaped egg masses—they are 4 to 6 inches long—of the queen conch are gathered from a nearby reef and brought to the hatchery complex at Leeward-Going-Through, on the island of Providenciales. Here, the microscopic larvae—10 will fit into a single drop of water—are hatched and tended until, at 3 weeks, they metamorphose into pin-head-size baby conch. The tiny conch are transferred to cages in shallow, in-shore pools, where they are fed on the algae, Laurencia, which is also grown by TWI. It takes 3 to 4 years to complete "growout" (that is, bringing the juvenile conch to maturity), and it takes 2 or 3 mature conch to produce a pound of meat. At the end of its 1986 season, TWI had an estimated 6 million conch in various stages of development.

Because of the time it takes to bring a queen conch to maturity, TWI is only just beginning to come "on line" as a commercial venture; until now, they have been selling young conch as "seed-stock" to other Caribbean countries, to replenish those in the wild. Soon, they hope to start exporting conch and thereby relieve the pressure that has so depleted the naturally occurring stocks. Eventually, TWI hopes to have its own conch meat processing facility.

Diver tags one of 400 broodstock conch that graze a 2-acre pasture surrounded by protective netting on Providenciales in the Turks and Caicos Islands. (Photo by Andrew Dalton)

TWI has pioneered the development of commercial conch farming. In the words of TWI president Chuck Hesse, "the company has a juvenile conch growout system that produces 90 percent survival in post-larval conch on natural algal foods." Conch is "the ideal tropical animal" to raise at sea because it is easily contained, and is far cheaper to feed than the carnivorous lobster or shrimp. Also, there exists a large, ready-made market for it with a rapidly declining natural supply. Hesse concludes: "We now have a mariculture grow-out business that can be set up in over 20 Caribbean and Latin American countries."

—P. J. Buehler

Traditional Fishi

Outboard engines are one of the few innovations of artisanal fishing technology in the last three centuries.

Steep rocks and rough seas are home to a Dominican c

All photos by Sandra T. Goodwin. © copyright.

Fish-aggregating devices ready for deployment.

Small boats used on St. Kitts and elsewhere limit the size and number of traps that can be set or recovered during one trip.

Hauling a traditional fish trap off the Dominican Republic.

n the Caribbean

ıp near surface, Dominican Republic.

Willing hands haul boat on St. Kitts in hope of a few fish.

Blowing conch shell on St. Kitts; the traditional signal of a man with fish to sell.

al fish market on St. Kitts: Many buyers for few fish.

The fishing fleet at sunrise, Pedernales, Dominican Republic.

Species Names

To clearly identify the fish species mentioned in this article, a list of common names and species names follows:

Dolphinfish (Coryphaena hippurus)
Kingfish (Scomberomorus cavalla)
Wahoo (Acanthocybium solanderi)
Ocean Gar (Tilosaurus crocodilus)
Croaker (Micropogon undulatus)
Sea Trout (Cynoscion regalis)
Catfish (Blachyplastystoma vaillant)
Porgy (Stenotomus caprinus)
Herrings (*Clupeidae*)
Anchovies (*Engraulidae*)
Sardines (Sardinella *sp.*; Harengula *sp.*)
Shrimp (Penaeus *sp.*)
Flying Fish (Hirundichthys affinis)
Swordfish (Xiphias gladius)
Conch (Strombus gigas)
Spiny Lobster (Panulirus argus)
Oyster (Crassostrea *sp.*)
Spider Crab (Mithrax spinosissimus)

of existing mariculture technology, the potential benefits warrant exploration through well-designed pilot projects. Particularly promising are culture of *Tilapia* (a freshwater African food fish favored by aquaculturalists because it is prolific, very adaptable to a variety of conditions, and does well in seawater), shrimp, and finfish using floating cage techniques developed in Martinique.

The potential of Caribbean fisheries relies heavily on coral reefs, mangrove forests, salt ponds, and estuaries. But these resources are limited and subject to growing impact from human activity. Simply leaving the resources alone is not a solution: it is imperative that they be used for economic development. Because such development also depends on the quality of natural resources, it is increasingly clear that development must be integrated with resource protection. Economic development and protection of natural resources are not alternative options; they are mutually dependent necessities.

Public Involvement. Fishermen logically should be part of fisheries development, but often are involved only after projects are well under way. More projects now involve fishermen early in the planning stage, and include activities that address immediate concerns of fishermen, as well as long-range development objectives. A fisheries development project in St. Kitts, for example, has established a fishing gear supply and outboard engine-repair service, along with vessel improvement and exploratory fishing activities.

Because fisheries are interrelated with other natural resources, the need for involvement and understanding extends beyond fishermen to farmers whose land management practices and use of chemicals affect coastal fish habitats; to restaurateurs whose refusal to purchase undersized lobsters and conch could discourage the harvest of juveniles; to developers whose sewage disposal and beach use arrangements can drastically alter natural fish nurseries; and to tourists whose repeated forays can cause major destruction to coral reefs. Many of the activities and processes associated with fisheries are invisible, and a strong agricultural tradition has caused public attention to focus elsewhere. But widespread understanding and appreciation of the importance of fisheries and their linkages to other systems are absolutely necessary for Caribbean nations to achieve full benefit from their living marine resources.

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Intermediate Technologies for Small-Scale Fishermen in the Caribbean

by Daniel O. Suman

In the Third-world countries, there are about 15 million small-scale fishermen employing traditional methods of fishing, and a comparable number of people involved in preservation and distribution. In the Caribbean, more than 60,000 small-scale fishermen exploit marine resources. For the families of these people and many others, fish caught by traditional methods represent the major source of protein.

As a Fellow of the Board on Science and Technology for International Development (BOSTID) of the National Research Council, Washington, D.C., I conducted a study on intermediate technologies that could benefit small-scale fishermen in developing countries. The report, *Fisheries Technologies for Developing Countries* (in press, and available from BOSTID in 1988), is global in scope, describing new fishing technologies throughout the world. The material applicable to the Caribbean has been extracted for this article.

Artisanal Fisheries

Caribbean artisanal fisheries primarily exploit reef and inshore species, such as jack, barracuda, herring, grouper, catfish, triggerfish, pompano, shark, grunt, shrimp, lobster, crab, and queen conch. With a few exceptions, there is minimal fishing in deeper waters.

These fisheries are characterized by low cash income and minimal-input management. The fishermen use traps, handlines, and beach seines to catch species near reefs. Investment in equipment is generally low, and a fisherman's wealth is usually measured in terms of his fishing gear. This is usually less than optimal, subject to constant and rapid deterioration, and sometimes total loss. These fishermen also face other obstacles that make it difficult or impossible to improve their fishing methods, and rise above their marginal standard of living. Government policies often concentrate resources on modern commercial fisheries, thereby limiting access of the traditional fishermen to credit and markets. Moreover, they are at a disadvantage when competing for limited fish stocks with the more efficient fishing technology of the modern sector. In addition, in many reef and near-shore areas, pollution and over-exploitation lower productivity even further.

Among the other limiting factors are inadequate processing facilities, which increase post-catch losses and limits the range of marketing. The decreasing availability of high-quality hardwood in many coastal areas is an obstacle to the construction of traditional fishing vessels. Moreover, the replacement of sail technology by outboard motors has been a drain on scarce economic resources, and often has not been cost-effective.

Under some circumstances, intermediate and relatively inexpensive technologies could help fishermen surmount some of their problems. Successful adaptation of a technology to a new situation implies that it solves a specific problem, does not generate social or economic tensions, is economically feasible, and is acceptable to the community. Recognizing that there are no universal answers, the BOSTID study details fishing technologies that have found successful application in specific regions and demonstrate potential for adaptation in other settings. Many of these intermediate technologies have been developed or tried in the Caribbean.

Fishing Boats

Alternative boat construction materials may substitute for high-quality hardwoods and provide advantages of strength and light weight. The Woods Hole, Massachusetts-based Ocean Arks International community development project has devised a system in Costa Rica for fabricating composite panels of epoxy and locally available "scrub" woods, such as the South American softwood, Baromalli (*Catostemma commune*). These pre-fabricated panels, in turn, are used in the construction of a 32-foot, sail-driven fishing trimaran, the "Ocean Pick-up" (Figure 1). This vessel is beachable, rowable, fast, and can carry 1,500 pounds of iced fish. It has successfully fished with traps, gillnets, longlines, and trolling lines.

Plastic tubes, ferrocement, and fiberglass all have been used successfully to construct traditional hull designs in Third World fisheries. In the Eastern

Figure 1. The Ocean Pick-up, developed by Ocean Arks International, Woods Hole, Massachusetts. The vessel is designed for easy construction using prefabricated panels of composite materials. (Photo by Nancy Jack Todd)

Caribbean, fiberglass-reinforced plastic is used to sheath traditional wooden boats, thus significantly extending their lifetimes. Ferrocement has become a favorite construction material for Cuban boats; the shipyards of their Naval Projects and Technology Center have designed and produced more than 1,000 ferrocement boats, including those designed for shrimp-trawling and longline fishing. The Yamaha Company of Japan, active in developing African fiberglass fishing canoes based on traditional boat designs, is about to launch a fishing canoe designed for Caribbean small-scale fisheries.

Small fishing boats with outboard motors are common sights throughout the Caribbean. Not only are the vessels usually overpowered, but the high cost of the motors, fuel, and repairs are great liabilities. Alternatives to the gasoline outboard motor are being explored in many Third World areas. Despite their high initial costs, diesel inboard motors could be cost-effective for some Caribbean artisanal fleets. Honduran fishermen from the Bay Islands have adopted reliable, economical inboard motors in their fishing canoes. Some small-scale fisheries are rediscovering sail to assist engines, or as the principal means of propulsion—saving fuel and reducing operating costs.

Fishing Methods

There are numerous fishing technologies that could be adopted by artisanal fisheries. Among these are mechanization of hauling, modernization of longlines, trolling with multiple lures, attracting fish with lights, and pair-trawling by two small boats. New fishing arts could tap offshore resources or underutilized species and, in addition, permit the small-scale fishermen to compete more effectively with the industrial fishing sector.

Octopus and squid are both underutilized resources that show high potential in the Caribbean. Less than 5 percent of the continental shelf from Venezuela to the Yucatan Peninsula in Mexico is exploited for octopus, but in eastern Venezuela, the octopus fishery is highly developed. Trawling is the predominant octopus fishing method, but traditional pots (artificial caves where the animals seek refuge) are still deployed. These are made from old tires cut into sections, pinned shut, and hung from longlines (Figure 2). The Cuban Fisheries Ministry has developed a hemispheric pot made of clay with a small opening at the bottom for the animals. Thus, no light penetrates into the pot during hauling. In Mexico, empty conch shells have been attached to lines and dragged slowly over the bottom, successfully capturing octopus. Small fishing vessels could simply use light arrays and hand-operated jigging reels to fish for squid, a common fishing art in Japan.

Fishing with light is not common in the Caribbean, but might find successful application. "Tight lining," a term used in Tobago for a variation of light fishing, involves directing a strong light into the water from an anchored boat. The squid, jack, sardine, and balao that are attracted are scooped up and used as bait to catch snapper, kingfish, and shark.

Longlines—unwatched lines with multiple hooks attached—may be placed either horizontally or vertically in the water, float on the surface or just off the bottom, drift, or be anchored. This fishing technology originated in Cuba, and has the advantage of being economical and requiring no mechanization to set or recover the line. It is excellent for shark, another underutilized resource, and may encourage fishing farther offshore. The introduction of light-emitting lures, detachable branch lines, and multiple hooks per branch are recent advances.

Many variations of fish traps (pots) exist throughout the region with spiny lobsters and shallow reef fishes, such as snapper and grouper, the common targets. The traps are ideal for the coral-reef fishing grounds that might damage trawl nets. Traditionally, traps were made of cane or bamboo fibers, but today marine mesh and chicken wire are increasingly common. West Indian or Antilles traps have curved surfaces and are shaped like a single or double "Z" with two or four opposing entrances. Entry funnels are turned down to prevent fish from escaping. Cuban box or cylindrical crab traps are made of wire and lined with mangrove boughs to provide attractive shade and shelter, and are run on a "train" or longline of 50 to 60 traps, so as to decrease loss and facilitate recovery. Recent trap innovations include "pop-ups" or timed-release floats that conceal the traps and reduce poaching, theft, or cut-off floats.

Larger trap nets, or weirs, are used in shallow shelf areas of the Caribbean. A nylon-mesh wing intercepts the migration path of fish or crabs. A second circular wing prevents escape and directs fish through a funnel toward a collecting corral.

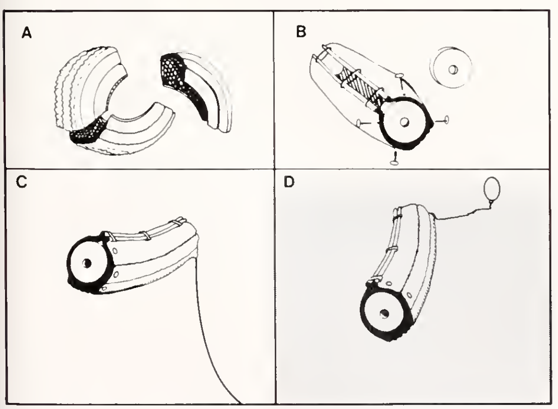

Figure 2. Octopus pots in Venezuela are made from sections of old tires that are pinned shut and hung from longlines.

Artificial Reefs and FAD's

Artificial reefs, made of brush bundles, tires, or rocks, show promise as effective management tools for traditional fisheries. By concentrating the fish, they facilitate the catch, thus saving time and fuel. An artificial reef has been built in Costa Rica of old tires, and that country is considering a national artificial reef program. Cuba's spiny lobster fishery is based on the use of artificial reefs that are constructed by laying mangrove boughs across two parallel branches and stacking them like pallets. The finished shelters have a useable lifetime of about one year, and are used in waters 4 to 6 meters deep. The shelters are fished monthly by divers who first shake them, and then catch the fleeing lobsters in scoop nets. More than 200,000 of these shelters are deployed in the Gulf of Batabano with an annual yield of 64,000 tons of lobster. Use of this same technique has spread to the Quintana Roo coast of Mexico.

Fish aggregating devices (FADs) attract fish simply by providing a visual reference point in otherwise relatively featureless surroundings. In Barbados, bundles of sugar cane are attached to vessels by lines. The bundles, along with a chum basket of crushed fish, attract schools of flying fish that are captured either by scoop nets or handlines. In Jamaica, the Caribbean Z-trap (made of reed) is buoyed at the surface and used to attract jack, rainbow runner, and barracuda. In Trinidad and Tobago, St. Kitts, Montserrat, and Puerto Rico, fish-attractors made of durable plastics have recently been used to increase the catch.

Sea Farming

Sea farming, or mariculture, in coastal waters offers an alternative to overexploitation of marine resources. Agricultural principles can be applied to improve yields of selected marine algae, invertebrates, and fish. A thriving commercial cultivation of red algae (*Eucheuma* sp. and *Gracilaria* sp.) has developed in Southeast Asian family farms. Seaweed species of these genera are collected from the wild in the English-speaking Caribbean islands. The species of *Gracilaria* sp., collectively referred to as seamoss, are used to thicken puddings and flavored drinks. Thus, the potential for commercial seaweed cultivation may exist in the Caribbean. A pilot project for seamoss cultivation in St. Lucia recognizes this potential. More than 600 meters of monofilament line, anchored in the water by stakes, serves as a surface for seamoss propagation and growth.

Research conducted by the Smithsonian Institution's Marine Systems Laboratory in the Dominican Republic, Antigua, and the Turks and Caicos Islands, suggests that algal turf mariculture adjacent to coral reefs may be biologically feasible. Algal turf, a mixture of red, blue-green, and green algae, is grown on screens suspended in the water and then fed to caged herbivores, such as Caribbean king crab, welk, or parrotfish. The life cycles of these animals have proved satisfactory for controlled spawning and the juvenile growth.

Queen conch (*Strombus gigas*), a popular seafood throughout the Caribbean, has been overexploited, resulting in a depletion of its stocks. To counteract this trend and rehabilitate depleted areas, several organizations in the region are attempting conch ranching procedures. Eggs are collected in the wild, and larval stages cultivated in hatcheries. The hatchery-reared juveniles are then seeded into formerly productive habitats. Conch hatcheries have been developed in the Netherlands Antilles, Quintana Roo (Mexico), Puerto Rico, Venezuela, Belize, and the Turks and Caicos Islands. In the latter country, an organization named PRIDE* has successfully integrated small-scale fishermen into its projects and promoted community development.

Crustaceans and mollusks are widely cultured in the marine environment. In the Caribbean, culture of the mangrove oyster has enjoyed the greatest success. This invertebrate cements itself to the roots of the red mangrove in the intertidal zone. Cubans have introduced longline cultivation in estuaries where oyster spawning occurs, thus permitting increased production. Mangrove or concrete stakes are placed at 3-meter intervals to form a 30-meter-long line. Wooden poles or galvanized steel lines are then suspended from cross beam to cross beam above the high tide. Mangrove branches, hung from the lines into the water, serve as a surface for oyster spat attachment. An artificial collector with 24 "feet" made of aluminum wire dipped in cement creates an improved surface for spat attachment. The oyster farm at Jujuru, Holguin, is Cuba's largest, with more than 100,000 mangrove-branch collectors, each producing 6 kilograms of oyster meat annually.

Another oyster culture project in Port Morant, Jamaica, uses sections of tire sidewalls for spat settlement (Figure 3). The sections hang from monofilament line in the intertidal zone. Once spat settlement has occurred, the tire substrate is restrung on long lines and suspended from bamboo rafts.

Another form of mariculture uses cages to protect fish from predators, insuring efficient food conversion and simplifying the harvest. A pilot project in Martinique grows finfish in large, revolving cages that are supported on the bottom and half submerged in water.

* The Foundation to Protect Reefs and Islands From Degradation and Exploitation

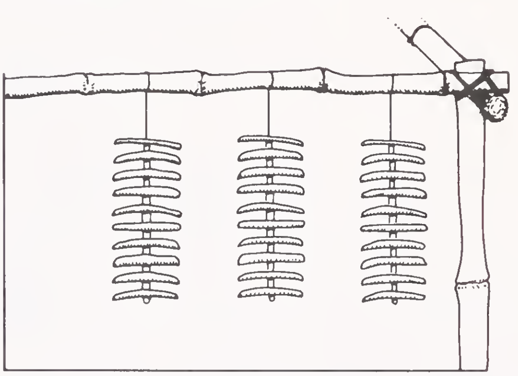

Figure 3. In Jamaica, strips of tires serve as the substrate for mangrove oyster spat attachment. These collectors are hung from wooden racks in coastal waters.

Fish Preservation

More than a third of the world's fish catch is lost after harvesting. Losses are particularly high in small-scale tropical fisheries. Icing is prohibitively expensive, and alternative preservation methods need to be popularized. Fish may be salted by wet or dry methods, once common in the Caribbean. Numerous models of solar driers also have been accepted in the tropics. They exclude insects and produce high enough temperatures to reduce mold and bacterial spoilage. Improved smokers, such as the Altona Oven and Chorkor Smoker, are gaining popularity in West Africa, but have yet to establish a foothold in the Caribbean.

Limitations to Technology Introduction

Any introduction of technology must be sensitive to the complete environment of the fishermen. Prior to the adoption of a new fishing technology, the living resources to be exploited should be identified and assessed. Their temporal and spatial distributions, population dynamics, behavior, and life histories should all be known. The impact of the new technology on fish stocks must be determined so effective management strategies can be implemented and enforced.

Careful cost-benefit analyses, feasibility studies, and pilot projects must be undertaken to insure that increased capital, operating, and maintenance costs are balanced by an increased catch translatable into increased profit. If a region is already overfished, the benefits from new technologies may be elusive. As many coastal waters in the Caribbean now have serious overfishing problems, new technologies should not be thought of as a panacea.

The cultural intricacies of a society must be clearly understood if technologies are to be successfully introduced. If not compatible with the managerial level or social organization of a community, a technology is doomed to failure. The negative social implications of the new technology (income disparities, increased unemployment, power shifts in the community) must be carefully considered.

If fishing technologies are to be successfully adapted by small-scale fishermen, these people must be directly involved in the prior planning and decision-making. Moreover, they must be convinced of the innovation's potential for success, economic feasibility, and harmony with the local environment and society.

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Caribbean Marine Mass Mortalities:

A Problem With A Solution

By Ernest H. Williams, Jr., and Lucy Bunkley Williams

When the largest fish kill known in the Caribbean occurred, the authors were in the Dominican Republic as guests of the Chief of Fisheries. Fortuitously, his guests were a fish-disease team. Unfortunately, unknown reasons prevented him from mentioning the fish kill to us. When he politely put us on a plane to Puerto Rico, we had no idea we were flying away from a massive fish kill and into a barrage of questions from Puerto Rican and U.S. agencies. Newspaper stories even reported that we were bringing fish samples from the Dominican Republic. This was only the beginning of the mass confusion that left a major Caribbean-wide catastrophe poorly studied and completely unexplained.

Unfortunately, aquatic animal health in the Caribbean has been characterized by chaos, ignorance, and disorder. The great epizootics* of commercial sponges, fishes, sea urchins, and corals roar through the Caribbean like prairie fires—bringing destruction, but shedding little light on their cause. We remain as vulnerable as ever to these highly publicized kills, and to equally important localized and minor mortalities.

The IRS and The Sea

Disease normally acts like the Internal Revenue Service of the marine environment. Disease extracts a surprisingly standard tax off-the-top of most plant and animal populations. A certain percentage of organisms die, many of them do not grow as large or as quickly as they could, and many experience reduced reproduction. Dying or sick organisms simply disappear, and disease is all but invisible—and easily ignored. But, over the long term, these losses are enormous. Diseases are a natural and vital part of marine ecology. Food webs are well studied, but little attention is paid to the equally intricate parasite and disease/host webs.

Millions of fishes perished in the Caribbean-wide mass mortality. Many of them washed up onto Caribbean beaches.

Occasionally a disease rampages through the marine environment, killing great numbers of organisms. The recent die-off of dolphins along the East Coast of the United States is an example. What should we do about these episodes? Let us examine two of the largest and most recent Caribbean-wide *disasters*, the *disorder* in attempting to study and solve these mortalities, and the future *direction* in Caribbean aquatic animal health.

Disasters

The Fish Mass Mortality. The Caribbean-wide die-off of fishes in August and September of 1980 had all

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* Diseases that affect many animals of one kind at the same time. "Epizootic" is the animal version of an "Epidemic." Only humans have epidemics. Some newspapers reported an "Epidemic of Urchins." That describes the very painful condition of people wandering around with urchins stuck all over themselves.

the elements of a thriller. It started with the most powerful hurricane recorded in the Caribbean; caused an international conflict over ocean dumping of chemical or radioactive contaminants; was blamed for human deaths; caused the economic disruption of most fish sales in the Caribbean; and provided cover for murder. It was characterized by the spectacle of listless, helpless fishes swimming up to the surface or lying just beneath the surface. Even the normally wary and elusive giant snappers and other game fishes could easily be grabbed by hand. For more than two months following hurricane Allen, uncounted tons of dead and dying fishes washed onto beaches, filled the bellies of humans and other predators, or sank unheralded into the depths. Anecdotal accounts of fishes that could not be held alive by previously established methods, and odd behavior in wild and captive fishes, suggests that fishes that survived the mortalities were "sick" for three to four additional months.

How does a whole ocean basin turn inhospitable to the fishes that live in its depths? What can keep so many fishes dying for two months and sick for months longer, over such a vast area? A monstrously important marine process? We do not know. We would not have believed that such a process could occur. We suspect that a Caribbean-wide physical process (or a series of processes) generated by hurricane Allen directly, or indirectly stressed the fishes (possibly by upsetting the plankton ecology of the region and increasing the abundance of toxic organisms). The fishes resistance against parasites and diseases broke down, and they succumbed to the common secondary* pathogens that are always on, in, or around them. Whatever the "monster" was, when the next great Caribbean hurricane hits, it may be released again. We hope that next time it occurs we are ready to understand this phenomenon.

* Secondary pathogens do not harm hosts unless the host defenses are reduced by other stresses. They are the "back shooters" of the disease world.

*Black longspined sea urchin (*Diadema antillarum*) on a Caribbean reef.*

Black Urchin Plague. In 1982, the black, long-spined sea urchin (*Diadema antillarum*) was probably the most abundant, large animal in the Caribbean. Untold billions munched algae and covered the bottom in dark, prickly mats. This urchin may have effectively regulated the environment of the coral reef—something man cannot begin to do. Man, in all of his collective might, could not have killed this urchin. Then along came a little pathogen and blew 99 percent of the urchins away. In the year it took the disease agent to spread through the Caribbean and subtropical Western Atlantic, the urchins were all but gone. The time from the first sign* of this disease in an area, to the utter dissociation and death of the urchins, was little more than two days. The typical signs (the few times they were recorded) were almost what you would expect had someone poured a powerful, concentrated acid on the urchins. This incredibly destructive disease makes the victims dissolve almost before your eyes. The pedicellaria (small, tube-shaped feet between the spines) stopped cleaning sediment and debris off the top of the urchins; spine control (for example, turning spines toward a disturbance) was lost; spines began to fall out, littering the bottom; and eventually, sections of the test (shell) fell apart.

This disease was first noticed off the Caribbean coast of Panama, and followed the main current patterns around the Caribbean. If anyone had wished, and had been prepared, they could have chased it, caught it, studied, and solved the mystery of this disease. Since this agent is so virulent, so host specific, and survives so well in seawater, it may be a spectacular virus that attacks the integument (outer layer) and spine musculature of the urchins. The "virus" is now spread all over the tropical and semi-tropical western Atlantic. The number of virus particles generated in destroying and replicating in billions of urchins is truly mind boggling.

This primary** pathogen either evolved from a more benign form (we are seriously degrading our near-shore and reef environment, and the microbes change more rapidly than the multicellular animals), or was imported. A disease of a Pacific black longspined urchin (*Diadema mexicanum*) might do little damage to its original host population because of natural host defenses, but an Atlantic population of hosts with no resistance, might succumb to it as a plague. The narrow isthmus of Panama is an easy location for an inadvertant transfer of a pathogen of this kind.

* "Sign" of a disease is like a "symptom" in humans. Symptoms are vocalized by a patient, signs are observed. No matter what question you ask an urchin, the most it will do is waggle its spines.

** Primary pathogens kill without any help from stress or fortuitous circumstances. They are the "Professional Killers" of the disease world.

Coral Reef 'Bleaching' Peril Reported

Colors are fading fast from Caribbean coral reefs. They are being replaced by white blotches, visible even from shore on some reefs. Stony corals (Coelenterata: Scleractinia), fire corals (Milleporina), gorgonians (Gorgonacea), sea anemones (Actiniaria), zoanthids (Zoanthidea), and sponges (Porifera: at least two orders) are losing their brown-green colors. Some are turning completely white, as if soaked in household bleach—thus the term "bleaching."*

After we submitted the adjacent article about mass mortalities, another mass mortality monster reared its ugly head. This one is not looking for a few sticky urchins (1983–84) or some fishes (1980), it is after the very basis for inshore marine life in our tropical and subtropical seas—the coral reef.

The white color is due to the loss of the symbiotic, single-celled algae zooxanthellae that normally live within the tissues of the marine animals listed previously. Many kinds of severe stress cause these animals to expel the algae from their systems. Divers in Puerto Rico and the Florida Keys, just before the bleaching was noted, described massive clouds of shed zooxanthellae blotting-out the visibility around the reefs down to a depth of 6 feet.

The photosynthetic zooxanthellae normally provide added nutrition, and the loss of this symbiont reduces the coral's ability to compete with other plants and animals. Without zooxanthellae most corals are white, but some show delicate colors that are otherwise hidden by the overpowering brown-green colors of the zooxanthellae.

Bleaching has been observed previously in the western Atlantic in isolated instances, but the present event is far more extensive than ever before recorded. As of 25 October 1987, affected animals have been observed for 6 to 15 weeks in Puerto Rico, Mona Island, the Dominican Republic, Haiti, Cuba, the Cayman Islands, Jamaica, the U. S. and British Virgin Islands, the Turks and Caicos, the Bahamas, the Florida Keys, and the Flower Garden banks off Texas. The bleaching appears to be spreading both geographically and in extent with animals affected from the surface to 200 feet (approximately the full depth range in which zooxanthellae occur).

The bleachings may be caused by unusually high temperatures, which have been reported in many areas; by increased ultraviolet radiation possibly due to ozone depletion, or by secondary pathogens after physical stress (as was suggested for the fish mass mortalities); or by some combination of these. Disease (unless a disease of the zooxanthellae) appears unlikely to be the primary cause, as does sediment damage.

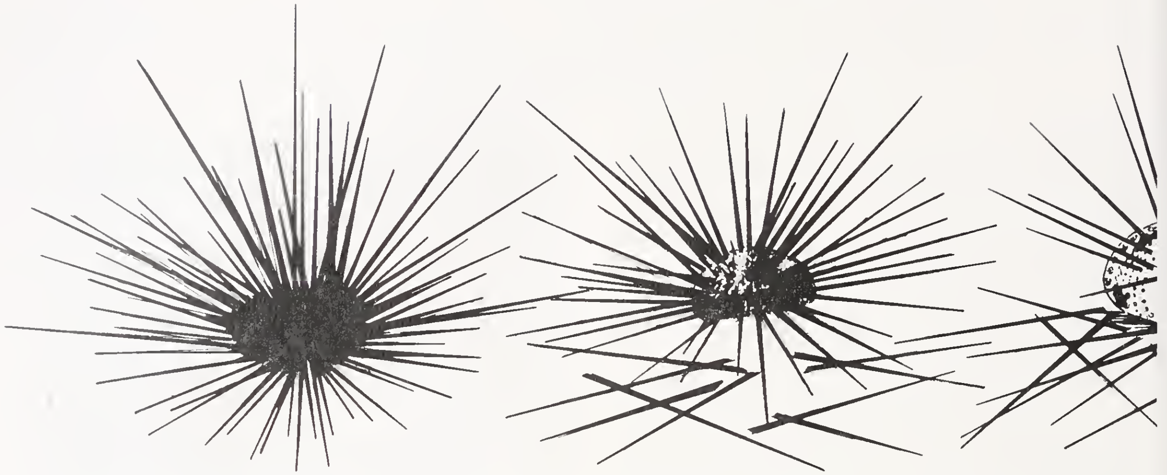
*The Caribbean Aquatic Animal Health Laboratory is attempting to document the geographic extent, timing, species affected and other details of this phenomenon by circulating a questionnaire; and making the data quickly available, in up-dated summaries, to all interested parties.***

Star coral, *Monastera annularis*, one of the most important reef-building corals in the Atlantic. An almost totally bleached colony of star coral about 4 feet high with normal colony at right. (Photo taken in 35 feet of water on Enrique Reef, La Parguera, Puerto Rico, by Jack Morelock)

Lucy Bunkley Williams,
and Ernest H. Williams, Jr.

* Civilian satellite photographs cannot distinguish patterns smaller than 10 meters across (33 feet).

** Summaries and questionnaires are available by writing the authors at Department of Marine Sciences, University of Puerto Rico, Mayaguez, Puerto Rico 00708, or by telephoning (809) 899-2048, or 899-1078.



Signs of the Black Sea Urchin Plague. From left to right: Healthy, loss of spines, test dissociation, and death.

The 1 percent of the urchins that survived probably carry the Black Urchin Plague agent. With a little luck, determination, and money, this virus might still be isolated and studied.

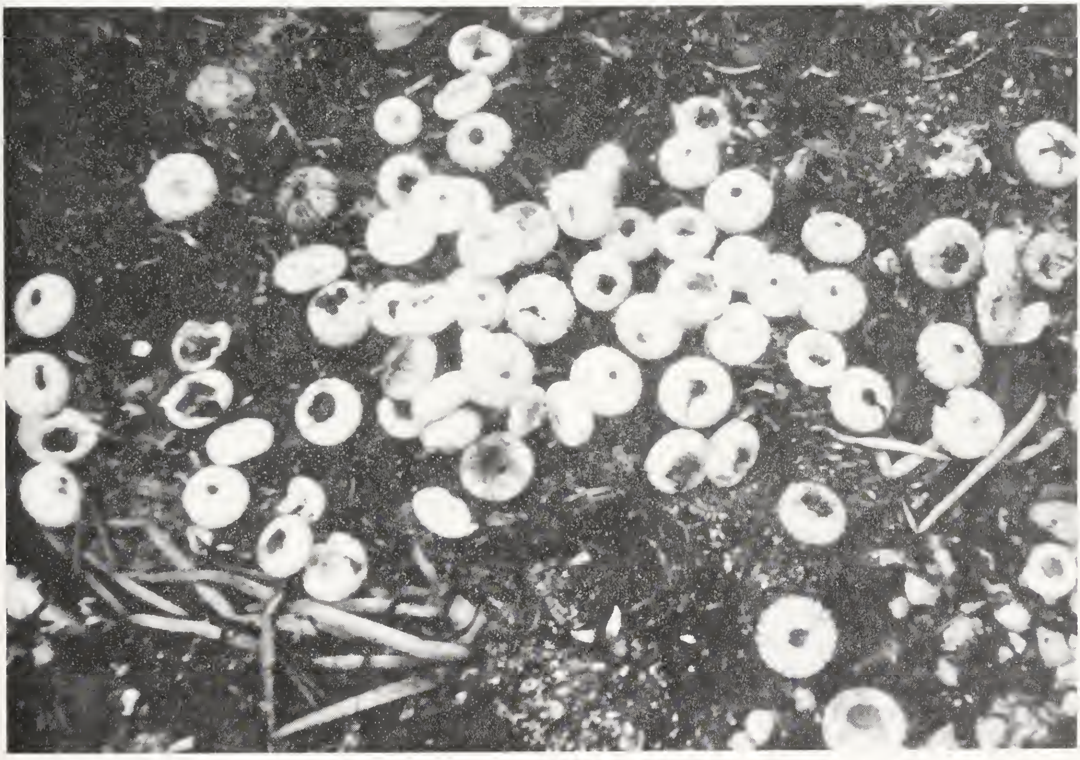
Disorder

The Fish Mass Mortality, and Mass Confusion. During the Carribean-wide fish kills, in most locations, samples were either taken too late or not at all. All investigations and collections were seriously delayed because of confusion over who should study what, and what agencies should examine samples. The seriousness and extent of the mortality was not fully realized until the event was almost over. However, some fish samples were sent to the United States, Venezuela, and other Caribbean countries. Unfortunately, many analyses cannot be performed on preserved or long-dead samples. Few field examinations on freshly dead or dying fishes were made (in fact, fishes were actually denied to local researchers so that samples could be sent to distant "experts"). The kill, we know, was not caused by chemical pollutants. However, the oceanographic community, it would seem, left a monumental marine process virtually unstudied. Whatever happened was a single and unified process over an entire ocean system, damaging many species and numerous individuals. To meet this menace next time, we must have some organization in place.

Much Reporting About Nothing. Ironically, since chemical pollutants were the only thing ruled out as the cause, a noted chemical oceanographer, Donald K. Atwood, brought together interested Caribbean marine researchers in an ad hoc symposium at the Gulf and Caribbean Fisheries Institute Meeting in Mayaguez, Puerto Rico, in November 1981. The accounts of the fish kill were largely anecdotal, and the parasite data inconclusive. Discussions, not surprisingly, found each specialist predicting their interest as the possible villain. Planktologists promoted subtle shifts in plankton ecology; physical oceanographers, temperature shocks due to isotherms; and parasitologists, suffocation due to gill protozoans. Almost everyone concluded that too little information was available to assign a definite cause. While no agent could be agreed upon, the need for future coordinated investigation was strongly emphasized. A report from this meeting was compiled and printed by Atwood (see references), and a committee of nine fisheries and disease experts, representing five Caribbean countries was formed, with the first author of this article as chairman.

Great Plan, No Action. The United Nations Intergovernmental Oceanographic Commission's Sub-commission for the Caribbean and Adjacent Regions (IOCARIBE) agreed to support a meeting of our fish kill committee as the "IOCARIBE Steering Committee for Regional Contingencies for Fish Kills." The meeting was held on 25 to 29 October 1982, in Mayaguez, Puerto Rico. We formed a plan to train existing local scientists from each Caribbean country with workshops at nine existing Caribbean labs; to organize a center for the coordination of information and investigation at one of six Caribbean facilities already possessing the necessary equipment and personnel; and to provide a detailed investigation and documentation manual for fish kills. We stopped short of recommending fish kill investigation teams and/or fish kill research facilities, to keep the proposal from becoming too costly, and because some members of the Committee felt such a team could seldom be made available in time. The proposal was made to IOCARIBE in a 20-page Summary Report (see references) immediately after the meeting. During the Second Session of IOCARIBE in Cuba, 8 to 13 December 1986, the Fish Kill Committee Report was endorsed and funding was recommended. A suggestion also was made to expand the proposal to cover all mass mortalities, and not just fishes. To date no action has been taken.

Urchin Plague Data Lacking. Caribbean scientists were no better prepared for this epizootic than they had been for the last. While the fish incident killed fish during a two-month period, the urchin disease quickly washed over each area within



Black longspined sea urchin (Diadema antillarum) *tests after the Black Urchin Plague. (Photo by Vance Vicente)*

days, leaving almost all of the urchins dead, and the biologists flabbergasted.

Few investigations were made on this mortality. Haris Lessios and others at the Smithsonian Tropical Research Institute in Panama collected mostly informal and incidental accounts of the black urchin plague. In a report that appeared in *Science*, in October 1984, they surmised that the agent responsible for this plague was a water-borne pathogen that was carried throughout the Caribbean by prevailing currents.

More Urchins? During a SCUBA dive in one of our routine study areas off Puerto Rico, we stumbled onto a die-off of the large, longspined seabiscuit urchins (*Astropyga magnifica*). The signs of the kill were strikingly similar to the Black Urchin Plague! Even though we knew little about urchins, we contacted local and international urchin experts, documented the kill, and reported it, along with another local urchin kill (*Eucidaris tribuloides*), in the *Bulletin of Marine Science* (see references). As a result, people began calling, writing, and talking to us about urchin kills all over the Caribbean. Information exists, although an effective recording system does not.

A parasitic isopod (*Anilocra haemuli*) on a conie (*Epinephelus fulvus*) (grouper) in the Bahamas. (Photo by L. B. Williams)

Red Tilapia (*Tilapia* spp. hybrid) being raised in seawater cages. (Photo by L. B. Williams)

Dead Fish Smell. Fish kills attract more attention than urchin and other invertebrate kills. Not only are fish of more direct economic interest to humans, they also tend to float, bloat, and generally make an unmistakeable nuisance. But, very few of these kills are ever reported. A series of large fish kills that occurred off the coast of Venezuela were reported in local newspapers, but along with a large kill of coastal fishes in Puerto Rico and the U.S. Virgin Islands two years ago, they went scientifically unrecorded. Smaller kills occur quite frequently. Although most Caribbean governments attempt to investigate fish kills, they usually lack the necessary training and equipment.

Diseases of corals and sea fans (*Gorgonia spp.*) have also received recent attention. A capability to adequately record, report, and alert others about all mass mortalities is urgently needed.

Direction

The needs outlined in the IOCARIBE Report, and elsewhere, are as follows:

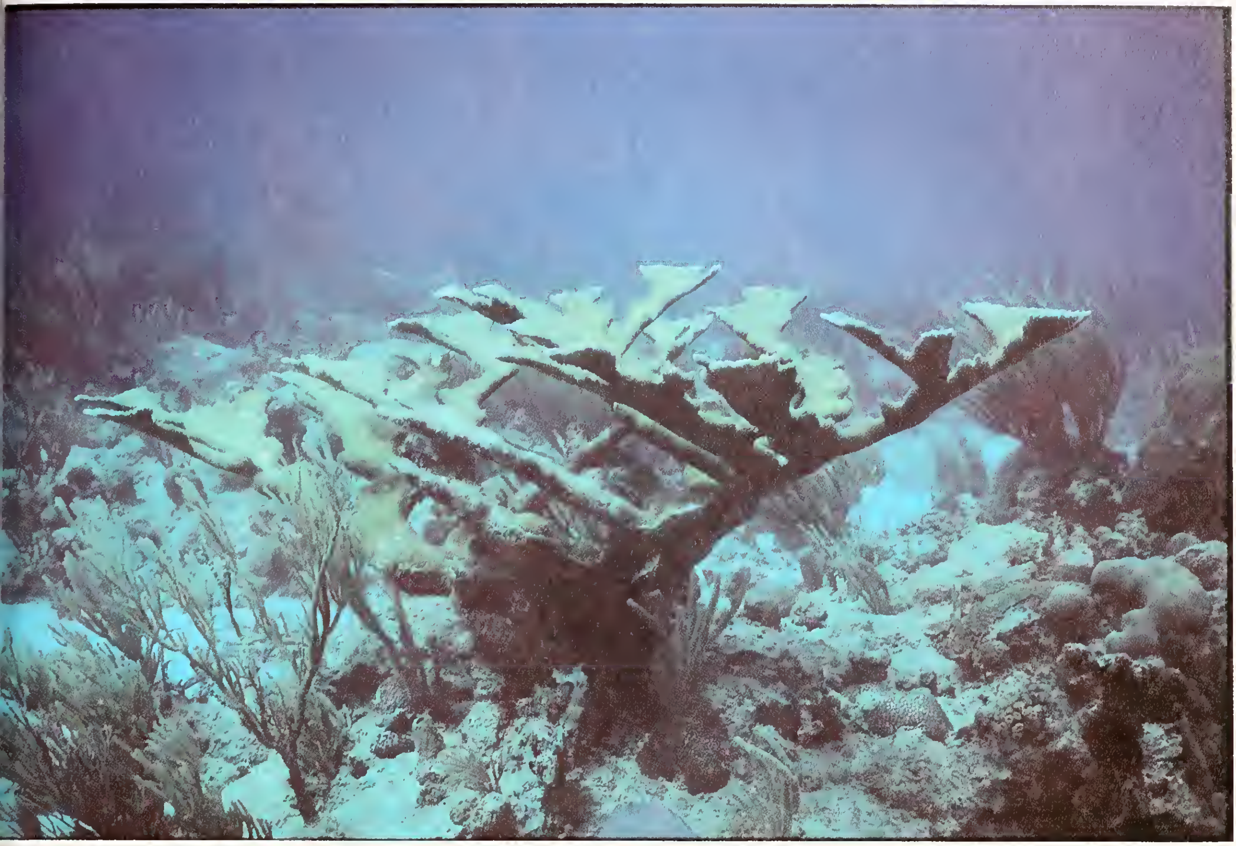
- **A Mass Mortality Investigation Manual** that describes standard field investigation techniques any lab can conduct; more complex techniques that most labs can conduct; and the proper methods of collecting, preparing, and sending all types of samples.
- **Training Workshops for Local Scientists.**
- **Report and Alert Center** to provide a place to report and document mortalities, and maintain contact with a network of Caribbean field scientists, a pool of mortality experts, and experts for each group of animals.
- **A Field Investigation Team** that can rapidly be sent to mortality areas. Locally trained personnel would be more desirable, but in the beginning a mobile team may serve to publicize the importance of the problem, and to train locals during and after the kill. For large-scale mortalities, an international team may be essential.
- **A Research Center** to diagnose samples, train Caribbean scientists, attract research funding to solve mortality problems, and to provide research facilities for scientists investigating Caribbean mass mortalities.

The Solution

Most people want to go to pristine Caribbean islands with clean white beaches and clear, blue, sparkling waters. Disease specialists are attracted to beaches covered with tons of dying, smelly, slimy marine life, and enjoy trying to determine what happened, and why. Each horrible mess represents a fascinating puzzle. The solutions will bring us better and healthier fishery products, management tools for fisheries, healthier and more economic aquaculture products, the possibility of a better understanding of ocean processes, and insight into combating present and future human diseases.

To fill this need in Puerto Rico and the U.S. Virgin Islands, an aquatic animal health laboratory has been started by the University of Puerto Rico, the Department of Natural Resources of the Commonwealth of Puerto Rico, the Division of Fish

A tumor (dermal fibroma) on a redband parrotfish (*Sparisoma aurofrenatum*) from the Hydrolab Undersea Habitat site in Salt River, St. Croix. (Photo by L. B. Williams)



Elkhorn coral (Acropora palmata) *towering over soft corals and sea fans* (Gorgonia spp.). *A reef top scene at Cane Bay, St. Croix. (Photo by L. B. Williams)*

and Wildlife of the Government of the U.S. Virgin Islands, Sea Grant of Puerto Rico and the U.S. Virgin Islands, the Caribbean Fisheries Management Council, and Auburn University. Support is also being sought from international agencies and from individual Caribbean countries to eventually provide regional, multiple country, or Caribbean-wide services in aquatic animal health, and to form a Center for Caribbean Aquatic Animal Health.

A Caribbean facility is urgently needed to record, preserve, and broadcast information about marine mortalities to accumulate the equipment, facilities, and part of the expertise to investigate mortalities, and to train Caribbean scientists and conduct long-term research. A small step is being made in what is hoped to be the proper direction. Comments, suggestions, cooperation, and support are welcomed.

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Acknowledgments

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Belize

by James H. W. Hain

Belize is an example of the "other Caribbean." For many, the Caribbean brings to mind images of green islands with white, sandy beaches set into azure seas. While this is partially true for the string of islands arcing along the northeast and eastern boundary of the Caribbean, the larger islands of Puerto Rico, Hispaniola (the Dominican Republic/ Haiti), Jamaica, and Cuba, are different in composition and character. More different still are the countries that border the southern and western rim of the Caribbean. Because of their size, population, and challenges, these countries are important to any discussion of the region. Yet, many readers might have difficulty naming them, or locating them on a map. Belize is such a country.

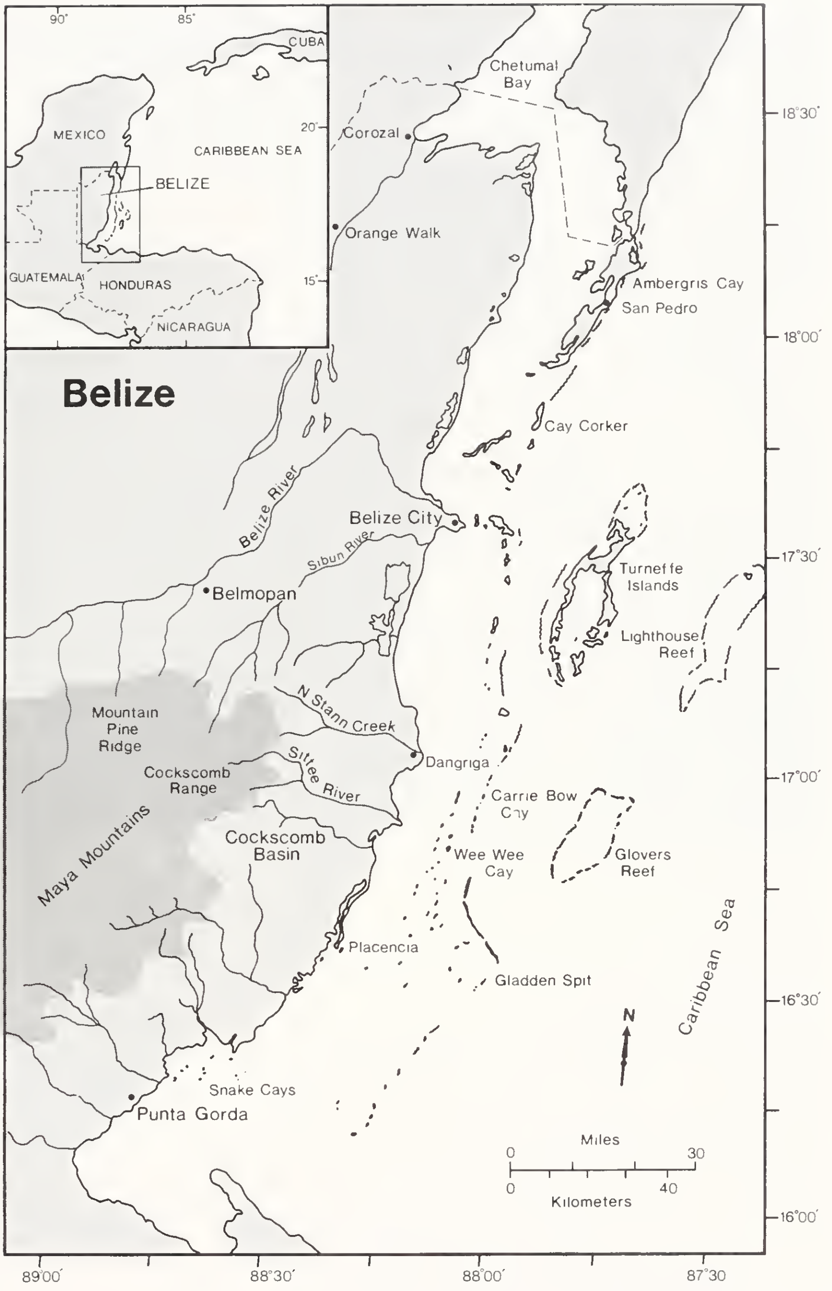
Perhaps the greatest asset of Belize is its marine environment. It has the second longest barrier reef in the world (the longest being the Great Barrier Reef of Australia, see *Oceanus*, Vol. 29, No. 2). The reef extends 220 kilometers from the Mexican border in the north to Sapodilla Cays in the south. Along Ambergris Cay, Belize's tourism center, the barrier reef is only a few hundred meters offshore, whereas at the southern town of Placencia, it is more than 40 kilometers (25 miles) offshore. Behind the reef, and across the shallow coastal waters dotted with approximately 450 sand and mangrove cays, is the coastline fringed with mangroves, and interrupted by numerous coastal lagoons and creek systems. Looking inland, across the coastal flatlands, lies the tropical lowland rain forest. To the west rise mountains of granite and limestone, serving as the origin for a series of short, often estuarine, rivers.

In Belize, the coast and the inlands are closely connected. Two of the world's most diverse and most complex ecosystems—the rain forest and the barrier reef—are found there.* These two systems are linked by the rivers, the coastal waters, and the mangroves.

Throughout the country, development and

Above, Carrie Bow Cay—site of the Smithsonian Institution's field station. (From Rützler and Macintyre, 1982, Smithsonian Contributions to the Marine Sciences No. 12*)*

* Other areas of the world where coral reefs and rain forest occur in close proximity are, for example, in Indonesia, and northeast Australia.



Belize, showing the barrier reef, three offshore atolls, and sites referred to in the text.

the economy are at the forefront. Agriculture (sugar, citrus, bananas, others) is the biggest source of revenue. Behind this comes tourism (snorkeling, diving, and sport fishing) and fisheries. (Agriculture and fisheries are primarily export-based.) Two out of the three depend largely on the marine environment.

With a few exceptions, Belize is not yet a full-blown tourist area, and tourist services are generally modest. Divers, naturalists, birdwatchers, and archaeologists are common visitors. At present, the country is known primarily for its diving and natural history tours.

On the broader scale, Belize is a young, developing country of 150,000 people. It has some of the most sparsely populated areas in the world, yet it has one of the highest birth rates. Today, more than half of the population is under 18 years of age. The government, operating under severe fiscal constraints, is faced not only with population concerns, but development pressures and conservation interests.

History

Belize has a rich history and heritage. Beginning back as far as 300 A.D., an exceptional Mayan civilization flourished in the area—a civilization that lasted more than 1,000 years. Evidence indicates that the Mayans used the coastal waters as fishing grounds, and the coast and cays for trading posts, ceremonial centers, and burial grounds.

The history and identity of Belize are closely related to its forests. The first European settlement of Belize was primarily for the cutting of logwood (*Haematoxylon campechianum*), used for making dyes. When the harvesting of logwood along the coasts and accessible lagoons waned during the mid-1700s, the British began to export another species—mahogany (*Swietania macrophylla*). The export of these woods from then-named British Honduras provided the basis for three centuries of British settlement. Despite this use, the country's forests remain healthy and nearly intact—and in many areas are true wilderness. In these forests, the jaguar—the third largest cat in the world—is still abundant, and roams relatively unmolested.

In the 17th Century, the coastal waters also became a haven for pirates and buccaneers, who looted Spanish and British ships. About this time, the name "Mosquito Coast" was applied to the region.*

Geology

In geology, as with several other topics, there are differences between the Caribbean most people are familiar with, and the "other Caribbean." The smaller islands of the Eastern Caribbean are basically the tops of volcanoes—formed as the Atlantic seafloor is driven downward beneath the Caribbean Plate (see page 42). These eastern islands are fairly young, in geological terms, and range in age from 5 to 10 million years. While the islands are often ringed by limestone and coral reefs, the predominant geology is young and volcanic.

The larger islands of the Greater Antilles likewise are associated with an active plate boundary. Their centers, too, are mountain ranges of volcanic origin. Here, the landmass has been increased by the accretion of deformed and crumpled sediments scraped from the ocean floor.

Where Belize is situated, on the western rim, the situation is different. Here, the geology is that of a mostly passive, interior plate location. Evidence of geologically-recent volcanic activity is absent, and earthquakes are rare. Rather than the land being of ocean-floor origin, the base is a continental-type landmass, and old—some 300 million years old. During most of the Cretaceous period (100 million years ago), much of the region was covered by the ocean—only the higher parts of the Maya Mountains remained above sea level. In the shallow seas, thick layers of marine limestone were deposited, with erosion and re-deposition occurring through time. Today, limestone is still being formed in the shelf lagoon and barrier reef areas.

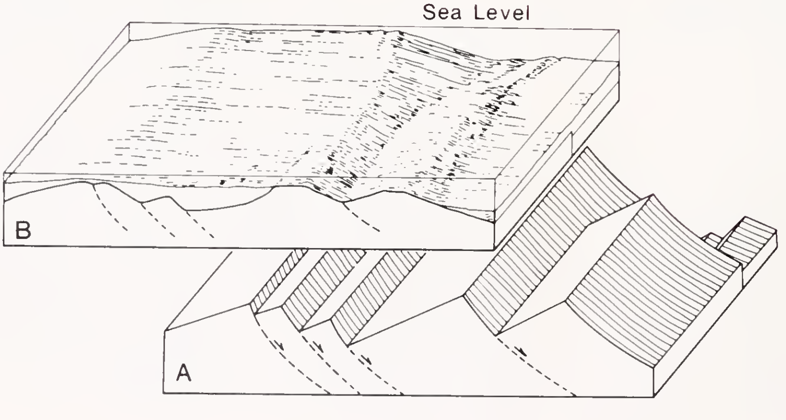
The formation of marine limestone is a remarkable process: As sea level rises and falls, the actions of small marine organisms result in the buildup of enormous sedimentary platforms.

Individual coral animals grow slowly, and the accumulation of their skeletons may take 10,000 years to form a reef. However, these reef-building corals, together with other reef builders—such as green and red calcareous algae, snails, shellfish, and others—can produce a hundred tons of almost pure calcium carbonate per square kilometer a year. While corals are often thought of as the principal reef-builders, the calcareous algae (*Halimeda* is an example—see *Oceanus*, Vol. 29, No. 2, page 43) are major contributors of calcareous debris and "lime mud." The coralline and algal debris and mud are often consolidated into an open-textured kind of "concrete"—limestone.

As sea level rises, or the seafloor sinks, the coral and algal reefs grow to maintain their optimal distance below the surface (the growth depth is limited to about 30 meters), and the carbonate-producing chain of events continues.

As sea level is lowered, or land is uplifted, the exposed limestone bedrock may develop into a karst

* The "Mosquito Coast" comprises a band approximately 40 miles (65 kilometers) wide that skirts the western rim of the Caribbean Sea for about 225 miles. The name of the region comes from its ancient Indian inhabitants, the Miskito or Mosquito Indians.



Suggested mode of development of the Belize continental margin. During the opening of the Yucatan Basin, rifted, trailing-edge plate boundaries were formed in the northwest Caribbean. Such rifting produced fault blocks (A), which subsided and were covered with thick limestone deposits (B). The high peaks of these fault blocks formed the base for features such as the offshore atolls of Turneffe Island, Lighthouse Reef, and Clovers Reef. (Courtesy of William P. Dillon, U.S. Geological Survey, Woods Hole, MA)

Belizean children, Hopkins Village. In the 1980 census, 50 percent of the population was under 18 years of age. (Photo by Fred Dodd, International Zoological Expeditions)

(solution-formed) topography. As the tropical rains and streams percolate through the soft and erodable layers, or along joints and faults, a rugged vertical topography, along with caves, underground streams, and sinkholes, sometimes forms. If the land again subsides, and/or sea level rises, some of these systems become submarine caves—complete with stalactites and stalagmites.* In Belize, as in several other locations with similar geology, some of these submarine caves, and sinkholes, called "cat's eyes" or "blue holes," are spectacular.

Some of these marine limestone formations are of particular interest to petroleum geologists because their porosity and solution cavities can form reservoirs for oil. Since 1956, more than 45 petroleum test wells have been drilled in Belize, with about 65 percent showing oil. R. Prasada Rao, Chief Technical Advisor to the Belize Petroleum Office, reports that exploration is continuing, and a few wells are planned for 1988—but that to date, there has been no commercial oil strike.

* Stalactites are deposits of calcium carbonate (as calcite) resembling an icicle, and hanging from the roof or sides of a cavern. A stalagmite, looking like an inverted stalactite, forms on the floor of the cave by the drip of calcareous water.

Fisheries

Fisheries management in Belize is faced with several formidable and interrelated problems—enforcement, assessment, and personnel—all linked directly or indirectly to the rather severe fiscal constraints of the government.

Fisheries exports in 1982 totalled US$6.2 million, ranking second in export earnings after sugar. The spiny lobster, *Panulirus argus*, with 1982 exports of 277 tons valued at US$5 million, accounted for about 81 percent of export earnings. The queen conch, *Strombus gigas*, with 143 tons valued at US$668,000, accounted for 11 percent.

The success of Belize's export fishery is largely attributable to the development of fishing cooperatives. The cooperatives—there are four major ones, with a total of 12—secure export markets, and collect, process, and package all products for export. They also provide loans, ice for the fishing boats, and other support. Aside from the cooperatives, there are approximately 400 independent fishermen catching finfish for local markets—an important source of protein in the Belizean diet.

Overall responsibility for the fishery is within the Fishery Unit, contained within the Ministry of Agriculture, Forestry, and Fisheries. The Acting Fisheries Administrator, Vincent Gillett, reports that the lobster fishery is now operating just at, or very close to, the sustainable yield, and that most lobster is shipped to the United States. The conch fishery, which peaked at 567 tons in 1972, is now one-fourth that, and is probably in a depleted state and in danger of overfishing.

Gillett describes that his office is "plagued with requests to exploit all aspects of the marine resources—both the traditional fisheries, and those outside the reef." On the other hand, he is faced with an almost complete lack of survey or assessment data on the resource itself, and on what harvest it will support.

There are other factors. Even though Gillett himself is a marine biologist, he laments the lack of trained personnel. The educational system of Belize, "is not now training fisheries scientists or managers."* Lastly, even though Belize has fisheries laws and regulations on the books, enforcement is a major problem.** The Fisheries Unit has only one or two small vessels, and few personnel. With only a limited ability to patrol the coastal waters, Gillett knows that there is illegal fishing, and that the resource is, at times, being hit hard. It has been reported that foreign poaching in southern Belizean waters is the most serious problem affecting the country's fisheries. When queried on this topic, Gillett nods in agreement.

Development

Coca-Cola Foods has recently acquired a 196,000-acre parcel in Belize—some of which may be developed for a citrus plantation and a concentrate processing plant. It is clear that the government, citizens, and conservationists of Belize want Coca-Cola to be there. To Coke's credit, reports the *Rainforest Action Network Newsletter* of last spring, they have made many proposals toward a responsible approach to their land-use plans and possible citrus operation—proposals that include environmental impact studies, and set-asides of wildlife preserves and sensitive habitats.

Another large corporation, Hershey Chocolate, is involved in projects for cacao production, supported by the Government of Belize and the U.S. Agency for International Development (USAID). Under this program, farmers are supplied with seedlings, technical assistance, and a market. This program, for example, brought the Blackshear family from Texas, with the prospect of re-settling in Belize. One early morning, outside the Mopan Hotel in Belize City, as the family, with backpacks, gear for the "bush," and a local guide, stepped into their rented Land Rover to inspect land in the north, Blackshear explained, "We're from Texas. Belize is a frontier. The Texas spirit will set well here."

Along the coast, development and change are also occurring. Although the coastal lagoons and mangrove swamps are easily regarded as unnecessary wasteland, they, like the salt marshes and wetlands of temperate climates, play an important ecological role.

The coastal lagoons provide nursery and feeding grounds for many near-shore fish species, act as sinks for terrestrial run-off, supply abundant nutrients to coastal waters, and provide habitat for many species of wildlife, such as the manatee (*Trichechus manatus*), and crocodile (*Crocodylus acutus*).

Mangroves (see article on page 16) are the principal source of nutrients enriching coastal waters, and like the lagoons, provide nursery and feeding areas for coastal fish species, function as sediment traps for estuarine waters, and act as a physical buffer against marine storms.

The seagrass system is frequently connected on the landward side to mangrove forests or fringes, and on the seaward side to the coral reefs. These marine grasses bind sediments and provide a stable substrate for benthic organisms (animals and plants living on the sea floor). The seagrasses also provide food and shelter to the organisms that support Belize's conch fishery. Shrimp and lobster also depend on the seagrass beds as a foraging area for food.

Lastly, coral reefs, like those in Belize, together with the tropical rain forest, are described as the richest biological communities on Earth. The reef also provides protection against ocean swells, supports Belize's lobster fishery, and attracts a growing tourist trade.

The value of these coastal areas is increased by the general hydrography of the Caribbean Sea. In general, a relatively stable thermocline (an area of rapid temperature change—has the effect of creating a boundary and "layering" the water column) prevents mixing of the surface and deep waters. The result is low nutrient levels in offshore surface waters, and a limited fishery. The primary fishing grounds, therefore, are in the more productive coastal areas—where a mixing of the water column and recirculation of nutrients can occur.

Ivan Valiela, a professor in the Boston University Marine Program at the Marine Biological Laboratory in Woods Hole, Massachusetts, describes the link between the inland rain forest and the coast as variable, requiring additional research. In general, he says, rain forests are normally not "leaky," and so release few nutrients to the rivers. The system is thrown awry, however, when forests are cut and land is cleared. One of the lesser-known consequences of deforestation, aside from the erosion and loss of the thin layer of fertile topsoil, is the destruction of seagrass beds, mangroves, and reefs through the choking effects of the river-borne load of soil and silt.

* Since this interview took place, a course in fisheries science has been added to the curricula at Belize Technical College.

** USAID has targeted enforcement as a primary goal of their assistance program to Belize in the coming years. Funds have been earmarked for training of personnel and upgrading of the boats and equipment used in patrolling the coastal waters.

It is these types of indirect effects that may be the most important. Jacque Carter, a Research Fellow with the New York Zoological Society (NYZS), and active in both research and environmental management in Belize, states: "The greatest immediate threat to the reef environment is not from the direct impact of overfishing or tourism, but from rapidly expanding inland and coastal agricultural and light industrial development, particularly around Belize City and Dangriga. The response of the reef ecosystem to external changes resulting from sewage discharge, sedimentation, and the release of chemical products associated with industry and agriculture—all of which are occurring in Belize—is generally a decrease in species diversity, and an altered reef metabolism and population structure."

Can development and the reef environment co-exist? In 1980, coastal inhabitants comprised 43 percent of the nation's population. As in any country where a high percentage of the population lives on or near the coast, there are coastal issues and problems. Major development projects include the clearing of mangroves for industrial sites, housing, ports, and recreational facilities. Dredging operations sometimes result in the dumping of debris in mangrove areas. Some coastal communities use mangrove areas as dumping grounds for wastes.

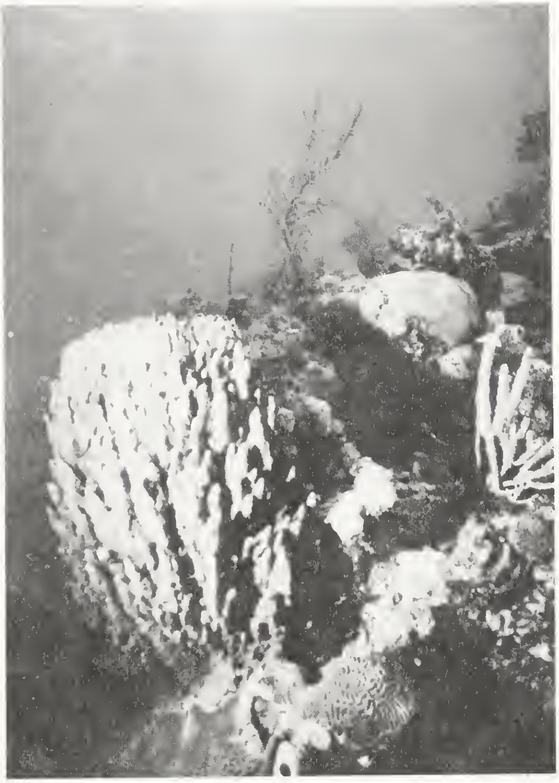
Marine Field Stations

Research and education may provide some of the answers. At present, there are only a small number of marine field stations in Belize. The three examples given here have basic research, applied research, and education as their primary missions—although there is some overlap.

The Smithsonian Institution's station on Carrie Bow Cay has been in existence since 1972, and conducts a program of basic research in tropical marine science (see page 24). It is the best-known research facility in the country.

An applied research effort is conducted through a joint effort of the Illinois Natural History Survey, the Harbor Branch Oceanographic Institution, and the Marine Sciences Center of the State University of New York (SUNY) at Stony Brook at a small but vigorous facility on Ambergris Cay. Under the sponsorship of USAID and the Belize Fisheries Unit, research on the biology and rearing of conch has been underway for several years (see also page 61). Jack Sobel, a graduate student at SUNY, and onsite Co-Director of the project, described that the project is aimed at examining the feasibility of rearing conch in a hatchery—through the vulnerable juvenile stages, up to a release size of 5 to 7 centimeters. The project includes an education and training program, and involves local people in the hatchery, the research, and the management of the resource.

There are a number of programs and stations whose missions are more education than research oriented. One of these—the dual facilities operated by the Northeast Marine Environmental Institution (NEMEI) of Monument Beach, Massachusetts—typifies the enterprise and initiative characteristic of much of what is taking place in Belize today.



The coral reef. (Photo by R. Sammon)

Paul A. Shave, NEMEI president, and a former employee of both the Marine Biological Laboratory and the Woods Hole Oceanographic Institution, and his wife, Mary, with little money and lots of gumption, have carved a base station out of the jungle 5 miles from the mouth of the Sittee River. They also have obtained a government lease on Wee Wee Cay, a small cay about 5 miles offshore from the river mouth, and halfway between the river and the barrier reef. Construction of housing, laboratory, and dock facilities on the cay is scheduled to begin this winter. When the marine facility is completed, students and naturalists can study the lowland tropical forest, river, mangrove swamp, lagoon, and coral reef environments. To date, the Shaves have hosted high school and college groups, professional organizations, and researchers.

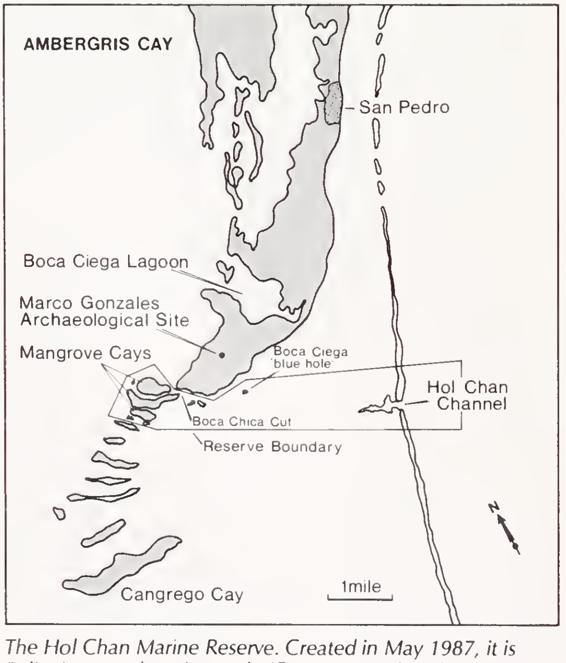
Tourism

Tourism ranks second to agriculture in foreign exchange earnings. Clearly, Belize has great potential for tourism development, and the reef offers diving, fishing, sailing, and other activities.

Among the factors that make Belize attractive is that it is one of the few English-speaking countries south of the United States. There is also a growing interest among travelers to visit lesser-known places of the world.

However, tourism development requires an infrastructure, facilities, and environments. A need to

At Ambergris Cay, the barrier reef lies only a few hundred meters offshore from Belize's main tourism center—the town of San Pedro. (Photo by J. Carter)



The Hol Chan Marine Reserve. Created in May 1987, it is Belize's second marine park. (Courtesy J. Gibson)

develop recreational facilities for foreign visitors as well as for Belizeans themselves has focused attention on a system of parks and reserves.

Hol Chan Marine Reserve

Setting aside parks and reserves is one way to balance conservation and development—and in Belize, a major milestone was recently experienced. On May 2, 1987, the Minister of Agriculture, Forestry, and Fisheries, Dean Lindo, signed legislation officially establishing the Hol Chan Marine Reserve. The new marine reserve, the second to be established in Belize, is significant because it represents a commitment to properly manage and conserve Belize's barrier reef, and because it is seen as part of the beginnings of a national parks system.

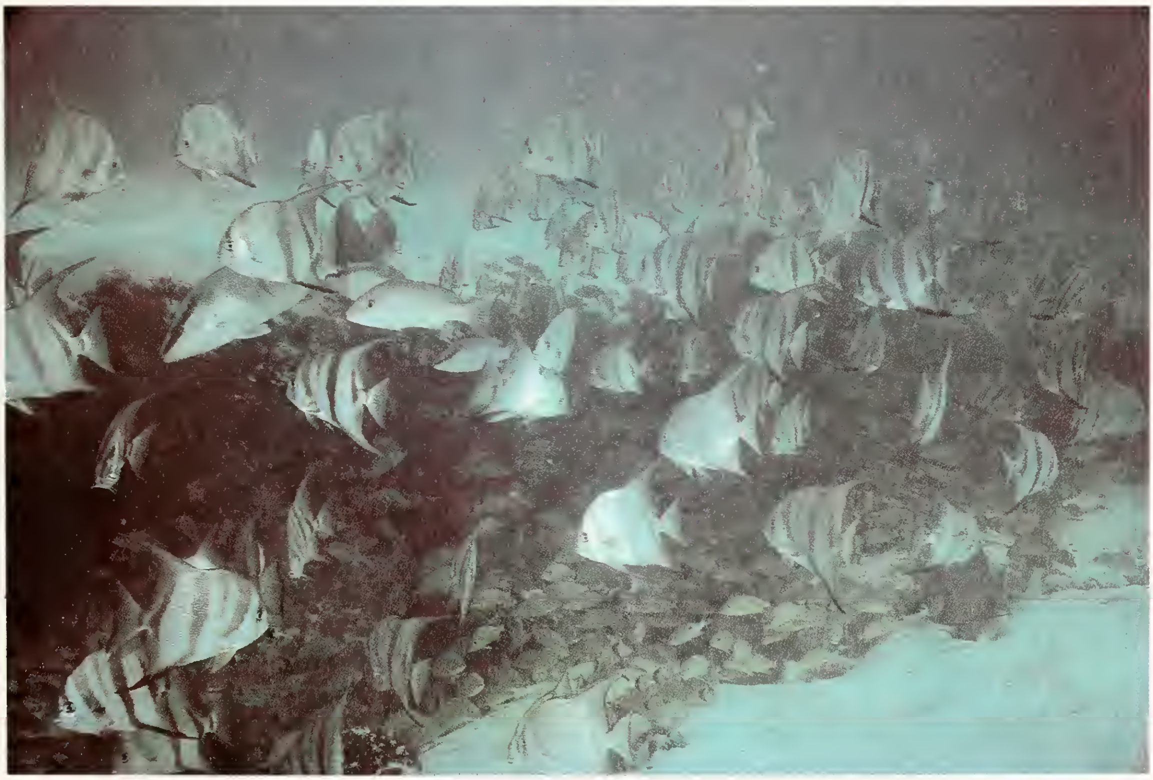
In economic terms, fishing and tourism are the largest commercial activities along the reef. Both have potential for economic development, and at the same time, degradation of their most valued asset—the reef. There was almost unanimous agreement as to the value of the reef, and the need to protect it was felt to be particularly urgent for areas near San Pedro on Ambergris Cay. With a total of 25 hotels, most of them geared to SCUBA divers and sportfishermen, San Pedro is the hub of the tourist industry. The reefs near San Pedro have already been exposed to heavy use, and show signs of stress caused by overcollecting, overfishing, and damage by anchors. Additional stress is caused by dredge-and-fill operations and sewage output. Additional development of the area is continuing.

The new Hol Chan Marine Reserve is located along the northern section of the reef, some four miles southeast of San Pedro. A central feature of the reserve is a natural break, or "cut" (the reserve takes its name from the Mayan term for this cut) in the reef. The cut contains striking coral formations, fish, and other sea life. The 5-square-mile reserve includes coral reefs, seagrass meadows, and mangrove swamps. A Mayan site, now under archaeological exploration, lies just outside the northwestern boundary of the main reserve—but has been included, as a "satellite location," within the defined reserve.

As envisioned, the reserve management plan will address the issue of achieving greater economic benefit from the reef, while at the same time maintaining its integrity and value in the face of expanding tourism, diving, fishing, and development. There are a number of hurdles to achieving this goal. For example, legislation adequately protecting marine resources is not yet in place. There also is some jurisdictional overlap between the various government ministries in the administration and management of marine and coastal resources.

To resolve problems of conflicts of use, legal clarity, and administrative organization, a number of interest groups are encouraging the government of Belize to establish a single agency to oversee the reef. The next step, then, will be toward establishing a Belize Barrier Reef Authority, modeled after the Australian Great Barrier Reef Marine Park Authority (GBRMPA) (see *Oceanus*, Vol. 29, No. 2, page 13). By applying the Australian concept of zoning, conflicting activities will be separated, areas will be

Belize City, showing the low coastline and river system characteristic of the western Caribbean. (Photo by J. Carter)



Reef fishes in a "cats eye," or little blue hole—formed by a collapsed karst dome in the Hol Chan Marine Reserve. (Photo by J. Carter) identified for specific activities, and some areas will be set aside and strictly protected.

As in Australia, the primary goal of the Authority would be to provide for the protection, sustainable use, and recreational enjoyment of the reef. GBRMPA has demonstrated that a solution to these diverse goals is possible. A draft marine park/barrier reef management plan is now in preparation by Janet Gibson, a Belizean active in conservation efforts, and affiliated with the Belize Audubon Society.

The financial underpinnings of these efforts are illustrative of many of the conservation efforts in the country. To date, almost all monies for studying and establishing the park have come from outside the country. Funds have been provided by international agencies such as USAID, the World Wildlife Fund, NYZS, the Massachusetts Audubon Society, and others. These monies have been directed through private environmental organizations, such as the Belize Audubon Society, which has played a key role in conservation efforts, and subsequent park management throughout the country; and to a lesser extent, government agencies, such as the Belize Fisheries Unit. It is hoped that charging user fees for the parks may provide some funds for park operation, and that, in time, the government may be able to commit some funds to its park system.

Promise

Belize achieved independence in 1981. The country is rich in history, culture, resources, and the character of its people. It is poor in dollars. In some ways at least, this example of the "other Caribbean" stands today perhaps several decades behind the "better-known" Caribbean. However, it looks to the pressures and problems of this and future decades. In facing, and meeting, these pressures, there is an underlying interest in avoiding the mistakes that have been made elsewhere. On this count, the future holds both threat and promise.

James H. W. Hain is Assistant Editor of Oceanus, *published by the Woods Hole Oceanographic Institution. He visited Belize in March of 1987, and is on the Board of Directors of the Northeast Marine Environmental Institution.*

Acknowledgments

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Letter Writers

The editor welcomes letters that comment on articles in this issue or that discuss other matters of importance to the marine community.

Early responses to articles have the best chance of being published. Please be concise and have your letter double-spaced for easier reading and editing.

From Jamaica

Managing Marine Resources

by Jeremy D. Woodley

Marine science in the Caribbean! The prospect of research in tropical environments was one of the main reasons that I came to Jamaica, 20 years ago. Academic research is necessary and desirable; it has brought me the greatest thrills and satisfaction. But when you are one of a small number of scientists in a developing country beset with economic and environmental difficulties, it begins to feel like a self-indulgent luxury. From a Caribbean viewpoint, the paramount problems of Caribbean marine research relate to the management of marine resources. That, of course, is no small field and many disciplines contribute to it; from geology and oceanography, through ecology, physiology and behavior, to fisheries, aquaculture, economics, sociology and public relations!

Our marine resources are of three main kinds: populations of valuable organisms, the coastal ecosystems whose productivity sustains them, and environmental amenities, such as good harbors, clean beaches, and clear water. In Jamaica, increasing population and development have put pressure on them all. Over-exploitation has greatly reduced accessible stocks of reef fishes, lobster, and conch. Many coastal wetlands have been drained and destroyed. Coral reefs are suffering from increased sedimentation in terrestrial run-off, and (I believe) from the ecological imbalance brought about by over-fishing. Marine pollution from coastal towns is increasing. These all present problems in coastal management to which, in a general sense, the solutions are already known. But their application can be difficult and expensive, even in developed countries; there are additional difficulties in under-developed ones.

Leaving these aside, for the moment, what are the purely scientific questions that need to be answered? Inventory of our resources is incomplete. Most environmental monitoring is inadequate. We need to know more about the life-histories of commercially important species. Our coral reef fisheries include scores of species, many of which spend long periods as larvae in the plankton. But we do not know enough about near-shore current patterns to predict their patterns of recruitment; studies of inshore oceanography would be highly relevant to this and other problems, such as pathways of pollution. We need to know more about other coastal processes, such as the transport of carbonate sediments.

Tropical coastal ecosystems, such as coral reefs, seagrass beds, mangroves, and their neighboring watersheds, are complex. Much progress has been made in the last 30 years toward understanding their ecology, but we need to know more. We need to understand and quantify the relationships between the systems, and how these affect their productivity. Further, although we begin to understand how various factors affect each community, they are complex enough (and I am particularly thinking of coral reefs) that some of the changes take us by surprise. Our explanations lag behind the events, and we are a long way from prediction or control.

What are the special problems that face Caribbean marine scientists? They can be attributed, directly or indirectly, to the lack of money in poor countries. To start with, there is only a small number of active scientists in each country. Then, insufficient supporting staff are employed. Equipment and facilities are often old and limited. Moreover, there are long delays in the import of spare parts and it is difficult to arrange local maintenance. The same sort of limitations attend efforts in environmental conservation by Government agencies. There are some good conservation laws, but there are insufficient staff, with inadequate resources, to enforce them. Further, there are no funds for compensation and no Welfare, so how does one reply to a fisherman who asks, "But what will we eat?"

Compounding these problems, at least in Jamaica, is a widespread lack of sensitivity to the environment. At all levels of society, people have been unaware of the fragility of our marine resources. Fishermen have often told me that the sea is boundless and therefore the supply of fish (or conch, or turtle) is unlimited. "Cyaan done," they say (meaning: it, or the resource, can never be depleted). Governments, too, have not given a high priority to environmental management, research, and monitoring. The importance of coastal and marine resources is much more obvious on a small island, such as Bonaire or Cayman, and they are way ahead of us in marine conservation. Jamaica is a large island with terrestrial resources (sugar and bauxite have been the principal exports) and nearly half the population live in the big city of Kingston. But things are changing. Sugar and bauxite exports are down, and the number one industry is tourism. This has focused attention on the coastal environment; for example, the Government is seeking to establish marine parks. Undoubtedly, the time is ripe for a wide-ranging program of public education; but that, too, will require funding.

Marine scientists in other Caribbean territories work in similar environments and face similar problems to ours, but we are very isolated from one another. True, we each have to work out our local solutions, but some research effort must be unnecessarily duplicated. I wish that communication between us were easier. If we can afford the fare, some of us meet at conferences of the Association of Island Marine Laboratories of the Caribbean, which are very welcome, but brief and infrequent. Perhaps it would help if we were linked by electronic mail, or to a network of databases. Perhaps we just need more time to write to each other!

Scientists from institutions outside the region also do research in the Caribbean, usually at one of several marine laboratories. I am in the fortunate position of running a Jamaican marine laboratory through which there is a high traffic of investigators and courses from the United States, Canada, and Britain. It is a symbiotic relationship, and a valuable channel of communication between scientists from the more and less developed worlds. I and my students are exposed to current theories and techniques; they and theirs learn about life in the tropics. Research by visitors has added greatly to knowledge of Jamaican marine systems. I should add that the fees they pay have helped to keep the Laboratory alive!

How else can foreign marine scientists and institutions help their Caribbean counterparts? First, remember we are here. Beware the ethnocentric view; the Caribbean is not a cultural desert and there are well-trained scientists there, few and overworked though they may be. Secondly, if you are concerned with aid, respect their perceptions of what are the critical areas for research. Thirdly, if at all possible, try to help them deal with their own problems by the provision of funds, equipment, and training; for them and their support staff. A good example of this was the National Science Foundation's support of oceanographic training cruises on the *Eastward* in the Caribbean, discontinued in the early 1970s.

With all respect for its good intentions, it seems to me that these three precepts were disregarded in at least the early stages of the Caribbean Initiative Plan. U.S. scientists were asked to submit proposals for development-related projects, but Caribbean scientists were not consulted. Many of the proposals submitted were on pet research topics that had little direct relevance to problems perceived as critical in the Caribbean. Foreign scientists should not regard aid funding as another way to get their own research done. If they cannot afford to help with our problems, they should raise the funds elsewhere and come to do their research at one of our marine laboratories!

Jeremy D. Woodley, who came to Jamaica from England in 1966, is Head of the Discovery Bay Marine Laboratory and Senior Lecturer in Zoology at the University of the West Indies.

From Panama

Protection of the Tropics

by Jeremy B. C. Jackson

The Smithsonian Tropical Research Institute (STRI) is an international bureau of the Smithsonian Institution with approximately 25 staff scientists from six nations based principally in the Republic of Panama. Our purpose is to increase scientific understanding of tropical environments and biota through basic research, and to make such information widely available to promote more effective use and protection of the tropics. More than 300 scientists and students do research at STRI each year.

The marine program at STRI includes six permanent staff biologists, plus numerous research associates, fellows, and contract scientists. Offices and major laboratory facilities are on Naos Island at the Pacific entrance to the Panama Canal. Naos serves as a base of operations for field work in the Bay of Panama, including a physical and biological monitoring program run jointly with the University of Panama. It also is the home port for a 62-foot research vessel.

Most of our research in the Caribbean is done at small laboratories at Punta Galeta, just east of the entrance to the Canal, and in the western San Blas Archipelago near Porvenir. Both stations are equipped with running seawater, numerous small boats, and facilities for SCUBA diving. STRI scientists also do research at other laboratories throughout the Caribbean, most frequently in Jamaica and Venezuela.

STRI staff scientists work independently on their own research projects, which include studies of the social systems of fishes and crustaceans, production and dispersal of larvae of many kinds, including crabs and fish, population biology of corals, bryozoans, and sea urchins, and patterns of speciation and extinction using molecular genetics and the fossil record.

Despite this diversity, there are several areas of common interest. Perhaps most important is our commitment to attaining a long-term perspective on biological phenomena in the tropics, which are not nearly so stable as was believed previously. Routine monitoring of populations has revealed many examples of extreme fluctuations in abundance, apparently unrelated to human disturbance.

For example, STRI scientists first detected and documented the spread of the catastrophic mass mortality of the sea urchin *Diadema antillarum*, which was until 1983 the most important grazer upon algae on Caribbean reefs, particularly those subjected to overfishing. As a result of the Caribbean-wide drop of 98 percent in the abundance of this urchin, many reefs are now carpeted with macroalgae that are smothering corals as deep as 10 to 15 meters.

In a similar vein, recruitment of fish larvae onto reefs can be highly episodic, as in the case of the queen triggerfish *Balistes*. Larvae of this important predator recently settled from the plankton in vast numbers over about one month, unlike anything observed before or since. The effect on future abundance of the fish is as yet unknown. Neither the death of *Diadema* or the recruitment of *Balistes* coincided with any obvious changes in environmental conditions measured at Galeta for more than 15 years. In contrast, mass mortality of corals in the eastern Pacific, and possibly also along our Caribbean coast, occurred in conjunction with major climatic changes associated with the last extreme El Niño warming event (1982–83).

A second common theme relates to our geographic position on the Panamanian Isthmus and the physical and biological changes that resulted from the formation of this barrier to marine organisms 3 to 4 million years ago. Environmental conditions in the Caribbean and eastern Pacific have diverged markedly, with concomitant but variable changes in fossilizable biota. Ongoing studies include molecular evolutionary characterization of genetic divergence among closely related species in the two oceans, and of morphological responses, speciation, and extinction in major fossil groups that are abundantly preserved in Panama.

Another topic of general interest relates to differences in conditions along different types of coastlines, and the importance of terrigenous inputs to coral reefs. Most reef studies have been done on offshore islands or banks where influxes of freshwater and sediments are small compared to Panama and elsewhere in the southwestern Caribbean, where annual rainfall commonly exceeds three meters. Despite such heavy inputs, reefs in these areas have grown surprisingly fast, although they are strikingly different from island reefs in overall morphology and species abundance and distribution. For example, the coral *Montastrea annularis* is rare on most mainland fringing reefs, yet typically dominates similar reefs on offshore islands.

A last goal, imposed by accident, is to document the short- and long-term biological consequences of the oil spill that occurred in April 1986, a few kilometers east of Punta Galeta. This spill, the largest recorded in the American tropics, resulted in mass mortality of many types of organisms in mangrove, seagrass, reef flat, and subtidal reef environments. Moreover, chronic pollution is resulting from continued slow release of oil trapped in mangrove sediments during the initial spill. A new research group of 15 scientists and assistants was formed especially for this project, which will last at least five years.

The several striking differences between marine communities in Panama and the central Caribbean, and the multitude of abrupt and major changes we have witnessed, clearly define a major research problem confronting Caribbean marine biologists. Most of the classic studies of Caribbean species are based on work at one or a few laboratories, with little feeling for the potential generality of results. Besides the environmentally correlated differences in distributions, as for *Montastrea* mentioned previously, many species dominant at some locations are rare or absent at others, despite lack of obvious environmental differences.

Three outstanding environmental problems of importance in Panama are oil pollution, overfishing, and deforestation. So far, severe oil pollution appears to have been limited to the area near the Canal entrance and the major spill in 1986 at Bahia las Minas to the east. This situation could change drastically in the event of an accident stemming from the transcontinental oil pipeline in the Laguna de Chiriqui in northwestern Panama, which harbors the greatest area of mangroves along our Caribbean coast.

Fishing is apparently nowhere so intense as around several of the Caribbean islands, thanks largely to absence of trap fishing. Nevertheless, local population growth, as by the Kuna People in San Blas, may require careful management of fisheries in the future.

Probably the most serious marine environmental problem in Panama, however, is the smothering of coral reefs by sediments as the result of rapidly progressing deforestation and erosion along much of the Caribbean slope. We have just begun to document the extent of these effects, using sclerochronology (measurement of the thickness and configuration of coral growth bands) tied in to dates of forest destruction known from aerial photographs. Our goal is to develop a quick, reliable assay of coral population condition that can be used by local authorities to evaluate the extent of reef stress due to sedimentation, oil pollution, and other human disturbance.

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concerns

The Whalers of Bequia

by Nathalie F. R. Ward

"Blo-o-ows, mon, Blows!"

"Ease de oar—becket de gyaf—run ou' de boom—look shyarp!" shouts the boatsteerer in his quick West Indian tongue, as the whaleboat slides over the steep, breaking seas, chasing the whale in the channel running to the east of Bequia.

These orders are familiar echoes of the last 100 years of whaling tradition on the small island of Bequia—a 15-square-mile island lying in the Grenadine chain south of St. Vincent, in the Windward Islands of the Caribbean Sea (Figure 1).

The Bequia humpback whale (*Megaptera novaeangliae*) fishery is the only existing relic of the historic land-based fisheries once operative in the Grenadines between the 1880s and the 1920s.

New England Origins

The Bequians learned the trade from the New England whalers. Yankee whaling activity in the Caribbean reached its peak during the 1860s and 1870s, and during this period a number of Bequians enlisted aboard Yankee whaleships—and learned the skills of whaling. William T. Wallace, a Bequian of Scottish ancestry, was one such apprentice seaman who joined the crew of an American whaler—a voyage that ended in Provincetown, Massachusetts. Wallace married a Yankee captain's daughter, Stella Curren, and returned to Bequia to found the present humpback fishery in 1875.

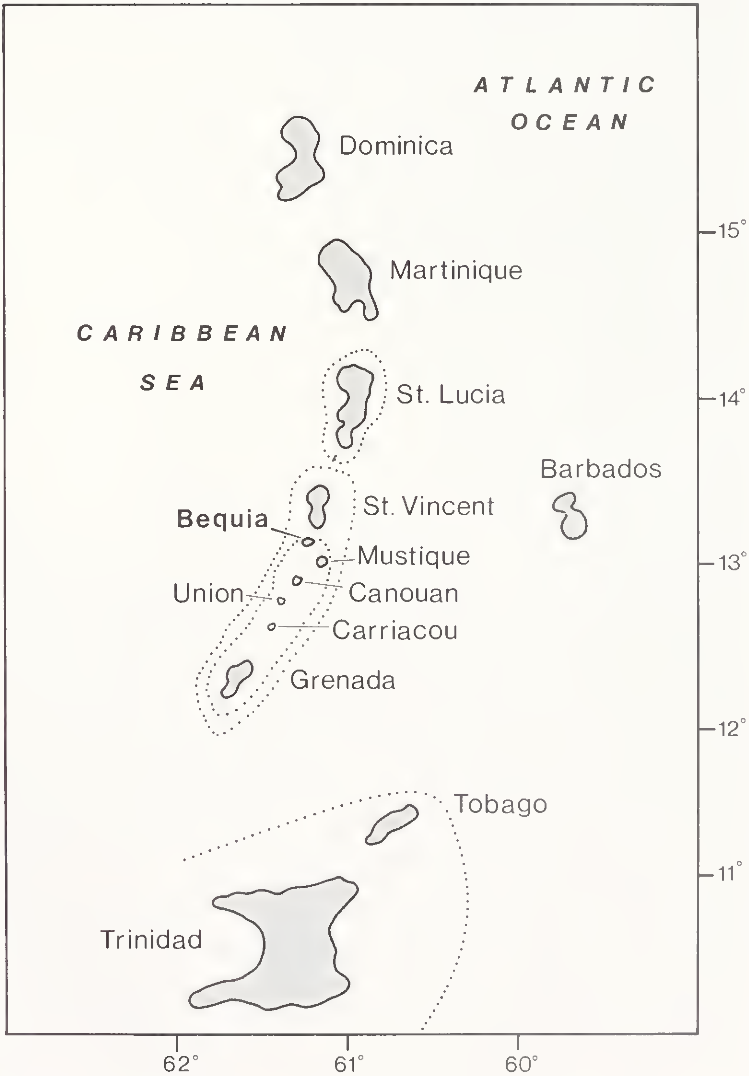

Figure 1. Bequia and the outlying islands showing the range of the whaling grounds. The hunt is focused to the windward of Bequia in the 7-mile channel running between Bequia and Mustique.

Wallace ("Old Bill") constructed the first shore station on Friendship Bay (Figure 2). Joseph Olliviere, an enterprising proprietor, following Wallace's lead, erected a second whaling station about 1878 on Petit Nevis, a small islet a quarter mile southeast of Bequia. The creation of the fisheries transformed Bequia from a declining agricultural economy to a thriving sea-based economy, which generated a steady income for the majority of the island's population.

The Bequia whaling industry initiated a string of 20 competing whaling concerns throughout the Grenadine chain from 1880 to 1925, each equipped with a shore station and from three to five whaleboats. The increased whaling effort heralded the need for a set of regulations for competing companies to abide by, in hopes of reducing tiresome quarrels over the rights or "ownership" of whales pursued. The "Whaler's Ordinances of 1887" were established to define responsibilities and to impose restrictions on the Grenadine concerns. Today, the historical catch logs (St. Vincent Bluebooks) serve as the access to past records for interpretations of catch statistics.

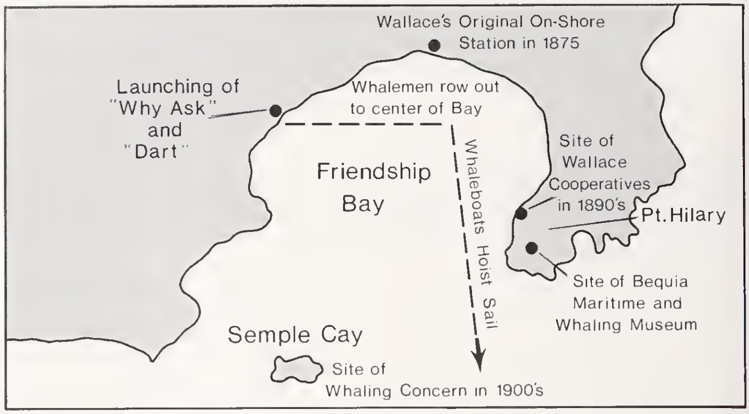

Figure 2. Friendship Bay, on the windward shore of Bequia, shows the shore stations of past whaling cooperatives, the site of launching of the present fishery, and the future site of the Bequia Whaling and Sailing Museum on Pt. Hilary.

Whaling Methods

The methods and tools of the present fishery remain nearly unchanged from the original whaling cooperatives. The present whale fishery is equipped with two boats, *Why Ask* and *Dart*, each with a crew of six men: the harpooner, the captain or boatsteerer, and four ordinary seamen. The boats, lying on whalebone skids, are launched from Friendship Bay January through May, six days a week—weather permitting. Lookouts are stationed on hilltops and outlying cays to signal the "humpbackers" (whalers) of sightings by mirrors and radio. The hunt is focused to the windward of Bequia, in a 7-mile channel running between Bequia and Mustique, to take advantage of the easterly trade winds when towing a whale back to shore. Historically, humpbacks are the primary quarry, cow and calf pairs the preferential take.

The Bequia whaleboats, modeled after the Yankee whaleboats, are 26-foot, double-ended wooden boats, with a jib and sprit-sail rig, five rowing stations, and a 20-foot steering oar. Perhaps more uncouth in appearance than their Yankee counterpart, the planks are hand-hewn from imported spruce; and the ribs are made from locally-cut white cedar whose natural curvature, due to the prevailing winds, is ideal for framing. A removable "daggerboard" or centerboard functions as keel and prevents lateral drift when beating through steep seas. Heavy stone is carried in the bilges to act as ballast, and gingerly rearranged with every tack.

The hand-thrown harpoon or "toggle iron," a 12-foot-long cinnamon wood shaft with a 2-inch barbed brass head, weighs about 25 pounds, and can be thrown accurately a distance of only about 12 feet. Once the whale is struck, and the harpoon "holds fast," an 11-foot lance is repeatedly thrown in attempts to puncture the whale's heart or lungs. As a last resort, a hand-held "darting gun" (a bayonet-like harpoon), or a "bomb gun" (a 40-pound shoulder gun), equipped with exploding cartridges, is used to secure the whale.

At present, Petit Nevis is the shore station where whales are flensed (stripped for blubber), and processed for their meat and oil. The processing facilities include: a concrete ramp and a winch with a block and tackle for hauling the carcass and facilitating the "cutting in" or butchering; the "tryworks" consisting of two large "coppers" or iron boilers for rendering the blubber to oil; and a cement building to house the cooling tubs, whaling implements, and wooden casks and cast-iron drums for the storage of oil.

The killing of a whale prompts a celebration of hundreds of the island's residents, who gather on Petit Nevis for the event of butchering and the joyous aftermath of buying oil and meat. In comparison to the 1920s, the export of oil is virtually non-existent today because of a dwindling market throughout the Lesser Antilles. The oil, however, continues to be used locally for lubricants, medicaments, illumination, and cooking. More importantly perhaps, the whale meat is considered a precious commodity. In 1986, meat, sold either fresh or corned, retailed for $3 a pound East Caribbean (EC) currency (about US$1.50).

Traditionally, there is no wage in the Bequia fishery. The humpbackers exert a strenuous effort and a determined fortitude during the long hours and the

Why Ask *under sail by Ramie Cay southeast of Bequia. Intrepid sailors sail their boats between coral heads and islets for strategic positioning when chasing humpbacks. (Photo by N. Ward)*

Athneal Olliviere, a descendant of Joseph Olliviere, is the chief harpooner and owner of the present fishery. He is the living legend of the last 30 years of the Bequia humpback fishery. (Photo by N. Ward)

often lean rewards of a 4-month whaling season. Earnings are dependent upon the sale of oil and meat. The income of whaling is divided into shares, and distributed among the 12 crew members, the look-out man, and the five owners of the fishery. Returns from whale oil are forthcoming only after its sale in St. Vincent and other local export markets in the Grenadines. Whale meat is marketed by individuals in the fishery, given to relatives, or sold to locals.

Due to the paucity of whales landed—about two a year (although many years pass without a catch)—and the structure of the fishery, the present fishery gives monetary advantage to a select few, preempting an economic contribution to the island's population of 9,000, and lessening the economic status as a "subsistence" fishery. Rather, the cultural and historical aspects of the fishery are the valuable "subsistence" cornerstones of a cherished maritime tradition.

An Uncertain Future

Whaling on Bequia does not have a sècure future. Only a handful of the islanders are practiced in the demanding ritual of the hunt, and the majority of whalers are well into their 60s. The risk and effort of whaling and the regular cash flow of conventional fishing, entice both current and potential whalers from the industry—making it difficult to recruit new members.

Athneal Olliviere, 67 years old, is the owner and prestigious harpooner of the fishery. A man of quiet dignity and confidence, Olliviere is the undisputed champion of the hunt. He has monopolized his position as the "last harpooner" for the last 30 years. Many of the traditions and skills of whaling have not been passed on to future generations.

Bequians hope the whale fishery will be allowed to follow its natural course and be supplanted by the Bequia Whaling and Sailing Museum. This is an important step in implementing the transition from an active whaling operation to historical status. The Bequia Heritage Foundation* recently purchased land for the museum on Pt. Hilary—an original site of the Wallace whaling cooperative. The museum will serve to document and to preserve local heritage for future generations before the fishery fades, as Bequians feel it inevitably will.

International Scrutiny

During the 1987 season, the Bequia whaling was the subject of scrutiny and concern. One result is that the 1988 season will mark the first time that a quota has been established by the International Whaling Commission (IWC) for aboriginal whaling in the Grenadines:

> *For the season 1987/1988 to 1989/90, the taking of 3 humpback whales each year is permitted by Bequians of St. Vincent and The Grenadines, but only when the meat and the products of such whales are to be used exclusively for local consumption in St. Vincent and The Grenadines. . . . It is forbidden to take or kill suckling calves or female whales accompanied by calves.*

In response, the Bequians feel that there is no evidence that the harvesting of one or two whales for food each year endangers the species, nor places a dent in the reproductive segment of the population. Bequians believe that the quota placed by the IWC has rarely been exceeded in the last 20 years.

The lookout man on top of Pt. Hilary on Bequia signals the whalers of sightings of humpbacks via mirror, and then communicates via radio the specifics of numbers and direction of travel of humpbacks. (Photo by N. Ward)

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* The Bequia Heritage Foundation was founded in 1984 by a group of concerned citizens, and in 1986 was formally incorporated by an Act of Parliament. The foundation's objectives are "to conserve the historical, cultural, and physical heritage of Bequia for future generations."

Resolving The Issues

To conservationists and the IWC, Bequia is an important location for conservation and management issues. Although political influence and pressure have been exerted toward the cessation of whaling practices, the means to preserve the past and present fisheries heritage has sometimes been overlooked. Regulating the fishery without the complement of a viable course of transition is seen as characteristic of outside involvement in many Third World countries. This situation negates the fostering of mutual expression and respect.

Hopefully, support for a museum and a local educational effort in Bequia will influence a pro-conservation ethic, arrest what is potentially a tenuous situation, and insure the natural sequel to the last humpback fishery.

Nathalie F. R. Ward is an independent marine mammal researcher who has worked with the Provincetown Center for Coastal Studies, Provincetown, Massachusetts. She has been studying the Bequia humpback whale fishery since 1984.

Acknowledgments

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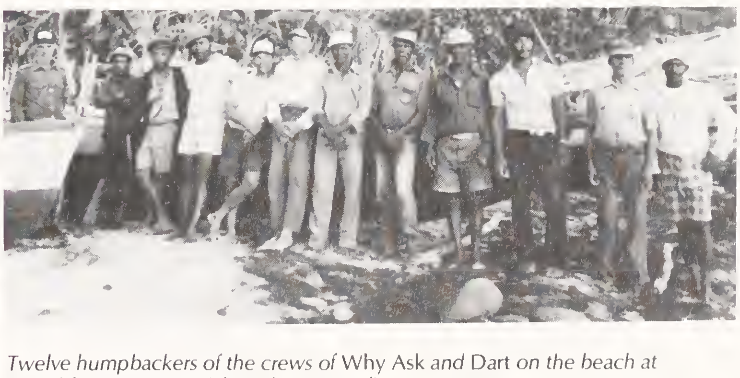
The whaleboat Why Ask, *built in 1983, lying on the beach at Friendship Bay. Although shorter in overall length, the Bequia whaleboat is basically a replica of the Nantucket prototype. (Photo courtesy of the Provincetown Center for Coastal Studies)*



Twelve humpbackers of the crews of Why Ask *and* Dart *on the beach at Friendship Bay, 1985. (Photo by N. Ward)*

The Future of the Panama Canal

by Ambler H. Moss, Jr.

Is the Panama Canal still commercially and strategically important, and will it be so in the year 2000?

Is the phased turnover to Panamanian management working well enough so that Panamanians can eventually run the Canal without U.S. help?

Is the present political turmoil in Panama an ominous sign for the Canal's future?

These are some of the frequently-asked questions as the midway point in the phased transfer of the Panama Canal to the Republic of Panama is approached (the transfer is to be concluded on the last day of 1999). The continuing political disturbances in Panama certainly do not ease the minds of those concerned with the Canal. Yet despite the cloudy horizon, there is cause for optimism. The ongoing need for an efficient, reliable waterway as an important asset to world commerce underlies that optimism. The legacy of cooperation between the United States and Panama in its management also provides strength for the future.

The New Treaty Relationship

Ten years ago last September, the United States and Panama signed two treaties. They were approved by the Senate in early 1978 after very long and acrimonious debate, and entered into force in October 1979. These two documents—the Panama Canal Treaty, and the Treaty Concerning the Permanent Neutrality and Operation of the Panama Canal—contain a complex scheme that defines U.S. rights and obligations concerning the Canal, and the use of military bases until the year 2000. Once the new century begins, the so-called "Neutrality Treaty" provides a regime of access and passage to all nations, and gives the United States certain rights to act in the Canal's defense. The Canal's actual operation at this point, however, passes entirely into Panamanian stewardship.

Doom was forecast by those opposed to the "giveaway" of the Panama Canal by the Carter Administration in 1977. Indeed, some of the Reagan Administration's new appointees in the Latin American area had been authors of the 1980 paper (*A New Inter-American Policy for the Eighties*, published by the Council for Inter-American Security) which termed Panama a "left-wing and brutally aggressive dictatorship," and saw the treaties as one more gain for communism in the Western Hemisphere.

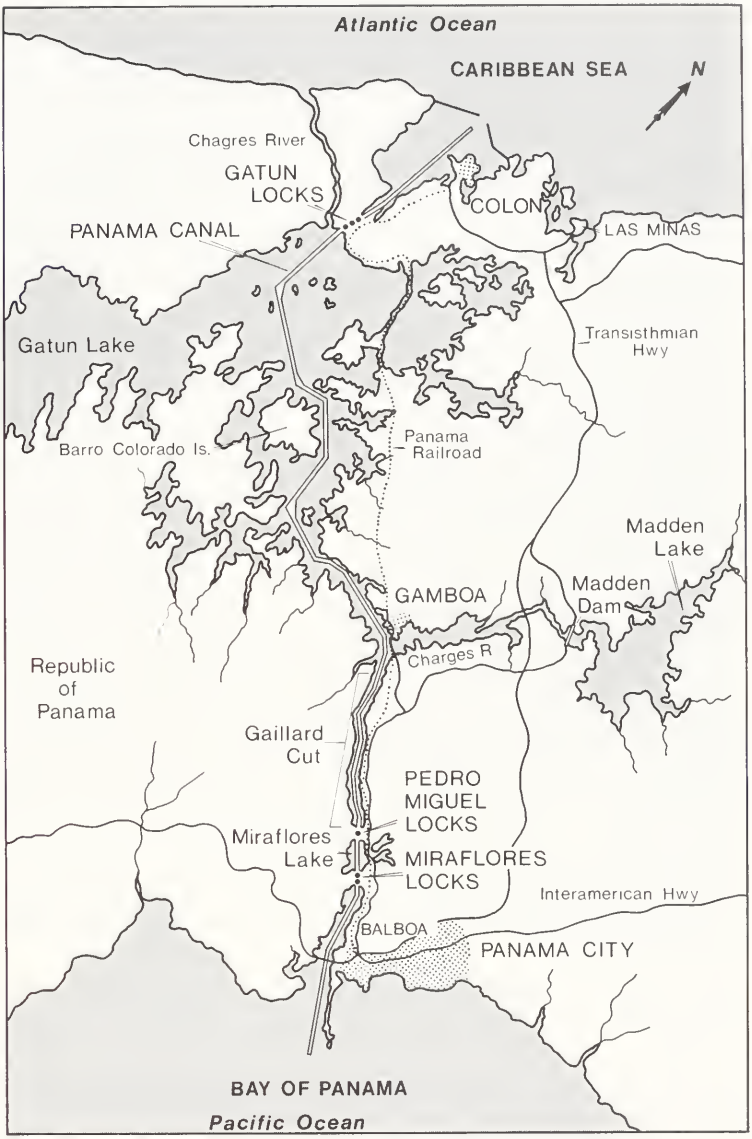
President Reagan himself had campaigned vehemently against Senate approval of the treaties in 1978. After his election, however, he behaved gracefully toward Panama. In early December of 1980, he allayed Panamanian fears by sending President Aristides Royo a letter promising the fullest cooperation in the Treaty relationship.

There were good reasons for him to do so. The entry into force of the treaties in 1979 had gone smoothly, and the Canal was to set new tonnage and ship transit records for the next three years. Residual anti-U.S. sentiment seemed to vanish from Panama altogether, encouraging U.S. businessmen and some Panamanian colleagues to start that country's first American Chamber of Commerce. In retrospect, the emotional fervor and extreme nationalism of the anti-treaty orators seemed unjustified on any rational grounds.

It must be recognized that certain aspects of the Panama Canal Act (P.L. 96-70, 22 U.S.C. 3601 et seq.), and the U.S. domestic legislation passed in 1979 in implementation of the treaty, caused friction between the two countries. Congress imposed certain changes to the Administration's Bill—such as the creation of two wage systems for "old" and "new" employees, and for positions traditionally hard to fill. Subsequent amendments have smoothed out some of the Act's difficulties, however.

Just as with any business, Panama Canal traffic has had its ups and downs, reflecting world economic conditions. Today, however, more ships and tonnage transit the Canal annually than did in 1977. The Canal pays for all of its operational costs from tolls and U.S. payments to Panama required by the Treaty (in fiscal 1986, these amounted to nearly $77 million). Tolls have not been increased since 1983, and are considered very competitive as a component of shipping costs.

Continuity of management under exceptional leadership has been an important factor in the success of the Panama Canal Treaty. Dennis P. McAuliffe, formerly Commander-in-Chief of the U.S. Southern Command based in Panama, has been Administrator of the Panama Canal Commission since 1979. His deputy, Fernando Manfredo, held cabinet positions in the Panamanian government during the 1970s, and is respected by U.S. and Panamanian workers equally. Manfredo has stressed the importance of timely preparation on the part of Panama to assume the task of running this large enterprise efficiently in the year 2000.



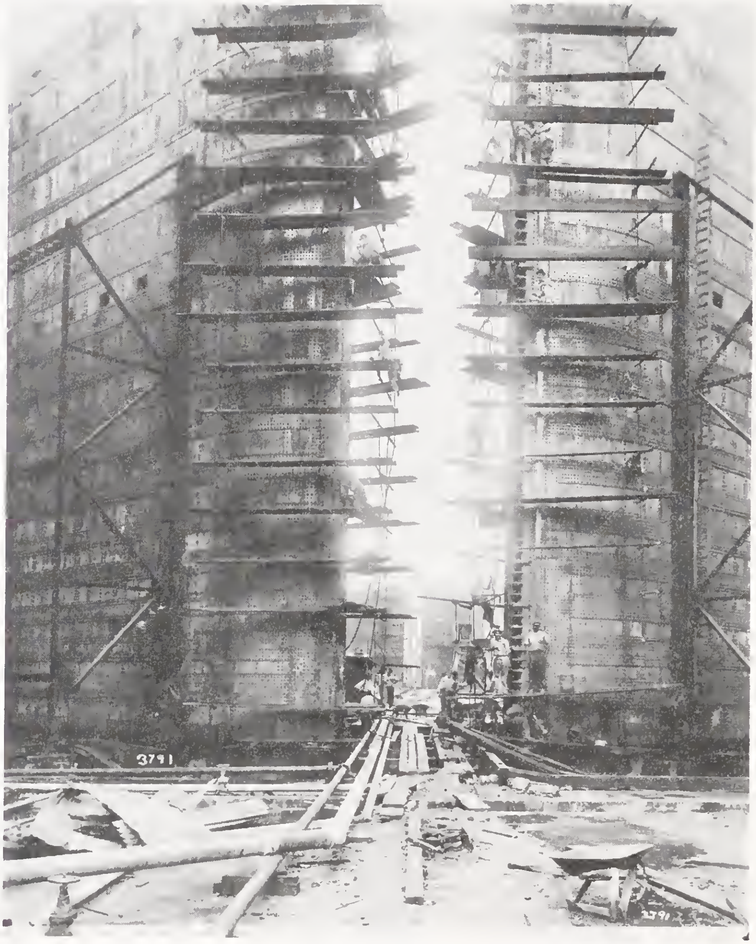
The Panama Canal is a lock-type canal, approximately 51 miles long, with a navigable channel whose minimum width is 500 feet. The channel depth can vary according to the water available in the storage areas. Vessels transiting the area are raised in three steps to the level of Gatun Lake and lowered in three steps on the opposite side. The canal opened on August 15, 1914, and since that date has transited more than 640,000 vessels. (Source: Panama Canal Commission)

Looking Toward the Future

Panamanian territory has been significant as a worldwide transit point ever since Spanish colonial days. Simón Bolívar ascribed great importance to the geography of the isthmus. In his *Letter from Jamaica*, the Liberator stated: "This magnificent position between the two seas can become, in time, the emporium of the universe." He compared it to Byzantium in an earlier age.

There is no reason to assume that Panama's location will be less important in the year 2000 than it is today. Nevertheless, the exact parameters of that importance are not easily predicted, and depend on a number of variables. With regard to the Canal itself, these variables are:

- Future growth and nature of world trade patterns.
- Changes in technology in the transportation industry.
- Availability of external funding either for Canal improvements or alternatives across the Central American isthmus.



Building the Gatun Locks around 1912. Construction of the Panama Canal involved excavation techniques that have long since vanished from the big engineering projects scene. (The Bettman Archive)

Military and security considerations, of course, were a large factor behind the huge investment of the United States in constructing the Canal between 1903 and 1914. In today's era of a two-ocean navy, however, they are less important and probably will remain so. In fiscal 1986, for example, only 85 of a total 12,023 Canal transits were by U.S. Government vessels. Because of its vulnerability to missile attack, the Canal would likely not be available in time of war. As its operation relies on the gravity-fed flow of fresh water from Gatun Lake, a perforation and drainage of the water supply would put the Canal out of action; refilling the lake could take up to three years.

World Trade Patterns

Great effort is made to keep tolls as low as possible, because the Panama Canal is facing new forms of competition from a technologically dynamic transportation industry. The opening of an oil pipeline across Panama in October, 1982, for instance, led to a decrease in traffic; this, among other factors, prompted the last toll increase, of 9.8 percent. Predicting future traffic flows is exceedingly difficult, as they are so dependent on unforeseeable world economic conditions and technological change.

It has long been known that Canal traffic is highly sensitive to toll rates. A toll sensitivity study performed by International Research Associates was the basis of the financial arrangements with Panama under the Panama Canal Treaty. The Panamanian negotiators, entering the discussions with high expectations of gain for their country, soon realized the need to limit any new toll increases resulting from the Treaty to around 33 percent.

Bulk goods such as petroleum products, grains, ores, and so on, make up a large part of the cargo, close to 65 percent. Other types of cargoes, however, such as containers, and Japanese automobiles destined for the East Coast of the United States, have accounted for recent tonnage increases. Containerized shipments, however, may alternatively be shipped across the United States by rail or truck transport at costs similar to ocean transport.

More recent studies reinforce the challenge of competitiveness. In 1986, a toll sensitivity study was performed by Temple, Barker & Sloane Inc., looking at the period from 1984 to 2010. The study showed that sensitivity is expected to increase over time, "reflecting greater cost competitiveness of diversion alternatives."

Technological Changes

Both the United States and Panama agree that new investment should be put into enhancing the Panama Canal's competitiveness. According to the Panama Canal Treaty, the United States is required to turn over the Canal free of any debt or liens at the end of 1999. The Panama Canal Commission has practiced a policy for the last several years of investing heavily in new capital equipment out of Canal revenues. In this manner the Canal tugboats and "mules" (locomotives) that assist ships through the locks have been upgraded greatly in capacity, as has the Commission's industrial repair facilities. High-mast lighting has been installed at all locks, a vessel tie-up station has been constructed just north of Pedro Miguel Locks, and solar panels that recharge power cells have been installed on all lighted buoys. The marine traffic control function is now automated to an unprecedented degree.

Average ship size has increased annually, making physical improvements in the Canal necessary. Today, vessels with beams of more than 80 feet account for nearly half of total traffic, posing problems of how to handle flow in both directions efficiently. The Commission considers it important to hold average time in "Panama Canal waters" to around 24 hours.

Although significant widening projects have been carried out in recent years—in 1986, one involved the removal of 185,400 cubic yards of material—still larger projects are needed. These probably cannot be financed out of toll revenues between now and the year 2000. The major proposal calls for widening the 9-mile Gaillard Cut, through the highest point of land along the Canal. This stretch, by far the greatest challenge to the turn-of-the-century engineers, was originally limited to a 300-foot width, later widened to 500 feet. Still, a ship with a beam exceeding 95 feet is not permitted, for safety reasons, to pass another ship in the cut—this creates bottlenecks that will become worse as ship sizes increase. A project to widen the cut to 630 feet along straight portions, and up to 730 feet on curves, could cost more than $400 million. However, many user countries, particularly those that depend more heavily on the movement of raw materials or finished products through the waterway, such as Japan, have an interest in Canal improvements.

In May of 1987, a financing study undertaken by Bear, Stearns & Co. and Samuel Montagu Ltd., outlined a range of alternatives: from 100 percent internal financing; to 100 percent external financing; and various multinational solutions. To date, no decisions on funding arrangements have been made. It should be recalled that a major improvement project for the Suez Canal during the 1970s was accomplished through multinational financing by user nations through the United Nations. Such a scheme has not been proposed for the Panama Canal, however.

Tie-up station north of Pedro Miguel Locks. This station is used to increase the traffic capacity of both Pedro Miguel and Miraflores Locks.

Alternatives and Funding Plans

A more ambitious study, looking into the feasibility of a sea-level canal, is concerned with the longer-range plans for trans-isthmian transportation. Article XII of the Panama Canal Treaty stipulated that both countries should consider this possibility, the advantage being that it could accommodate the supercarriers of 200,000 tons and greater. As a result of diplomatic talks, a Panama Canal Alternatives Study Commission has been established, which includes Japan. This commission has an initial $20 million budget, shared by the three member countries. Ironically, a recommendation to build a sea-level canal is perhaps the least likely outcome of the study. The cost of such a project is generally thought to exceed $20 billion, a figure hard to justify on the basis of commercial advantage.

The mandate of the commission goes well beyond a sea-level canal study, however, and has been set to include all alternatives for more efficient use of Isthmian geography. A Panamanian engineering firm, Lopez y Moreno, has proposed an expansion of the present lock canal to handle supercarriers. Additional pipelines, including a coal slurry pipeline, and new rail connections to handle containers will probably be examined.

The Commission announced that additional countries could join the study (and share the cost), but so far none have. Whatever new projects the Commission recommends, however, it is likely that they must appeal to the international community of user nations for financing. Since the turnover of the Canal to Panama is still fresh in U.S. Congressional memory, it is extremely unlikely that Congress would appropriate funds for these projects.

Panama as a Reliable Partner

One basic assumption must be made, however, before any of the projects relating to the Canal's future can be faced; it is that Panama will be a reliable partner. This question relates not only to the future of the canal, but to strategically-important regional quesions for the United States such as: the outcome of present Central American conflicts; the future of Soviet involvement in Latin America; the future of Cuba as the post-Castro era approaches and becomes a reality (Castro will be in his 70s by the year 2000); and the outcome of terrorist threats and "low-intensity conflict" in the northern countries of South America and Peru.

In early 1978, Panama's former military strongman, Omar

Torrijos, responded to pressure from U.S. Senators debating the Treaties. At that time he made, and subsequently kept, three promises to them: to restore freedom of the press; to allow the return of political exiles; and to allow political parties to operate freely. Torrijos then began a process of transition to democracy by retiring to the barracks in favor of a civilian government, which the military nonetheless controlled from behind the scenes.

Torrijos died in an airplane crash in July, 1981. A year later the president, Aristides Royo, was forced by the military to resign. His successor, Ricardo de la Espriella, met the same fate, again after one year, in 1983.

Presidential elections were held on schedule in October, 1984. The winner by a narrow margin was Nicolás Andito Barletta, an economics Ph.D. from the University of Chicago, and former vice-president of the World Bank. The opposition charged electoral fraud. In late September of 1985, Ardito Barletta was forced to resign, again under pressure from the Panamanian Defense Forces, headed by General Manuel Antonio Noríega. Ardito Barletta was replaced by his vice-president, Eric Arturo Delvalle, but the military have clearly continued to control the country's politics from behind the scenes. Panama's economy has stagnated, and the country suffers from a lack of confidence on the part of the private sector.

In June, 1987, a rival of Noríega, Colonel Roberto Diaz Herrera, retired (perhaps forcibly) and launched a series of public charges against Noríega: that he had assassinated a political enemy (Hugo Spadafora); that he was involved in drug trafficking and money laundering; and that he had rigged the 1984 elections. Demonstrations—staged by students, the opposition, and private-sector civic organizations—reached large-scale proportions. The Panamanian Defense Forces responded with an unusual degree of repression for Panama, and shut opposition newspapers down. Street demonstrations still occur frequently, and the atmosphere is tense.

The outcome of the political standoff remains uncertain. In the meantime, the threat of economic deterioration looms large. Panama's economy is fragile, as more than 60 percent of it is in the services sector. Its 120 banks employ 8,000 people, and the potential loss of such an industry threatens the country's future. Following a resolution this last July by the United States Senate on the situation in Panama, Noríega and Delvalle have now levelled charges of U.S. interference, and relations have reached their lowest point since resolution of the Canal Treaty issue 10 years ago. Washington is clearly disturbed by events in Panama, but there are no easy answers as to how the direction of Panamanian politics can be changed.

U.S. Policy Options

Whatever the United States may think of Panama's government, there is no turning back on its treaty obligations. The present situation would indicate the most desirable U.S. posture is to:

1. ***Keep the Panama Canal relationship separate from other issues.*** *The treaties are not dependent on the character of the government in power. They represent a long-term joint venture, responsive to both countries' interests in the Panama Canal.*

2. ***Maintain pressure in favor of democratization.*** *This is a delicate and medium-range objective, the definition of which is to wean the Panamanian military away from the exercise of political power. Our military-to-military relationships in Panama can help. The U.S. military commander in Panama, General Fred Woerner, is a seasoned expert on Latin America and an outspoken proponent of democracy and civilian rule.*

3. ***Be prepared to rescue the Panamanian economy before it collapses.*** *Continued economic crisis could bring on an explosion of the social time-bomb whose clock is already ticking. Although U.S. bilateral aid has been suspended as a sign of displeasure with the regime, issues such as the resolution of Panama's huge debt service problem; multilateral agency lending; and the development of a private-sector, export-oriented economy should continue to be of concern to Washington.*

At present, optimism regarding Panama is in short supply both in Washington and in Panama. Nevertheless, there are 12 years left to run under the present canal treaty regime; this is time enough for positive developments to take place. Panamanians have traditionally been practical people. Their future interest in an efficient Panama Canal will be at least as great as that of the United States, and arguably even greater.

Ambler H. Moss, Jr. is Dean of the Graduate School of International Studies, Professor of International Studies, and Director of the North-South Center at the University of Miami, Coral Gables, Florida. He was U.S. Ambassador to Panama from 1978 to 1982, and a member of the negotiating team for the Panama Canal Treaties signed in 1977.

profile

Athelstan Spilhaus

Photo by Nelson McClary

Renaissance Man

by Paul R. Ryan

The bathythermograph—one of the principal tools developed at Woods Hole for the study of oceanography—is 50 years old. The man who pioneered the development of the BT, which played a prominent role in the defense against German submarines in World War II, is Athelstan Spilhaus. This Renaissance Man has jauntily worn the silk top hats of inventor, scientist, engineer, author, raconteur, comic strip creator, professor, dean, institute president, sculptor, architect-designer, toy collector, meteorologist, advisor to presidents of the United States, and father of the Sea Grant College concept. In short, a very unusual, energetic man, who has packed more experiences into his 76 years than most people would in 10 lifetimes.

Born in Capetown, South Africa, on November 25, 1911, the son of Karl Antonio and Nellie (Muir) Spilhaus, Athelstan Frederick Spilhaus, fondly referred to as "Spilly," spent his early years on a farm called Bell Rock in the Transkei, a sector south of Natal. The youngest of five children—three boys and two girls—he remembers that he "never really went to school until I was ten.

"A series of prim young governesses from England were brought out to teach my sisters and myself, but I resisted formal education." There is a family tale that when one young governess tried to get Spilly into school, he took off all his clothes and stood in the middle of a dam, daring her to come and get him. This sense of mischievousness and humor would become a permanent character trait.

"I got a much better education at home [his mother was the first woman graduate of the University of Capetown and his grandfather the Superintendent General of Education in South Africa]. It often makes me think, with the quality of some of our schools nowadays, and with the good education of many parents, why we have laws that prevent well-educated parents from keeping their children home learning, instead of sending them to schools where there are badly educated teachers."

After World War I, Spilhaus' father, a successful merchant, was appointed Minister Plenipotentiary in Europe to rebuild commerce interrupted by the war. Young Spilly was packed off to a British public school where he received a classical education—lots of Latin, Greek, French, English, mathematics, and a little science.

With only five years of formal schooling, Spilhaus was admitted to the University of Capetown at the age of 15. The following year, he attracted attention in the local press by building a sand yacht out of an old automobile and sailing it on nearby salt flats, much the same as an ice boat with wheels. He was edging closer to the sea.

His first summer job while at the university was as an apprentice engineer on a cargo vessel plying the Indian Ocean. He gained much practical engineering experience by going to sea, finishing his degree at the university in 1931. However, his interest was turning from the sea to the sky. He had observed the flying boats of Imperial Airways as they set down like huge birds on Lake Entebbe in Uganda. He decided he wanted to be an

Good engineering, he feels, is the ability to understand both the medium and the machine.

aircraft engineer and, through his father's European connections, got a job in Germany at the Junkers factory, where he worked as a volunteer for six months.

The volunteer work at Junkers convinced Spilhaus that he wanted to continue studying—this time aerodynamics. But where? Well, he'd never been to America. There were two places that taught aerodynamics—the Massachusetts Institute of Technology and the California Institute of Technology, and he made the fateful decision to go to MIT over Cal Tech because he did not have the money to cross the continent.

MIT and Woods Hole

Spilhaus arrived at the Dean of Admissions office suitcase in hand. The dean looked up and said: "Do you have an application in?" "No," Spilhaus replied, "I wrote for a catalog and decided to come here."

"You know," the dean said, "we get lots of applications, and we have to process them." Spilhaus replied, "Look, I've come all the way from South Africa."

The dean asked, "Where did you go to school?"

"University of Capetown," Spilhaus replied.

"Never heard of it," the dean commented.

"You will."

Spilhaus was admitted on probation, and the rest, as they say, is history. The influences on the young aerodynamics engineer began to grow—Norbert Wiener, Charles Stark Draper, Manfred Rauscher, Hurd Willett, Harry Wexler, Carl Rossby, and others.

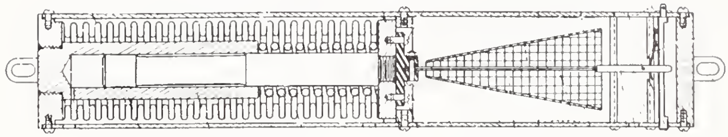
Spilhaus recalls that money was short at the time (1932). "Cases of scotch and other whiskeys with floats on them were dumped outside the three-mile limit off Cape Cod. My contact was a philosophy student at Harvard. He rounded up a few of us who could sail small boats. We went out to the three-mile limit at night to bring back the cases of liquor. We simply picked up whatever floating cases we could, wrote our mark on them, and left them on the beach. We never saw who picked them up. We were a little ambivalent about the repeal of Prohibition, and this operation certainly helped me get through MIT."

Another thing that helped him get through MIT was his invention of a "comfortmeter," an instrument that recorded where temperature and relative humidity crossed. An air conditioning company bought the rights, which "was the last anyone heard of my invention."

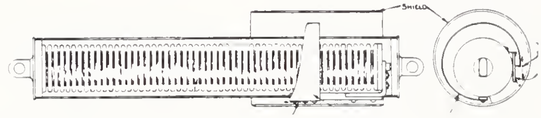
In 1933, Spilhaus finished his degree in aerodynamics, and then went on to study meteorology for about two years. He switched subjects because he realized that man had not truly conquered the air. Planes were at the mercy of weather conditions, many going down because of icing conditions. Good engineering, he felt, was the ability to understand both the medium and the machine.

In June of 1935, after finishing his degree work at MIT, he married Mary Atkins, a granddaughter of Henry

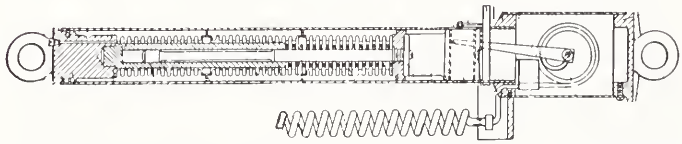
Evolution of the Bathythermograph



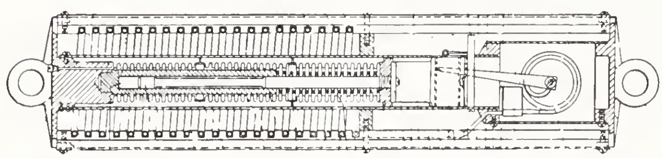
A. 1936–37, 1st BT (thermal lag)



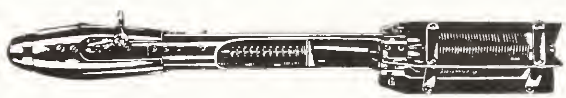
B. 1937, 2nd BT, (thermal lag reduced but bad vibration)



C. 1937, Bourdon tube BT, (lag reduced, vibration eliminated)



D. 1939, Bourdon tube BT, (lag further reduced by thin tube bulb)



E. 1941, Production BT, (first built at Woods Hole)

Hornblower of Boston. They would have five children: Athelstan Spilhaus Jr., now Executive Director of the American Geophysical Union; Molly; Eleanor; Margaret Ann; and Karl, now President of the Northern Textile Association in Boston. The first year of the Spilhaus' marriage was spent back in South Africa, specifically in Pretoria, where he was appointed a temporary First Lieutenant in the South African Defense Force, a branch of the British Army. Part of his time was spent destroying dud shells left over from the Boer War.

The desire to get back into science began to gnaw at him. He wrote to his professor and great mentor Carl Gustav Arvid Rossby, who arranged for Spilhaus to become a research assistant at the Woods Hole Oceanographic Institution while working also at MIT. Spilhaus and his new wife decided to come back to Boston and Woods Hole by way of Cairo and Alexandria. They bought a used 1934 Buick and a compass and set off from Capetown. In many places, such as the Serengeti Plains, there were no roads. Pygmies and other natives helped them to cross rivers and to get them unstuck from the mud. The trip took about nine weeks. At one meat market on the border of the Belgian Congo and Sudan, they saw human flesh displayed. Spilly found it "stringy, like venison. Needs to be larded." The trip could not be done today.

On arrival in Boston, Spilhaus discovered that Rossby, who was then involved in his work on jet streams and vorticity, wanted him to construct a rotating model ocean with a jet stream somewhat like the Gulf Stream in it. The only space MIT had to offer was a seldom-used men's room. And this is where the aerodynamist/meteorologist began his work—the only interruptions coming from an occasional student with a pressing hydrodynamic problem.

"The features in which Rossby was interested," Spilhaus recounts, "were the eddies on both sides of the jet stream. Not only was he doing his theoretical studies, but he was also trying to delineate the real eddies on the edge of the Gulf Stream, eddies which were well known to bring unusually warm water close in to Nantucket." The rotating model ocean would later lead William von Arx to construct a more sophisticated rotating basin at Woods Hole.

"During an earlier cruise on the WHOI research vessel *Atlantis* in 1934, Rossby had constructed a great box-like contraption which he called an Oceanograph in an attempt to get continuous tracings of temperature versus depth in the surface layers of the ocean more conveniently than with the then standard procedure of lowering a string of reversing thermometers attached to Nansen bottles."

The Bathythermograph Is Born

The Oceanograph was cumbersome and not practical. Its linkages became fouled in seaweed and the instrument vibrated, making the recordings useless. Spilhaus, who accompanied Rossby on the 1934 summer cruise, had thought about the problem during his year in South Africa, devising a solution. Now, back at MIT, he started to build it on a bootleg basis.

"Woods Hole, in the wonderful personae of Henry Bigelow, the director, and Columbus Iselin, were intrigued with the first crude model, giving me the opportunity to sail on a number of cruises in late 1936 and early 1937 to test the gadget, many of which were disappointing. I once went shamefacedly to Iselin and Bigelow and apologized for taking up so much valuable ship time. Both encouraged me to go on. Bigelow said, "Not to worry, it's just the perversity of inanimate objects."

"By the summer of 1937," Spilhaus recalls, "I had a workable instrument. It recorded temperature against pressure, but the word barothermograph was already in widespread use for a meteorological station instrument that recorded atmospheric temperature and barometric pressure on a chart. So I used the Greek root for depth "bathos," and coined the word bathythermograph—universally known as the BT later on."

While the initial application of the instrument was for biologists and oceanographers and those in the fisheries, it was Iselin who saw another sphere of application for the instrument—the detection of submarines in conjunction with sonar. He arranged for sonar/BT tests aboard the *Atlantis* from August 23 to 31, 1937, in conjunction with the U.S.S. *Semmes* and a Navy submarine out of New London, Connecticut.

"At that early stage, the detection of submarines was a hit-and-miss proposition," Spilhaus remembers, "and the sound engineers were attributing failures to deficiencies in the sonar equipment, whereas we were trying to convince them that it was the thermal layering of the oceans and the lens-like bending of the sound waves by the thermocline that was responsible for the misses."

The skipper of the *Semmes* noticed that many echoes were missed in the afternoon, which he attributed to his sonar operators' sleepiness after a big lunch. The real cause was the heating up of the shallow surface layer by the daytime sunshine. Along about this time, the U.S. Navy became aware that Spilhaus was not an American citizen, but an "alien." "I came out with the old gag," he states. 'Yes, I know foreigners are aliens, but I'm British.'"

After the *Semmes* tests, the Navy asked Spilhaus to arrange for the manufacture of two bathythermographs. He was by this time head of the Department of Meteorology at New York University. With uses by biologists, oceanographers, and fishermen in mind, as well as the Navy, he approached H.J.W. Fay, then Vice-President of the Submarine Signal Company of Boston.

"Every Oceanographer will be wanting one," Spilhaus recalls saying in making his sales pitch. Fays' laconic reply was, "Yes, all six of them."

Fay nevertheless agreed to commercialize the bathythermograph. The Submarine Signal Company filed for a patent in Spilhaus' name, but assigned to them, on August 10, 1938.

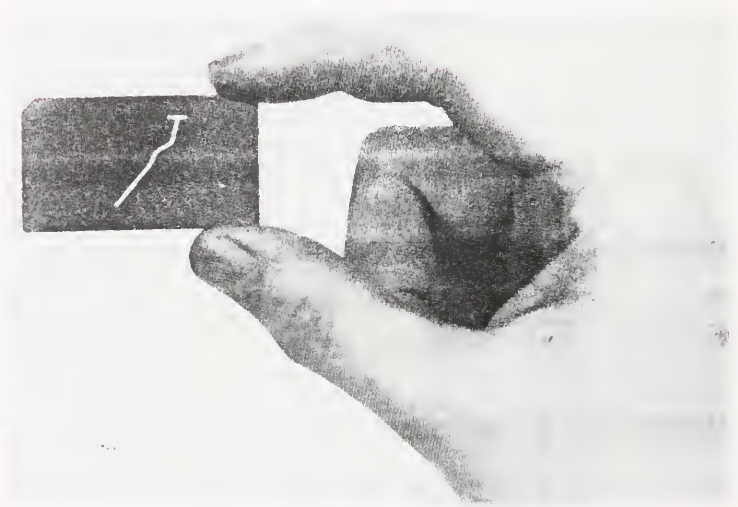
From the very beginning of BT development, there had been a small problem with the glass slides used to obtain the graph drawn by the stylus. Spilhaus used smoked glass microscope slides, easily obtainable and easily smoked. However, the smoke washed off with seawater. The solution was to rub a forefinger along the side of one's nose and then onto the slide before smoking it. Once in production, Iselin suggested another oil, used at that time to lubricate valve mechanisms on the old Nansen bottles. It was skunk oil, easily obtainable in Woods Hole where skunks live in great numbers. Later, the slides were covered with a monomolecular coating of gold that was evaporated onto them. To this day, Spilhaus is convinced, nose grease and skunk oil are as good as gold.

Thanks for the Memo, 'W.C.'

On September 3, 1939, Britain and France declared war on Germany. Within a short period there were many sinkings of British ships by German U-boats in the approaches to the Straits of Gibraltar, and elsewhere.

Iselin and Spilhaus believed that the Germans were hiding beneath the sharp thermocline that existed between the warm, less saline, low density surface layers flowing into the Mediterranean, and the dense cooler saline water flowing out underneath through the Straits. This sharp difference in density refracted the sonar beams of the primitive British Asdic (Anti-Submarine Detection Investigating Committee) sonar, allowing the U-boats to operate in relative safety.

With the United States still neutral in the war, Spilhaus, with the backing of Iselin despite the risk to Woods Hole's Navy connection, passed along a memorandum and the latest drawings of the BT to a British Navy captain in a New York apartment. The memorandum



Example of glass slide.

was unsigned, undated, and unaddressed, but clearly pointed toward the British Admiralty. "I did receive, much later, a 'thank you' by circuitous paths [Iselin told Spilhaus the message came to Woods Hole] from the First Lord of the Admiralty himself, signed simply "W. C.," but this only came after the British had asked President Roosevelt to send them a quantity of about 200 bathythermographs."

In October of 1940, Iselin informed Spilhaus that Woods Hole, dissatisfied with the slowness of the Submarine Signal Company in manufacturing the BT, would build "a bathythermograph of your newest design in our shop where we can work night and day." The project was turned over to Maurice Ewing and his student Allyn Vine, the scientist who later played a principal role in the design of the deep-sea submersible *Alvin*.

"They streamlined the whole apparatus into a projectile shape with a heavy weight at the nose, fins protecting the coiled temperature bulb at the tail, and made it so that it could fall rapidly through seawater," Spilhaus says. "They also designed a special winch with a thin wire which ran freely on the descent. On reaching the desired depth, the BT was retrieved by engaging the clutch on the winch and pulling it up to the surface. This made the bathythermograph highly practical for the Navy's uses, as it could be used from destroyers at convoy speeds."

"In addition to these modifications," Spilhaus remarks, "Vine made a fundamental improvement by compensating for the difference in temperature between the water surrounding the Bourdon tube [a pressure-sensing element] inside the body and the sea temperature around the outside capillary tube which formed the bulb of the Bourdon tube thermometer. He compensated for this difference in temperature by putting a reverse response bimetallic coil between the end of the Bourdon tube and the stylus."

About 200 BTs were made in WHOI's shop. Spilhaus, meanwhile, was training more than a thousand Navy and Air Corps cadets to be meteorologists at the then University Heights campus of NYU. In 1943, by special act of Congress, Spilhaus became a temporary officer in the Army Air Corps (although still a British citizen).

From November 1944 until September 1945, he ran about 90 weather "stations" in northern China. Landing behind Japanese lines, Spilhaus lived in the caves of Yenan, Shensi Province, northern China, headquarters at that time for Mao Tse-Tung, who lived a scant three caves away. They sometimes ate together. Spilhaus' weather reports were critical for U.S. bombers out of Guam and Saipan that were raiding Japan. While still in uniform at the close of the war, Spilhaus became a U.S. citizen.

We have land grant colleges, "Why not Sea Grant Colleges?"

Minnesota Years

After the war, Spilhaus became Director of Research at NYU, and, because of his knowledge of German, played a part in bringing German rocket scientists to the United States to participate in the Vanguard Program. In 1949 he left NYU to become Dean of the Institute of Technology at the University of Minnesota, a position that would occupy the next 18 years. The bathythermograph during these years came into routine use around the world for peaceful purposes, the Submarine Signal Company became a division of Raytheon, and the expendable BT (XBT) came into use.

In 1951, he took on the job of Scientific Director of Weapons Effects for two Nevada Atomic Tests; in 1952, he accepted a position as consultant to the Armed Forces Special Weapons Project under the Defense Department. Later that year he was awarded the Exceptional Civilian Service Medal by the U.S. Air Force.

While at Minnesota, Spilhaus launched a number of projects, one of which was the creation of a weekly comic strip called "Our New Age." The idea for the science comic strip, which was syndicated in more than 100 newspapers around the world, came from a meeting Spilhaus attended while U.S. Ambassador to UNESCO (the United Nations Educational, Scientific, and Cultural Organization) in Paris. The Indian delegate attacked the United States for exporting brainless comic strips to India's new literates, a term meaning older people just learning to read English. Why not write a comic strip with some substance?

Spilhaus also took heat from his faculty at Minnesota, some of whom thought it was below the dignity of a Dean to write a comic strip, even a factual, science-oriented one. After being berated one afternoon by a professor, Spilhaus asked, "How many students do you have in your class?"

"About 25," the professor replied. "On Sundays, I have more than a million," the Dean remarked.

The Sea Grant Idea

In September of 1963, Spilhaus made another great contribution to marine science by calling for the establishment of Sea Grant Colleges. The call came in a keynote address to the American Fisheries Society meeting in Minneapolis. Pointing out the then-dreadful state of ocean fishing by the United States, the Dean suggested that another approach—other than controls—be taken to protect American fisheries:

> *"Why, to promote the relationship between academic, state, federal, and industrial institutions in fisheries, do we not do what wise men have done for the better cultivation of the land a century ago. Why not have Sea Grant Colleges?"*

About two years earlier, in March of 1961, President John F.

Kennedy had told the U.S. Senate that "Knowledge and understanding of the oceans promise to assume greater and greater importance in the future. This is not a one-year program (referring to his request to increase funding for oceanographic research from about $60 million to nearly $100 million in 1962)—or even a 10-year program. It is the first step in a continuing effort to acquire and apply the information about a part of the world that will ultimately determine conditions of life in the rest of the world. The opportunities are there. A vigorous program will capture these opportunities." Spilhaus offered a plan that would fulfill Kennedy's dream.

In his pamphlet *Creating the College of the Sea*, John Miloy writes: "Spilhaus has been called a 'flywheel of the machine of American science' and its 'incurable optimist.' By his own definition he is a 'pragmatic idealist: an innovator of the living' and a 'committed futurist.' All this suggests that 'this remarkable scientist has an exceptional gift for pulling into his mind an encyclopedia of assorted facts and synthesizing from them better approaches by which science may serve humanity.' The Sea Grant idea was typical of this innovative, imaginative engineer and scientist from South Africa."

The Sea Grant concept took root at the University of Rhode Island under the hand of John A. Knauss, the Dean of the Graduate School of Oceanography. Senator Claiborne Pell of Rhode Island, and Representative Paul Rogers of Florida steered the necessary legislation through Congress in 1966.

The 1960s saw some major changes in Spilhaus' life. He got a divorce from his first wife and in 1964 remarried. His second wife was Gail Thompson. In 1961, President Kennedy appointed him United States Commissioner to the Seattle World's Fair (President Eisenhower had appointed him U.S. Representative to the Executive Board of UNESCO in 1954, and President Johnson would appoint him a member of the National Science Board from 1966 to 1972).

Spilhaus left the University of Minnesota in 1966, and became President of the Franklin Institute in Philadelphia in 1967, a position he held until 1969. The 1970s would see Spilhaus become President of the American Association for the Advancement of Science, a Fellow at the Woodrow Wilson International Center for Scholars, and a consultant to the National Oceanic and Atmospheric Administration. Along the way, he collected 11 honorary doctorates, became a member of the Cosmos Club in Washington, D.C., and the Explorers Club, in New York, N.Y., and received several awards, including the French Legion of Merit and Sweden's Berzelius medal. In 1978, his second wife, Gail, died. In 1979, he married his third wife, Kathleen.

"I've often found the first practical appearance of an idea is in a toy."

As if all this activity has not been enough, Spilhaus is also a sculptor, several of his pieces gracing various cities across the country. He is probably best known for his "triangle of the sun" sculpture, which encompasses the entire plaza in front of the McGraw-Hill Building on the Avenue of the Americas in New York City. In fact, Spilhaus has been an advocate of building experimental cities in much the same way as the Japanese have suggested (see *Oceanus*, Vol. 29, No. 3, pp. 52–62).

Playing With Ideas From Toys

What does this man do to relax? He collects toys—antique mechanical toys. Since 1965, he has collected some 4,000 of these—all with moving parts. The hobby has forced him to build four rooms onto his comfortable 1763 white stuccoed house in the rolling, horse country of northern Virginia—just 2.3 miles from the flashing light in the center of Middleburg, as visitors seeking directions are often advised. The toy rooms have become a museum; indeed, the Smithsonian sometimes calls to see if they can arrange a tour. There are American, Japanese, and German tin toys, cast-iron toys, tin trains, tractors, musical toys, plus the mechanical toys of Fernand Martin, and the papier-mâché figures of Ernest Decamps, both 19th Century French toy masters.

"I enjoy toys," Spilhaus says. "They're simple, yet ingenious. They're also prototypes. I've often found the first practical appearance of an idea is in a toy. They're the forerunners of practical inventions. All my toys do something."

And how much might one be worth? "I once traded one for a nearly-new Lincoln Continental. The guy who got the toy, got the better of the bargain. The toy will be around a lot longer than the Lincoln."

Spilhaus also designs toys—one of his latest efforts being a jigsaw puzzle of the Earth's surface. The main pieces are cut along the actual tectonic plates of oceans and continents and can be arranged in at least 150 configurations, including the original super-continent of Pangea of 300 million years ago.

What next? Spilly's already pragmatically turning an idea over in his gray-haired attic where the child in him has always pretended.

Paul R. Ryan is Editor of Oceanus, published by the Woods Hole Oceanographic Institution.

letters

To the Editor:

In *Oceanus* magazine, Volume 30, Number 2, Summer 1987, there is an article entitled "Marine Biological Research in the Galápagos: Past, Present, and Future."

In the second paragraph under the heading "Millionaires" (page 37 of this issue) regarding private expeditions on yachts, it is written "The Vanderbilt family enthusiastically partook of this fashion. In the 1920s and 30s, the collection of Galápagos species at the Centerport, New York, Vanderbilt Museum grew, thanks to such activities as the George Vanderbilt South Pacific Expedition of 1937."

The Vanderbilt Museum, in Centerport, New York, is the former summer home of William K. Vanderbilt II. On the Museum grounds there is a Marine Museum (also referred to as the "Hall of Fishes"), an area of zoological dioramas called the "Habitat," and some rooms within the Mansion which contain birds and invertebrates. The wet collections of fishes and invertebrates, including those from the Galápagos Islands, were collected by William K. Vanderbilt II. There is a seven volume set, *Bulletin of The Vanderbilt Marine Museum*, which was printed on the marine collections of William K. Vanderbilt II and has been given to marine research institutions, and museum and university libraries around the world.

William K. Vanderbilt II went to the Galápagos Islands in 1926 and in 1928 on his yacht the *Ara* to collect marine specimens for his private Marine Museum in Centerport, New York. There is a motion picture film which has since been transferred to video of the 1926 expedition. There are also photo albums in our archives of both expeditions. William K. Vanderbilt II also wrote a book entitled "To Galápagos on the *Ara*" complete with color plates made from the watercolor paintings of specimens by the artist William Belanske.

I would like to make it clear that the extensive private marine collections housed at the Vanderbilt Museum in Centerport, New York, are those of William K. Vanderbilt II. The Vanderbilt Museum does not, and never has to my knowledge, contained any zoological collections collected by George Vanderbilt.

Christina H. Hamm
Collections Manager
The Vanderbilt Museum
Centerport, N.Y.

To the Editor:

The article by Tim Hawley in your Fall 1987 issue about our new Institute is very much appreciated. It serves to provide needed visibility to the Institute in its early stages of development.

For the most, the article is accurate and projects the essence of the Institute's program. However, there are two errors I need to bring to your attention.

First, Figure 1 suggests that the University Corporation for Atmospheric Research (UCAR) operates and manages 55 other research institutions in addition to The Institute for Naval Oceanography (INO) and the National Center for Atmospheric Research (NCAR). That is incorrect. I think Tim was confused with the fact that UCAR is a consortium of 57 universities, 55 American and 2 Canadian. UCAR operates and manages NCAR, INO, and a few other activities.

Second, the caption of Figure 2 incorrectly lists NRL as the National Research Laboratory; it is the Naval Research Laboratory.

Finally, there is a need for clarification of a point in the first paragraph of page 55, where it is suggested that ocean prediction may be more feasible than (atmospheric) weather prediction due to the relative smallness of ocean eddies. That attribute is actually a liability to ocean prediction because, as a consequence, more eddies can fit into an ocean basin; and, thus, there are more variable ocean features to track at any instant, and with higher spatial resolution, than would otherwise be the case. (Similarly, numerical ocean models need greater spatial resolution; and, thus, the demands on computational speed and computer memory size are high.) However, the relatively slow movement and long existence of ocean eddies are offsetting of the small size and can be exploited in observing and modeling the ocean. The efforts to explore the feasibility of ocean prediction, and to develop ocean prediction capability, are made easier because of the technical precedents and progress established in atmospheric weather prediction.

Christopher N. K. Mooers, Director
Institute for Naval Oceanography
Bay St. Louis, Mississippi

To the Editor:

Your summer issue on the Galápagos Marine Resources Reserve is fantastic. I recently worked at the Darwin Station for a year, and it does my heart good to see the marine environment of those islands receive proper attention.

Jerry Emory
Oakland, California

To the Editor:

In our recent article in *Oceanus* (Vol. 30 (3):69–77), we [Frank Lowenstein—co-author] erroneously noted that "Dogwhelks [*Nucella lapillus*] feed on algae and other microscopic organisms coating rocks and other hard substrates in the intertidal zone." *Nucella* is a carnivore that principally feeds on barnacles and mussels. These two prey organisms, in turn, are filter feeders taking up algae from the near-surface water column. There are at least two potential routes of TBT exposure for *Nucella*. One is through the food chain, the other is that TBT could be absorbed through the gastropod's foot as it crawls over the surface film of epiphytes which have been repeatedly exposed to high TBT concentrations from the surface microlayer. We are indebted to Peter Gibbs of the Marine Biological Association Laboratory, Citadel Hill, Plymouth, England, for bringing this to our attention.

Michael A. Champ
Senior Scientist
Science Applications International Corporation
Rockville, Maryland

To The Editor:

I want to express my interest and fascination at Diane K. Stoecker's article, "Photosynthesis Found in Some Single-Cell Marine Animals" found in the Fall 1987 issue. As a marine aquarist, without a formal education in marine biology, it is difficult to find such enlightening reading. Ms. Stoecker's ability to turn a complex subject such as the interrelationships of microzooplankton, into an understandable lesson for the novice, is truely appreciated.

I have visited many of the libraries in this area and have found that articles and books dealing with various disciplines within marine biology are either too simple to be of much valve, or written in a dialogue which is incomprehensible to a novice such as myself.

Thomas I. Parsons
Devon, Pennsylvania

To The Editor:

The article "Submersibles for Scientists" by L. C. Hanson and S. A. Earle is a very narrow view of undersea science in the U.S. today. A reader unfamiliar with submersibles would think vehicles like the *Johnson-Sea-Links* I & II are limited to surveying shipwrecks (i.e. USS *Monitor*) or salvaging space shuttle debris (i.e. STS *Challenger*). The authors give very little consideration to the scientific accomplishments of the several other vehicles presently available to the science community.

A great deal of submersible vehicle time is available to scientists in the U.S. through NOAA's Office of Undersea Research (OUR) and their regional National Undersea Research Programs (NURP). Vehicles like *Alvin*, *Makali'* I, *Mermaid*, *Johnson-Sea-Link* I & II, *Delta*, and *Pisces* V perform hundreds of dives each year, with hundreds of scientists, who produce a wealth of new information. *Johnson-Sea-Link* I & II and *Delta* alone, during the last two years, have conducted 444 dives in support of NURP at the University of Connecticut. OUR and the regional NURPs have conducted, since 1971, in excess of 2,500 submersible dives, placing more than 1,500 scientists safely underwater, in 12 different vehicles. Research and test/evaluation dives have also been conducted utilizing very sophisticated, as well as low-cost, ROVs. One hundred ninety-two peer reviewed journal publications, and 545 technical reports on diverse topics are the result of these efforts. These figures represent a considerable amount of scientific productivity. Diving effort is supported through a system which requests proposals from the scientific community and selects only *the very best* science.

The science accomplished in various vehicles is not *generally* limited by the vehicle itself. It is the ingenuity and imagination of the scientists and engineers who design the sensors, samplers, and ancillary apparatus to accomplish the work that limits the results. Certainly, some vehicles have more maneuverability than others, or are better suited to mid-water operations. We find that pre-mission exchanges between the scientist-users and the operators/engineers of the submersible are extremely productive for designing and building the right tool for the anticipated job. After all, many of the planned dives will be examining a phenomenon for the very first time and off-the-shelf samplers are often not available or appropriate.

The article was very slanted toward the use of one-person vehicles. As far as we can ascertain, only 5 *scientific* diving programs have been conducted with one-person vehicles (1 with WASP and 4 with *Deep Rover*). Since so few science dives have been conducted, and so few scientists have used these vehicles, one can hardly point to these as examples of the cutting edge of undersea research.

We would like the opportunity, in a future issue of *Oceanus*, to present an overview of undersea research in the U.S. A review of the history, accomplishments, present status, and future directions of undersea research and exploration would make interesting reading.

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Alexander Malahoff, Director
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EDITOR's NOTE: The Hanson/Earle article made no claim to being a comprehensive view of undersea science in the U.S.—I refer the authors to *Oceanus*, Vol. 25, No. 1, pp. 18–29, "Submersibles: Past, Present, and Future" by Eugene Allmendinger—but rather was inspired by a NOAA initiative to "examine new directions for undersea research." While the focus of the article is on one-man vehicles, considerable space was devoted to the activities of larger manned submersibles. As for the scientific accomplishments of other vehicles, I refer you to our summer issue (Vol. 30, No. 2, p. 69) and the article on the *Johnson Sealink I*'s activity in the Galápagos Islands.

AUTHORS' REPLY: We are puzzled by the comments submitted by four representatives of the NOAA/NURP Program in response to our article "Submersibles for Scientists." Both of us are well-known for our fondness for submarines and ROVs of all sorts, and our long-standing efforts to encourage cooperation and support for ocean research, no matter who is doing it, or what tools are being used.

The letter suggests that we presented a narrow view of "undersea science in the U.S. today." Herein is the puzzle. No pretense was made that we were offering a compendium of undersea science, or a comprehensive review of submersibles for scientists. Working with the editors of *Oceanus*, we focused the article on new developments in small, portable manned and robotic systems. Our working title was: "New Tools for Marine Scientists." The editors selected photographs they believed to be appropriate from dozens that were submitted. Those who read the article will discover that, after providing background information on various vehicles currently in operation, we describe some technology primarily developed and used by industry in the past decade that the scientific community is just beginning to discover and adapt in creative ways for ocean research and exploration.

The letter suggests that the article was "very slanted toward the use of one-person vehicles." While it is true that 8 of the 32 paragraphs included describe the new small, portable systems such as *Wasp* and *Deep Rover*, and the uses scientists are making of them, this is, after all, what the article was supposed to be about. Nine paragraphs describe other manned subs and six relate to ROVs. The fine history and performance of vehicles supported by the NOAA/NURP Program are well known and widely admired. Not so well known are the opportunities that await the application of the small manned and robotic systems that we described.

Those who read the article will realize that it originated as an outgrowth of a workshop called together by the Center for Ocean Management Studies at the University of Rhode Island. At that meeting (attended by Dr. Cooper and Dr. Hulbert), an effort was made to focus the attention of the marine community on advances being made in low-cost ROVs and submersibles and the scientific opportunities that await those who can make use of them. It encouraged various funding sources (NSF, ONR, NOAA/NURP) to jointly support projects and the users to cooperate in applying these new systems. A Newsletter, *InSitu News* (partially sponsored by NOAA/NURP) has been established to continue this cooperative spirit. Any increased interest in and use of underwater vehicles is an advance for the entire community.

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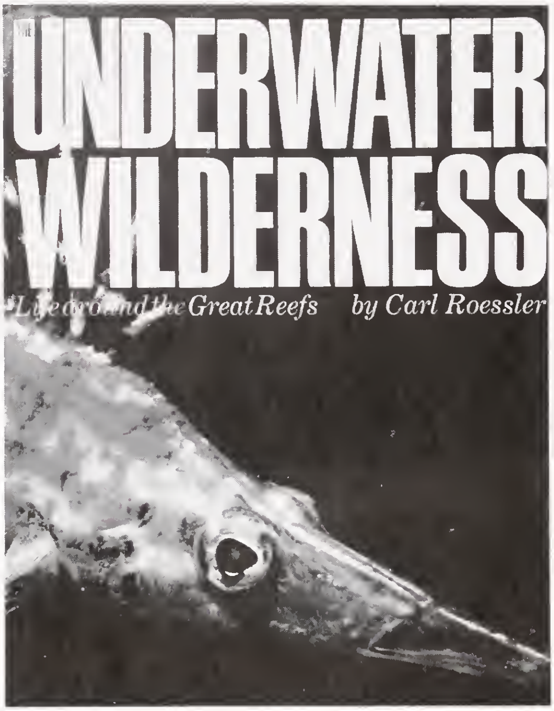
University of Rhode Island

Sylvia A. Earle
Research Biologist, California Academy of Sciences
Vice-President, Deep Ocean Engineering, Inc.

book reviews



The Underwater Wilderness: Life Around the Great Reefs **by Carl Roessler. 1987. McGraw-Hill Book Company, New York, NY. 320 pp. $29.95.**

A large-sized book (9" × 12") full of underwater photographs, *Underwater Wilderness* is typical of the kind one finds on coffee tables. It is clearly aimed at the general public who have no background in marine biology, and is a fine presentation and overview of the variety of fishes and invertebrates found on coral reefs. The book presents descriptions and examples of fishes and invertebrates which are common on many reefs throughout the world. Written mostly from the author's personal viewpoints and experiences, it is similar to articles found in SCUBA diving magazines. The theme throughout the book is very strong—the underwater wilderness is in great peril. The term "underwater wilderness" was chosen by the author, Carl Roessler, to convey the image of a place where the natural community of plants and animals flourish without the destructive influence of mankind.

The first section of the book reviews very basic coral reef natural history. The topics covered include how atolls are formed, cooperation and aggression between species, cleaning symbiosis, parasitism, color patterns and nocturnal habitats. All of these topics have been covered in dozens of popular articles by many authors and there is no new information presented in this book.

The second section of the book is the author's personal travelogue of diving in the world's most famous coral reefs, and would be particularly interesting for people planning to dive for the first time in these places. The regions covered include the Caribbean, Hawaii, Baja California, Galápagos, the tropical South Pacific, Australia, the Coral Sea, the Mediterranean and the Red Sea.

The key selling point for a book of this type is the collection of underwater photographs. The collection in this book is very good, but not outstanding. An experienced amateur diver or marine biologist will find many good pictures, but none that are unique or of very rare species. Many of the pictures are of animals that are commonly photographed and published. Most of the photographs are crystal clear, but some of the ones chosen for enlargement are fuzzy and not well composed. A few have been enlarged to fill the double page and some of these are not in sharp focus and the page's center crease is a serious detraction. But in general, the photographs are good and correctly identified.

This book is a fine introduction to the art of watching animals underwater. It will surely inspire some youngsters to study marine biology. Hopefully, it will also serve as a valuable source document to educate politicians on the beauty and fragility of the animals under the sea.

Phillip S. Lobel
Assistant Scientist
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Books Received

Biological Sciences

A Functional Biology of Echinoderms by John Lawrence. 1987. The Johns Hopkins University Press, Baltimore, MD 21211. 340 pp. $56.50.

Animals Without Backbones, Third Edition by Ralph Buchsbaum, Mildred Buchsbaum, John Pearse, and Vicki Pearse. 1987. The University of Chicago Press, Chicago, IL 60637. 572 pp. + x. Cloth $25.00, Paper $17.00.

Islands by H. W. Menard. 1987. W. H. Freeman and Company, New York, NY 10010. 230 pp. $32.95.

Fishes of the North-eastern Atlantic and the Mediterranean, Volume III edited by P. J. P. Whitehead, M.-L. Bauchot, J.-C. Hureau, J. Nielsen, and E. Tortonese. 1986. UNESCO, Paris; distributed in the United States by UNIPUB, Lanham, MD 20706. pp. 1015–1473. $45.00.

Observing Marine Invertebrates: Drawings from the Laboratory by Donald P. Abbott, edited by Galen Howard Hilgard. 1987. Stanford University Press, Stanford, CA 94305. 380 pp. + xxiv. $29.50.

Sharks edited by Dr. John Stevens. 1987. Facts On File Publications, New York, NY 10016. 240 pp. $29.95.

Chemistry

Petroleum Hydrocarbons by Alexander A. Petrov. 1987. Springer-Verlag, Secaucus, NJ 07094. 255 pp. + ix. $95.00.

Diving

The Silent World by Jacques Cousteau, with new introduction. 1987. Nick Lyons Books, New York, NY 10010. 250 pp. + xii. $12.95.

Underwater Photography: Sport Diver's 1987 Annual and Directory edited by Tricia Reilly. 1987. Sport Diver Publications, Washington, DC 20007. 79 pp. $7.95.

Earth Sciences

A View of the Sea: A Discussion between a Chief Engineer and an Oceanographer about the Machinery of the Ocean Circulation by Henry Stommel. 1987. Princeton University Press, Princeton, New Jersey 08540. 161 pp. $19.95.

Baroclinic Processes on Continental Shelves edited by Christopher N. K. Mooers. 1986. Coastal and Estuarine Sciences Volume 3, American Geophysical Union, Washington, DC 20009. 130 pp. + vii. $25.00.

Biolaminated Deposits by Gisela Gerdes and Wolfgang E. Krumbein. 1987. Lecture Notes in Earth Sciences Volume 9, Springer-Verlag, Secaucus, NJ 07094. 183 pp. + ix. $24.00.

Geotectonic Evolution of China by Ren Jishun, Jiang Chunfa, Zhang Zhengkun and Qin Deyu. 1987. Springer-Verlag, Secaucus, NJ 07094. 203 pp. + x and plates. $69.00.

Mesozoic and Cenozoic Oceans edited by Kenneth J. Hsü. 1986. Geodynamics Series Volume 15, American Geophysical Union, Washington, DC 20009. 153 pp. + xi. $22.00.

Modern Sedimentation in the Coastal and Nearshore Zones of China edited by Ren Mei-e. 1986. China Ocean Press, Beijing, China; distributed by Springer-Verlag, Secaucus, NJ 07094. 466 pp. + vi. $136.00.

Observation of the Continental Crust through Drilling II edited by H.-J. Behr, F. G. Stenhli, and H. Vidal. 1987. Exploration of the Deep Continental Crust, Springer-Verlag, Secaucus, NJ 07094. 229 pp. + viii. $46.50.

Quaternary coastal geology of West Africa and South America: Papers prepared for the INQUA-ASEQUA Symposium in Dakar, April 1986. 1987. Unesco reports in marine science 43. UNESCO, Paris; distributed in the United States by UNIPUB, Lanham, MD 20706. 145 pp. Price unavailable.

Nautical Quarterly: Number 39, Autumn 1987. Nautical Quarterly Co., Essex, CT 06426. 120 pp. $16.00.

Speciation of Metals in Water, Sediment and Soil Systems edited by Lars Landner. 1987. Lecture Notes in Earth Sciences Volume 11, Springer-Verlag, Secaucus, NJ 07094. 189 pp. + v. $21.70.

Time series of ocean measurements, Volume 3—1986. Intergovernmental Oceanographic Commission Technical Series 31. UNESCO, Paris; distributed in the United States by UNIPUB, Lanham, MD 20706. 62 pp. $7.50.

The Zechstein Facies in Europe edited by Tadeusz M. Peryt. 1987. Lecture Notes in Earth Sciences Volume 10, Springer-Verlag, Secaucus, NJ 07094. 272 pp. $49.50.

Environmental Sciences

Annual Report of the Executive Director 1985, by the United Nations Environment Programme. 1986. UNEP, Nairobi; distributed in the United States by UNIPUB, Lanham, MD 20706. 246 pp. $10.00.

Fate and Effects of Oil in Marine Ecosystems edited by J. Kuiper and W. J. Van Den Brink. 1987. Martinus Nijhoff Publishers, Dordrecht, The Netherlands. 338 pp. $195.00.

Silent Spring by Rachel Carson. 1962. 25th Anniversary Edition, 1987 by Houghton Mifflin Co., Boston, MA 02108. 368 pp. + xiv. $17.95.

The Solomon Islands Project: A Long-term Study of Health, Human Biology, and Culture Change edited by Jonathan Scott Freidlaender. 1987. Oxford University Press, New York, NY 10016. 409 pp. + xii. $90.00.

The State of the Environment: Environment and Health 1986 by the United Nations Environment Programme. 1987. UNEP, Nairobi; distributed in the United States by UNIPUB, Lanham, MD 20706. 83 pp. + ix. $7.50.

The Toxic Cloud: The Poisoning of America's Air by Michael H. Brown. 1987. Harper & Row, New York, NY 10022. 307 pp. $18.95.

Field Guides

A Field Guide to the Atlantic Seashore by Kenneth L. Gosner. 1978. New cover, 1987. The Peterson Field Guide Series Number 24, Houghton Mifflin Co., Boston, MA 02108. 329 pp. + xvi. $12.95.

Alaska Mammals edited by Jim Rearden. Alaska Geographic Vol. 8, No. 2. 1981. The Alaska Geographic Society, Anchorage, Alaska 99509. 184 pp. $12.95.

Alaska's Saltwater Fishes and Other Sea Life by Doyne W. Kessler. 1985. Alaska Northwest Publishing Co., Anchorage, Alaska 99509. 358 pp. $19.95.

An Underwater Guide to Hawai'i by Ann Fielding and Ed Robinson. 1987. University of Hawaii Press, Honolulu, HI 96822. 156 pp. $14.95.

Fisheries

Design of Small Fishing Vessels edited by John Fyson. 1985. The Food and Agriculture Organization of the United Nations, Rome; distributed in the United States by UNIPUB, Lanham, MD 20706. 320 pp. $50.00.

Occupational and geographical mobility in and out of Thai fisheries by Theodore Panayotou and Donna Panayotou. 1986. The Food and Agriculture Organization of the United Nations, Rome; distributed in the United States by UNIPUB, Lanham, MD 20706. 77 pp. $7.50.

General Reading

Coasting by Jonathan Raban. 1987. Simon and Schuster, New York, NY 10020. 302 pp. $17.95.

Dictionary of Military and Naval Quotations by Robert Debs Heinl, Jr. 1966. Naval Institute Press, Annapolis, MD 21402. 367 pp. + xl. $21.95.

The Dolphin Doctor by Sam Ridgway. 1987. Yankee Books, Dublin, NH 03444. 159 pp. $12.95.

Extraterrestrials: Science and Alien Intelligence edited by Edward Regis, Jr. 1987. Cambridge University Press, New Rochelle, NY 10801. 278 pp. + x. $12.95.

The Mariner's Pocket Companion: 1988 Calendar by Wallace E. Tobin III. 1971. Naval Institute Press, Annapolis, MD 21402. 101 pp. + calendar. $6.95.

Mountain Light: In Search of the Dynamic Landscape by Galen Rowell. 1986. Sierra Club Books, San Francisco, CA 94109. 224 pp. $19.95.

The River That Flows Uphill: A Journey from the Big Bang to the Big Brain by William H. Calvin. 1986. 528 pp. + xiv. $12.95.

Steichen at War by Christopher Phillips. 1981. Harry N. Abrams, Inc., New York, NY 256 pp. $40.00.

"The Navy Needs You!" U.S. Navy Poster Art of the Twentieth Century: U.S. Naval Institute 1988 Engagement Calendar. 1987. Naval Institute Press, Annapolis, MD 21402. $9.95.

History

Between the Devil and the Deep Blue Sea: Merchant Seamen, Pirates, and the Anglo-American Maritime World, 1700–1750 by Marcus Rediker. 1987. Cambridge University Press, New Rochelle, NY 10801. 322 pp. + xv. $24.95.

The Development of a Modern Navy: French Naval Policy 1871–1904 by Theodore Ropp, edited by Stephen S. Roberts. 1987. Naval Institute Press, Annapolis, MD 21402. 439 pp. + xi. $28.95.

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This Night Lives On: New Thoughts, Theories, and Revelations About the Titanic by Walter Lord. 1986. William Morrow and Company, Inc. New York, NY 10016. 272 pp. $15.95.

Raiders & Rebels: The Golden Age of Piracy by Frank Sherry. 1986. Quill/William Morrow, New York, NY 10016. 399 pp. $9.95.

Marine Policy

The Antarctic Treaty regime: Law, Environment and Resources edited by Gillian D. Triggs. 1987. Studies in Polar Research, Cambridge University Press, New Rochelle, NY 10801. 237 pp. + xxi. $54.50.

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Living with the Lake Erie Shore by Charles H. Carter, William J. Neal, William Haras, and Orrin Pilkey, Jr. 1987. Duke University Press, Durham, NC 27708. 263 pp. + xiii. $12.95, paper.

Ocean Yearbook 6 edited by Elisabeth Mann Borgese and Norton Ginsburg. 1986. The University of Chicago Press, Chicago, IL 60637. 686 pp. + ix. $49.00.

Review of the Protected Areas System in Oceania Prepared by the International Union for Conservation of Nature and Natural Resources, Commission on National Parks and Protected Areas, in collaboration with the United Nations Environment Programme. 1986. IUCN, Gland, Switzerland; distributed in the United States by UNIPUB, Lanham, MD 20706. 239 pp. $20.00.

State of the World 1987 edited by Linda Starke. 1987. Worldwatch Institute, Washington, DC 20036. 268 pp. + xvii. $9.95.

The Status of the North Sea Environment: Reasons for Concern, Proceedings of the 2nd North Sea Seminar '86, Volume 1 edited by E. Hey and G. Peet. 1986. Werkgroep Noordzee, Amsterdam; distributed in the United States by UNIPUB, Lanham, MD 20706. 54 pp. (Vol. 1 and 2) DFL 75.

The Status of the North Sea Environment: Reasons for Concern, Proceedings of the 2nd North Sea Seminar '86, Volume 2 edited by G. Peet. 1987. Werkgroep Noordzee, Amsterdam; distributed in the United States by UNIPUB, Lanham, MD 20706. 352 pp. (Vol. 1 and 2) DFL 75.

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Introduction to the Physics and Techniques of Remote Sensing by Charles Elachi. 1987. John Wiley & Sons, New York, NY 10158. 413 pp. + xvii. $44.95.

Nonlinear diffusive waves by P. L. Sachdev. 1987. Cambridge University Press, New Rochelle, NY 10801. 246 pp. + vii. $49.50.

Physical Oceanography of the Eastern Mediterranean (POEM): Initial Results 1987. Unesco reports in marine science Number 44, Unesco, Paris, France. 92 pp. + vi. Price Unavailable.

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Knowing Everything About Nothing: Specialization and change in research careers by John Ziman. 1987. Cambridge University Press, New Rochelle, NY 10801. 196 pp. + xvii. $29.95.

Stet! Tricks of the Trade for Writers and Editors edited by Bruce O. Boston. 1986. Editorial Experts, Inc., Alexandria, VA 22312. 310 pp. + xiv. $15.95.

Ships and Sailing

Chapman Piloting: Seamanship & Small Boat Handling by Elbert S. Maloney. 58th Edition, 1987. Hearst Marine Books, New York, NY 10016. 652 pp. $24.95.

Mariner's Atlas of the Texas Gulf Coast by A. P. Balder. 1987. Gulf Publishing Company, Houston, TX 77001. 103 pp. $37.50.

Nautical Quarterly: Number 39, Autumn 1987. Nautical Quarterly Co., Essex, CT 06426. 120 pp. $16.00.

The Porticello Shipwreck: A Mediterranean Merchant Vessel of 415–385 B.C. by Cynthia Jones Eiseman and Brunilde Sismondo Ridgway. 1987. Texas A & M University Press, College Station, TX 77843. 126 pp. $85.50.

A WORKSHOP ON INSTRUMENTATION AND MEASUREMENTS IN THE POLAR REGIONS

The San Francisco Bay region section of the Marine Technology Society will present a 2-day workshop on instrumentation and measurements in the polar regions. The workshop will feature sessions on atmospheric, oceanographic, ice, biological, and geophysical instrumentation and measurements.

The workshop will be held at the Monterey Aquarium, Monterey, California, January 27–28, 1988. Registration fee for the workshop is $100, and includes the proceedings. Persons with professional interests in the polar regions are invited to attend.

The workshop is being sponsored by the Marine Technology Society and the IEEE Oceanic Engineering Society. For more information, contact Dr. Warren Denner at:

C/O Science Applications International Corp.
205 Montecito Ave.
Monterey, CA 93940
(408) 649-5242

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- **Industry and the Oceans,**

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- **Ocean Energy,**

Vol. 22:4, Winter 1979/80.

Issues not listed here, including those published prior to 1977, are out of print. They are available on microfilm through University Microfilm International, 300 North Zeeb Road, Ann Arbor, MI 48106.

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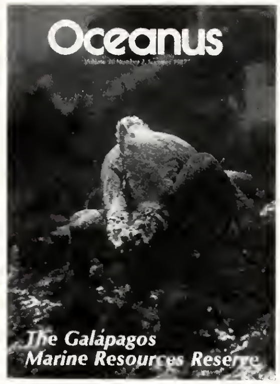
Columbus, Plastics, Sea-Level Rise, TBT

Vol. 30:3, Fall 1987—A collection of topics of current interest, including new information on Columbus' landfall, loss of coastal upland because of sea-level rise, a new generation of submersibles for science, Chernobyl fallout in the Black Sea, mass extinctions, plastics in the ocean, and the TBT dilemma.



Galápagos Marine Resources Reserve

Vol. 30:2, Summer 1987—In 1986, Ecuador declared the waters and seabed surrounding the Galápagos Islands a marine reserve. The legal, political, management, and scientific aspects are described. Includes description of 1982-83 El Niño, and historical articles on Darwin, and on the taking of whales and tortoises in the 1800s.

Japan and the Sea

Vol. 30:1, Spring 1987—The first comprehensive view of Japanese ocean science written primarily by Japanese authors. Describes how tradition and innovation combine to continue forging a strong link between Japan and the sea. Includes fishing, submersibles, SWATH vessel, recovery of uranium, ocean space, and much, much more.

Changing Climate and the Oceans

Vol. 29:4, Winter 1986/87—Forecasts of near-term climate change have challenged scientists to understand complex interactions between the atmosphere, the ocean, and the Earth. The wobbling Earth, changing sunlight, carbon dioxide, polar ice sheets, and deforestation—along with a new generation of research satellites—are described.

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- **The Titanic Revisited,**
Vol. 29:3, Fall 1986—Radioactivity of the Irish Sea, ocean architecture, more.
- **The Great Barrier Reef: Science & Management,**
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