Coastal region and small island papers 3

C A R I C O M P

CARIBBEAN CORAL REEF, SEAGRASS AND MANGROVE SITES

EDITED BY BJÖRN KJERFVE

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UNESCO, 1 rue Miollis,
75732 Paris Cedex 15, France.
fax: +33-1 45 68 58 08
e-mail: csi@unesco.org
website: http://www.unesco.org/csi

Front photo: Buck Island Reef, St. Croix. Species shown are: *Acropora palmata* (elkhorn coral); *Mulloidichthys martinicus* (yellow goatfish); and *Kyphosus secatrix* (Bermuda chub). By John Ogden

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Foreword

Nowadays the importance of coastal regions and their resources, particularly for small island developing States, hardly needs argument. The challenge lies in arriving at enduring solutions to the complex problems facing these unique areas, where considerable ecosystem services and high human population pressure coincide.

In publishing *CARICOMP – Caribbean Coral Reef, Seagrass and Mangrove Sites,* UNESCO's intent is to draw attention to a network which has been successful in monitoring the state of these three critical coastal ecosystems. The systems under study are vital to the continuing health of the biosphere and crucial for the sustainable development of coastal countries, particularly in the tropical belt.

A regional effort involving a number of Caribbean laboratories, parks and reserves, the CARICOMP project has received support for over a decade from the John D. and Catherine T. MacArthur Foundation, US National Science Foundation, US Department of State, as well as from UNESCO. The Organization's involvement, originally within the framework of its coastal marine programme, is currently being continued as part of the endeavour entitled Environment and Development in Coastal Regions and in Small Islands (CSI). Launched in 1996, CSI is designed to serve as a cooperative platform, encouraging cross-sectoral actions that assist Member States towards environmentally sound, socially equitable and culturally appropriate development in their coastal areas.

The principal objective of the CARICOMP project is to determine the productivity of the afore-mentioned ecosystems and to assess the nature and influence of land-sea interactions. In order to establish ecological baselines, the initial focus has been on less disturbed habitats. In view of the need to render explicit the societal relevance of the project and influenced by CSI's intersectoral mandate, CARICOMP has begun to address, more directly, human-environment interactions with respect to these three key ecosystems. As a result, an intersectoral workshop was recently organized, bringing social and natural scientists together to reflect upon the role of social sciences in understanding the dynamics of coastal resource use.

Recognizing the global concern about the threat to coral reefs, the Intergovernmental Oceanographic Commission is coordinating a worldwide effort to provide data on the trends in the status of these fragile ecosystems. IOC's Subcommission for the Caribbean and Adjacent Regions (IOCARIBE) will expand UNESCO's cooperation with CARICOMP by helping to make the latter's experience and expertise available to other regions of the world.

The Coastal Region and Small Island Papers series, a responsibility of the CSI platform, disseminates information to managers and stakeholders to assist in the search for adequate solutions to coastal problems. This volume is the product of many years of study and evaluation by a number of CARICOMP specialists. Under the supervision of the editor and through the diligent work of his colleagues and himself, these efforts have come together herein as a series of concise descriptive texts. Naturally recognition is given, first of all, to the institutions in the Caribbean region that have cooperated effectively in this mutually beneficial enterprise.

The publication of this sizeable document received support both from programmes within the Secretariat as well as from co-sponsors external to the Organization. In addition to IOC's support, further assistance was received, through UNESCO's Man and the Biosphere (MAB) Programme, from Germany's Ministry for Economic Co-operation and Development (BMZ) which supports the sustainable development of coastal ecosystems.

Printing and distribution were facilitated also by the co-sponsorships of the Florida Institute of Oceanography (FIO), USA, a long-standing supporter and current administrative center of CARICOMP, and of the International Institute of Tropical Forestry (IITF), Rio Piedras, Puerto Rico, of the Forest Service, United States Department of Agriculture (USDA). In particular, Drs. John C. Ogden and Dean M. Milliken (Director and Associate Director, respectively, of FIO) and Dr. Ariel E. Lugo (Director of IITF) have been instrumental in securing the cooperation of their respective institutions.

Prólogo

La importancia que tienen las regiones costeras y sus recursos, particularmente en los pequeños Estados insulares en desarrollo, es universalmente reconocida. El desafío es el de encontrar soluciones duraderas a los problemas complejos que confrontan estas áreas únicas, en las cuales convergen una cantidad de intereses considerable de servicios y funciones de los ecosistemas, así como una fuerte presión demográfica humana.

Con la publicación de *CARICOMP – Caribbean Coral Reef, Seagrass and Mangrove Sites* (CARICOMP estudia arrecifes de coral, praderas de fanerógamas marinas y manglares del Caribe), la UNESCO intenta poner en relieve la existencia de una red que ha realizado una efectiva vigilancia continua del estado de estos tres ecosistemas costeros de importancia fundamental. Los sistemas estudiados son vitales para la salud de la biósfera y son esenciales para el desarrollo sostenible de los países costeros, en particular en la franja tropical.

Desde hace ya más de una década, el

proyecto CARICOMP, en el que participan diversos laboratorios, parques y reservas del Caribe, ha recibido apoyo de la Fundación John D. y Catherine T. MacArthur, la Fundación Nacional para las Ciencias de los EEUU, el Departamento de Estado de los EEUU, y de la UNESCO. Al inicio, la participación de la Organización se llevó a cabo en el marco de su programa sobre áreas costeras marinas y continúa actualmente como parte de una iniciativa llamada Medio Ambiente y Desarrollo en Regiones Costeras e Islas Pequeñas (CSI). Lanzada en 1996, ésta ha sido diseñada para servir como plataforma de cooperación, estimulando actividades intersectoriales para asesorar a los Estados Miembros en lograr un desarrollo de sus zonas costeras que sea ecológicamente sano, equitativo desde el punto de vista social y apropiado culturalmente.

El principal objetivo de CARICOMP es determinar la productividad de dichos ecosistemas y evaluar la naturaleza e influencia de las interacciones tierra-mar. Con el propósito de establecer las bases ecológicas necesarias para tales objetivos, se ha focalizado inicialmente sobre habitats poco perturbados. Recientemente, reconociendo la necesidad de mostrar de modo explícito la pertinencia social del proyecto y teniendo en cuenta el mandato intersectorial del CSI, CARICOMP ha comenzado a ocuparse más directamente de las interacciones entre población humana y medio ambiente con respecto a estos tres ecosistemas clave. Como resultado de esta medida, se organizó recientemente un taller intersectorial que reunió a especialistas en ciencias sociales y naturales para reflexionar sobre el papel de las primeras en la comprensión de la dinámica de la utilización de los recursos costeros.

Reconociendo la preoccupación mundial acerca de la amenaza que enfrentan los arrecifes coralinos, la Comisión Oceanográfica Intergubernamental coordina un esfuerzo international para proporcionar información sobre las tendencias en la salud de estos frágiles ecosistemas. La Subcomisión de la COI para el Caribe y Zonas Adyacentes (IOCARIBE) aumentará la cooperación de la UNESCO con CARICOMP, poniendo a la disposición de otras regiones del mundo la experiencia y conocimientos de este último.

La serie de publicaciones 'Coastal Region and Small Island Papers' difunde información para gerentes, administradores y otros interesados a fin de contribuir a la búsqueda de soluciones adecuadas a los problemas costeros. Este volumen es el producto de muchos años de estudio y evaluación por parte de los especialistas de CARICOMP. Bajo la supervisión y gracias a la esmerada labor del redactor jefe, profesor Kjerfve, y de sus colegas, se han conjugado así sus esfuerzos en una serie de textos concisos y descriptivos. Se deja constancia, ante todo, del debido reconocimiento a las instituciones de la región del Caribe que han cooperado eficazmente en esta operación tan beneficiosa para todos.

Esta importante publicación contó con aportes tanto de programas de la Organización como de copatrocinadores externos. Además de la contribución de la COI, una ayuda canalizada a través el Programa sobre el Hombre y la Biósfera (MAB), provino del Ministerio Alemán para la Cooperación Económica y el Desarrollo (BMZ), el cual apoya el desarrollo sostenible de ecosistemas costeros.

La impresión y la distribución beneficiaron de los copatrocinios del Instituto Oceanográfico de Florida (FIO) – una institución que presta su apoyo desde hace muchos años y que alberga actualmente el centro administrativo de CARICOMP – y del Instituto Internacional de Dasonomía Tropical (IITF) en Río Piedras, Puerto Rico, perteneciente al Servicio Forestal del Departamento de Agricultura de los EEUU. En particular, los Dres. John C. Odgen y Dean M. Milliken (Director y Director Adjunto, respectivamente, del FIO) y el Dr. Ariel Lugo (Director de IITF) cumplieron un papel fundamental en garantizar la cooperación de sus respectivas instituciones.

Avant-Propos

L'importance des régions côtières et de leurs ressources n'est plus à démontrer, en particulier dans le cas des petits États insulaires en développement. Il s'agit désormais de trouver des solutions durables aux problèmes complexes que connaissent ces zones d'un intérêt exceptionnel, où coexistent la multitude des services rendus par les écosystèmes et une forte pression démographique.

En publiant *CARICOMP – Caribbean Coral Reef, Seagrass and Mangrove Sites* (les sites de récifs coralliens, de phanérogames et de mangroves aux Caraïbes), l'UNESCO se propose de faire connaître un réseau d'activités qui a réussi à exercer une surveillance continue de trois écosystèmes côtiers exposés à des situations critiques. Leur préservation est indispensable au maintien de l'équilibre de la biosphère et à la réalisation d'un développement durable dans les pays côtiers, notamment ceux de la ceinture tropicale.

Opération de portée régionale, à laquelle collaborent plusieurs laboratoires, de nombreux parcs et réserves naturelles des Caraïbes, le projet CARICOMP bénéficie, depuis plus d'une décennie, du soutien de la Fondation John D. et Catherine T. MacArthur, de la Fondation nationale des États-Unis pour la Science (NSF) et du Département d'État des États-Unis qui viennent s'ajouter à celui de l'UNESCO. Lancée initialement au titre du programme côtier marin de l'UNESCO, cette campagne s'inscrit désormais dans le cadre de l'action de l'Organisation intitulée "Environnement et développement dans les régions côtières et les petites îles (CSI)". Inaugurée en 1996, la CSI constitue la plaque tournante de la coopération en encourageant la création d'activités à caractère intersectoriel dans le but d'aider les États membres à s'engager sur la voie d'un développement de leurs zones côtières qui soit écologiquement sain, socialement équitable et culturellement approprié.

Le projet CARICOMP a pour principal objectif de mesurer la productivité des trois écosystèmes étudiés et d'analyser la nature des interactions terre-mer. Dans un premier temps, les lignes de bases d'un point de vue écologique ont été déterminées à partir de l'étude des habitats les moins perturbés. Puis, par souci de mieux prendre en compte la finalité sociale du projet et de respecter le caractère intersectoriel du mandat de la CSI, le CARICOMP a commencé à s'intéresser plus nettement aux interactions population-environnement de ces trois systèmes. C'est dans cet esprit qu'a été récemment organisé un atelier intersectoriel qui a permis à des spécialistes des sciences sociales et des sciences naturelles de préciser dans quelles mesures les sciences sociales peuvent contribuer à l'utilisation fonctionnelle des ressources côtières.

Prenant en compte l'inquiétude grandissante relative aux menaces pesant sur les récifs coralliens, la Commission océanographique intergouvernementale coordonne une entreprise mondiale ayant pour but de fournir des données sur l'évolution de ces fragiles écosystèmes. La Sous-Commission de la COI pour la mer des Caraïbes et les régions adjacentes (IOCARIBE) se charge d'étendre la coopération de l'UNESCO avec CARICOMP en contribuant à rendre disponibles l'expérience et l'expertise de ce dernier à d'autres régions du monde.

La collection Dossiers régions côtières et petites îles, une initiative de CSI, diffuse, auprès des gestionnaires et autres personnes intéressées, des informations susceptibles de les aider à trouver des solutions appropriées aux problèmes côtiers. Le présent document constitue le résultat de plusieurs années d'analyses et de conclusions de nombreux spécialistes du CARICOMP. Placés sous la supervision et la direction éclairée du Professeur Kjerfve et de ses collègues, leurs travaux sont réunis ici sous forme de descriptions succintes. Il convient d'en remercier, au premier chef, les organismes de la région des Caraïbes qui ont oeuvré en commun à cette entreprise d'intérêt collectif. Cette publication a reçu, à travers le Programme sur l'Homme et la Biosphere (MAB), le soutien du Ministère fédéral allemand pour la coopération économique et le développement (BMZ), qui appui le développement des écosystèmes côtiers.

L'impression et la diffusion de ce document également ont été facilitées par le parrainage de deux institutions : l'Institut d'océanographie de Floride (FIO) des États-Unis – partenaire éprouvé du CARICOMP, qui lui sert actuellement de siège administratif, et l'Institut international de sylviculture tropicale (IITF) à Rio Piedras, Porto Rico, dépendant de l'Office des forêts du Département d'agriculture des États-Unis. Les Drs John C. Ogden et Dean M. Milliken (Directeur et Directeur adjoint du FIO) et le Dr Ariel E. Lugo (Directeur de l'IITF) ont en particulier joué un rôle clé pour obtenir la coopération de leurs institutions respectives.

Dirk G. Troost
UNESCO-CSI, Paris, December 1998

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  USDA Forest Service,
  PO Box 25000,
  San Juan, Puerto Rico 00928-5000.
  Fax: (1-787) 766 6302

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- Coastal Regions and Small Islands (CSI) platform,
  UNESCO,
  1, rue Miollis,
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  Fax: (33-1) 45 68 58 06/08
  E-mail: csi@unesco.org

Within the limits of stocks available, extra copies can be obtained, free of charge, from IITF and UNESCO-CSI.

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List of Acronyms

AEROCE	Atmosphere/Ocean Chemistry Experiment (Bermuda)
AMLC	Association of Marine Laboratories of the Caribbean
ASEAN	Association of South East Asian Nations
BBSR	Bermuda Biological Station for Research
CARIPOL	Caribbean Pollution Program
CARMABI	Caribbean Research and Management of Biodiversity (Curaçao)
CERC	Coastal Ecosystems Research Center (Cuba)
CIMAR	Centro de Investigación en Ciencias del Mar y Limnología (Costa Rica)
CINVESTAV	Centro de Investigación y de Estudios Avanzados (Mexico)
COMAR	UNESCO's Coastal Marine Program
CONACYT	Consejo Nacional de Ciencia y Tecnología (Mexico)
CONICIT	Consejo Nacional de Investigaciones Científicas y Tecnológicas (Costa Rica)
DBML	Discovery Bay Marine Laboratory (Jamaica)
DMC	CARICOMP Data Management Centre (Jamaica)
DUMAC	Ducks Unlimited de México, A.C.
EDIMAR	Estación de Investigaciones Marina de Margarita (Venezuela)
EPOMEX	Centro de Ecología, Pesqueirias y Oceanografía del Golfo de México
FoProBIM	Fondation pour la Protection de la Biodiversité Marine (Haiti)
GCRMN	Global Coral Reef Monitoring Network
GOOS	Global Ocean Observing System
ICGC	Instituto Cubano de Geodesia y Cartografía (Cuba)
ICRI	International Coral Reef Initiative
ICRS	International Coral Reef Symposia
IES	Institute of Ecology and Systematics (Cuba)
IGEO	Instituto de Geografía (Cuba)
IGN	Instituto Geográfico Nacional (Cuba)
INTECMAR	Instituto de Tecnología y Ciencias Marinas (Venezuela)
INVEMAR	Instituto de Investigaciones Marinas y Costeras (Colombia)
IO	Institute of Oceanology (Cuba)
IOC	UNESCO's Intergovernmental Oceanographic Commission

MARENA	Ministerio del Ambiente y Recursos Naturales y del Medio Ambiente (Nicaragua)
NOAA	National Oceanic and Atmospheric Administration (USA)
RAMSAR	Convention on Wetlands of International Importance, Especially as Waterfowl Habitat
UCBMRC	University College of Belize Marine Research Centre
UNCLOS	United Nations Conference on the Law of the Sea
UNEP	United National Environment Programme
UNESCO	United Nations Educational, Scientific, and Cultural Organization
USAID	U.S. Agency for International Development

Editor's Note

The purpose of this volume is to document the international Caribbean Coastal Marine Productivity (CARICOMP) program, network, and activities by describing the state of coastal habitats where the participating institutions, parks, and reserves have implemented synchronized environmental monitoring. Most of the participating institutions have provided chapters for this book, detailing the local mangrove, seagrass, and coral reef habitats, the salient meteorological and oceanographic characteristics, and the anthropogenic activities and impacts on coastal ecosystems. In addition, the synoptic time series and habitat data 1993-1995, covering the first three years for which the network was fully functional in a data monitoring mode, are included. The data, which were collected by the participants in the network, have been summarized in tables in the concluding chapter by the CARICOMP Data Management Centre at the University of the West Indies on the Mona campus in Kingston, Jamaica.

This volume thus represents a snapshot of the state of coastal ecosystems in the wider Caribbean region from Yucatan to Barbados and from Bermuda to the Caribbean coasts of Colombia and Venezuela, as well as from many small and large islands and the coast of Central America in between.

Like most books, this one has taken its time to be born, conceived in 1992 and only now coming to fruition. What was initially thought to be a quick publication turned out to be not very quick after all. Subsequent to meeting with the chapter authors at a number of CARICOMP Site Directors' meetings, starting in Port Royal in 1993, and continuing in St. Petersburg in 1994, Boca Chica in 1995, and Cancún in 1996, this volume began taking shape. Initially, most communications and exchanges with the authors were handled by sending either air or courier mail back and forth. When needed — and that was quite often — fax transmissions were used to speed up communications. However, over the past two years most communication with authors has been handled by e-mail and the attachment of binary formatted text and graphics files. Thus, all text, tables, figures, and photographs contained in this volume are now in a digital format and may be readily transmitted and reformatted as needed. Although this technology now is used widely around the world, to get to this point was not an easy task from locations in the Caribbean.

I would like thank the many persons who have helped make this book a reality. Unfortunately, they are too numerous to list individually. They include the enthusias-

tic CARICOMP chapter authors, and colleagues both near and far who reviewed the manuscripts and offered constructive criticism. I would like to thank my colleagues on the CARICOMP Steering Committee for their support and generous help in reviewing the manuscripts. Thanks also to Dulcie Linton of the Data Management Centre at the University of the West Indies-Mona in Kingston, Jamaica, who provided information and data in a timely fashion and on many occasions helped me reach difficult-to-contact authors.

I would also like to express my gratitude to UNESCO, most recently to its unit on Environment and Development in Coastal Regions and in Small Islands (CSI). Over the past two decades, four people in the Paris Secretariat have been intimately involved in the project's development. Dr. Marc Steyaert, of the former UNESCO Marine Science Division, helped create CARICOMP in the early 1980s within the framework of the Division's Coastal Marine (COMAR) Programme, and managed to secure the necessary co-funding for several years. Marc remains a staunch supporter and a great friend in his retirement. Over the last three years, Dr. Dirk Troost, Chief of CSI, has also supported the project in spirit and with funding. Gary Wright and Micheline Turner, UNESCO editor and editorial assistant, respectively, deserve very special thanks for their help, patience, and advice during the many years that this text has been in development.

At the University of South Carolina, Constance M. Prynne, Grants/Publications Editor for the College of Science and Mathematics, deserves appreciation and thanks for her help in all aspects of the production of this book. She reformatted and produced the camera-ready version of each manuscript and of the book as a whole. In addition, she has assisted me for more than two years in editing text, scanning and enhancing illustrations, preparing tables, and communicating with authors. However, errors that no doubt still hide on many pages are my responsibility.

Production of this volume would not have been possible without the generous contributions of the University of South Carolina in personnel time, resources, and logistics.

Finally, I would like to acknowledge the patience and support of my family during the CARICOMP book years — with love to my wife Tânia and to my daughters Jenny Heather and Clara Maria.

Björn Kjerfve (bjorn@sc.edu)
Marine Science Program, Department of Geological Sciences, and
Belle W. Baruch Institute for Marine Biology and Coastal Research
University of South Carolina, Columbia, SC 28208 USA
October 1998

CARICOMP: A Caribbean Network of Marine Laboratories, Parks, and Reserves for Coastal Monitoring and Scientific Collaboration[1 2]

Björn Kjerfve[1], John C. Ogden[2], Jaime Garzón-Ferreira[3], Eric Jordán-Dahlgren[4], Kalli De Meyer[5], Pablo Penchaszadeh[6], William J. Wiebe[7], Jeremy D. Woodley[8], and Joseph C. Zieman[9]

[1] *Marine Science Program, Department of Geological Sciences, and Belle W. Baruch Institute for Marine Biology and Coastal Research, University of South Carolina, Columbia, SC 29208, USA*

[2] *Florida Institute of Oceanography, 830 First Street South, St. Petersburg, FL 33701, USA*

[3] *Instituto de Investigaciones Marinas y Costeras, Apartado 1016, Santa Marta, Colombia*

[4] *Instituto de Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México, AP 1152, Cancún 77500, Quintana Roo, Mexico*

[5] *Bonaire Marine Park, PO Box 368, Bonaire, Netherlands Antilles*

[6] *Instituto de Tecnología y Ciencias Marinas (INTECMAR) and Departamento de Estudios Ambientales, Universidad Simón Bolivar, PO Box 89000, Caracas, Venezuela*

[7] *Department of Microbiology, University of Georgia, Athens, GA 30602, USA*

[8] *Center for Marine Sciences, University of the West Indies-Mona, Kingston 7, Jamaica*

[9] *Department of Environmental Sciences, University of Virginia, Charlottesville, VA 22901, USA*

Caribbean Coastal Marine Productivity (CARICOMP) is a regional scientific program and a network of marine laboratories, parks, and reserves to study land-sea interaction processes in the wider Caribbean region. The program focuses on understanding and comparing the structure and function of mangroves, seagrasses, and coral reefs — the three main coastal ecosystems in the Caribbean. The CARICOMP program was established in 1985. The CARICOMP network, started in 1990, has to date negotiated with 27 institutions in 17 countries to make standardized synoptic ecosystem measurements in relatively undisturbed mangrove, seagrass, and coral reef systems, together with relevant oceanographic and meteorological measurements. Since 1993, twelve institutions have fully implemented the protocol, eight institutions have partially implemented the protocol, and eight institutions have not progressed beyond the planning phase. Detailed site characterizations for 21 of the 27 participating institutions have been completed and are included in this volume. The principal goals of the program are to

[1] *CARICOMP — Caribbean Coral Reef, Seagrass and Mangrove Sites* (edited by B. Kjerfve), pp 1-16. UNESCO, Paris, 1998, 347 pp.

[2] The authors of this chapter are the members of the CARICOMP Steering Committee as of May 1998.

determine the dominant influences on coastal productivity, to monitor for ecosystem change, and ultimately to discriminate human disturbance from long-term natural variation in coastal systems over the range of their distribution. The CARICOMP network is coordinated by the Data Management Centre at the University of the West Indies in Jamaica. There is an increasing number of examples of regional responses to large geographic scale perturbations. CARICOMP is capable of responding to events related to coral bleaching, mass mortality, disease, and storm and El Niño phenomena, and regularly organizes workshops and training sessions.

Coastal Tropical Ecosystems: A Caribbean Perspective

Mangrove wetlands, seagrass beds, and coral reefs dominate the land-sea margin in the tropics. They harbor the highest biological diversity within the ocean. We exploit them for food, building materials, and firewood at the same time that they represent the natural infrastructure for tourism. Too often they are modified or destroyed to accommodate development. Within the wider Caribbean region, there is consensus that coastal marine systems are changing for the worse. The ultimate causes are exponential population growth and anthropogenically driven changes both in the coastal zone and in the upstream watershed. This, in turn, affects the coastal ecosystems, which are dynamic and changing in their natural state. Because the underlying causes of this decline are diverse, there is no agreement on how the ecosystems can be stabilized and restored to their former state, or what constitutes sustainable development.

In fact, all coastal ecosystems of the tropics are in decline from the direct and indirect disturbances as a result of population growth (Wells, 1988; Wilkinsön, 1994; ICRI, 1995). The Caribbean Sea is entirely located in the tropics. It covers 1,943,000 km^2 — or 0.38% of the global surface, whereas the wider Caribbean is significantly larger. The Caribbean coastal environment is a mosaic of interlinked marine ecosystems at the border between sea and land, in geographically diverse settings. As a whole, the coastal zone in the Caribbean supports approximately 100 million people in more than 25 countries and territories, with a predicted population doubling time of only 30 years at the current rate of growth (Population Reference Bureau, 1996). Under pressure of rapidly increasing human population, urbanization, and demands for resources, the coastal zone is the focus of intense housing, industrial, and tourism development.

The Caribbean is interconnected by currents and tides and it shows great uniformity with respect to marine biota but, at the same time, exhibits high habitat diversity (Ogden, 1997; Roberts, 1997). A slow moving east-to-west flowing ocean current through the Caribbean, the Caribbean Current is part of the general North Atlantic circulation (Wüst, 1964; Brucks, 1970; Kinder, 1983). As it traverses the Caribbean, the flow is characterized by large cyclonic and anticyclonic gyres. The Guyana Current enters the Caribbean via the Windward Islands as the extension of the North Equatorial Current, and the flow exits the Caribbean through the Yucatan Channel into the Gulf of Mexico and to the northwest into the North Atlantic. Muller-Karger *et al.* (1989) have shown that the plume of the Orinoco River, as tracked by satellite imagery, seasonally penetrates across the Caribbean Basin, potentially exerting a region-wide influence. Tides likewise show a great degree of coherence. The Caribbean tides are of the mixed type with the exception of a band from Puerto Rico to Venezuela where diurnal tides predominate (Kjerfve, 1981). However, the astronomical tidal range is everywhere only 20-30 cm. As most marine organisms have a planktonic larval phase of from several weeks to over a year, propagules can be carried over long distances. For example, Shulman and Bermingham (1995) found a high degree of gene flow among widely separated populations of 8 species of reef fishes, regardless of spawning strategy or duration of planktonic larval cycle. Mitton *et al.* (1989) also found high gene flow among 17 widely distributed populations of the queen conch *(Strombus gigas)*.

The extensive coral reefs, seagrass beds, and mangrove wetlands of the Caribbean are under acute threat. Mangroves are being cut down for lumber, agriculture, aquaculture, and coastal construction and mining; seagrasses are being dredged for harbors; deforestation is leading to increased runoff and sedimentation, increased nutrients from sewage; and coastal fish stocks are being depleted (Rogers, 1985; Ogden and Gladfelter, 1986; Ginsburg, 1994; ICRI, 1995). Pollution from agricultural, urban, and industrial centers adds to the cumulative impact. Governments acknowledge the need for conservation and restoration, but the development of rational management strategies is crippled by both politics and an insufficient understanding of how coastal ecosystems function, how they interact, and how disturbance in one system can impact adjacent systems.

Human disturbances are superimposed on patterns of ecosystem variation at different time scales due to naturally occurring variability, including storms, hurricanes, and El Niño events (Woodley *et al.*, 1981; Kjerfve *et al.*, 1986; Ogden, 1992), white- and black-band coral diseases (Gladfelter, 1982; Rützler and Santavy, 1983), coral bleaching, and other suspected manifestations of physical environmental stresses and global climate change (Brown, 1990; Smith and Buddemeier, 1992; Brown and Ogden, 1993). Distinguishing the effect of human impacts from natural events can be difficult, but it is critical to our understanding of ecosystem function and eventual management.

The decades-long die-back of corals in the genus *Acropora* in the Caribbean is a little understood, potentially pathogenic condition operating on a long time-scale (Gladfelter, 1982). There is also evidence of synergistic interactions between natural and anthropogenic causes. For example, when corals started bleaching throughout the Caribbean in 1987, there was speculation that corals under stress from terrestrial sediment input showed a greater tendency to bleach, although the primary factor appears to be abnormally high or prolonged summer seawater temperatures (Williams *et al.*, 1987; Ogden and Wicklund, 1988; Brown and Ogden, 1993). Other sublethal stresses may be similarly magnified by natural impacts. For example, reef herbivore populations have declined in the Caribbean through over-fishing and a 90-99% die-off of the sea urchin *Diadema antillarum* during the past two decades, apparently caused by a pathogen which tracked the surface currents with remarkable fidelity (Hay, 1984; Lessios *et al.*, 1984; Rogers, 1985). The resultant reduction in grazing, presumably exacerbated by increased nutrient availability and hurricane disturbance, has resulted in increased algal abundance and decreased coral cover and recruitment at some locations (Hughes, 1989, 1994).

Caribbean Mangroves, Seagrasses, and Coral Reefs

Caribbean mangroves, seagrasses, and coral reefs are closely associated (Fig. 1); they exist in a dynamic equilibrium influenced by contact with land (Ogden, 1988) and constitute approximately one third of the tropical coastline globally. Sediments and nutrients, carried by freshwater runoff, are first filtered out by coastal forests, then by mangrove wetlands, and finally by seagrass beds. The existence of coral reefs is directly dependent upon the buffering capacity of the shoreward coastal ecosystems. Coral reefs, in turn, buffer the influence of the open ocean on the land. Coral reefs, seagrass beds, and mangroves are among the most productive ecosystems in the world, ranking with intensively cultivated agriculture such as sugar cane (Lewis, 1977).

The high productivity of mangrove forests and seagrass beds depends upon external sources of nutrients. Productive mangrove forests are found in river basins and on coastal floodplains, along the shores of estuaries and lagoons, and in other protected areas with abundant discharges of nutrients. Mangroves are also found on offshore sandbars, low islands, and desert coasts with minimal runoff, where they grow in a scrub form, the productivity of which is an order of magnitude lower than in areas with abundant nutrient input (Lugo *et al.*, 1973; Snedaker and Snedaker, 1984). Similarly, the most productive stands of seagrasses occur where a balance exists between nutrient enhancement by runoff from river or coastal mangrove forests and high water clarity.

Coral reefs have a tight internal cycling of nutrients because of a symbiotic association between zooxanthellae and corals. They depend less on external sources of nutrients. Their vigorous development, however, requires clear water. They are strongly affected by sediments and pollutants from terrestrial runoff. Unchecked runoff, or riverine discharge containing a heavy sediment load, can destroy or severely restrict coral reef community development. Careless clearing of land within watersheds, whether for agriculture, industry, or tourism purposes, combined with destruction of coastal mangrove forests for construction of aquaculture ponds or to provide ocean access, is the most damaging influence on coral reefs in the Caribbean.

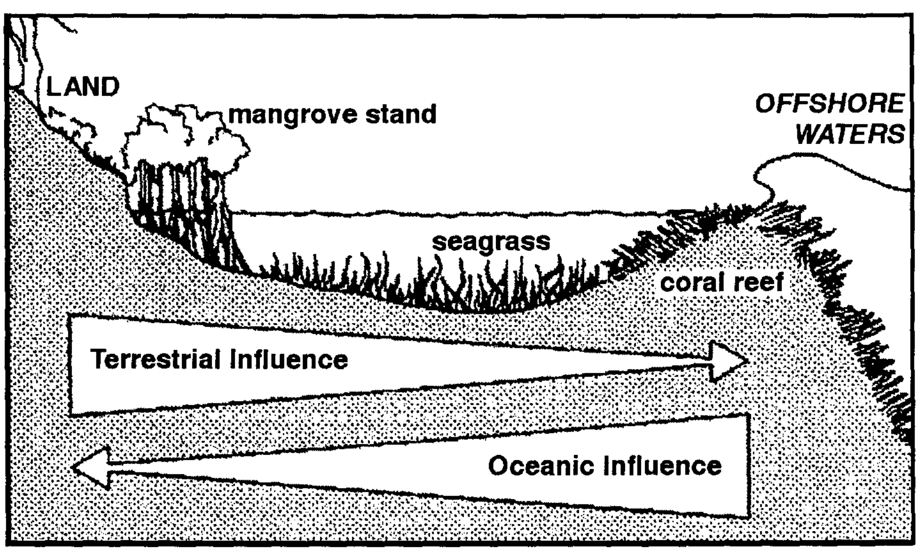

Fig. 1. Schematic representation of interactions between the principal coastal marine ecosystems of the Caribbean.

Because of their different environmental requirements, coral reefs and mangroves rarely adjoin one another. When these communities are directly adjacent, one or both are usually highly stressed. However, some of the most productive areas along tropical and subtropical coasts are found where broad seagrass meadows are interposed between the mangrove and coral reef communities (Ogden and Gladfelter, 1986).

Coral reefs, seagrasses, and mangroves may interact through nutrient transfer by organisms migrating daily or seasonally from one ecosystem to another (Ogden and Zieman, 1977; Zieman *et al.*, 1979; Meyer *et al.*, 1983), but the significance of this interaction is largely unknown. In one instance, the utilization of mangrove trees as resting and nesting areas for birds increased the development and food quality of both seagrasses and mangrove communities. Seagrass beds and mangroves are important nursery areas for many species of reef fishes and invertebrates that are the basis for commercial fisheries (Ogden and Gladfelter, 1983). The planktonic larvae of the French grunt (*Haemulon flavolineatum*, Haemulidae), for example, selectively settle in seagrass-covered lagoons where they spend the first few months of their life, moving gradually to reef habitats as small juveniles. Because of the presence of juvenile fish, mangrove and seagrass nurseries are excellent fishing areas for predatory fishes (McFarland *et al.*, 1985). In another study, 70% of recreational fishery species and 90% of commercial fishery species depend on mangrove-lined estuaries and coastal embayments at some stage in their lives (Yokel *et al.*, 1969; Hooks *et al.*, 1976; Fry and Parker, 1979).

While terrestrial ecosystems contribute to the coastal zone with nutrients and sediments, ecosystems at the land-sea boundary buffer these influences. Estuaries and coastal areas trap significant quantities of riverborne material, acting as filters between continents and ocean. To quantify the capacity of coastal sedimentation basins as filters for different constituents and elements is an important undertaking. The trapping is not solely a physical process but also due to biogeochemical processes, which play an important role in trapping and mobilization of sediment discharge.

Mangrove forests and seagrass beds buffer the effect of the land, reducing sediment load in the water column and interrupting freshwater discharge, stabilizing the salinity of the coastal zone, and promoting the growth of coral reefs offshore. Conversely, coral reefs dissipate the impact of waves on the coastal zone (Jordán and Martín, 1987), creating lagoons and protected waters that favor the growth of seagrasses and mangroves. Thus, the principal and perhaps most important interaction between tropical coastal ecosystems is that of buffering the effect of the sea on the one hand and the land on the other.

Although these and other interactions have been recognized, we lack the quantitative data necessary to measure their importance and to compare different locations. Moreover, although the productivity of mangroves, seagrasses, and coral reefs drives the production of coastal fisheries, we have not measured these processes and cannot compare their relative importance between diverse geographical locations. How do the relative roles of the four ecosystems (three coastal, one oceanic) differ between continents and islands? Between high and low islands, windward and leeward shores, high and low latitudes, or upstream or downstream locations with respect to the Caribbean Current? It was to address these questions that CARICOMP was formed: to collect information on factors affecting coastal marine productivity by the use of identical methods at diverse sites across the wider Caribbean.

Unfortunately, we lack long-term information about even the most basic physical parameters — *e.g.*, seawater temperature. Although elevated water temperature is the parameter most suspected as the cause for coral bleaching (Williams *et al.*, 1987), continuous temperature data sets are sparse in the Caribbean, with the exception of sea surface temperature measurements from the thermal AVHRR channel onboard NOAA satellites. However, because of the 1.1 km pixel size, these data are of only limited use in coastal waters. With increased concern for global warming and sea level rise (Buddemeier and Smith, 1988), the need for basic environmental monitoring has become acute (Stewart *et al.*, 1990). This need can also be met by CARICOMP. Over the next decades, the Caribbean will undergo significant changes. The CARICOMP Program is designed to address such problems by providing much needed data along with employment of local scientists and technicians, thus providing local governments and private enterprises with in-house expertise for environmental management and problem solving.

The CARICOMP Network

The CARICOMP program is a unified, long-term, Caribbean-wide initiative to identify the factors responsible for sustaining mangrove wetland, seagrass meadow, and coral reef productivity, to examine the interaction between these systems, and to determine the role of terrestrial and oceanic influences on them. This information is needed for management, for setting priorities, and for defining optimum solutions where competing human activities impact the coastal zone, thereby providing feedback from science to management.

The CARICOMP network grew out of the 35-year old Association of Marine Laboratories of the Caribbean (AMLC). The initial objectives of CARICOMP were to foster research, education and training, information and data exchange, and research applications. With support from UNESCO's Coastal Marine (COMAR) Program, the first workshop was held at Discovery Bay Marine Laboratory in Jamaica in 1985. The rationale for a regional monitoring and research network of Caribbean marine laboratories, parks, and reserves was established and an international Steering Committee was selected (Ogden and Gladfelter 1986; Ogden, 1987). Over the next 10 years, the Steering Committee negotiated Memoranda of Understanding (MoUs) with 27 institutions in 17 countries (Fig. 2; Table 1) within the greater Caribbean region. While each institution had considerable local background information and reference material, very few of the institutions had ecosystem monitoring programs in place prior to the start of the CARICOMP Program (Smith and Ogden, 1994). The sites represent a variety of environmental settings, including low and high islands, continental margins, windward and leeward exposures, high and low rainfall rates, and areas of frequent and infrequent hurricane activity.

The MoUs specify the responsibilities of each institution to the network, including the nomination of a Site Director and the obligations of the network in terms of equipment and logistical support. In the autumn of 1990 and 1992, workshops were held at the University of the West Indies (UWI) in Jamaica to draft the *CARICOMP Methods Manual-Level I* (CARICOMP, 1994a), consisting of a number of standardized observations and simple measurements, permitting an institution to participate in network

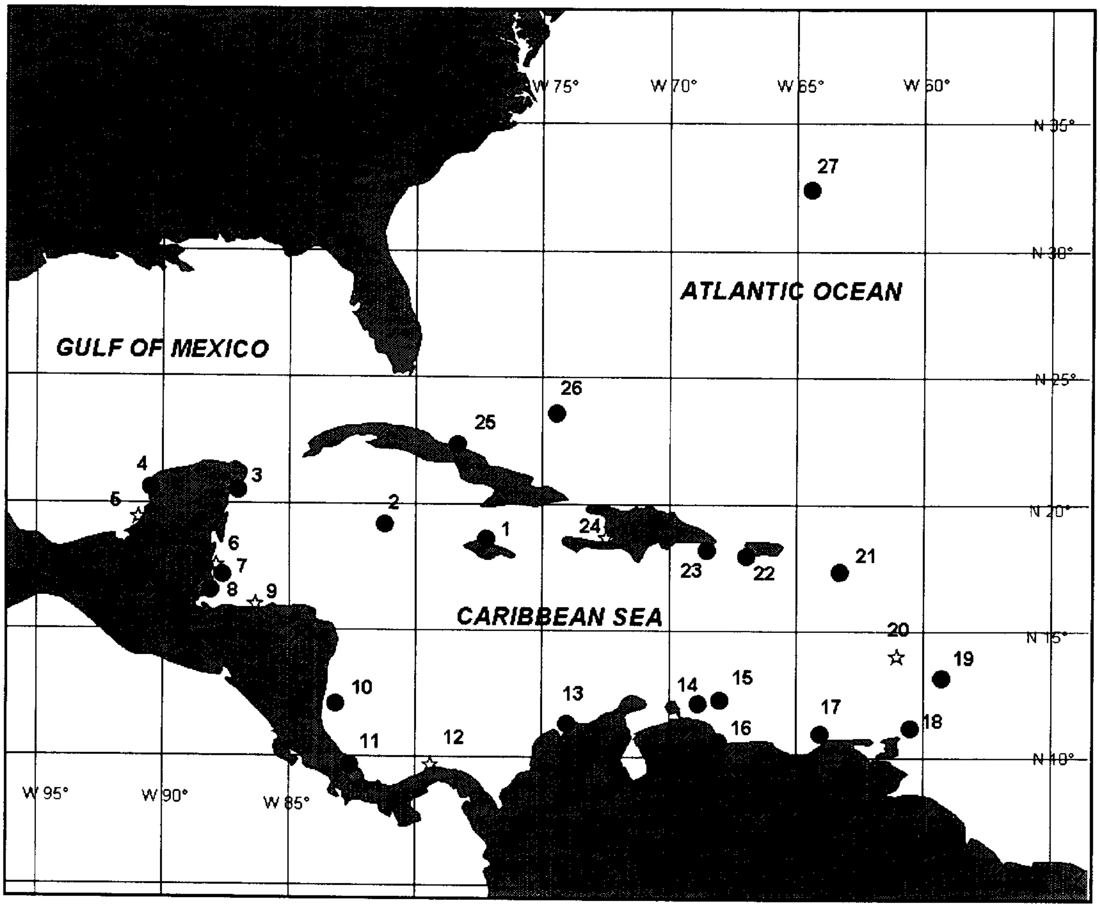

Fig. 2. The CARICOMP network. Filled circles indicate the institutions which are participating in the network and which have chapters in this volume. Stars indicate institutions which have yet to implement the CARICOMP protocol and which are not included in this volume (numbers 5, 6, 9, 12, 20, and 24).

1. Discovery Bay, Jamaica
2. Grand Cayman, British West Indies
3. Puerto Morelos, Quintana Roo, Mexico
4. Laguna de Celestún, Yucatán, Mexico
5. EPOMEX, Campeche, Mexico
6. Hol Chan, Belize
7. Calabash Caye, Turneffe Islands Atoll, Belize
8. Carrie Bow Cay, Belize
9. Cayo Cochinas, Honduras
10. Great Corn Island, Nicaragua
11. Cahuita and Laguna Gandoca, Costa Rica
12. Panamá
13. Bahía de Chengue, Parque Natural Tayrona, Colombia
14. Curaçao, Netherlands Antilles
15. Bonaire, Netherlands Antilles
16. Parque Nacional Morrocoy, Venezuela
17. Punta de Mangle, Isla de Margarita, Venezuela
18. Buccoo Reef and Bon Accord Lagoon, Tobago, Republic of Trinidad & Tobago
19. Barbados
20. Santa Lucia
21. Saba, Netherlands Antilles
22. La Parguera, Puerto Rico
23. Parque Nacional del Este, Dominican Republic
24. Port au Prince, Haiti
25. Cayo Coco, Sabana-Camagüey Archipelago, Cuba
26. San Salvador, Bahamas
27. Bermuda

activities. An equipment package was sent to all participating institutions in 1992, and the Data Management Centre was established at UWI in Kingston, Jamaica.

Some institutions in the CARICOMP network began collecting data in the autumn of 1992. The data are sent to the Data Management Centre and distributed to all participating institutions on a quarterly basis. In addition to providing centralized data processing and data storage, the Data Management Centre coordinates regional investigations of transient oceanographic, biological, and meteorological phenomena and serves as a clearinghouse for new ideas and methods (Nagelkerken, 1997). Under a 1991 grant from the U.S. National Science Foundation, five institutions received support for the purchase of automated environmental monitoring equipment as part of a long-term plan to upgrade the manual to *CARICOMP Methods Manual Level II.*

To date, twelve institutions have regularly implemented most of the CARICOMP protocol, while eight have implemented portions of the protocol. Seven institutions have not progressed beyond the planning phase, and some of them might never do so. However, two new institutions are likely to join in 1998. Participation in CARICOMP is open to laboratories, parks, and reserves willing to sign the MoU and to provide data on a regular basis to the Data Management Centre. Since 1993, an annual meeting of the CARICOMP Site Directors and the Steering Committee has been held at a participating site to report on network progress and problems, to discuss funding and logistics, to refine data collection and analysis, and to report on measurement protocols. The members of the Steering Committee are the authors of this introductory paper.

The data for the first three years, 1993-1995, are presented in tabular form in the last chapter of this book. To our knowledge, no such synoptic regional coastal marine data exist elsewhere. In addition, the network and data monitoring have already resulted in the publication of several scientific papers dealing with the status of the coastal marine ecosystems in the wider Caribbean, including CARICOMP (1994a; 1997a-g), Ledgister *et al.* (1997), and Nagelkerken *et al.* (1997). The plans are to publish a summary of future CARICOMP data annually in a regional scientific journal.

Other Regional Coastal Programs

Recent discussions and workshops (Pernetta and Hughes, 1990; D'Elia *et al.*, 1991; Smith and Buddemeier, 1992; Wilkinson and Buddemeier, 1994; Committee on Biological Diversity in Marine Systems, 1995; ICRI, 1995) have emphasized the need for regional coastal data sets. While monitoring is often distinguished from research, our ability to pose significant research hypotheses and understand ecosystem functioning, biodiversity, and global change responses in the coastal zone of the tropics improves immensely with the availability of long time-series of relevant data at multiple sites. Question-driven monitoring is long-term ecological research.

As far as we know, the CARICOMP network is currently the only functioning international coastal marine monitoring program. The Caribbean Pollution (CARIPOL) Program of UNEP and the Intergovernmental Oceanographic Commission (IOC/IOCARIBE) of UNESCO was the first program to collect regionally, standardized data on oil pollution, with centralized data analysis for 6 years, beginning in 1979 (CARIPOL, 1980; Atwood *et al.*,1987). The ASEAN (Association of South East Asian

Nations)/Australia Marine Science Project: Living Coastal Resources operated from 1984 through 1989 and developed a methods manual and a system of data reporting and analysis (English *et al.*, 1994). The International Coral Reef Initiative (ICRI, 1995) has recently proposed linking tropical regions into a global network through the Global Coral Reef Monitoring Network (GCRMN), as a part of the IOC's Global Ocean Observing System (GOOS). The GCRMN intends to promote development of a series of regional nodes and to work towards globally standardized methods of assessing coral reefs. CARICOMP will participate in the system.

Data from the multiple sites of the CARICOMP network provide the backdrop against which observations at single sites may be better understood. For example, Hughes (1994) interpreted the results of 17 years of monitoring and research on the north shore of Jamaica and suggested that control of over-fishing was the key to recovery of the degraded reefs. By comparing this conclusion with qualitative data from 14 sites, the five sites showing no change in coral cover over the past 10 years were in parks, reserves, or other areas where control of fishing was the major management tactic (CARICOMP, 1994b; Smith and Ogden, 1994). While this is a preliminary conclusion, it grew out of the comparison of regional observations, and could not have been reached with confidence without the network.

Aerial and satellite remote sensing and the application of geographical information system (GIS) databases are likely to become even more critical tools in future studies of coastal ecosystems. The network provides the infrastructure to integrate satellite and *in situ* observations into GIS databases. However, the challenge and frustration in analyzing coral bleaching in the Caribbean has been the inability to make the 1.2 km^2 pixel size of AVHRR satellite-derived sea surface temperature (SST) measurements ecologically meaningful at the 1 m^2 scale at which observations of coral bleaching are made. As a component of future coastal marine studies, satellite ocean color measurements will certainly become increasingly more important tools, providing data on chlorophyll, dissolved organic material, and sediments, using SeaWIFS and other newer generation higher resolution satellite and aerial sensors.

Recently, much attention has been directed towards increases in atmospheric greenhouse gases and the accelerated rate of global warming and rising sea level. Increased water temperature is, on one hand, likely to cause bleaching and stress on shallow water corals. Also, Buddemeier and Smith (1988) suggested that even with a conservative rate of sea level rise, the vertical accretion rates of protected coral reef flats will be insufficient to keep up, and the buffering capacity will be threatened. The most likely rate of global sea level rise is 6 ± 3 cm per decade (Stewart *et al.*, 1990). Reefs may indeed become inundated and subjected to increasing wave erosion.

It is interesting to note that the network grew out of a regional association of scientists and institutions in response to regional concerns. It was not imposed by governments or international agencies. Rather, the network is based at marine laboratories, parks, and reserves with the capability to contribute financially and logistically to the program and to serve as local repositories of long-term data from the local coastal region. By scientific collaboration across the region, such as the Caribbean, regional issues are more likely to be resolved rationally in a timely fashion.

Table 1a. CARICOMP participating institutions and site locations.

Country	Institution	Site	Lat °N	Long °W	Included in this volume
Bahamas	Bahamian Field Station (BFS) c/o Twin Air 1100 Lee Wagener Blvd Ste 113 Ft Lauderdale, FL 33315 USA	San Salvador	24.03	74.29	Yes
Barbados	Bellairs Research Institute Holetown St James, Barbados	Barbados	13.18	59.63	Yes
Belize	University College of Belize Marine Research Centre PO Box 990 Belize City, Belize	Calabash Caye	17.88	87.83	Yes
Belize	Caribbean Coral Reef Ecosystem Program, Smithsonian Institution, MRC 163 Washington, DC 20560 USA	Carrie Bow Cay	16.80	88.08	Yes
Belize	Hol Chan Marine Reserve San Pedro Ambergris Cay, Belize	Hol Chan	17.92	87.98	No
Bermuda	Bermuda Biological Station 17 Biological Lane Ferry Reach GE01 Bermuda	Bermuda	32.40	64.80	Yes
British West Indies	Dept. of Environmental Protection and Conservation PO Box 486 George Town Grand Cayman BWI	Grand Cayman	19.30	81.27	Yes
Colombia	Instituto de Investigaciones Marinas y Costeras (INVEMAR) AA 1016 Santa Marta, Colombia	Bahía de Chengue, Parque Natural Tayrona	11.13	74.33	Yes
Costa Rica	CIMAR Universidad de Costa Rica San Pedro, Costa Rica	Cahuita and Laguna Gandoca	09.73	82.78	Yes
Cuba	Instituto de Oceanología Calle Ira 18406, Playa Ciudad de Habana, Cuba	Coco Cay, Sabana-Camagüey Archipelago	22.55	78.43	Yes
Dominican Republic	Centro de Investigaciones de Biologia Marina Univ Auto de Santo Domingo PO Box 748, Santo Domingo, Dominican Republic	Parque Nacional del Este	18.25	68.77	Yes
Haiti	Fondation pour la Protection de la Biodiversité Marine (FoProBIM) PO Box 642 Port-au-Prince, Haiti	Port-au-Prince	18.62	72.37	No

Table 1b. CARICOMP participating institutions and site locations.					
Country	Institution	Site	Lat °N	Long °W	Included in this volume
Honduras	Honduras Project, Smithsonian Tropical Research Institute PO Box 2072 Balboa, Panamá	Cayo Cochina	16.00	86.55	No
Jamaica	Discovery Bay Marine Lab PO Box 35 Discovery Bay, St Ann, Jamaica	Discovery Bay	18.47	77.41	Yes
México	Programa EPOMEX-UAC Estación El Carmen-UNAM Univ Auto de Campeche CP 24030, AP 520 Campeche, México	Campeche	19.67	90.92	No
México	Centro de Investigaciones y de Estudios Avanzados del IPN Unidad Mérida Carr Antigua a Progreso km 6 AP 73, Cordemex 97310 Mérida, Yucatán, México	Laguna de Celestún, Yucatán	20.75	90.25	Yes
México	Estación Puerto Morelos, ICMyL Univ Nac Auto de México AP 1152 Cancun, 77500 QR, México	Puerto Morelos, Quintana Roo	20.87	86.87	Yes
Netherlands Antilles	Bonaire Marine Park PO Box 368 Bonaire, Netherlands Antilles	Bonaire	12.17	68.25	Yes
Netherlands Antilles	Carmabi Foundation Ecological Institute PO Box 2090 Biscadera Baai Curaçao, Netherlands Antilles	Curaçao	12.03	68.74	Yes
Netherlands Antilles	Saba Marine Park PO Box 18 Fort Bay Saba, Netherlands Antilles	Saba	17.62	63.25	Yes
Nicaragua	Ministerio del Ambiente y Recursos Naturales y del Medio Ambiente (MARENA) Aptdo 5123 Carr Norte km 12.5 Managua, Nicaragua	Great Corn Island	12.17	83.00	Yes
Panamá	Fac Cien Naturales y Exactas Cent Cie del Mar y Limnologia Universidad de Panamá Republica de Panamá	Panamá	09.63	79.83	No
St Lucia	Caribbean Environmental Health Institute, The Morne PO Box 1111 Castries, St Lucia	St Lucia	14.03	61.05	No

Table 1.c CARICOMP participating institutions and site locations.

Country	Institution	Site	Lat °N	Long °W	Included in this volume
Trinidad & Tobago	Institute of Marine Affairs Hilltop Lane, Chaguaramas Carenage PO Box 3160 Republic of Trinidad & Tobago	Buccoo Reef and Bon Accord Lagoon, Tobago	11.10	60.51	Yes
Venezuela	Inst Technol y Cien Marinas (INTECMAR), Univ Simon Bolívar, PO Box 89 Caracas, Venezuela	Parque Nacional Morrocoy	10.87	69.27	Yes
Venezuela	EDIMAR/Fundación La Salle de Ciencias Naturales Final Calle Colón, Aptdo 144 Punta de Piedras Estado Nueva Esparta Porlamar 6301-A, Venezuela	Punta de Mangle, Isla de Margarita	10.86	64.06	Yes
United States of America	Department of Marine Sciences University of Puerto Rico Isla Magüeyes Lab PO Box 906 Lajas, PR 00667 USA	La Parguera, Puerto Rico	18.02	66.98	Yes

Participation in the network is voluntary and open, requiring only an institutional pledge that the protocols will be implemented and the data reported. The *CARICOMP Methods Manual: Level I* (CARICOMP, 1994) is deliberately simple and requires only basic equipment for full participation. Future versions of the manual will permit the inclusion of more sophisticated observations as part of the network protocol. The annual meeting reinforces collaboration and affords an opportunity for discussing and sharing scientific and logistic issues, and for participating in training workshops. While the network is concerned with natural sciences, there exists an urgent need to extend the data collection to include social and economic considerations appropriate for resources management. However, this will require an infusion of significant new capital into the network and the participation of social scientists and resource economists; a first step was taken with an interdisciplinary CARICOMP/ UNESCO-IOC workshop held in Kingston, Jamaica, in May 1998.

The Regional Seas Programme, established by UNEP after the 1972 United Nations Conference on the Human Environment, demonstrated that regional marine ecosystems have scientific, social, and political dimensions. The political basis for cooperation in research and management of marine resources in the Caribbean was established by the 1983 UNEP Cartagena Convention on the conservation of marine resources and the control of pollution. This grew out of the United Nations Conference on the Law of the Sea (UNCLOS), to which many Caribbean countries are signatories. The success of the CARICOMP network depends on the recognition by the countries bordering the Caribbean of the region's interconnection and the need for regional cooperation in resource management. It will be a challenge for the network to participate in this development and to collaborate by making available the appropriate scientific data.

Ecosystem research has traditionally been constrained to single sites or small spatial scales; it seldom encompassed the regional range of ecosystem structure and variability. Long-term monitoring and comparative research conducted at multiple sites is required to understand the dynamics of regional variability and local and regional perturbations. Such understanding is the key to ecosystem management. The results of well designed regional studies will aid in the process of discriminating between anthropogenic disturbances and natural variation for the purpose of resources management (Jackson, 1991; Committee on Biological Diversity in Marine Systems, 1995). CARICOMP will participate in achieving this goal by providing scientific information and helping develop predictive capabilities across the Caribbean for improved management of coastal resources.

Acknowledgments

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References

Atwood, D. K, F. J. Burton, J. E. Corredor, G. R. Harvey, A. J. Mata-Jiménez, A. Vásquez-Botello, B. A. Wade. 1987. Petroleum pollution in the Caribbean. *Oceanus*, **30**(4):25-32.

Brown, B. E., J. C. Ogden. 1993. Coral bleaching. *Scientific American*, **268**(1): 64-70.

Brown, B. E. (ed.). 1990. Coral bleaching. *Coral Reefs* (Special Issue), **8** (7).

Brucks, J. T. 1970. Currents of the Caribbean and adjacent regions as deduced from drift-bottle studies. *Bulletin of Marine Science*, **21**:455-465.

Buddemeier, R. W., S. V. Smith. 1988. Coral reef growth in an era of rapidly rising sea levels: Predictions and suggestions for long-term research. *Coral Reefs*, **7**: 51-56.

CARICOMP. 1994a. *CARICOMP Methods Manual–Level I: Manual of Methods for Mapping and Monitoring of Physical and Biological Parameters in the Coastal Zone of the Caribbean.* CARICOMP Data Management Centre, University of the West Indies, Mona, Kingston, Jamaica, 54 pp.

CARICOMP. 1994b. Coral reef catastrophe [Letter to the Editor]. *Science*, **266**:1931.

CARICOMP. 1997a. Caribbean Coastal Marine Productivity (CARICOMP): A research and monitoring network of marine laboratories, parks, and reserves. **In:** *Proceedings of the 8th International Coral Reef Symposium (Panama, June 1996)* (edited by H. A. Lessios and I. G. Macintyre), Vol. I, pp 641-646. Smithsonian Tropical Research Institute, Balboa, Republic of Panama.

CARICOMP. 1997b. Physiography and setting of CARICOMP sites: A pattern analysis. **In:** *Proceedings of the 8th International Coral Reef Symposium (Panama, June 1996)* (edited by H. A. Lessios and I. G. Macintyre), Vol. I, pp 647-650. Smithsonian Tropical Research Institute, Balboa, Republic of Panama.

CARICOMP. 1997c. CARICOMP monitoring of coral reefs. **In:** *Proceedings of the 8th International Coral Reef Symposium (Panama, June 1996)* (edited by H. A. Lessios and I. G. Macintyre), Vol. I, pp 651-656. Smithsonian Tropical Research Institute, Balboa, Republic of Panama.

CARICOMP. 1997d. Meteorological and oceanographic characterization of coral reefs, seagrass and mangrove habitats in the wider Caribbean. **In:** *Proceedings of the 8th International Coral Reef Symposium (Panama, June 1996)* (edited by H. A. Lessios and I. G. Macintyre), Vol. I, pp 657-662. Smithsonian Tropical Research Institute, Balboa, Republic of Panama.

CARICOMP. 1997e. Variation in ecological parameters of *Thalassia testudinum* across the CARICOMP network. **In:** *Proceedings of the 8th International Coral Reef Symposium (Panama, June 1996)* (edited by H. A. Lessios and I. G. Macintyre), Vol. I, pp 663-668. Smithsonian Tropical Research Institute, Balboa, Republic of Panama.

CARICOMP. 1997f. Structure and productivity of mangrove forests in the greater Caribbean region. **In:** *Proceedings of the 8th International Coral Reef Symposium (Panama, June 1996)* (edited by H. A. Lessios and I. G. Macintyre), Vol. I, pp 1565-1568. Smithsonian Tropical Research Institute, Balboa, Republic of Panama.

CARICOMP. 1997g. Studies on Caribbean coral bleaching, 1995-1996. **In:** *Proceedings of the 8th International Coral Reef Symposium (Panama, June 1996)* (edited by H. A. Lessios and I. G. Macintyre), Vol. II, pp 673-678. Smithsonian Tropical Research Institute, Balboa, Republic of Panama.

CARIPOL. 1980. *Manual for Petroleum Pollution Monitoring*. Atlantic Oceanographic and Meteorological Laboratory, NOAA, Miami FL, USA.

Committee on Biological Diversity in Marine Systems. 1995. *Understanding Marine Biodiversity: A Research Agenda for the Nation*. National Academy Press, Washington DC, USA, 114 pp.

D'Elia, C. F., R. W. Buddemeier, S. V. Smith. 1991. *Workshop in Coral Bleaching, Coral Reef Ecosystems and Global Climate Change: Report of Proceedings*. Maryland Sea Grant College Publication, 49 pp.

English, S., C. Wilkinson, V. Baker (eds.). 1994. *Survey Manual for Tropical Marine Resources*. Australian Institute of Marine Science, Townsville, 368 pp.

Fry, B., P. L. Parker. 1979. Animal diet in Texas seagrass meadows: ^{13}C evidence for the importance of benthic plants. *Estuarine and Coastal Marine Science*, **8**:499-509.

Ginsburg, R. N. (compiler) 1994. *Proceedings of the Colloquium on Global Aspects of Coral Reefs: Health, Hazards, and History, 1993*. Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami FL, USA, 420 pp.

Gladfelter, W. B. 1982. White band disease in *Acropora palmata*: implications for the structure and growth of shallow reefs. *Bulletin of Marine Science*, **32**: 639-643.

Hay, M. E. 1984. Patterns of fish and urchin grazing on Caribbean coral reefs. Are previous results typical? *Ecology*, **65**:446-454.

Hooks, T. A., K. L. Heck Jr., R. J. Livingston. 1976. An inshore marine community: structure and habitat associations in the northeastern Gulf of Mexico. *Bulletin of Marine Science*, **26**: 99-109.

Hughes, T. P. 1989. Community structure and diversity of coral reefs: The role of history. *Ecology*, **70**:275-279.

Hughes, T. P. 1994. Catastrophes, phase shifts, and large-scale degradation of a Caribbean reef. *Science*, **266**:1547-1549.

ICRI (International Coral Reef Initiative). 1995. *Partnership Building and Framework Development.* Final Report of the ICRI Workshop, Silliman University, Dumaguete City, The Philippines, 64 pp.

Jackson, J. B. C. 1991. Adaptation and diversity of reef corals. *Bioscience*, **41**:475-482.

Jordán, E., E. Martín. 1987. Chinchorro: structure and composition of a Caribbean atoll. *Atoll Research Bulletin*, **310**:1-27.

Kinder, T. 1983. Shallow currents in the Caribbean Sea and Gulf of Mexico as observed with satellite-tracked drifters. *Bulletin of Marine Science*, **33**:239-246.

Kjerfve, B. 1981. Tides of the Caribbean Sea. *Journal of Geophysical Research*, **86**(C5):4243-4247.

Kjerfve, B., K.E. Magill, J. W. Porter, J. D. Woodley. 1986. Hindcasting of hurricane characteristics and observed storm damage on a fringing reef, Jamaica, West Indies. *Journal of Marine Research*, **44**:119-148.

Ledgister, R., D. M. Linton, J. D. Woodley. 1997. Use of spreadsheet templets for general data entry and their subsequent integration into the database system. **In:** *Proceedings of the 8th International Coral Reef Symposium (Panama, June 1996)* (edited by H. A. Lessios and I. G. Macintyre), Vol. II, pp 1565-1568. Smithsonian Tropical Research Institute, Balboa, Republic of Panama.

Lessios, H. A., D. R. Robertson, J. D. Cubit. 1984. Spread of *Diadema* mass mortality through the Caribbean. *Science*, **226**:335-337.

Lewis, J. B. 1977. Processes of organic production on coral reefs. *Biological Review*, **52**:305-347.

Lugo, A. E., G. Evink, M. M. Brinson, A. Broce, S.C. Snedaker. 1973. Diurnal rates of photosynthesis, respiration and transpiration in mangrove forests of south Florida. **In:** *The Role of Mangrove Ecosystems in the Maintenance of Environmental Quality and a High Productivity of Desirable Fisheries* (edited by S. C. Snedaker and A. E. Lugo), pp D1-D45. Final Report submitted to the Bureau of Sport Fisheries and Wildlife, State of Florida USA, 406 pp.

McFarland, W. N., E. B. Brothers, J. C. Ogden, M. J. Shulman, E. L. Bermingham, N. M. Kotchian-Prentiss. 1985. Recruitment patterns in young French grunts, *Haemulon flavolineatum* (Family Haemulidae), at St. Croix, Virgin Islands. *Fisheries Bulletin*, **83**:413-426.

Meyer, J. L., E.T. Schultz, G. S. Helfman. 1983. Fish schools: An asset to corals. *Science*, **220**:1047-1049.

Mitton, J. B., C. J. Berg Jr., K. S. Orr. 1989. Population structure, larval dispersal, and gene flow in the queen conch, *Strombus gigas*, of the Caribbean. *Biological Bulletin*, **177**:356-362.

Müller-Karger, F. E., C. R. McClain, T. R. Fisher, W. E. Esaias, R. Varela. 1989. Pigment distributions in the Caribbean Sea: Observations from space. *Progress in Oceanography*, **23**:23-64.

Nagelkerken I., K. Buchan, G. W. Smith, K. Bonair, P. Bush, J. Garzón-Ferreira, L. Botero, P. Gayle, C. Heberer, C. Petrovic, L. Pors, P. Yoshioka. 1997. Widespread disease in Caribbean sea fans: I. Spreading and general characteristics. **In:** *Proceedings of the 8th International Coral Reef Symposium (Panama, June 1996)* (edited by H. A. Lessios and I. G. Macintyre), Vol. II, pp 679-682. Smithsonian Tropical Research Institute, Balboa, Republic of Panama.

Ogden, J. C., J. C. Zieman. 1977. Ecological aspects of coral reef-seagrass bed contacts in the Caribbean. *Proceedings of the 3rd International Coral Reef Symposium (Miami)*, **1**: 377-382.

Ogden, J. C., E. H. Gladfelter (eds.). 1983. *Coral Reefs, Seagrass Beds, and Mangroves: Their Interaction in the Coastal Zones of the Caribbean.* UNESCO Reports in Marine Science 23, 133 pp.

Ogden, J. C., E. .H. Gladfelter (eds.). 1986. *Caribbean Coastal Marine Productivity.* UNESCO Reports in Marine Science 41, 59 pp.

Ogden, J. C. 1987. Cooperative coastal ecology at Caribbean marine laboratories. *Oceanus*, **30**: 9-15.

Ogden, J. C. 1988. The influence of adjacent systems on the structure and function of coral reefs. *Proceedings of the 6th International Coral Reef Symposium*, **1**:123-129.

Ogden, J. C., R. Wicklund (eds.). 1988. *Mass Bleaching of Coral Reefs in the Caribbean: A Research Strategy.* National Undersea Research Program, Research Report 88-2, 50 pp.

Ogden, J. C. 1992. The impact of Hurricane Andrew on the ecosystems of south Florida. *Conservation Biology*, **6**:488-490.

Ogden, J. C. 1997. Marine managers look upstream for connections. *Science*, **278**:1414-1415.

Pernetta J. C., P. I. Hughes (eds.). 1990. *Implications of Expected Climate Changes in the South Pacific Region: An Overview.* UNEP Regional Seas Reports and Studies 128, 279 pp.

Population Reference Bureau. 1996. *World Population Data Sheet of the Population Reference Bureau.* Washington DC, USA, 16 pp.

Roberts, C. M. 1997. Connectivity and management of Caribbean reefs. *Science*, **278**:1454-1457.

Rogers, C. S. 1985. Degradation of Caribbean and Western Atlantic coral reefs and decline of associated reef fisheries. *Proceedings of the 5th International Coral Reef Symposium (Papeete, Tahiti)*, **6**:491-496.

Rützler, K., D. L. Santavy. 1983. The black band disease of Atlantic reef corals, I: Description of the cyanophyte pathogen. *Marine Ecology Progress Series*, **4**:329-358.

Shulman, M. J., E. Bermingham. 1995. Early life histories, ocean currents, and the population genetics of Caribbean reef fishes. *Evolution*, **49**: 897-910.

Smith S. R, J. C. Ogden (eds.). 1994. Status and recent history of coral reefs at the CARICOMP network of Caribbean marine laboratories. **In:** *Proceedings of the Colloquium on Global Aspects of Coral Reefs: Health, Hazards, and History (1993)* (compiled by R. N. Ginsburg), pp 73-79. Rosenstiel School of Marine and Atmospheric Sciences, University of Miami FL, USA, 420 pp.

Smith, S. V., R. W. Buddemeier. 1992. Global change and coral reef ecosystems. *Annual Review of Ecological Systems*, **23**:89-118.

Snedaker, S. C., J. G. Snedaker (eds.). 1984. *The Mangrove Ecosystem: Research Methods.* UNESCO Monographs on Oceanographic Methodology 8, 251 pp.

Stewart, R. W., B. Kjerfve, J. Milliman, S. N. Dwivedi. 1990. Relative sea level change: A critical evaluation. *UNESCO Reports in Marine Science*, **54**:1-22.

Stoddart, D. R., R. E. Johannes. 1978. *Coral Reefs: Research Methods.* UNESCO Monographs on Oceanographic Methodology 5, 581 pp.

Wells, S. M. 1988. *Coral Reefs of the World.* Vol. 1: *Atlantic and Eastern Pacific.* UNEP/IUCN, 373 p.

Wilkinson, C. R., R. W. Buddemeier. 1994. *Global Climate Change and Coral Reefs: Implications for People and Reefs. Report of the UNEP-IOCASPEI-IUCN Global Task Team on the Implications of Climate Change on Coral Reefs.* IUCN, Gland, Switzerland, 124 pp.

Wilkinson, C. 1994. Coral reefs are facing widespread extinctions: Can we prevent these through sustainable management practices? *Proceedings of the 7th International Coral Reef Symposium (Guam)*, **1**:11-21.

Williams, E. H., C. Goenaga, V. Vicente. 1987. Mass bleaching on Atlantic coral reefs. *Science*, **238**:877-878.

Woodley, J. D., E. A. Chornesky, P. A. Clifford, J. B. C. Jackson, L. S. Kaufman, N. Knowlton, J. C. Lang, M. P. Pearson, J. W. Porter, M. C. Rooney, K. W. Rylaarsdam, V. J. Tunnicliffe, C. M. Wahle, J. L. Wulff, A. S. G. Curtis, M. D. Dallmeyer, B. P. Jupp, M. A. R. Koehl, J. Niegel, E. M. Sides. 1981. Hurricane Allen's impact on Jamaican coral reefs. *Science*, **214**:749-755.

Wüst, G. 1964. *Stratification and Circulation in the Antillean-Caribbean Basins.* Columbia University Press, New York NY, USA, 201 pp.

Yokel, B. J., E. S. Iverson and C. P. Idyll. 1969. Prediction of the success of commercial shrimp fishing on the Tortugas grounds based on enumeration of emigrants from the Everglades National Park Estuary. *FAO Fisheries Report*, **57**:1027-1039.

Zieman, J. C., G. W. Thayer, R. B. Robblee, R. T. Zieman. 1979. Production and export of seagrasses from a tropical bay. **In:** *Ecological Processes in Coastal and Marine Systems* (edited by R. J. Livingston), pp 21-34. Plenum Press, New York NY, USA.

Discovery Bay, Jamaica[1]

Peter M. H. Gayle[1] and Jeremy D. Woodley[2]
[1]*Discovery Bay Marine Laboratory, PO Box 35, Discovery Bay, St. Ann, Jamaica*
[2]*Centre for Marine Sciences, University of the West Indies (Mona), Kingston 7, Jamaica*

The CARICOMP site in Jamaica is located in waters adjacent to the Discovery Bay Marine Laboratory (DBML). A rocky shoreline supports a tangled mass of *Rhizophora mangle*.adjacent to protected euryhaline waters. Mature beds of the seagrass *Thalassia testudinum* grow offshore in the lagoon behind the reef flat. The fringing coral reef is a spur-and-groove system on a narrow submarine shelf; it shows the effects of natural catastrophes and anthropogenic impacts. Daytime onshore northeasterly trade winds alternate with lighter, southerly, offshore land breezes at night. Human influences on the ecology of the area, which supports a small town, include terrestrial runoff from agricultural and residential developments, the activities of about one hundred fishermen based at two small fishing beaches, and the shipping of bauxite. Current research at DBML seeks to develop community-based management of fishery resources and to define the oceanography, water chemistry, and benthic processes of Discovery Bay.

Introduction: Geology and Geography

Jamaica is the third largest island in the Greater Antilles (235 km long, 99 km wide; Fig. 1), with mountains over 2,000 m high. The CARICOMP site, Discovery Bay (18°28'00"N, 77°24'30"W; 1.4 km^2, maximum depth of 55 m), is located in the west-central portion of the north coast.

On Jamaica, Cretaceous basement rocks are capped by Tertiary limestones and, on the north coast, by the Coastal Formation of Pleistocene reef deposits. Quaternary sea-level changes have created terraces above and below the present sea level, bounded by raised or drowned sea cliffs. On land, subaerial solution has created a karst lithology, with terraces covered by Dry Limestone Woodland. Along the north coast, a narrow submarine shelf (<1 km wide) supports well defined Holocene fringing and sill reefs.

The fringing reef is continuous across the 1.2 km wide mouth of Discovery Bay, and the bay is almost cut off from the open sea. The reef crest breaks the surface in the western half of the bay, but it is just below the surface in the eastern half. Basement levels are lower in the east, due to displacement at a fault that divides the western and eastern halves of the bay (Liddell and Ohlhorst, 1981). The

[1] *CARICOMP — Caribbean Coral Reef, Seagrass and Mangrove Sites* (edited by B. Kjerfve), pp 17-33.
UNESCO, Paris, 1998, 347 pp.

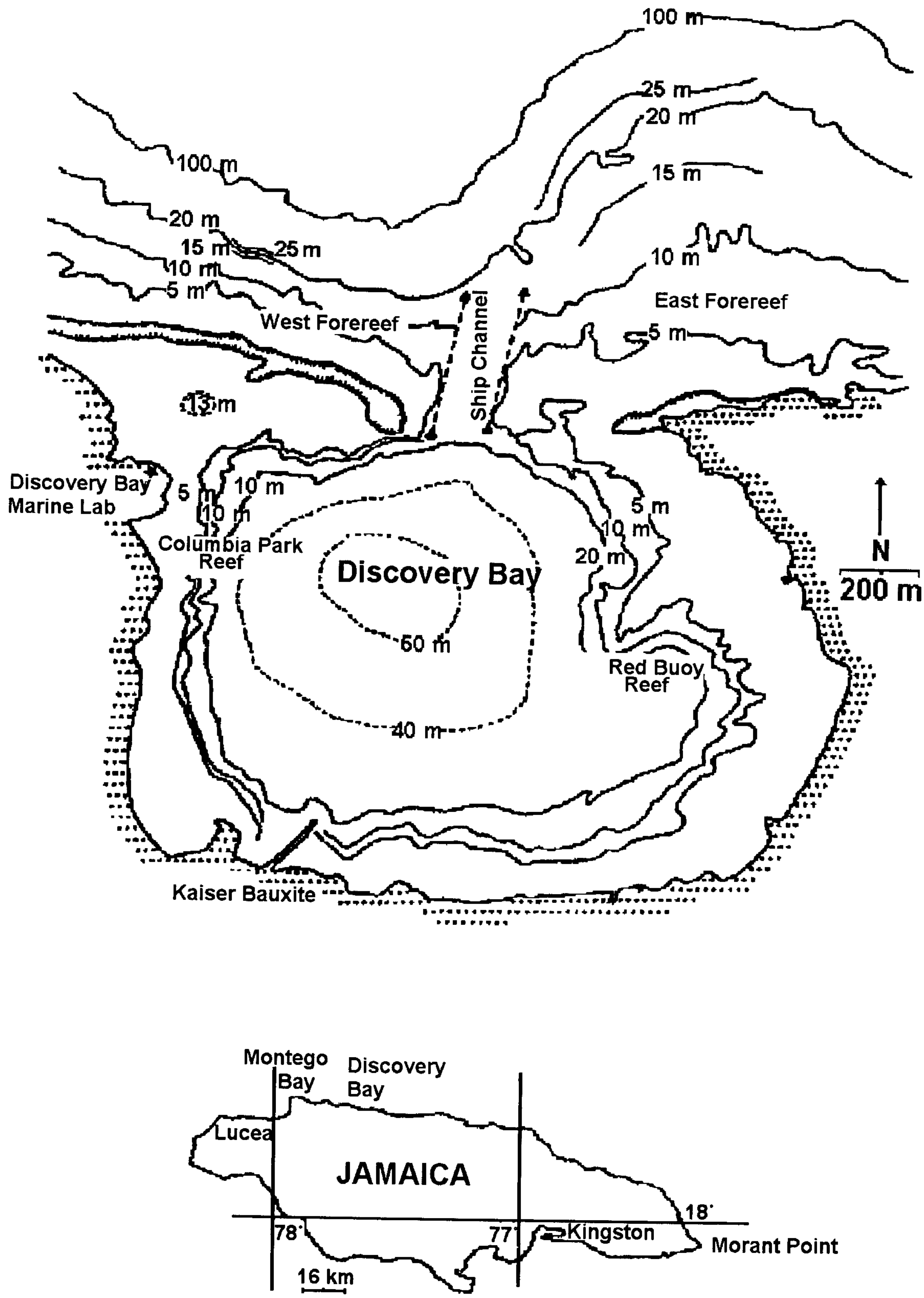

Fig. 1. Map of Jamaica and bathymetry of Discovery Bay.

entrance to the bay lies between these two sections; it was 300 m wide and only 5 m deep, but in 1964 a channel 120 m wide and 12 m deep was cut in order to allow the passage of bauxite freighters.

Within the bay, steeply sloping submerged cliffs descend to the muddy floor of a deep central basin where sediments are up to 50 m thick (Hine *et al.*, 1991). On the eastern side of the bay and in the northwestern quadrant, shallow, sandy shelves are covered with seagrass beds. The southern and western sides of the bay are lined by headlands rising from near the water's edge. Most of the shoreline is rocky, but there is a gently sloping, 400 m long stretch of sand in the southwestern corner of the bay known as Puerto Seco Beach. The Discovery Bay Marine Laboratory is located atop the low headland on the northwestern side of the bay. A 13 m deep drowned sink-hole (a blue hole) is nearby (Fig. 1).

The small town of Discovery Bay extends up the southern slopes and over the flat land to the east of the bay. A row of large private houses fronts the sheltered, eastern side of the bay, and the wooded land behind them to the east is the site of proposed housing developments. The southwestern corner of the bay contains Port Rhoades, the loading facility of the Kaiser Jamaica Bauxite Company, which can accommodate ore carrier vessels up to 25,000 dwt. The bauxite, which is excavated from the interior of the Parish of St. Ann, is received and dried at the top of the hill behind Port Rhoades. Most of the rocky, wooded land west of the bay is owned by Kaiser and is undeveloped. Columbus Park, an educational and historical park that contains tourist lookouts, is located on the cliffs extending along the western shore between Port Rhoades and the Marine Laboratory.

The largest employer in Discovery Bay, with over 500 workers, is Kaiser. Fishing, tourism, research, and teaching, as well as the usual social support services characteristic of small towns, are the other main activities in the area. In 1982 the town's population was estimated to be 1,151 (SIJ, 1993), which doubled by 1996. Prior to the establishment of the bauxite company, the main source of employment was artisanal fishing; now many of the fisherman have other jobs to supplement their income. Sary (1995) indicates that about 25% of the fishermen work with Kaiser, while another 25% are also involved with tourism; the remainder are self-employed tradesmen or are retired. Discovery Bay itself boasts a population of 74 resident fishermen (Vatcher, 1995) based at two main beaches within the confines of the bay. The fish populations being exploited are mainly pelagic and reef fishes, lobster, conch, and octopus (traps, 46%; spearfishing, 28%; hook-and-line fishing, 22%; gill nets, 4%).

Climate and Oceanography

Jamaica's climate is subtropical, traditionally marked by two wet and two dry seasons, and irregularly modified by cold fronts from North America in winter and by tropical disturbances from the Atlantic in summer and autumn. Persistent rains, sometimes continuing for a week or more without interruption, occur between October and December; a second period of heavy rainfall often occurs during April and May. However this general pattern can vary significantly from year to year. June and July are normally the driest months of the year; rainfall in Discovery Bay during the dry season of 1983 totaled 260 mm, compared to 875 mm during the wet season of the same year (Fig. 2). Not surprisingly, Ohlhorst (1980) found that rainy days and windy days per month are inversely correlated ($p<0.01$).

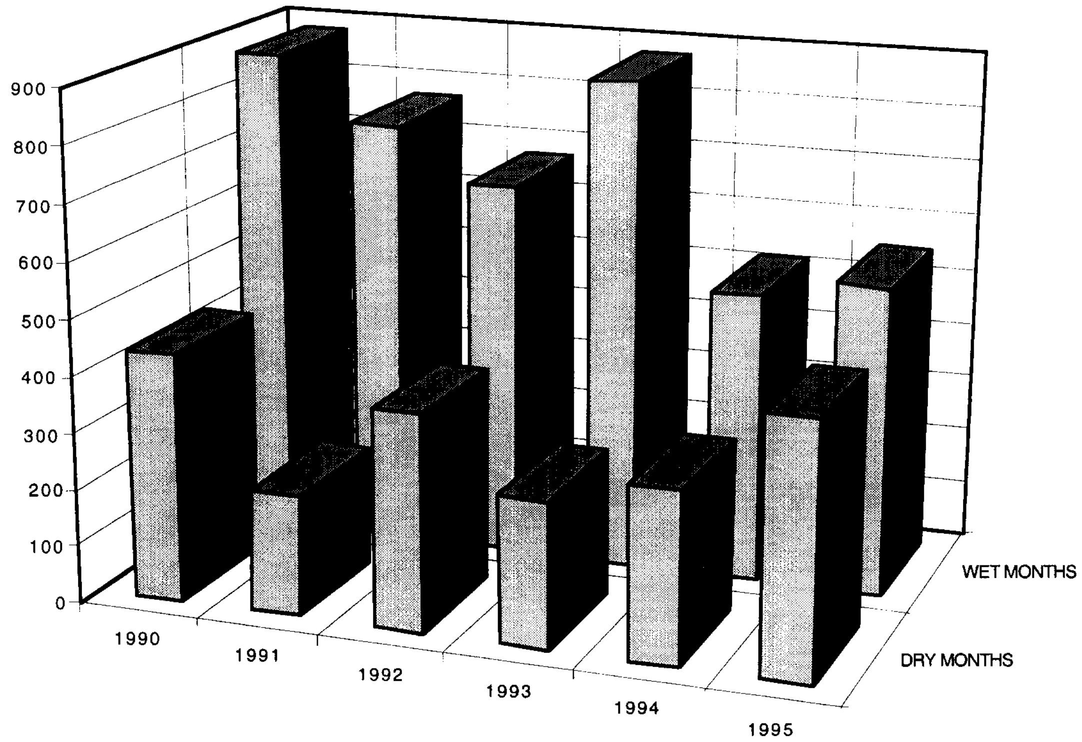

Fig. 2. Total rainfall compared between wet and dry seasons at the Discovery Bay Marine Laboratory, Jamaica: 1990-1995.

Porter (1985) recorded solar radiation at 843 E m^{-2} yr^{-1} in February 1983 and 1,384 E m^{-2} yr^{-1} in August 1983. During the period 1993-1995, the monthly mean maximum air temperature was lowest in January (28.4°C) and highest in August and September (32.9°C). The monthly mean minimum air temperature was lowest in March (20.9°C) and highest in May and August (25.9°). In Discovery Bay, Porter (1985) recorded an instantaneous high of 34.2°C in August 1983 and a low of 18.1°C in January 1984.

The name given to Discovery Bay by Columbus was Puerto Seco (Dry Harbor) because, unlike the neighboring Rio Bueno, there are no permanent rivers flowing into it. However, groundwater does enter the bay through deep cracks in the basement limestone, especially on the fault line that runs through the ship channel and on the western side. The salinities of the submerged springs are greater than 20‰, yet they cause a marked stratification in temperature and salinity in the shallow western back reef. They also help to account for differences in these parameters between the three CARICOMP sites. Average monthly water temperatures between 1993 and 1995 (Fig. 3) were cool near the mangroves (25.8-26.7°C), moderate at the coral reef site (27.9-28.7°C), and quite warm over the shallow-water seagrass beds (28.3-29.03°C). Seasonal variability in rainfall was reflected in the monthly means of the salinity measurements at the mangrove site (25.6-27.1‰), while the shallow seagrass and coral reef sites exhibited a higher range of values (34.1-36.2‰) indicative of oceanic water influences (Fig. 4). There is no marked stratification in salinity within the main body of Discovery Bay.

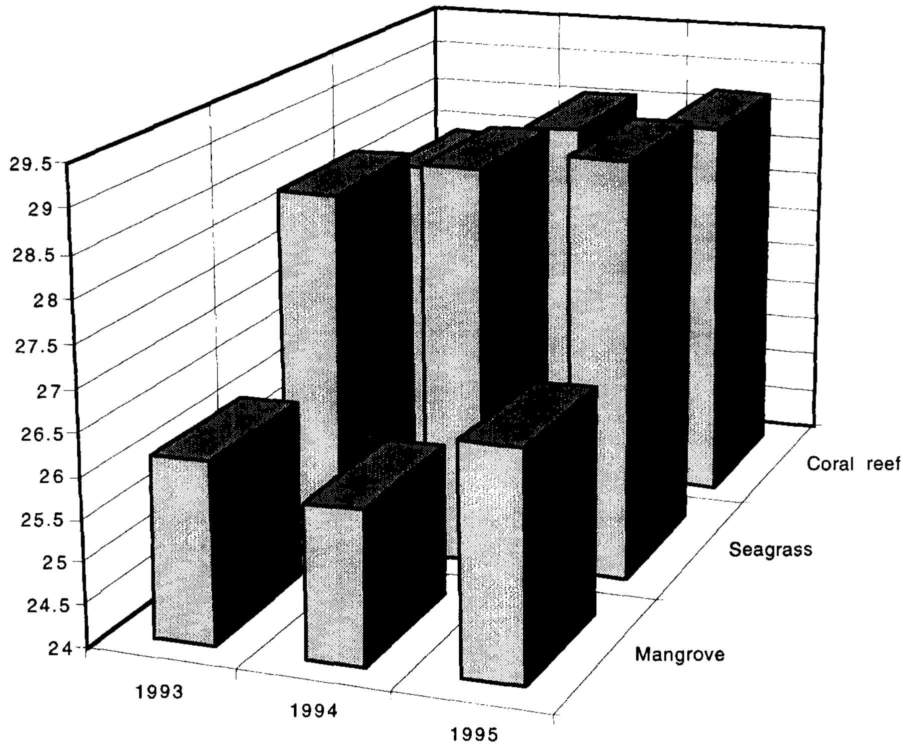

Fig. 3. Mean water temperature at CARICOMP sites, Discovery Bay, Jamaica: 1993-1995.

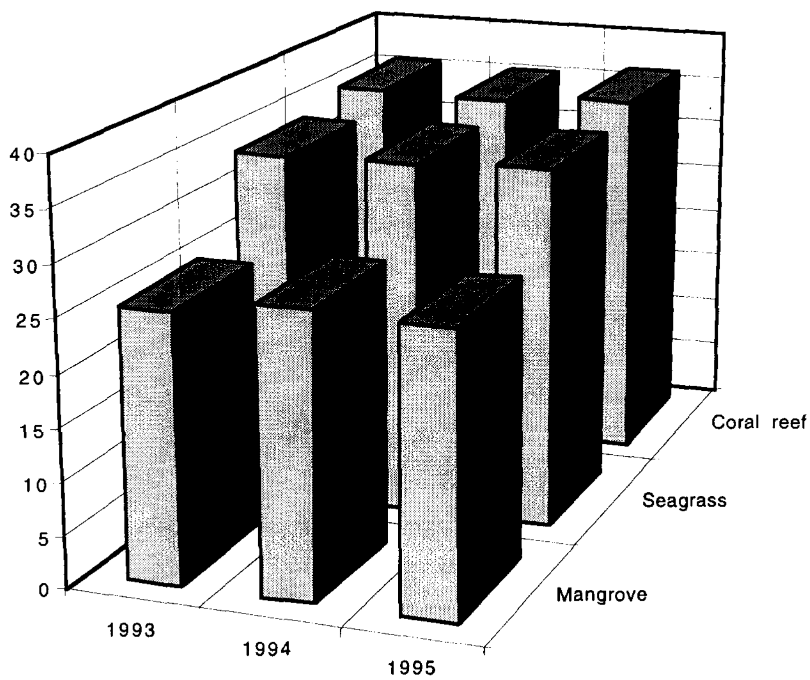

Fig. 4. Mean salinity at CARICOMP sites, Discovery Bay, Jamaica: 1993-1995

The weather of the north coast of Jamaica is dominated by northeasterly tradewinds, modified by local sea and land breeze systems. The trades combined with sea breezes usually give rise, by mid-morning (1000 hours local time), to a wind from the northeast that increases from an initial speed of 1-2 m s^{-1} to 4-9 m s^{-1} in mid-afternoon (1400 hours) and returns to 1-2 m s^{-1} in early evening (1800 hours). There is usually no wind between 2100 and 0500 hours because the differences in heat capacities of the land and sea masses generate land breezes that counteract the constant tradewinds (Kjerfve, pers. comm., 1993). Porter (1985) showed that the major changes in wind parameters are not in direction but in speed, with average wind speeds lowest in October and as high as 13 m s^{-1} in May. During the months December to March, the regular tradewind and land-sea breeze patterns may be interrupted by the passage of cold fronts from North America. These "northers" occur with irregular frequency from year to year; they typically last for three to four days and are accompanied by rain and strong northwesterly winds of 2-15 m s^{-1} (18-40 km h^{-1}). During summer and early fall, the tradewinds are weaker and less predictable, and there may be extended periods of unusually calm weather with little or no wind during early morning hours.

The north coast of Jamaica is sheltered from oceanic swells by Cuba, which lies 150 km north, and the prevailing tradewinds have limited fetch. The local wave regime is primarily generated by the local wind pattern; when the wind drops in the evening, the sea generally becomes calm and may remain so until the sea breeze returns the next morning, at which time the sea rapidly reaches wave heights of 1.5 m or more. The waves over the shallow back reef within Discovery Bay are capable of resuspending bottom sediments for relatively short periods (days), a factor which may help to restrict coral growth (Dodge *et al.*, 1974). Much higher waves are generated during northers or hurricanes.

Jamaica usually experiences a mixed tidal regime, with primarily diurnal spring tides and low-amplitude semi-diurnal neaps. DBML data for a three-month period in 1984 showed a daily tidal range between 15 and 60 cm; due to seasonal variations in sea level, however, the annual range may be as much as 1 m. Because of the limited tidal range, currents within the bay are primarily wind driven. The fringing reef is generally swept by the slow east-west Caribbean Current, but the prevailing tradewinds generate steep, short period waves (2-3 sec) that approach the Discovery Bay reefs from the northeast and create a distinct bi-directional surge current combined with a slow (0.25 m s^{-1}), uni-directional westerly current on the shallow forereef. Occasional stronger and deeper currents (~0.75 m s^{-1}) may run in opposition to the surface currents on the forereef. This situation is not confined to rough (northwesterly) weather; it has been noted on exceptionally calm days (pers. observation). Behind the reef crest, the tradewinds generate a slow, clockwise surface current as water enters the bay along its eastern margin. Several smaller circulation gyres form inside the bay, before the water exits over the western reef crest. At night, the gentle southerly land breeze creates a general movement of surface water out of the bay through the ship channel and over the entire reef crest. Water enters over the western side of the reef crests during the episodic northwesterlies, again forming gyres inside the bay before exiting to the east of the ship channel (Fitzpatrick, 1993).

Since 1871, Discovery Bay has experienced thirteen hurricanes (Woodley, 1992). Only two of these occurred after 1944, but they were the strongest hurricanes ever recorded in the western Atlantic. Hurricane Allen (1980) and Hurricane Gilbert (1988) generated wind speeds estimated in Discovery Bay at

110 and 180 km h^{-1}, respectively. Although Hurricane Allen weakened as it passed Jamaica, maximum deep-water wave height at 160 km north of Discovery Bay was hindcast at 7.8 m, with a significant wave period of 10.4 sec. After shoaling and refracting as the waves passed over the forereef slope, peak breakers 11.5 m high were calculated to have impacted the eastern forereef (Kjerfve *et al.*, 1988). This analysis is supported by photographs of 12-m-peak waves taken at the site by Woodley *et al.* (1981). On the western forereef (where the CARICOMP site is located), wave heights were hindcast to have been at least 8 m (Kjerfve *et al.*, 1986). Because of wave refraction, the calculated breaker heights at different points varied by a factor of 2.6. These waves, from the first major storm in 36 years, generated high levels of destruction of corals on much of the completely exposed reefs of the north coast. A secondary effect was the creation of a new substratum for the growth of algae. The deeper reefs (>25 m deep) were only slightly affected by Hurricane Allen (Porter *et al.*, 1981). Woodley and his colleagues documented the cumulative effect of all this destructive power on the reefs of Discovery Bay (Woodley *et al.*, 1981; Woodley, 1989).

Anthropogenic Impacts

In contrast to some other parts of the Caribbean, few fishes are to be found in Jamaican coastal waters. The major cause of their depletion is believed to be overfishing (Koslow *et al.*, 1986). The impact of fishing is especially pronounced along the north coast, where the submarine shelf is very narrow and fishing efforts are concentrated in a small area (Munro, 1983). The fishing methods used are selective and exert the greatest pressure on medium to large herbivores and predators. The large breeding flocks of striped parrotfish (*Scarus croicensis*) described by Colin (1978) are a tenth of their former size. Roving flocks of surgeon fish are no longer evident in the lagoons, and it is noteworthy when any fish as long as 30 cm is seen. Since the mid-1970s, there has been a marked increase in the number of spearfishers, and spearfishing at night with underwater lamps and scuba gear has also increased in popularity. Pollnac (1995) reports that spearfishers visiting from as far afield as Trelawny Parish, and even some displaced by increased enforcement activities at the Montego Bay Marine Park, are pressuring Discovery Bay fish stocks. In 1996, a group of 15-20 spearfishers was seen cooperating, in a shoulder-to-shoulder line, to sweep sections of the coast. It is possible that the surviving fishes have learned to flee both snorkelers and scuba divers, perhaps making the problem appear to be worse than it really is.

Kaufman (1983) postulates that the loss of spatial heterogeneity caused by Hurricane Allen in 1980, and reinforced by Hurricane Gilbert in 1988, has reduced the carrying capacity of the reef. Hughes (1994) goes further and argues that the combination of anthropogenic and natural factors acting on the reefs has caused a phase shift from high diversity, coral-dominated reefs to a low diversity, algae-dominated system. Changes in the reef community resulting from intensive fishing activity have also been suggested by Woodley (1979). Small territorial damselfish have increased in abundance, and there are still large numbers of midwater plankton feeders such as Creole Wrasse (*Clepticus parrai*) and Blue Chromis (*Chromis cyanea*). These possible overfishing indicator species may act as filter screens, decreasing the successful recruitment of other reef fishes, such as happens with fishes and intertidal barnacle populations in temperate waters (Gaines and Roughgarden, 1987).

The problem of overexploited reef fish stocks is the main focus of the Fisheries Improvement Program based at DBML since 1988. The aim of the program is to work with fishermen to help them better manage their fishery resources. One approach used in 1991 was a "two-for-one" exchange program, which involved replacing more than 250 small-mesh pots (3.3-4.1 cm mesh) with large-mesh pots (5.5 cm mesh). Subsequent beach monitoring of fish catches demonstrated an increase in length-at-first-capture and a change in size frequency distribution of the redband parrotfish (*S. aurofrenatum*; Sary *et al.*, 1997a). By 1994, trap catches had increased in both weight and numbers, and catch composition had shifted toward larger and more economically valuable species (Sary *et al.*, 1997b).

Recreational and residential use by locals and tourists places great pressure on the marine environment of Discovery Bay. Water skiing, jet skiing, and snorkel/scuba diving occur in the shallow backreef waters. Puerto Seco Beach is heavily used on holiday weekends, not only by locals and tourists but also by 15-20 large busloads of people making day trips from surrounding areas. With no central sewage disposal system, there is a proliferation of individual units from residences and businesses surrounding the bay; these range in type from numerous soakaways to a few state-of-the-art tertiary systems. Moreover, blasting for construction of piers and beaches along the eastern shoreline has resulted in cases of erosion.

D'Elia *et al.* (1981) demonstrated that groundwaters in this part of Jamaica typically contain 80 µmol of nitrogen per liter, primarily as nitrate, but are essentially devoid of phosphates. Therefore, the submarine springs that feed Discovery Bay are a significant source of nitrate and there is a strong, linear, inverse correlation between salinity and nitrate concentration. These investigators suggested that the nitrates were derived naturally (from forest leaf litter and meteoric water) rather than anthropogenically. More current research indicates that nitrate and phosphate levels in the bay are either undetectable at some sites or are approximately equivalent to accepted critical values established for the health of coral reefs (1 µM nitrogen, 0.1 µM phosphorus). These low nutrient values, comparable to those obtained by D'Elia *et al.* (1981), indicate that small, quickly absorbed amounts are entering the bay and/or that there is good mixing and flushing of bay waters. It is also possible that some nutrient-rich urban waste waters flow underground north to the sea rather than into the bay.

Despite the above, there are recent indications that a problem with excess nutrients is developing. Algae such as *Chaetomorpha* and *Dictyosphaeria* spp. are more noticeable in the lagoon and on the forereef. Also, black-stained sediments are being found just beneath the surface of sediments near the southern and eastern shores. Spills of fuel, oil, and contaminated bilge water have occurred at Port Rhoades, which, because of the localized circulation gyres within the bay, have affected primarily the eastern side. Kaiser has occasionally used chemical dispersants to break up these spills, but there is no evidence of negative, long-term effects on the flora and fauna of the bay.

Ecosystems and Major Impacts

Jamaica's reefs were the first in the Caribbean to be studied intensively, and more stony coral species have been recorded here than anywhere else in the Caribbean — 64 species (Wells and Lang,

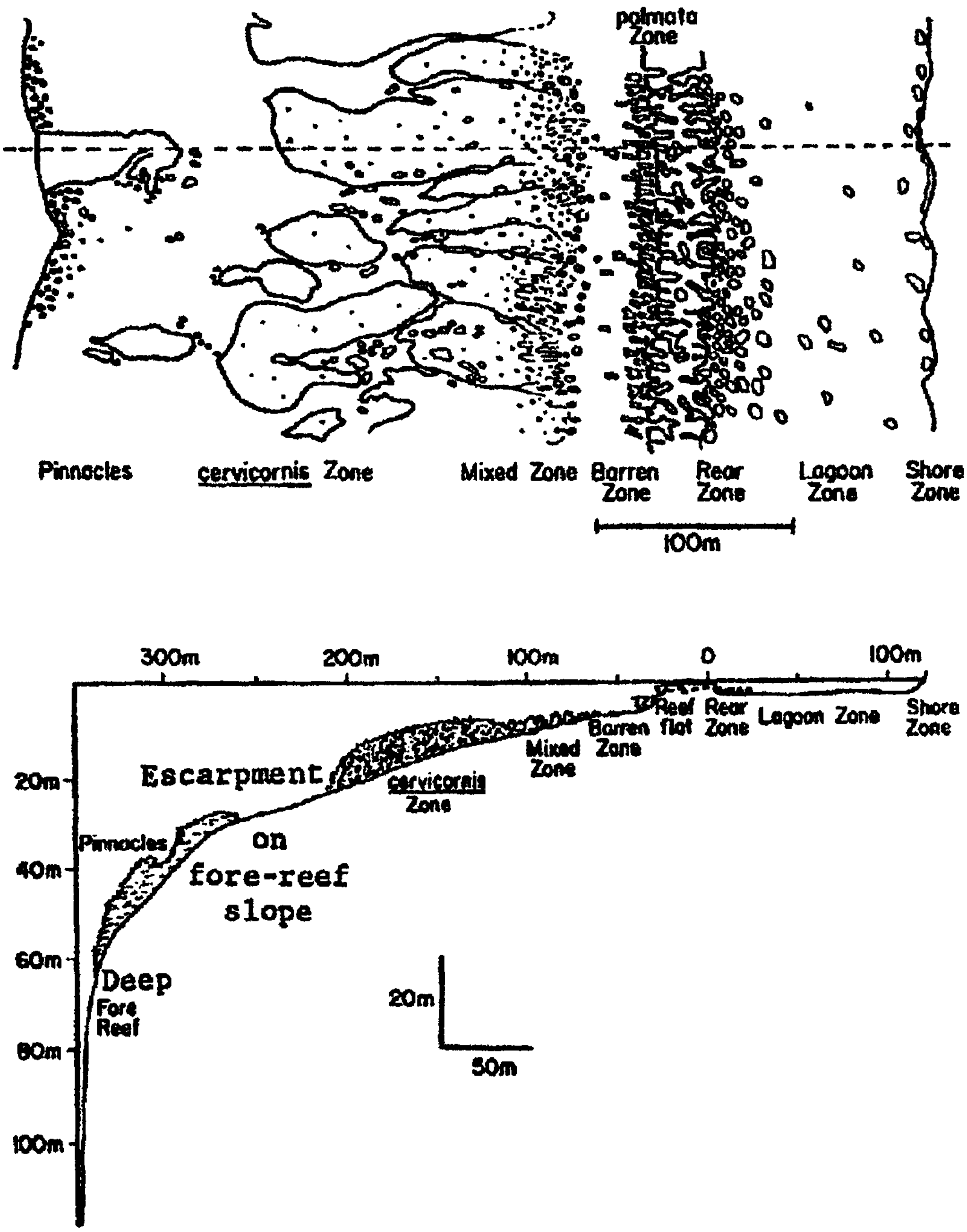

Fig. 5. Zonation profile of Discovery Bay reefs (after Kinzie, 1973).

1973). The most studied Jamaican reefs are those at Discovery Bay. Figure 5 illustrates the characteristic zonation pattern for these reefs prior to Hurricane Allen in 1980 (from Woodley and Robinson, 1977).

The reef flat in the western portion of Discovery Bay is founded primarily on erect dead skeletons of *Acropora palmata* and *Millepora complanata*. Seaward of the reef flat was a broad thicket of living *A. palmata* which is now a rubble slope. Farther out on the gently sloping terrace, where massive corals grew among bramble bushes of staghorn (*A. cervicornis*), the corals now arise from a cemented, eroded mat of staghorn twigs. By 1988, there had been some recruitment by *A. agaricites* and *Porites* spp., and colonies of staghorn had become established in some areas and were beginning to thrive; all were smashed by Hurricane Gilbert in 1988. What used to be a chain of islets (the Allen Islands, created by Hurricane Allen in 1980 from *A. palmata* rubble) united into an almost continuously visible barrier, was remobilized and spread out inside the bay by Hurricane Gilbert in 1988. Although now emergent in only a few places, the barrier effect of the reef crest remains. *Montastraea annularis*, in the mixed zone at 5-10 m depths (Goreau and Wells, 1967), is still the chief foundation of incipient buttresses, where they occur. The outer part of the terrace is dissected by sand drainage channels to form a spur-and-groove system. The spurs (built by *A. cervicornis*) terminate at the outer edge of the shallow terrace as a steep intermittent escarpment that slopes steeply from a depth of 17 m to about 25 m. Major sand channels continue down the forereef slope between pinnacles of reef growth before discharging over a submarine cliff at a depth of about 55 m to the talus slope below at a depth of about 130 m. The deep pinnacles (25-40 m depths) are largely composed of the flattened morphs of *M. annularis*, whereas species of *Agaricia* are the dominant corals at greater depths, down to 70 m.

It has often been assumed that the primary causes of hurricane-induced mortality on a reef are high wave energy and low salinity due to heavy rain during the storm event. Knowlton *et al.* (1981) demonstrated substantial tissue and colony mortality in *A. cervicornis* **after** Hurricane Allen, an episode that was sustained for 5 months and was an order of magnitude greater than that caused by the immediate effects of the storm. This was a consequence of predation and "white-band" disease, and it resulted in the elimination of more than 98% of the original hurricane survivors. The previously unsuspected but combined effects of disease and predation would go a long way toward explaining widely variable rates of reef recovery previously reported. The coral-eating snail *Coralliophila caribbea* was particularly effective in killing survivors and recruits of *A. cervicornis* (Knowlton *et al.*, 1988). This animal might have been unusually abundant due to removal of its predators by overfishing. By 1988, however, the snail was again scarce, and small *A. cervicornis* colonies were common. Then came Hurricane Gilbert.

By 1983, removal of herbivorous fishes had apparently allowed free-living algae to become more abundant in deeper waters while they remained relatively scarce in shallow waters. There, the grazing sea urchin *Diadema antillarum* had become more common over the years, due to removal of its predators (Woodley, 1979; Hay, 1984). This urchin had become the single most important herbivore to a depth of about 20 m, and it was maintaining a low level of algal cover that was of benefit to the corals. A Caribbean-wide epidemic disease occurred in 1983 and all but eliminated this important herbivore from Jamaican reefs (99% mortality; Hughes *et al.*, 1985). At Discovery Bay, Liddell and Ohlhorst (1986) found that population density at depths between 0 and 20 m had decreased from 6.6 urchins per square meter to zero; after one year, bottom cover showed a concomitant increase in non-crustose algae from 30.7% to 64.7%. This occurred at the expense of other reef benthos such as crustose coralline algae and sponges. This rich bloom of algae still persists in Jamaican waters because there has been very little recovery in the general *Diadema* population and herbivorous fishes are still scarce (Hughes *et al.*, 1987). The algae *Dictyota* and *Halimeda* spp., *Caulerpa racemosa*, and *Lobophora variegata* are particularly abundant. When adjacent to corals, these algae often over-shade them, causing eventual coral death (Liddell and Ohlhorst, 1986). Also, the profuse algal growth may be preventing settlement of coral as well as other invertebrate larvae. From random transects on the Discovery Bay forereef in 1992, coral cover was as low as 2.0%. However, some sessile invertebrates are relatively abundant, such as gorgonians, sea anemones, and zoanthids. It is worth noting that the death of *Diadema* has not had this catastrophic effect in other Caribbean localities where herbivorous fishes are still abundant, such as the Cayman Islands and Belize. In recent years, the population of urchins at Discovery Bay has been increasing, but only in small groups in shallow water; they are still absent beyond a depth of about 6 m.

In 1987-1988, corals in many parts of the Caribbean, including Discovery Bay, suffered the first mass bleaching on record — apparently in response to high sea temperatures (Sandeman, 1988; Gates, 1990). Additional bleaching events occurred in 1989, 1990, and 1995. Some corals recovered when temperatures fell after the first warm spell, but many died in subsequent years. The last major bleaching event (1995) affected 43% of the existing corals on the CARICOMP transect lines. Bleached polyps were seen on ~63% of the total surface area of the corals. Five months later, ~9.5% of the surface area of the corals had died. Interestingly, mortality was not confined to the bleached areas of the coral heads (CARICOMP, 1997).

Coral Reef Site

The actual CARICOMP coral reef site is situated in the mixed/buttress zone of the west forereef in 6-8 m of water (Fig. 6). In 1977, this area was described by Woodley and Robinson as a mixed zone of high coral abundance and diversity; there were a few incipient buttresses, mostly consisting of numerous massive heads of *M. annularis* in a field of staghorn coral, *Porites* spp., and castle-like colonies of *Dendrogyra cylindrus*, with many other coral species and diverse gorgonians. In 1984, Liddell *et al.* reported that *M. annularis* had maintained its dominance, with colonies exhibiting great variations in size. Other branching and boulder corals were well represented, including species of *Acropora, Porites,* and *Diploria*. Sponge and algal diversity was usually low, whereas gorgonians of *Briarium* and *Plexaurella* spp. were reported as being common.

At present — after two hurricanes, four bouts of bleaching, and a shortage of herbivores — the huge stands of the two *Acropora* species leveled in 1980 have not recovered. They have also suffered from "white-band" diseases. Meanwhile, the massive heads of *Montastraea* are being overgrown by the flat clinging leaves of *Lobophora* as well as other turf algae. Opportunistic corals have again recruited in small numbers on the terrace, but they are having to compete with numerous algae.

Coincidently, the CARICOMP site is only a few meters from a permanent photoquadrat site at a depth of 6-7 m; coral cover here was measured in 1978 and found to be 54% (Porter *et al.*, 1981). Data from the first five CARICOMP coral reef transects in 1993 returned an average hard coral cover of 17.7% (Fig. 7). A further decrease in coral cover over the same five transects was demonstrated in 1994; hard coral cover was found to be 9.5%, with *Montastraea* spp. being the primary coral species. This level of coral cover was maintained during the 1995 and 1996 reef surveys, which utilized five and ten transects, respectively.

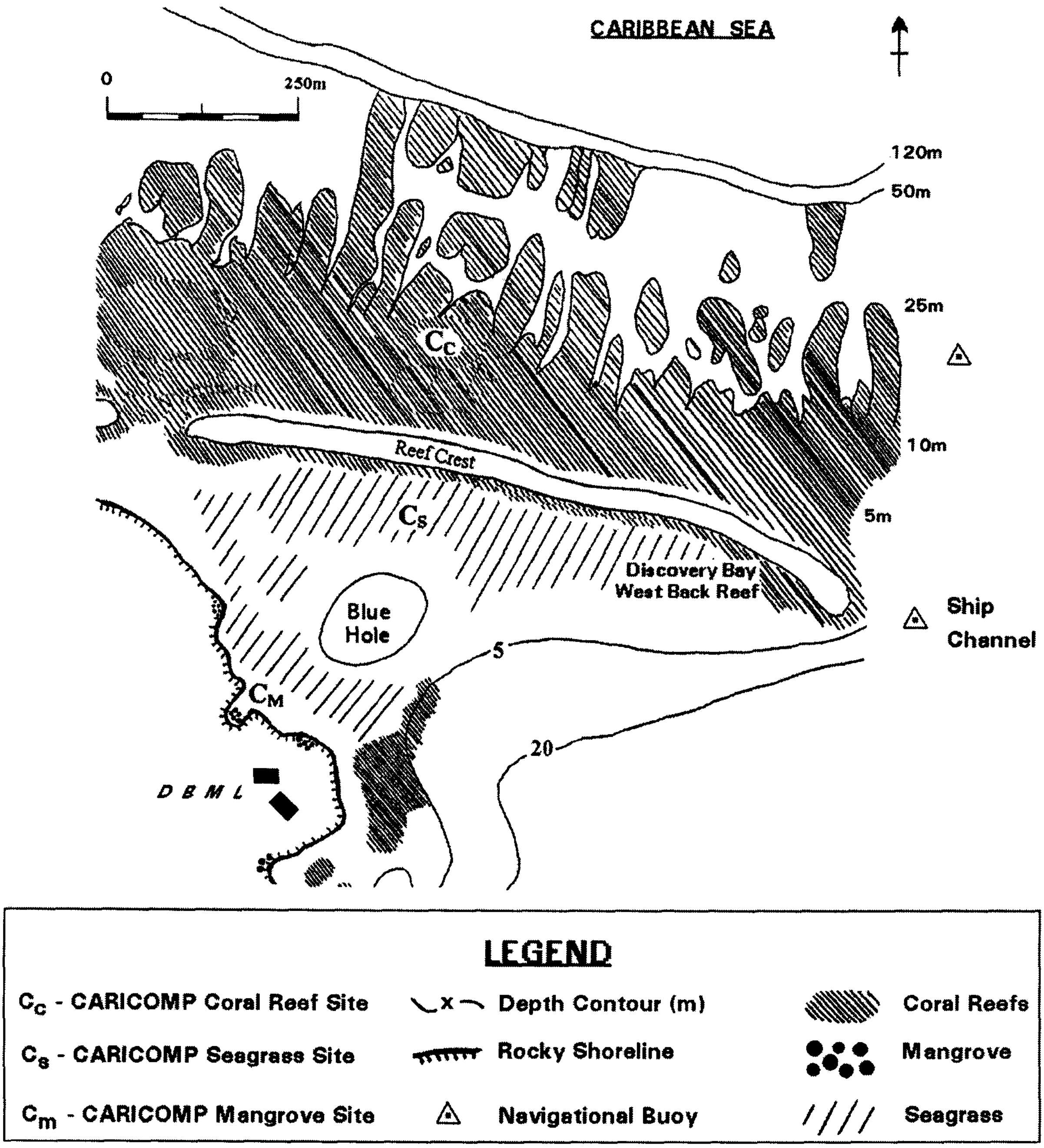

Fig. 6. CARICOMP sites at Discovery Bay, Jamaica

The backreef area on each side of the bay supports a lagoon environment, with generally coarse calcareous sand, scattered coral heads, small patch-reefs, large beds of turtle-grass, and soft mud at its deeper points. Wave action from storms and norwesters scours the shallow area of the bay. At sheltered depths (>10 m), fine sediment accumulates and light levels are relatively low. Conditions on the sides of the deep basin (at 20 m depth) are similar to those on the forereef at 40 m depth. Species and growth forms generally characteristic of greater depths on the forereef are found here in the shallow waters of Red Buoy or Columbus Park reefs. Various forms of suspension feeders dominate the scene; while the diversity of the corals appears to be high in this region, they are not numerous. The shallow lagoon

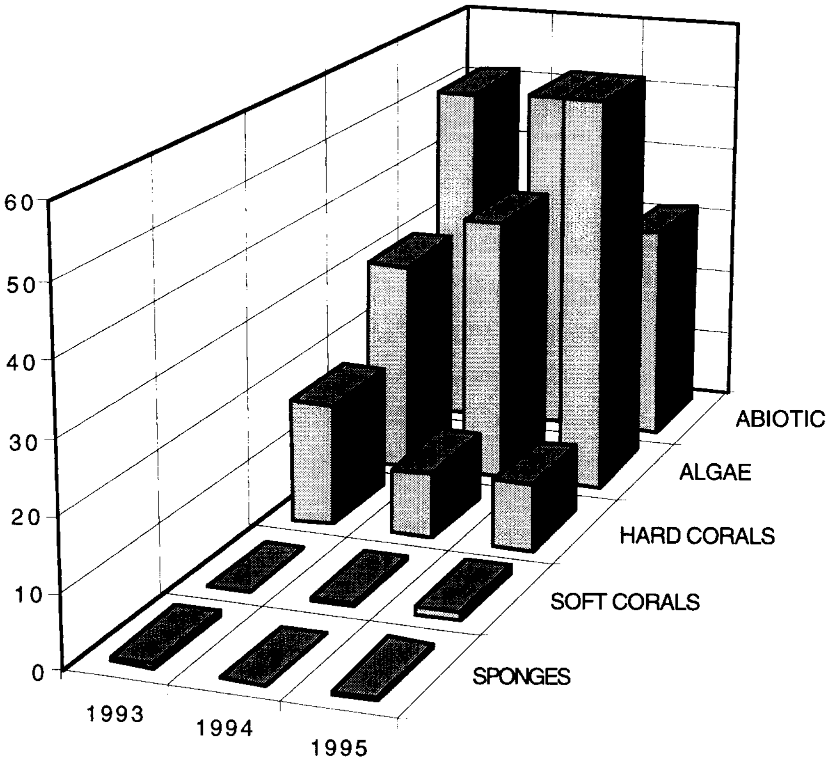

Fig. 7. Benthic composition at the CARICOMP coral reef site, Discovery Bay, Jamaica: 1993-1995.

exhibits a transition from coarse sand along its margins to fine silt in its deeper regions, which are hummocked by intermittent burrow-mounds of the ghost shrimp — *Callianassa* spp. The usual assortment of mobile invertebrates is found, such as holothurians and grazing, rock-boring, and burrowing echinoids (Aller and Dodge, 1974), in addition to numerous cnidaria such as *Condylactis gigantea* and *Cassiopea xamachana*. Small patch and fringing reefs occur, especially on the southern and western margins. Quantities of coral rubble, mostly old slabs of *A. palmata*, beneath which is a rich invertebrate fauna, are found within 100 m of the reef flat. Approaching the rear zone, extensive carpets of coelenterates such as *Stoichactis* and *Palythoa* spp. are found in the sand as well as covering hard substrate. These mats are interspersed with isolated heads of boulder corals — *M. annularis* and *S. siderea* (many of them dead and eroded) as well as the more delicate *P. porites*. The lagoon contains abundant algae, including the calcareous greens *Halimeda* and *Penicillus* spp., which are major components of backreef sediment (Liddell *et al.*, 1984). Extensive carpets of *Chaetomorpha linum* grow in the well-lit shallow waters during warm summer months, covering the bottom sands. During windy weather that creates rougher conditions, these mats slough off the bottom and float around the bay.

Seagrass Site

For CARICOMP, the important backreef component is the angiosperm *Thalassia testudinum*, which serves as a habitat for numerous small fishes and mobile or benthic invertebrates. At Discovery Bay, the root system of this particular grass bed overlies a layer of coral rubble and is not particularly thick (0.3 to 0.5 m), nor is there much in the way of fleshy algae or other types of grass in this area. Data for 1995 indicate that mean *Thalassia* biomass was 1,045.1 g m^{-2} dry weight, with a calcareous algal fraction of 105.9 g m^{-2}. For the same site, productivity averaged 2.95 g m^{-2} d^{-1}, with a daily turnover of 3.1% during the summer (Fig. 8). Although not a particularly dense or tall grass bed to the naked eye, the biomass appears to be increasing slowly, and this area serves as an important feeding site for schools of small grunt, silversides, and parrotfish in the bay. Despite the reduced numbers of these fishes, their daily migrations into and out of the site can still be observed at dawn and dusk.

Mangrove Site

The shoreline in Discovery Bay is typically highly phytokarsted Pleistocene limestone inhabited in a narrow intertidal range by numerous molluscs and rock-boring echinoids, interspersed with endolithic blue-green and red calcareous algae as well as zoanthids (Fig. 6). This base substrate supports a variable growth of mangrove trees (*Rhizophora mangle*) showing the expected change in species type as distance from shore increases inland, so that a few white mangroves (*Laguncularia racemosa*) and

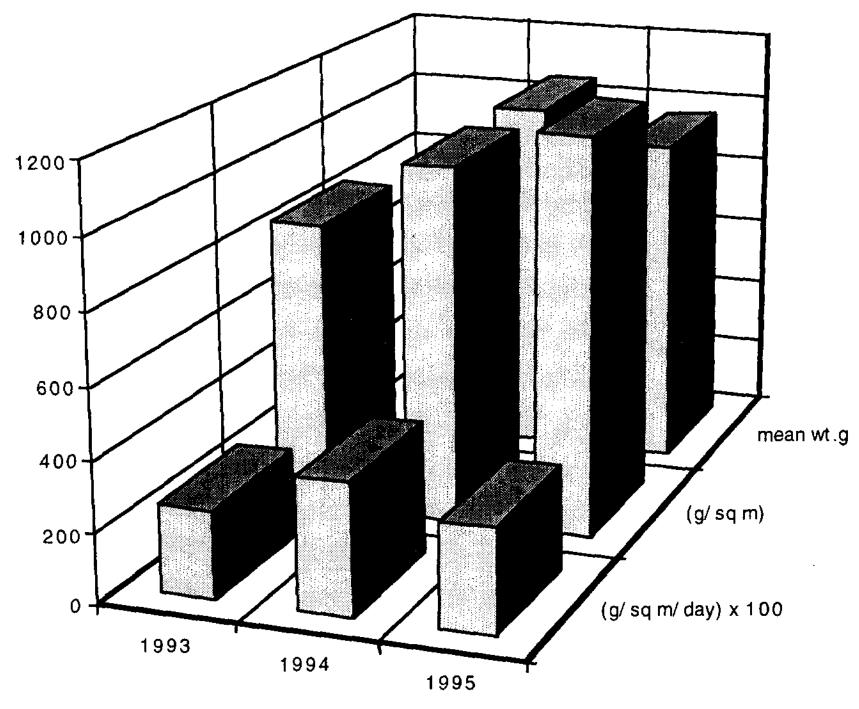

Fig. 8. Biomass (g/sq m and mean wt.g) and productivity (g/sq m/day) at the CARICOMP seagrass site, Discovery Bay, Jamaica: 1993-1995 (1993 productivity is the mean of four numbers).

black mangroves (*Avicennia germinans*) are also found in this relatively small stand of trees. In the sheltered westernmost corner of the bay, there is a pocket (~50 m^2) of mangrove trees and an adjacent pool of quiet, shaded water known locally as the Blue Maze. Although small in size, this area is ecologically important to the bay because the largest upwellings of freshwater are located in and around this site. As a result, a large fraction of the dissolved nutrients entering the bay does so in this area.

The site contains a stand of largely convoluted red mangrove (*Rhizophora mangle*) trunks, interspersed with white mangrove (*Laguncularia racemosa*). It has little or no topsoil; prop roots are supported mainly by a limestone substrate. Despite the lack of peaty substrate, the prop roots bear a healthy community of sessile plants and animals, with many different species of juvenile fishes taking shelter and feeding among them. The *R. mangle* trunks grow at various angles from the ground, causing them to lie upon one another at times. This creates an almost impenetrable maze of twisting branches, trunks, and roots at varying heights from the substrate. The stand itself is surrounded by brackish water on all sides, with *R. mangle* occurring mostly at the periphery where prop roots easily reach the water. Data from 1996 indicate that the mean total height of the *R. mangle* stand is 2.9 m, with a biomass of 7.85 kg m^{-2} (Golley *et al.*, 1962) and basal area of 10.38 m^2 ha^{-1}. Productivity estimates for this site range from 2.10 to 4.09 kg m^{-2} yr^{-1} for the months of June to October 1996.

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References

Aller, R. C., R. E. Dodge. 1974. Animal-sediment relations in a tropical lagoon, Discovery Bay, Jamaica. *Journal of Marine Research,* **32**:209-232.

CARICOMP. 1997. Studies on Caribbean coral bleaching, 1995-1996. **In:** *Proceedings of the 8th International Coral Reef Symposium (Panama, June 1996)* (edited by H. A. Lessios and I. G. Macintyre), Vol. II, pp 673-678. Smithsonian Tropical Research Institute, Balboa, Republic of Panama.

Colin, P. L. 1978. Daily and summer-winter variation in mass spawning of the striped parrotfish, *Scarus croicensis. Fishery Bulletin,* **76**(1):117-124.

D'Elia, C. F., L. Webb, J. W. Porter. 1981. Nitrate-rich groundwater inputs to Discovery Bay, Jamaica: A significant source of N to local coral reefs? *Bulletin of Marine Science,* **31**(4):903-910.

Dodge, R. E., R. C. Aller, J. Thompson. 1974. Coral growth related to resuspension of bottom sediments. *Nature,* **247**:574-577.

Fitzpatrick, F. 1993. *A Preliminary Investigation into the Circulation Pattern of Discovery Bay, North Jamaica.* Report to the Centre for Marine Sciences, University of the West Indies, 51 pp.

Gaines, S. D., J. Roughgarden. 1987. Fish in offshore kelp forests affect recruitment of intertidal barnacle populations. *Science,* **235**:479-480.

Gates, R. 1990. Seawater temperature and sublethal coral bleaching in Jamaica. *Coral Reefs,* **8**:193-197.

Golley, F., H. T. Odum, R. F. Wilson. 1962. The structure and metabolism of a Puerto Rican red mangrove forest in May. *Ecology*, **43**:9-19.

Goreau, T. F., J. W. Wells. 1967. The shallow water Scleractinia of Jamaica: Revised list of species and their vertical distribution range. *Bulletin of Marine Science*, **17**(2):442-453.

Hay, M. E. 1984. Patterns of fish and urchin grazing on Caribbean coral reefs: Are previous results typical? *Ecology*, **65**:446-454.

Hine, A. C., L. S. Land, T. D. Clayton, M. L. McCullough. 1991. Seismic stratigraphy of Discovery Bay, Jamaica. *Marine Geology*, **98**:83-97.

Hughes, T. P. 1994. Catastrophies, phase shifts and large-scale degradation of a Caribbean coral reef. *Science*, **265**:1547-1551.

Hughes, T. P., B. D. Keller, J. B. C. Jackson, M. J. Boyle. 1985. Mass mortality of the echinoid *Diadema antillarum* in Jamaica. *Bulletin of Marine Science*, **36**:377-384.

Hughes, T. P., D. Reed, M. J. Boyle. 1987. Herbivory on coral reefs: Community structure following mass mortalities of sea urchins. *Journal of Experimental Marine Biology and Ecology*, **113**:39-59.

Kaufman, L. S. 1983. Effects of Hurricane Allen on reef fish assemblages near Discovery Bay, Jamaica. *Coral Reefs*, **2**:43-47.

Kinzie, R. A. III. 1973. The zonation of West Indian gorgonians. *Bulletin of Marine Science*, **23**(1):93-155.

Kjerfve, B. J., K. E. Magill, J. W. Porter, J. D. Woodley. 1986. Hindcasting of hurricane characteristics and observed storm damage on a fringing reef, Jamaica, West Indies. *Journal of Marine Research*, **44**:119-148.

Knowlton, N., J. C. Lang, C. Rooney, P. Clifford. 1981. Evidence for delayed mortality in hurricane-damaged Jamaican staghorn corals. *Nature*, **294**:251-252.

Knowlton, N., J. C. Lang, B. D. Keller. 1988. Predation on Caribbean staghorn coral: Threshold models and their implications. *Proceedings of the 6th International Coral Reef Symposium*, **2**:83-88.

Koslow, J., F. Hanley, R. Wicklund. 1988. Effects of fishing on reef fish communities at Pedro Bank and Port Royal Cays, Jamaica. *Marine Ecology Progress Series*, **43**:201-212.

Liddell, W. D., S. L. Ohlhorst. 1981. Geomorphology and community composition of two adjacent reef areas, Discovery Bay, Jamaica. *Journal of Marine Research*, **39**:791-804.

Liddell, W. D., S. L. Ohlhorst, A. G. Coates. 1984. Modern and ancient carbonate environments of Jamaica. **In:** *Sedimenta X* (edited by R. N. Ginsburg). University of Miami, Miami FL, USA, 98 pp.

Liddell, W. D., S. L. Ohlhorst. 1986. Changes in benthic community composition following the mass mortality of *Diadema* at Jamaica. *Journal of Experimental Marine Biology and Ecology*, **95**:271-278.

Munro, J. L. 1983. *Caribbean Coral Reef Fishery Resources*. ICLARM, Manila, Philippines, 276 pp.

Ohlhorst, S. L. 1980. *Jamaican Coral Reefs: Important Biological and Physical Parameters*. Ph.D. Thesis, Yale University, New Haven CT, USA, 147 pp.

Pollnac, R. B. 1995. *Aspects of the Human Ecology of the Coral Reefs of Discovery Bay*. RAMP Project Report 4.

Porter, J. W., J. D. Woodley, J. G. Smith, J. E. Neigel, J. F. Battey, D. G. Dallmeyer. 1981. Population trends among Jamaican reef corals. *Nature*, **294**:249-251.

Porter, J. W. 1985. The maritime weather of Jamaica: Its effects on annual carbon budgets of the massive reef-building coral *Montastraea annularis*. *Proceedings of the Fifth International Coral Reef Congress (Tahiti)*, **6**:363-379.

Sandeman, I. M. 1988. Coral bleaching at Discovery Bay, Jamaica: A possible mechanism for temperature-related bleaching. **In:** *Mass Bleaching of Coral Reefs in the Caribbean: A Research Strategy* (edited by J. C. Ogden and R. Wicklund). *National Undersea Research Program Report*, **88**(2):46-48.

Sary, Z. 1995. *Response of an Overexploited Caribbean Trap Fishery to the Introduction of a Larger Mesh Size in Discovery Bay, Jamaica.* M.Sc. Thesis, University of the West Indies-Cave Hill, Barbados, 112 pp.

Sary, Z., M. Picou-Gill, M. Miller, W. van Barneveld, J. D. Woodley, I. M. Sandeman. 1997a. Effects of the increase in trap mesh-size on the Discovery Bay fishery. *Proceedings of the Gulf and Caribbean Fisheries Institute*, **45**:686-708.

Sary, Z., H. A. Oxenford, J. D. Woodley. 1997b. Effects of an increase in trap mesh size on an over-exploited coral reef fishery at Discovery Bay, Jamaica. *Marine Ecology Progress Series*, **154**: 107-120.

SIJ [Statistical Institute of Jamaica]. 1993. *Population Census 1982: Parish of St. Ann.*

Vatcher, S. 1995. The fisheries improvement project: Biological and socio-economic findings. *43rd Annual Conference of the Gulf and Caribbean Fisheries Institute (Charleston, South Carolina, 1990).*

Wells, J. W., J. C. Lang. 1973. Systematic list of Jamaican shallow-water Scleractinia. *Bulletin of Marine Science*, **32**(1):55-58.

Woodley, J. D., E. Robinson. 1977. Modern reef localities — West Discovery Bay. **In:** *Field Guidebook to the Modern and Ancient Reefs of Jamaica*, pp 18-26. 3rd International Coral Reef Symposium, Atlantic Reef Committee, University of Miami, Miami FL, USA, 33 pp.

Woodley, J. D. 1979. The effects of trap-fishing on reef communities in Jamaica [abstract]. *13th Meeting of the Association of Island Marine Laboratories of the Caribbean* (edited by E. H. Williams), p. 23. University of Puerto Rico, Mayagüez PR, USA, 27 pp.

Woodley, J. D., E. A. Chornesky, P. A. Clifford, J. C. B. Jackson, L. S. Kaufman, N. Knowlton, J. C. Land, M. P. Pearson, J. L. Wulff, A. S. G. Curtis, M. D. Dallmeyer, B. P. Jupp, M. A. R. Koehl, J. Neigel, E. M. Sides. 1981. Hurricane Allen's impact on Jamaican coral reefs. *Science*, **214**:749-755.

Woodley, J. D. 1989. The effects of Hurricane Gilbert on coral reefs at Discovery Bay. **In:** *Assessment of the Economic Impacts of Hurricane Gilbert on Coastal and Marine Resources in Jamaica* (edited by P. Bacon), pp. 79-82. CEP Technical Report No. 4, UNEP Caribbean Environment Programme, Kingston, Jamaica, 87 pp.

Woodley, J. D. 1992. The incidence of hurricanes on the north coast of Jamaica since 1870: Are the classic reef descriptions atypical? *Hydrobiologia*, **247**:133-138.

Grand Cayman, British West Indies[1]

Phillippe G. Bush
Protection and Conservation Unit
Department of the Environment
PO Box 486 GT
Grand Cayman, BWI

The Cayman Islands are situated on a major submarine ridge that extends west from the Sierra Maestra range in southeastern Cuba. The ridge parallels the Cayman Trench, which is more than 6,000 m deep and is located 6 km to the south. The islands are low-lying limestone formations of an older Bluff core of mid-Tertiary limestone origin, fringed by younger Ironshore formations, Pleistocene calcareous deposits, and recent carbonate sediments. Their narrow insular shelves support prolific coral reef communities. Grand Cayman is the largest of the three Cayman Islands, with a surface area of 197 km^2. The two dominant features of Grand Cayman are the Central Swamp and the North Sound. The large Central Swamp, which has a unique geomorphology, measures 50 km^2 and borders the North Sound on the east and southeast. The North Sound is a 85 km^2, semi-enclosed, shallow lagoon, historically fringed with mangrove swamp to the west, south, and east, and with an exposed acroporid fringing reef to the north. Approximately 60% of the sound is covered by well developed beds of *Thallassia testudinum*. There is limited runoff from surrounding lands during the rainy season, May-November. The CARICOMP transect for mangroves, seagrass beds, and coral reefs begins at the coastal edge of the Central Swamp, traverses the seagrass beds of the North Sound, and finishes to the north at the outer shallow reef terrace.

Introduction

The Cayman Islands are situated along the Cayman Ridge, which extends from southeastern Cuba into the bay of Honduras and is flanked by the 6,000 m deep Cayman Trench 6 km to the south (Fig. 1). The largest of the three islands, Grand Cayman is located at 19°18'N, 81°16'W). It is an oddly shaped island, 35 km long and oriented east-west. The two most conspicuous features of Grand Cayman are the contiguous Central Swamp and North Sound (Fig. 2). The main portion of the island, 8 km at its widest point, lies east of North Sound, and the other portion is a hook-shaped peninsula south and west of the sound. Narrow reef-protected lagoons occur along much of the northern, eastern, and southern coasts.

[1] *CARICOMP — Caribbean Coral Reef, Seagrass and Mangrove Sites* (edited by B. Kjerfve), pp 35-41. UNESCO, Paris, 1998, 347 pp.

The western or leeward side of the island has no lagoons and is exposed to open sea. Together, the Central Swamp and North Sound are the ecological heart of Grand Cayman, and their fringing mangroves and seagrass beds are critical breeding and nursery habitats for marine fauna (Ebanks-Petrie, 1993). The CARICOMP monitoring transect lies within these two contiguous features and crosses the outlying reefs to the north.

Central Swamp

Over 50% of Grand Cayman is covered by swamp communities. The Caymans inter-tidal swamps are very different from others (Watson, 1928; Thom, 1967); they are not deltaic, having developed on autochthonous peat substrate rather than on allochthonous silts (Burton, 1994). Fringing the eastern portion of North Sound, the Central Swamp, which measures 50 km^2, is geomorphologically unique. While there is some evidence of zonation in small areas, it does not demonstrate the classical zonation pattern representative of a typical mangrove swamp. Instead, it is a complex mosaic of swamp communities with varying degrees of mixing of the three principal species, *Rhizophora mangle*, *Avicennia germinans*, and *Laguncularia racemosa*, along its coastal fringe (Burton, 1994).

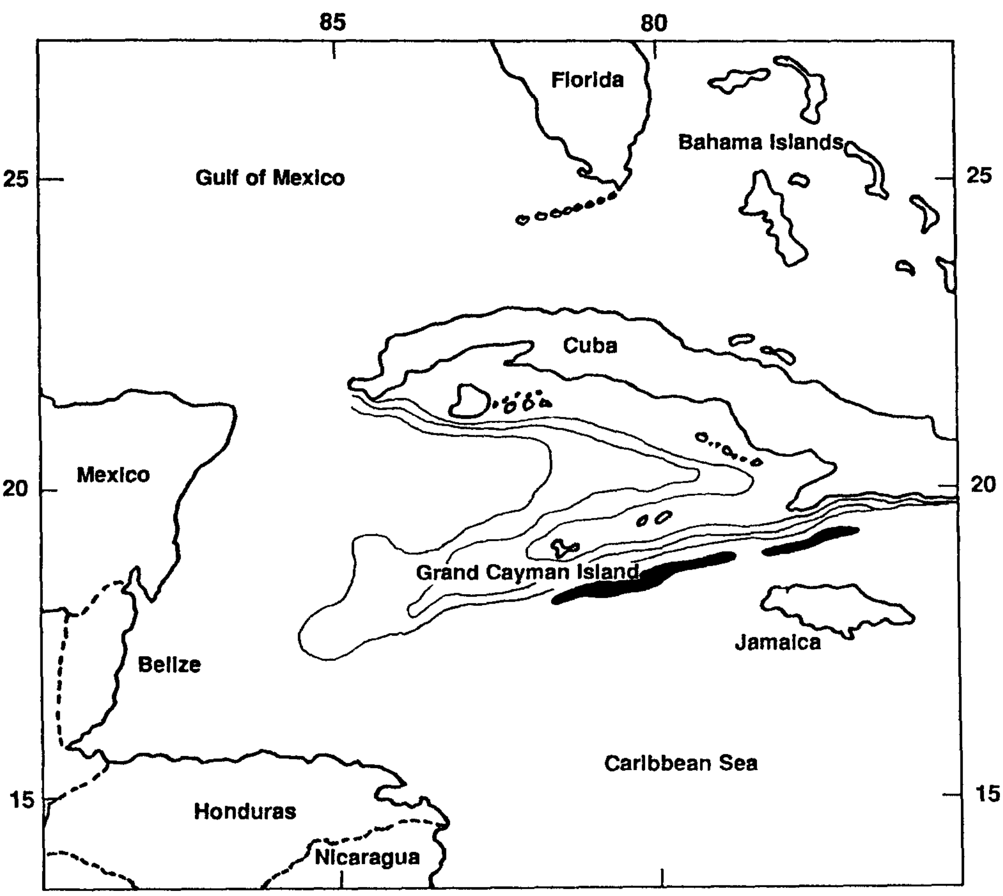

Fig. 1. Location of Grand Cayman, British West Indies (solid black).

North Sound

The periphery of North Sound has the most extensive development of coastal fringing mangroves of the entire island. Except for a few small sheltered areas where new *Rhizophora* seedlings can establish, the physical conditions and shoreline topography of the North Sound are now unsuited for new mangrove establishment (Burton, 1994). Like the mangroves around most of the North Sound, the fringe of the Central Swamp is not progressing, and in fact, there is evidence that this fringe is receding. As illustrated in Fig. 2, four bottom communities are recognized in the North Sound: shore zone, grass plain, restricted lagoon, and reef shoal (Roberts, 1976). The shore zone occupies the shallowest (average depth 1.0-2.5 m) part of the sound and is an area 1-2 km wide along the western and southern periphery of the lagoon. Sediments are thin, and the benthos is made up of stunted *Thalassia,* verious species of alcyonarians and calcareous green algae, loggerhead sponges (*Speciospongia vesparium*), and small colonies of *Porites* and *Siderastrea*. The grass plain occupies the largest and central portion of the lagoon. Here, thick beds of *Thalassia*, abundant green algae, and the sediment mounds of burrowing marine worms and crustaceans dominate the bottom. The CARICOMP seagrass site is located in this zone; however, no data on productivity are yet available. The restricted lagoon of Little Sound, so called because of its partial isolation from the main body of North Sound, is similar to the grass plain in its assemblage of benthic organisms. The sediments are darker, owing to the abundance of organic detritus produced by fringing mangroves of the Central Swamp where peats presently are being formed. Some *Thalassia* in this zone exhibit leaf growth of up to 45 cm in length. The reef shoal zone consists of

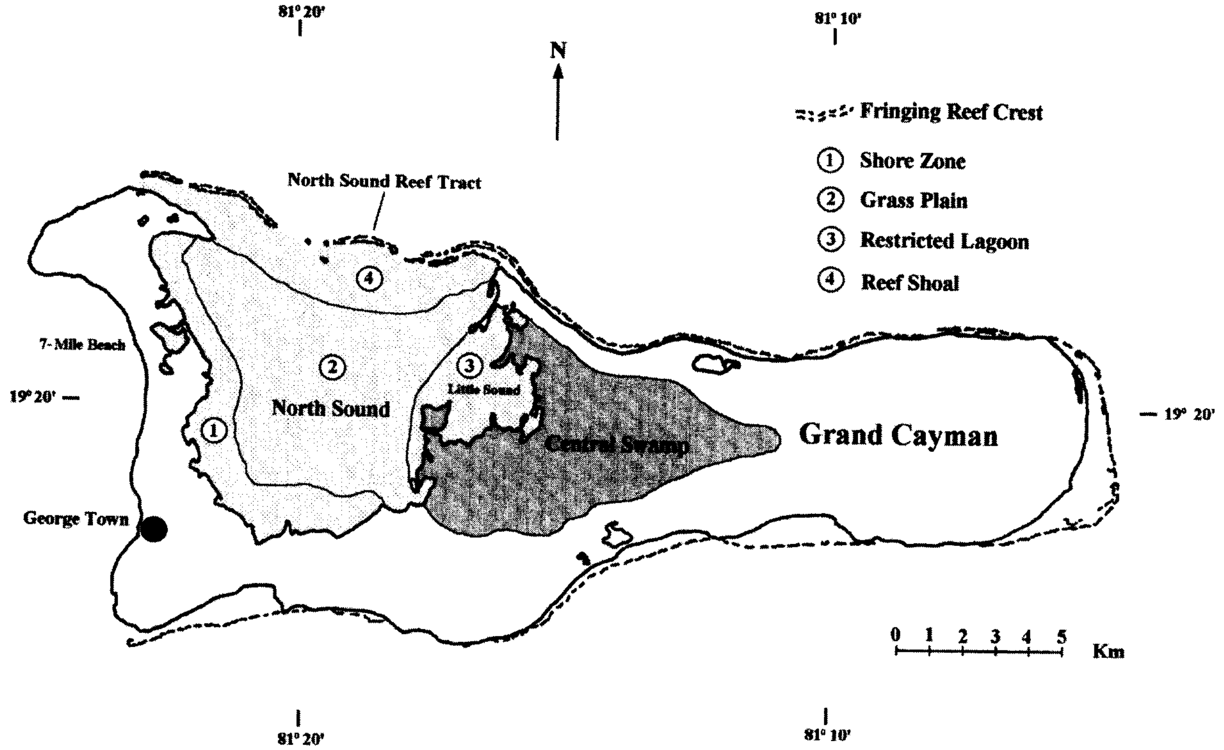

Fig. 2. Geography of Grand Cayman Island, BWI.

both hard and soft carbonate substrate communities and exhibits the high-energy conditions associated with such backreef environments. Stony corals such as *Acropora, Diploria, Montastraea,* and *Siderstrea* are abundant, along with *Millepora* and various coralline algae. Sand and rubble areas support brown and green algal assemblages. This zone is bounded on its outer side by a tidally exposed acroporid reef ridge that is perforated in places by outflow channels through which strong tidal currents are generated. In proportion to the size of the island, this lagoon, which has an area equal to 43% of the total land mass, is of major ecological value.

Coral Reefs

Grand Cayman has a narrow, insular, carbonate shelf, rarely exceeding 1.5 km in width and frequently less than 0.75 km. The submarine topography past the fringing reef of North Sound is characterized by two well developed spur-and-groove terraces (Rigby and Roberts, 1976), a shallow terrace reaching to a depth of 9 m, and a deeper one at 15 m that plunges into the abyss. Past the reef crest, the shallow rocky sill is dominated by alcyonarians, along with sparse colonies of *Agaricia agricites, Siderastrea sidera,* and *Montastraea annularis*. The latter two are the least abundant but form large prominent heads. Stony corals gradually increase in number seaward and away from this bedrock zone to a depth of 12 m, where large heads of *Montastraea annularis* (some up to 5 m in height) dominate.

CARICOMP data indicate live benthic cover (excluding algae) and rugosity to be 24.15% and 1.7%, respectively. This is and may be attributed to the fact that the sampling area, as determined by the prescribed methodology at the 10 m contour, was more shallow than the best developed reef. Typically, there is a deep sand plain of varying width and depth separating this shallow terrace and the deeper terrace. The deep terrace is distinctive in that it has a dramatic relief, the highest diversity of stony corals, the greatest percentage cover of sponges, and the highest density of fish (Burgess, 1994).

Climate and Hydrology

Lying midway within the northeast tradewind belt, Grand Cayman has a subhumid tropical climate with distinct seasonal variation. There are no large land mass within a 200 km radius and the climate is strongly moderated by the sea (Burton, 1994). The wet season occurs from May through November, with an average maximum daily midday temperature of 28.4°C, occurring in July. The dry season, December-April, has an average minimum daily midday temperature of 24.8°C, occurring in February. Average annual rainfall is 1,107 mm in the eastern portion of the island and 1,595 mm in the western portion (Burton, 1994). Although weather patterns are generally stable, low pressure systems in the form of tropical waves, depressions, storms, and hurricanes frequently affect the island during the summer months. Also, during the winter, sporadic cold fronts from the north bring cooler air and strong winds from the north and northwest, a weather pattern locally known as a norwester. Grand Cayman has an average tidal range of 26 cm (Burton, 1994); the tidal pattern is mixed, primarily semi-diurnal (Rigby and Roberts, 1976). Although tidal fluctuation is slight, there is a seasonal variation in mean sea level; surges during the late summer months bring mean high tides above 31 cm throughout July, August, and September (Burton, 1994). This elevation corresponds to the general flooding threshhold for coastal mangroves on Grand Cayman (Brunt and Burton, 1994) and is significant for the fringing mangroves of North Sound. While evidence suggests that frequent tidal inundation of the Central Swamp mangroves extends only 200-300 m inland, the opposite movement of rainwater towards the lagoon is more common (Burton, 1994). After heavy rains, the entire Central Swamp may become covered by sheet flow. From mid-dry to mid-wet season, the maximum drainage of tannin-stained water from the surrounding mangroves flows into the sound and may cover substantial areas. The maximum area of staining was calculated to be 30.04 km^2 (Giglioli, 1976). It has been suggested that significant quantities of available organic detritus affect the food web and therefore the nursery potential of the sound. Sustained southeast winds periodically push this plume of organically laden water from the Central Swamp as far out as the shallow reef terrace, more than 6.5 km away.

There is a strong correlation (0.92) between temperature and litterfall within this mangrove fringe, and while there is a correlation of only 0.54 between rainfall and litterfall (CARICOMP data, 1994), the fact that maximum litterfall, rainfall, and drainage occur simultaneously suggests detrital outflow from the mangrove fringe. With the recent decline in fringing mangroves to the west and south, the contribution of organic material may now be reduced. Currents on the narrow shelf of Grand Cayman generally flow from east to west, but they experience large and periodic variations in both magnitude and direction (Rigby and Roberts, 1976). Salinity varies between 35‰ and 38‰ in open ocean waters around Grand Cayman (Moore 1973). Salinity within shallow sounds varies in relation to amount, duration, and periodicity of rainfall, as a result of coastal topography, upwelling, and circulation. Because the Cayman Islands lack rivers, the waters of the open sea and the narrower, shallower sounds around Grand Cayman are very transparent. Average visibility is 30 m (Rigby and Roberts, 1976), and clarity is affected at any particular location by conditions of wind speed and direction, as well as by sediment concentration.

Human Impacts

The major population centers are situated within the peninsular region, particularly on the western side along 7-Mile Beach, where hotels, condominium housing, and shopping amenities cater to tourism that is based largely on the marine environment. Over 900,000 visitors come to Grand Cayman annually to experience the "sun, sea, and sand" activities that this center of scuba diving has to offer. The majority of tourists participate in some form of water sports. Although most of the scuba diving takes place off 7-Mile Beach, many sites have been established outside the North Sound's acroporid reef ridge, where visitors come to experience the thrill of diving the "North Wall" and its associated reefs. Other recreational activities within the outer reef shoal zone of North Sound include day trips to experience "Stingray City" and "Sand Bar," excellent areas for snorkeling and also harvesting queen conchs. Despite earlier efforts to establish marine conservation laws and the marine park system, the sheer numbers of visitors and watercraft are cause for concern over issues such as the carrying capacities of dive sites, pollution, over-fishing, and overall environmental degradation from overuse. Since the 1960s, large-scale speculative development has resulted in the destruction of 61.6% of the mangroves within a half-kilometer of the western periphery of the North Sound (Ebanks-Petrie, 1993). Approximately 2.15 km^2 of the shallow lagoon bedrock facies of the shore zone of the North Sound has been dredged (Fig. 3) to supply marl for the reclamation of swampland (Ebanks-Petrie, 1993). During heavy rainfall in the wet season, runoff is evident from these developments, where the marl fill level is higher than retaining bulkheads. During heavy noreasters in the winter season, fine sediments from dredged borrow pits are stirred up and redistributed over a much wider area of the seabed. Over 83% of the total waterfront canal lot developments that were built on speculation since the late 1970s remain unoccupied, calling into serious question the benefit of continued development without proper management of the coastal zone.

Conclusion

The CARICOMP transect of mangrove, seagrass, and coral reef sites was established where these three habitats are contiguous, functionally integrated, and left largely undisturbed (Fig. 3), and the monitoring sites are located in legally protected areas. This should ensure the environmental quality and ecological integrity of these habitats. The mangrove site lies within an "Environmental Zone," the most strictly regulated of the three marine park zones of Grand Cayman. It includes all of Little Sound (the restricted lagoon area east of the North Sound) and the coastal fringe of the Central Swamp, a distance of approximately 300 m. It was set aside to preserve the pristine nature of this area of mangroves and sea grasses, and it is also currently being considered for declaration as a RAMSAR site. Because the Central Swamp is so important in terms of its environmental role in rainfall, wildlife

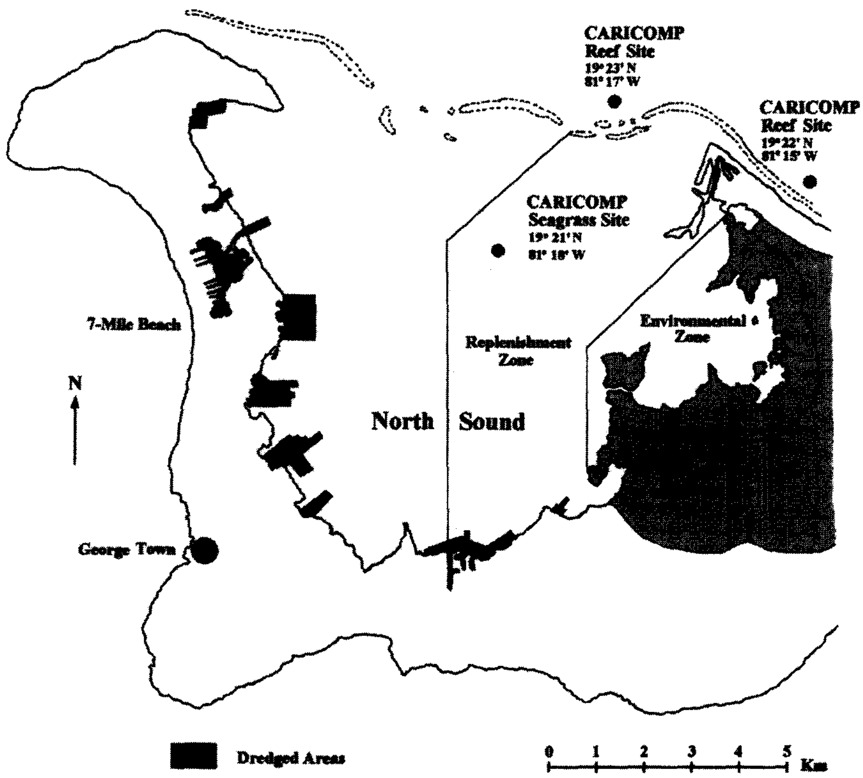

Fig. 3. North Sound, Grand Cayman, showing CARICOMP sites.

refuge, and groundwater maintenance, the National Trust for the Cayman Islands, in conjunction with the government, is actively pursuing the purchase of remaining inland parcels not already protected by the Environmental Zone.

The seagrass site is located within a replenishment zone, so designated for the protection of breeding stocks of conch and lobster. Regulations prohibit harmful types of fishing such as spearing, trapping, netting, and trawling. This monitoring station is also quite distant from any coastline or other in-water area where human activities may possibly impact the seagrass beds. The coral reef site, located seaward of the fringing reef, is also protected by marine conservation laws that control anchoring, polluting, and the taking or harming of marine life. Like all dive sites, permanent moorings are installed at the CARICOMP sites, thereby eliminating the need for any vessel to anchor.

In the face of increasing development, both locally and regionally, the government of the Cayman Islands is looking to establish a comprehensive environmental policy. The legislation will include an integrated approach to managing the coastal zone. Such a move can only be complemented by more in-depth scientific studies of the functional integrity of coastal and marine resources. The CARICOMP program provides an effective means to help achieve such knowledge through research.

References

Brunt, M. A., F. J. Burton. 1994. Mangrove swamps of the Cayman Islands. **In:** *The Biogeography and Ecology of the Cayman Islands* (edited by M. A. Brunt and J. E. Davies) , Vol. 15, pp. 283-305. Kluwer Academic Publishers, Dordrecht, The Netherlands, 604 pp.

Burgess, G. H., S. H. Smith, E. D. Lane. 1994. Fishes of the Cayman Islands. **In:** *The Biogeography and Ecology of the Cayman Islands* (edited by M. A. Brunt and J. E. Davies) , Vol. 11, pp. 199-228. Kluwer Academic Publishers, Dordrecht, The Netherlands, 604 pp.

Burton, F. J. 1994. Climate and tides of the Cayman Islands. **In:** *The Biogeography and Ecology of the Cayman Islands* (edited by M. A. Brunt and J. E. Davies) , Vol. 3, pp. 51-60. Kluwer Academic Publishers, Dordrecht, The Netherlands, 604 pp.

Ebanks-Petrie, G. E., 1993. *Assessment of Coastal Management on Grand Cayman, B.W.I.* MSc Thesis in Environmental Management, University of Stirling, Stirling, Scotland, UK, 98 pp.

Giglioli, M. E. C. 1976. *Cayman Islands Natural Resources Study; Part II, The Boom Years: Environmental Deterioration, Planning and Administration.* UK Ministry of Overseas Development, 42 pp.

Moore, C. H. 1973. Intertidal carbonate sedimentation, Grand Cayman,West Indies. *Journal of Sedimentary Petrology*, **43**:591-602.

Rigby, J. K., R. H. Roberts. 1976. Geology, reefs and marine communities of Grand Cayman Island, British West Indies. **In:** *Geology Studies Special Publication No. 4: Grand Cayman Island — Geology, Sediments, and Marine Communities* (edited by J. K. Rigby and E. Shaw), pp 1-95. Department of Geology, Brigham Young University, Provo UT, USA, 122 pp.

Roberts, H. H. 1976. Carbonate sedimentation in a reef-enclosed lagoon, North Sound, Grand Cayman Island. **In:** *Geology Studies Special Publication No. 4: Grand Cayman Island — Geology, Sediments, and Marine Communities* (edited by J. K. Rigby and E. Shaw), pp 97-121. Department of Geology, Brigham Young University, Provo UT, USA, 122 pp.

Thom, B. G. 1967. Mangrove ecology and deltaic geomorphology, Tabasco, Mexico. *Journal of Ecology*, **55**:301-343.

Watson, J. G. 1928. *Mangrove Forests of the Malay Peninsula.* Malay Forest Rec. No. 6. Fraser and Neave Ltd., Singapore, 275 pp.

Laguna de Celestún, Yucatán, México[1]

Jorge A. Herrera-Silveira and Javier Ramírez-Ramírez
Centro de Investigación y de Estudios Avanzados, IPN
Unidad Mérida. Carr. Ant., a Progreso km 6, Apdo. Postal 73 CORDEMEX
CP 97310, Mérida, Yucatán, México

Laguna de Celestún, on the northwest coast of the Yucatán Peninsula, is separated from the sea by a sand bar. The lagoon system is markedly affected by infiltration of cold nutrient-rich groundwater discharges and is estuarine in nature. There is an inner zone characterized by low salinity, high nitrate, and soluble reactive silica concentrations, and a seaward zone characterized by high salinity and low concentration of nutrients. The middle zone is characterized by intermediate salinity and higher concentrations of soluble reactive phosphorus and ammonium than those found in the remainder of the lagoon. Phytoplankton productivity and chlorophyll-*a* values show a seasonal pattern without regard to variations in salinity. The macrophyte community is represented by *Chara fibrosa* and *Batophora oerstedi* in the inner zone, *Halodule wrightii* and *Chaetomorpha linum* in the middle zone, and *Halodule wrightii* and *Thalassia testudinum* in the seaward zone. The mangrove community is represented on the sand barrier side of the lagoon by a small fringe of *Rhizophora mangle*, followed by *Avicenia germinans*, which dominates the area. Behind the fringe is a forest of *Laguncularia racemosa* mixed with sand dune vegetation. On the continental side of the lagoon, mangroves show a similar gradient from the seaward to the inner zone but with better structural development. There are no coral reefs in this area.

Introduction

Laguna de Celestún is a macrophyte-mangrove co-dominated system situated at 20°45'N and 90°15'W on the western shore of the Yucatán Peninsula, southern Gulf of México. Although most coastal systems are inherently variable in time and space, macrophytes and mangroves dominate the lagoon, with strong seasonal pulses and spatial heterogeneity due to size, morphology, communication with the sea, and freshwater input.

[1] *CARICOMP — Caribbean Coral Reef, Seagrass and Mangrove Sites* (edited by B. Kjerfve), pp 43-55. UNESCO, Paris, 1998, 347 pp.

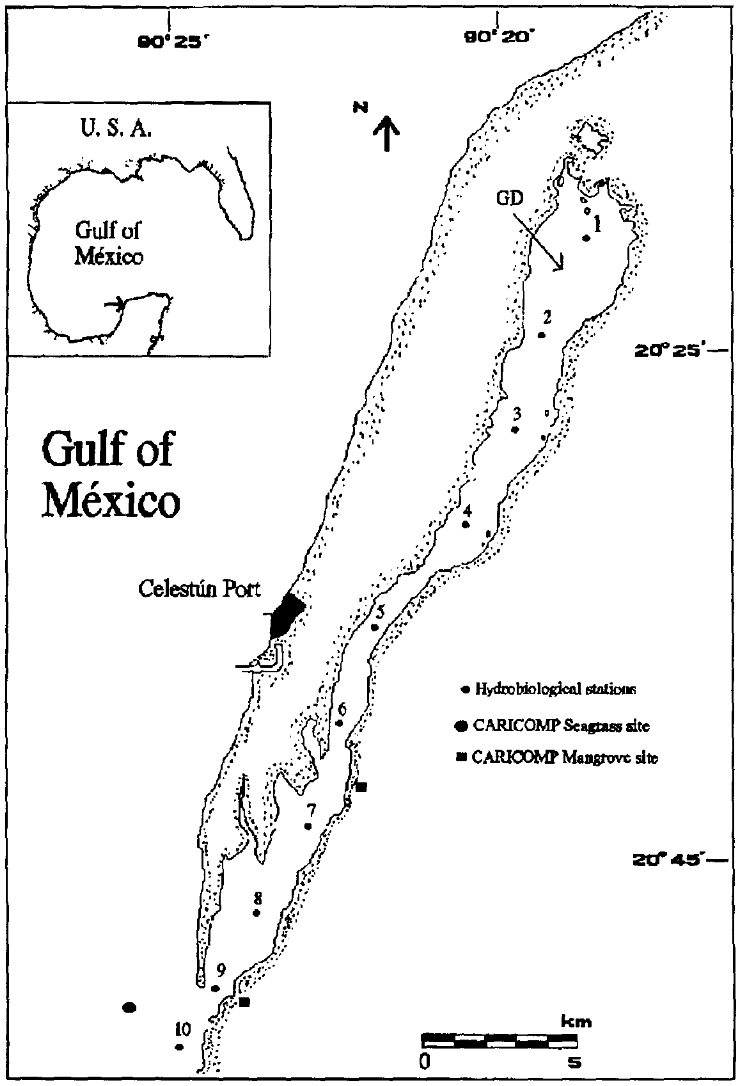

Fig. 1. Location of Laguna de Celestún; hydrobiological, groundwater discharge (GD), and CARICOMP sites.

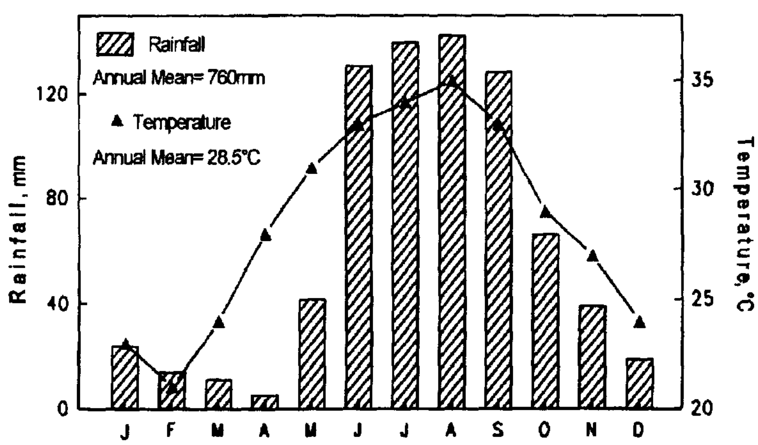

Fig. 2. Mean monthly variations in air temperature and rainfall over a period of thirty years.

The northern portion of the Yucatán Peninsula contains over 148,000 ha of coastal lagoons; specific features differentiate these systems hydrologically from other lagoons. The extremly high permeability of the rock and the relatively featureless morphology in this area permit unrestricted filtration during and after rainfall, resulting in no surface runoff (Butterlin, 1958; López Ramos, 1974). Rainfall feeds a lens of fresh water that drains laterally towards the sea, forming coastal freshwater springs (Robles Ramos, 1950) in areas below mean sea level. Therefore, Laguna de Celestún can receive freshwater input from either direct rainfall or groundwater discharge (GD) but not from river discharge.

Celestún Port, a fishing village of 4,500 inhabitants, is located on the Gulf Coast one kilometer from the lagoon. Both the coastal zone and lagoon are heavily fished; this area is the second most important fishery region in Yucatán.

Laguna de Celestún is a long (22.4 km), narrow (0.5-2.4 km), and shallow (0.05 m to 3 m, mean = 1.2 m) feature located parallel to the coastline on the western shore of the Yucatán Peninsula. Contact with the sea is via a 410-m-wide entrance at the southern edge. The bottom of the lagoon is almost flat. A tidal channel (100 m wide, 15 km long) is the major bathymetric feature (Fig. 1). The lagoon is protected by a sand barrier, and it is a low-energy site because of a low tidal range (0.2-0.6 m; Instituto de Geofísica, 1990). However, marine processes such as storm tides and frontal systems can have a strong influence on the hydrological regime (Herrera-Silveira, 1993).

In 1979, the Mexican Goverment declared the lagoon a Wildlife Reserve because of its biological diversity, providing natural habitats for a variety of endangered species of birds and reptiles. It is particularly important as a nesting ground for the flamingo *Phoenicopterus ruber ruber*, (Barrios, 1988) and the king duck *Chairina moschata*. The sight of more than 40,000 birds has been a focal point for the development of tourist activities, which have steadily increased during the 1990s. Government economic policies emphasize the coastal zone as a mechanism to drive development, but little environmental information is available for decision making. We describe this CARICOMP site in the southern Gulf of Mexico and review what is known about the ecosystem.

Climate and Oceanography

The Celestún region has a moderate annual variation in solar radiation, from 230 ly d^{-1} in December to 500 ly d^{-1} in August (Almanza and López, 1978). The climate in the region is hot semi-arid (Fig. 2): the annual mean temperature is 28.5°C, varying from 21°C in February to 35°C in August; the mean annual rainfall is 760 mm (data from 1960-1990, SARH, 1991). The two main seasons are the dry season with low rainfall (March-May, 0-50 mm), and the rainy season (June-October) with high rainfall (>500 mm), both with weak winds from the southeast (<15 km h^{-1}). Futhermore, in this part of the Gulf of Mexico the period from November to February is known locally as the *nortes* season, which is characterized by strong north winds (>80 km h^{-1}), little rainfall (20-60 mm), and low temperatures (<22°C) imposed by low pressure systems from the north (SARH, 1989). Additionally, Laguna de Celestún is affected by tropical storms and hurricanes from September through October.

The hydrologic regime of the lagoon varies substantially during a year. Seasonal variations in environmental conditions are related to residence times and to fluxes of water and materials. In the dry season, high evaporation rates, low groundwater discharge (GD), and minor changes in mean sea level (MSL) limit fluxes toward the sea (1.1×10^6 $m^3 h^{-1}$) and moderate residence times (190 days); tide-GD co-dominate the flows. During the rainy season, GD-tide co-dominate the flows; the highest GD and greatest variations in MSL promote high ebb fluxes (2.5×10^6 $m^3 h^{-1}$) and lesser residence times (<150 days). During the *nortes* season, low GD and moderate variations in MSL reduce the water flux (0.6×10^6 $m^3 h^{-1}$). In addition, high sea level in the coastal zone due to frontal passages favors the longest residence time (>250 days). The water column of the inner zone is red in color because of tannins accumulated and not exported during the *nortes* season (Herrera-Silveira, 1993).

The hydrologic regime results in the transport of materials dominated by inorganic forms during the rainy season, by particulate material during the *nortes* season, and probably by organic compounds during the dry season. Seasonal variation in flux of each material results from changes in both water flux and seasonal concentration of nutrients due to the relationship between the GD and biogeochemical processes in the lagoon. The system traps NO_3^- and SRSi (soluble reactive silicate) in the inner zone during all three seasons and releases NH_4^+. SRP (soluble reactive phosphate) is trapped during both dry and rainy seasons but is released during the *nortes* season. Despite these seasonal and spatial changes in uptake and release of nutrients in the lagoon, the system functions primarily as an exporter of nutrients (Herrera-Silveira and Comín, 1995).

In terms of the functional classification proposed by Kjerve (1986), Laguna de Celestún exhibits a mix of characteristics of a choked and a restricted lagoon. There is a co-dominance of hydrologic cycle and tidal circulation, modified by wind forcing. As a choked lagoon, Celestún experiences seasonal water level changes, which exceed one meter, in response to the onset of the rainy season or related to wind forcing. Seiching and set-up/set-down cycles are particularly intense in response to frontal passages during the *nortes* season, and residence times are on the order of months. As a restricted lagoon, Celestún is located on a low wave energy coast with a small tidal range (0.3-0.7 m). Tidal water level and current variability are readily transmitted into the lagoon, almost without filtering. As a result, the lagoon has good tidal circulation, which is modified by wind forcing and freshwater discharge. Salinity fluctuates less dramatically (10-35‰) than in a choked lagoon (1-80‰); it is usually well mixed vertically. Fresh to brackish water is found near the freshwater discharge. During flood discharge, the entire restricted lagoon may turn fresh or brackish (Herrera-Silveira and Comín, 1995).

The water column does not exhibit stratification because of mixing processes due to low mean depth (1.2 m) and wind mixing. During a one-year sampling cycle, water temperature varied 9°C, with the highest values occurring in June (31.4°C) and the lowest in February (22.4°C). The maximum difference between air and water temperatures occurs during the rainy season, due to the input of groundwater with lower temperatures than found in the lagoon (Table 1).

The horizontal salinity gradient in the lagoon was observed over one year. In the inner zone, salinity was always lower than 20‰, while in the seaward zone it was greater than 30‰ (Fig. 3). The lowest salinity (19.6‰) was observed in October after the rainfall peak. During the *nortes* season, mean salinity was <25‰ throughout the lagoon. The highest salinity was observed at the end of the dry season, with mean concentrations of 30‰ occurring in May. Mean pH values follow an inverse relation-

Table 1. Mean values of various parameters (±1 standard error in parentheses) in Laguna de Celestún, groundwater discharge (GD) and seawater (SW) during a one-year cycle (data from Herrera-Silveira, 1993).

	Temp °C	DO mg^{-1}	S ‰	NO_3^- µM	NO_2^- µM	NH_4^+ µM	SRP µM	SRSi µM
Lagoon	27.4 (0.3)	4.83 (0.46)	25.4 (0.91)	7.67 (1.36)	0.44 (0.06)	5.41 (0.69)	1.98 (0.72)	54.1 (15)
GD	22.5 (0.02)	0.63 (0.03)	3.0 (0.01)	51.8 (11.7)	1.38 (0.22)	1.85 (0.36)	0.45 (0.10)	168 (27.1)
SW	26.2 (0.4)	6.65 (0.19)	34.5 (0.21)	1.5 (0.85)	0.48 (0.02)	3.0 (0.48)	0.43 (0.25)	5.4 (1.2)

Key: Temp, temperature; DO, dissolved oxygen; S, salinity; NO_3^-, nitrates; NO_2^-, nitrites, NH_4^+, ammonium; SRP, soluble reactive phosphate; SRSi, soluble reactive silicate.

ship to mean salinity: high values (8.3) in the inner zone during the rainy season and low values (6.8) during the dry season in the middle segment of the lagoon (Herrera-Silveira, 1993).

Annual dissolved oxygen concentrations ranged from 2.5 mg l^{-1} in the inner zone to >8.5 mg l^{-1} in the seaward zone during the sampled year; the highest values occurred during the *nortes* season. The highest NO_3^- concentrations were observed in the inner zone (>40 µM); NO_3^- values increased in all zones of the lagoon at the start of the rainy season. During the *nortes* season, the highest concentration (10 µM) was observed in the middle of the lagoon. Nitrate concentrations decreased from the inner zone of the lagoon seaward at all times during the annual cycle. Ammonium concentrations in the lagoon were higher than those in the inflowing groundwater and seawater (Table 1). The highest NH_4^+ concentrations were observed in July (15 µM) and February (11 µM) in the central part of the lagoon.

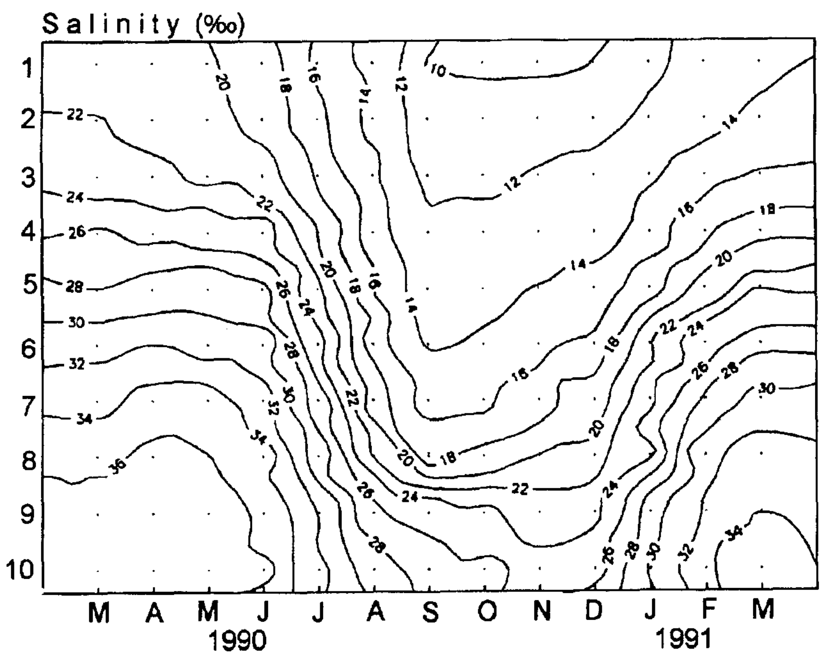

Fig. 3. Space-time diagram of salinity (‰) in Laguna de Celestún during a one-year cycle.

The spatial and temporal distributions of SRP differed from those of NO_3^- and NH_4^+. SRP concentrations were higher (>9 μM) in the inner and middle zones of the lagoon during the *nortes* season (November-February) than during the rest of the year. The maximum SRP (2 μM) was observed in the central part of the lagoon at the beginning of the rainy season. Thus, the highest concentrations of SRP evidently are not associated with groundwater discharge. SRSi concentrations ranged from <1 to 280 μM. They followed the same spatial and temporal patterns as NO_3^-, decreasing from the inner zone to the seaward zone and increasing between the dry and rainy seasons. During the *nortes* season, SRSi fluctuated between <10 μM and >200 μM.

Based on the results of multivariate analysis, three zones are identified in the lagoon according to variations in physical and chemical characteristics present during a year. The inner part of the lagoon is characterized by low salinity and high NO_3^- and SRSi. Clearly, it is strongly affected by groundwater discharge. As expected, the seaward zone of the lagoon is characterized by high salinity and low nutrient concentrations. The zone in the middle of the lagoon is characterized by intermediate values of salinity, as expected; however, concentrations of SRP and NH_4^+ are higher than in the rest of the lagoon as a consequence of non-conservative behavior of these compounds, probably due to biological processes (Herrera-Silveira, 1994). This zonation represents a typical pattern for coastal lagoons with one seawater inlet and freshwater discharge occurring at the landward end (Kjerfve, 1986; Guélorget and Perthuisot, 1992).

The data indicate differences between the three seasons (dry, rainy, *nortes*) and the three zones (inner, middle, seaward), revealing spatial and seasonal patterns. The differences between seasons and groups were due to the coupling of the intensity and frequency of external factors, such as rainfall, winds, frontal systems, and biogeochemical processes, including primary production, mineralization, conservative and non-conservative behavior of nutrients, fertilization, and bioturbation. If these patterns are found to repeat from year to year, a microsuccession process can be inferred (Herrera-Silveira, 1993).

Phytoplankton

During a one-year cycle, chlorophyll-*a* values ranged from <1 to 28.5 mg m^{-3} (Fig. 4). Chlorophyll-*a* levels were lowest (3.1 mg m^{-3}) during the dry season and the end of the *nortes* season (0.88 mg m^{-3}), when GD was low, temperatures dropped, and the water column became less transparent. The highest chlorophyll-*a* concentrations were observed in the middle zone of the lagoon during the rainy season (14-28.5 mg m^{-3}). In the inner zone, a lower peak of chlorophyll-*a* (11.5 mg m^{-3}) was observed early in the *nortes* season (Fig. 4). There is no relationship with salinity variations. The annual range of net phytoplankton productivity in the lagoon is 0.22-1.9 g C m^{-2} d^{-1}, within the range observed in other Gulf lagoons (0.1-3.3 g C m^{-2} d^{-1}; Vannucci, 1969; Day *et al.*, 1982) that receive input from rivers. Also, these other lagoons are quite different from Celestún with respect to GD, particulate matter, and SRP input. The levels of SRP in the GD of Laguna de Celestún and seawater were low (<1 μM), but high levels (2-9 μM) were observed in the middle zone. In addition, the shallowness of Celestún (1.2 m) suggests intense coupling between sediments and water column; thus, remineralized nutrients are probably available to

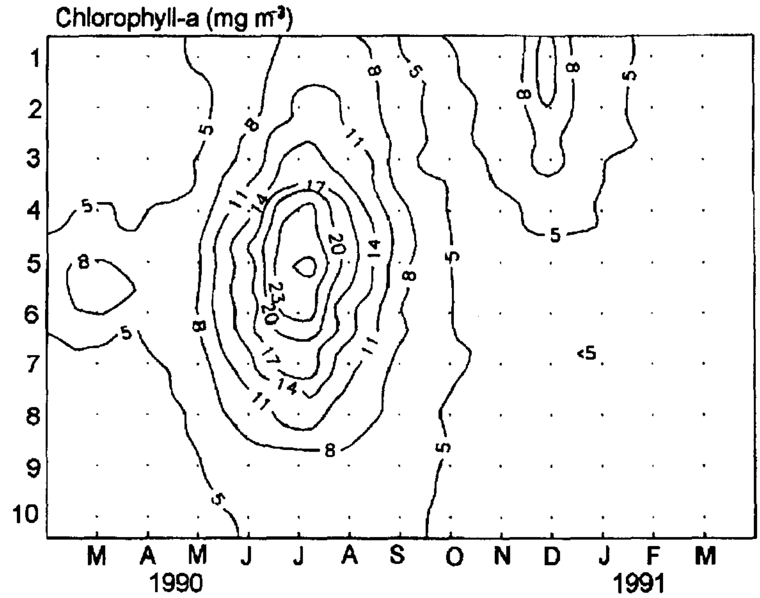

Fig. 4. Space-time diagram of chlorophyll-*a* (mg m^{-3}) in Laguna de Celestún during a one-year cycle.

the water column through this pathway. The average phytoplankton productivity and chlorophyll-*a* levels showed the same seasonal pattern that is characterized by two peaks, one in July and one in December; the former is related to the May-September rainy season and the latter to the November-February *nortes* season. The first peak is the maximum for both for chlorophyll-*a* (18.82 mg m^{-3}) and productivity (>900 mgC m^3 d^{-1}), reached after a period of increasing chlorophyll-*a* and productivity associated with the beginning of the rainy season. The second peak is lower, and the period of relatively higher chlorophyll-*a* and productivity is shorter than during first peak.

No information is available with regard to species composition of the phytoplankton community. Nevertheless, spatial heterogeneity will be less as compared to other lagoons because the spatial salinity range is relatively narrow (12-18‰) and, as freshwater enters the lagoon via groundwater discharge, there is no contribution to the community from continental aquatic ecosystems.

Macrophytes

The spatial distribution of macrophytes in Laguna de Celestún is heterogeneous. *Chara fibrosa* forms very dense stands in the inner zone of the lagoon, and mixed stands of *Ch. fibrosa* and *Batophora oesterdi*, are found in the central part of the inner zone. The shoal grass *Halodule wrightii* and the green algae *Chaetomorpha linum* form dense mixed stands in the middle zone. The seaward zone is occupied mostly by *H. wrightii* in the lagoon and by *Thalassia testudinum* outside the lagoon. Other algae (*Caulerpa cupresoides, Hypnea musciformes, Dyctiota* sp., *Cladophoropsis membranoce, Cladophora* sp., among others) are found near the mouth of the lagoon, but their coverage and seasonal changes comprise less than 5% of the entire biomass of macrophytes.

During a one-year cycle (Fig. 5), the total biomass of macrophytes ranged from 50 to >1,000 g m^{-2} dry weight. The two distinct biomass peaks observed during the year were due to different species: the peak in August was due mainly to *H. wrightii* (721 g m^{-2}); the second, in January, was due to *Ch. fibrosa* (320 g m^{-2}). *Batophora oesterdi* showed the same general temporal pattern as *Ch. fibrosa* but with less biomass (90-145 g m^{-2}). The mean total biomass of *Halodule wrightii* increased during the rainy season to a peak of about 700 g m^{-2} dry weight in August. A second, shorter, growing period was observed during the *nortes* season, with a peak of 308 g m^{-2}. The below-to-above ground ratio shifted from 0.3 in August to 1.6 in December, a growth strategy that produces seeds during good conditions and takes up new zones and/or supports unfavorable water column conditions (low transparency, low temperatures). The mean biomass of *Chaetomorpha linum* ranged from 20 to 212 g m^{-2} and showed two distinct high biomass periods: (1) from the end of the dry season to the beginning of the rainy season (95-280 g m^{-2}), before the *H. wrightii* growth period; and (2) during the *nortes* season (62-135 g m^{-2}), before the second annual period of growth of *H. wrightii*. There is no information available on *Thalassia testudinum*.

All primary producers (phytoplankton and macrophytes) in Laguna de Celestún have the same seasonal pattern of productivity: two periods of relatively high productivity during the rainy and *nortes* seasons (March-August and November-February), separated by periods of low productivity during the dry season (March-April) and during the last months of the rainy season (September-October). This pattern is similar to that observed in other lagoons, whether tropical (Day *et al.*, 1982; Flores-Verdugo *et al.*, 1988) or temperate (Morgan and Kitting, 1984). In all cases, the covariance of enviromental factors (temperature, nutrient input) contributes to the two peaks observed. However, differences between the productivities of the different groups of plants studied in Laguna de Celestún, both temporally and spatially, provide clues to explain this pattern. The primary productivity of the inner zone of the lagoon and of the rest of the lagoon correspond to different groups of plants. *C. fibrosa* and *B. oesterdi* are restricted to the inner zone. *Ch. linum* and *H. wrightii* are mostly restricted to the middle and seaward zones of the lagoon, with *T. testudinum* and other macroalgae in the adjacent coastal zone. The spatial heterogeneity in distribution and abundance of primary producers is common in coastal lagoons and is mostly related to salinity gradients (Flores-Verdugo *et al.*, 1988; Sand-Jensen and Borum, 1991). The salinity gradient along the longest axis of the lagoon is maintained year round, and probably is the major factor controlling spatial distribution of macrophytes in the lagoon.

The observed space-time changes in biomass of phytoplankton and macrophytes suggest a shift in competition capacity driven by N:P ratio, salinity gradient, and temperature (Wium-Andersen *et al.*, 1982; Sand-Jensen and Borum, 1991). Another probable factor is the accumulation of toxic compounds, such as tannins from decomposition of mangrove leaves (the reddish color of the water in the inner zone during this period; Herrera-Silveira, 1993). These compounds have demonstrated negative effects on microbiota (Lee *et al.*, 1990).

Laguna de Celestún shows a pattern of primary production that is quite different from other lagoons along the Pacific coast and the Gulf of México (Day *et al.*, 1982; Villalobos-Figueroa *et al.*, 1984, Flores-Verdugo *et al.*, 1988), In other regions, phytoplankton grows during the rainy season and, later, macrophytes increase in biomass. In Laguna de Celestún, the primary producers follow a distinctive sequential order of growth: the *Ch. linum* population develops during the late dry season; after this, phytoplankton biomass increases, followed by *H. wrightii*, *Ch. fibrosa*, and *B. oesterdi* during the rainy season. A similar order of biomass peaks is observed during the *nortes* season (Fig. 5).

As in other coastal lagoons, Celestún shows an apparent spatial and seasonal primary production succession between phytoplankton and macrophytes (Flores-Verdugo *et al.*, 1988). The changes in primary production and spatial heterogeneity, supported by climatological patterns in the northern Yucatán Peninsula, affect the biomass changes of the different producers and its relative importance in space and time in the lagoon. The patterns suggest different optimum conditions for phytoplankton and macrophytes. During the dry season, the remineralization process should support a high biomass of *Chaetomorpha linum*, but during the rainy season, the nutrient input from groundwater discharge and remineralization support phytoplankton blooming. The increase in water temperature and uptake of nutrients from sediments by *H. wrightti* support the high biomass during this period. During the *nortes* season, strong climatological oscillations attenuate remineralization and loss of organic matter from middle and seaward zones to the coastal area, limiting the growth of phytoplankton and seagrasses. However, the inner zone is less affected by these phenomena, where *Ch. fibrosa* reaches peak development.

This suggests that there are two scales of factors operating separately and/or together to cause the seasonal succession of primary producers in Laguna de Celestún: (1) interaction between species as competition or allelopathic behavior; (2) the relationship between life cycles of the primary producers and both external factors (temperature, groundwater discharge, and frontal systems) and internal processes (mineralization, bioturbation).

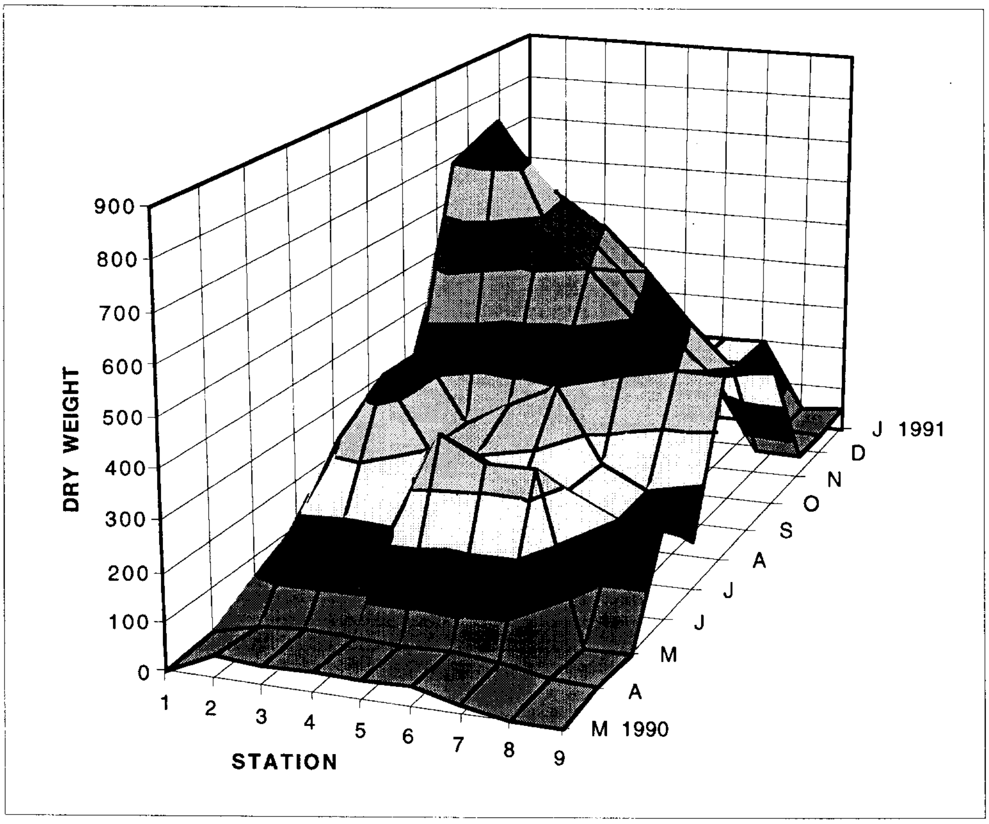

Fig. 5. Mean seasonal changes in the biomass (g m^{-2} dry weight) of submerged macrophytes in Laguna de Celestún during a one-year cycle.

Mangrove Forests

The mangrove forest shows differing structural development along a horizontal gradient and also differences between its barrier and continental sides related to soil characteristics (texture, organic mater, salinity), competition with other vegetation, and human development.

A narrow fringe of red mangrove (*Rhizophora mangle*) on the barrier side is followed by black mangrove (*Avicennia germinans*), which exhibits the greatest importance values (IV = 63%). Behind the fringe, white mangrove (*Laguncularia racemosa*) mixes with sand dune vegetation. From the seaward zone to the inner zone, tree heights increase from 10.2 m to 12.2 m and the IV of *R. mangle* shifts from 24% to 31%. In the marginal forest, the mean basal area is 22 m^{-2} ha^{-1}, the mean complexity index is 7.

On the continental side of the lagoon, the mangrove forest shows a better structural development than on the barrier side but with a similar horizontal gradient landward. In the seaward zone (Fig. 6A), the forest is dominated by *A. germinans* (IV = 74.6%) with a mean height of 11 m, a basal area of 21 m^{-2} ha^{-1}, and a complexity index of 15. In the central zone of the lagoon (Fig. 6B), the dominance shifts to *R. mangle* (69.6%) followed by *A. germinans* (29%), with a mean height of 13 m, a basal area of 23 m^{-2} ha^{-1}, and a complexity index of 16.5. Finally, in the inner zone (Fig. 6C), the forest reaches its greatest structural development, dominated by *R. mangle* (74%), followed by *L. racemosa* (20%), with a basal area of 36 m^{-2} ha^{-1}, a mean height of 15 m, and a complexity index of 21 (Herrera-Silveira, 1993). Changes of basal area and complexity index indicate the gradient of mangrove forest type from fringe forest in the seaward zone, to basinal forest in the middle zone, to riverine forest in the inner zone.

On the barrier side of the lagoon, the soil is sandy, poor in organic matter, and salt-stressed. *A. germinans* is hardy under these conditions and dominates this side. Additionally, the mix with dune vegetation favors the competence of this species. On the continental side of the lagoon, the forest is large, extending >5 km from the lagoon. Its configuration is heterogeneous because the dominant species changes according to the spatial gradient, from *A. germinans* in the seaward zone to *R. mangle* in the inner zone. The capacity of *A. germinans* to occupy zones with the lowest flood and highest salinity variations explains the high importance values in the seaward zone. However, increasing groundwater discharge in the middle and inner zones favors a shift of dominance to *R. mangle*; in the inner zone, *L. racemosa* is replaced by *A. germinans* because of its tolerance of low salinity (Pool *et al.*, 1975; Snedaker, 1982).

The mean density of trees in the mangrove forests of Celestún (1,826 trees ha^{-1}) is less than the mean reported previously (2,503 trees ha^{-1}; Pool *et al.*, 1977; Brown and Lugo, 1982; Twilley, 1982; Flores-Verdugo *et al.*, 1990). The basal area is not related to mean height, probably because Celestún is susceptible to hurricanes, which have a "pruning" effect.

Changes in soil salinity, from 2‰ in the inner zone to 60‰ in the seaward zone (Trejo, 1986), could have favored the spatial differences in structural development of the mangrove forest. The low nutrient input from groundwater and the seasonal change yield low litterfall production (Snedaker and Snedaker, 1984). The high litterfall production in the inner zone is related to the salinity gradient (Pool *et al.*, 1975). However, mangrove development is poor farthest inland where *A. germinans* forms a dwarf forest.

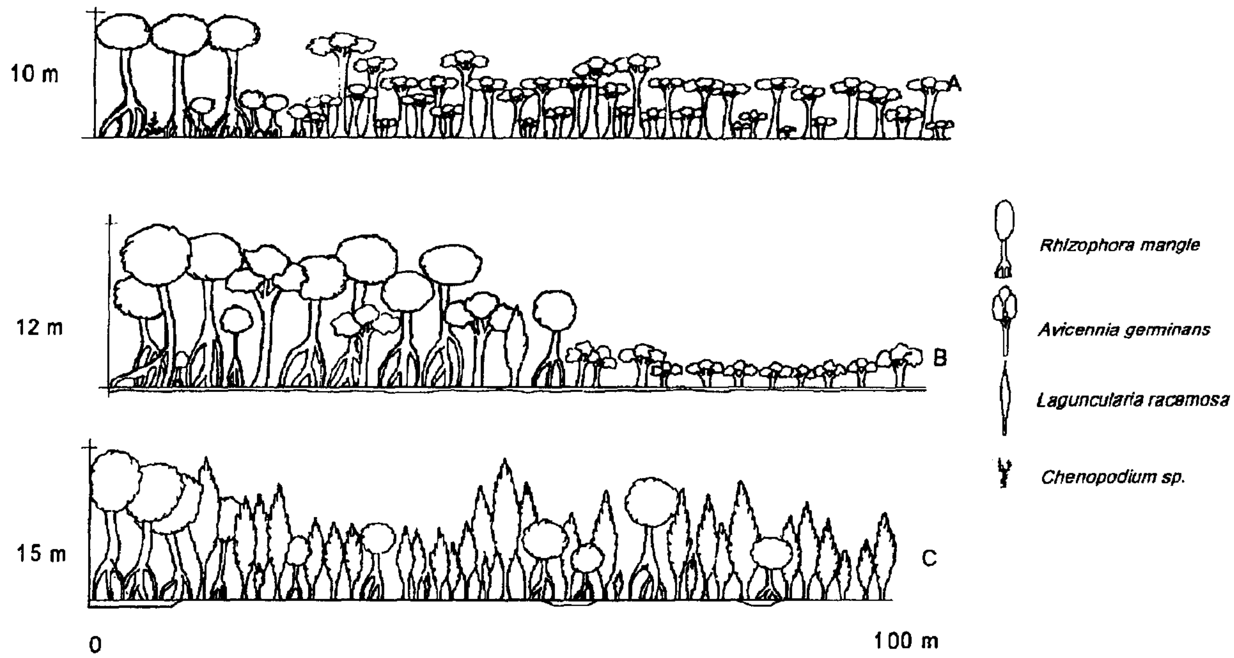

Fig. 6. Diagrammatic mangrove vegetation profile in Laguna de Celestún: (A) seaward zone, (B) middle zone, and (C) inner zone.

Conclusion

Laguna de Celestún is an ecosystem in which frontal systems, rainfall, and tides influence the development of gradients in hydrological and biological characteristics. The seasonality and distribution of groundwater discharge is important in establishing a longitudinal salinity gradient, which is the main factor affecting distribution and organization of primary producers through dispersion of nutrients and particulate material. Temporal and spatial distribution patterns are related to the frequency and intensity of rains, tides, and meteorological forces. Thus far, research efforts been have concentrated on the middle and inner zones of the lagoon. Information is still sparse on primary production in the seagrasses and mangrove forests of the inlet zone. Only through systematic studies and standardization of methodology will it be possible to obtain an overall view of this system, detect both short-term and long-term trends, and develop a reliable database to understand and manage the ecosystem efficiently (Shaffer-Novelli *et al.,* 1990).

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References

Almanza, R., S. López. 1978. Total solar radiation in Mexico using sunshine hours and metereological data. *Solar Energy,* **21**:441-448.

Barrios-Espino, G. R. 1988. *Aspects of the Ecology of the Caribbean Flamingo (Phoenicopterus ruber ruber) in Yucatán, Mexico.* M.Sc. Thesis, Auburn University, Auburn AL, USA, 65 pp.

Brown, S., A. E. Lugo. 1982. A comparison of structural and functional characteristics of saltwater and freshwater forested wetlands. **In:** *Wetlands Ecology and Management: Proceedings of the First International Wetlands Conference, New Delhi, India* (edited by P. Gopal, R. E. Turner, R. G. Wetzel, and D. F. Whigham), pp 109-130. National Institute of Ecology and International Scientific Publications.

Butterlin, J. 1958. Reconocimiento geológico del territorio de Quintana Roo. *Boletín de la Asociación Mexicana de Geológos Petroleros,* **2**:531-570.

Day, J. W., R. H. Day, M. T. Barreiro, F. Ley-Lou, C. J. Madden. 1982. Primary production in Laguna de Terminos, a tropical estuary in the southern Gulf of Mexico. *Oceanologica Acta,* **5**:269-276.

Flores-Verdugo, F., J. W. Day, L. Mee, R. Briseño. 1988. Phytoplankton production and seasonal biomass variation of seagrass, *Ruppia maritima* L., in a tropical Mexican lagoon with an ephemeral inlet. *Estuaries,* **11**(1):51-56.

Flores-Verdugo, F., F. Gonzalez-Farias, O. Flores-Ramírez, F. Amescua-Linares, A. Yañez-Arancibia, M. Alvarez-Rubio, J. W. Day. 1990. Mangrove ecology, aquatic primary productivity, and fish community dynamics in the Teacapán-Agua Brava lagoon-estuarine system (Mexican Pacific). *Estuaries,* **13**(2):219-230.

Guélorget, O., J. P. Perthuisot. 1992. Paralic ecosystems. Biological organization and functioning. *Vie et Milieu,* **42**(2):215-251.

Herrera-Silveira, J. A. 1993. *Ecologia de los Productores Primarios en la Laguna de Celestún, México. Patrones de Variación Espacial y Temporal.* Ph.D. Dissertation, Universidad de Barcelona. España, 233 pp.

Herrera-Silveira, J. A. 1994. Spatial heterogeneity and seasonal patterns in a tropical coastal lagoon. *Journal of Coastal Research,* **10**(2):738-746.

Herrera-Silveira, J. A., F. A. Comin. 1995. Nutrient fluxes in a tropical coastal lagoon. *Ophelia,* **42**: 127-146.

Instituto de Geofísica. 1990. *Tablas de Predicción de Mareas (1989-1991).* Universidad Nacional Autónoma de México, México DF, 30 pp.

Kjerfve, B. 1986. Comparative oceanography of coastal lagoons. **In:** *Estuarine Variability* (edited by D. A. Wolfe), pp 63-81. Academic Press, New York NY, USA, 509 pp.

Lee, K-H., M. A Moran, R. Benner, R. E. Hodson. 1990. Influence of soluble components of red mangrove (Rhizophora mangle) leaves on microbial decomposition of structural (lignocellulosic) leaf components in seawater. *Bulletin of Marine Science,* **42**(2):374-386.

López-Ramos, E. 1974. Estudio geológico de la Península de Yucatán. *Boletín de la Asociación Mexicana de Geólodos Petroleros,* **25**:25-76.

Morgan, M. D., C. L. Kitting. 1984. Productivity and utilization of the seagrass *Halodule wrightii* and its attached epiphytes. *Limnology and Oceanography,* **29**(5):1066-1076.

Pool, D. J., A. E. Lugo, S. C. Snedaker. 1975. Litter production in mangrove forests of southern Florida and Puerto Rico. **In:** *Proceedings of the International Symposium on the Biology and Management of Mangroves* (edited by G. E. Walsh, S. C. Snedaker, and H. J. Teas), pp 213-237. Institute of Food and Agricultural Science, University of Florida, Gainesville FL, USA.

Robles-Ramos, R. 1950. Apuntes sobre la morfología de la Península de Yucatán. *Boletín de la Sociedad Mexicana de Geografía y Estadística*, **69**:113-134.

SARH. 1989. *Datos Climatológicos del Norte de Yucatán*. Reporte Anual, Secretaría de Agricultura y Recursos Hidráulicos, 18 pp.

SARH. 1991. *Datos Climatológicos del Norte de Yucatán*. Reporte Anual, Secretaría de Agricultura y Recursos Hidráulicos, 29 pp.

Sand-Jensen K., J. Borum. 1991. Interactions among phytoplankton, periphyton, and macrophytes in temperate freshwaters and estuaries. *Aquatic Botany*, **41**:137-175.

Schaeffer-Novelli,Y., M. H. S. Lima, G. Cintrón-Molero. 1990. The Cananéia lagoon estuarine system, Sao Paulo, Brazil. *Estuaries*, **13**(2):193-203.

Snedaker, S. C. 1982. Mangrove species zonation: Why? **In:** *Task for Vegetation Science* (edited by D. N. Sean and K. S. Rajpurohit), Vol. II, pp 111-125. W. Junk, The Hague.

Snedaker, S. C., J. G. Snedaker (Editors). 1984. *The Mangrove Ecosystem: Research Methods*. Monographs on Oceanographic Methodology, UNESCO/SCOR, Paris, France, 251 pp.

Trejo, F. A. 1986. *Estudio de la Vegetación de Manglar de la Zona Costera Inundable de la Laguna de Celestún, Yucatán, México*. Reporte de Servicio Social, Universidad Autónoma Metropolitana-Iztapalapa, México DF, 29 pp.

Twilley, R. R. 1982. *Litter Dynamics and Organic Exchange in Black Mangrove (Avicennia germinans) Basin Forest in Southwest Florida Estuary*. Ph.D. Dissertation, University of Florida, Gainesville FL, USA.

Vannucci, M. 1969. What is known about the potential of coastal lagoons. **In:** *Lagunas Costeras — un Simposio: Memorias Simposio Internacional Lagunas Costeras* (edited by A. A. Castañares and F. B. Phleger), pp 601-620. UNAM-UNESCO, México DF, 686 pp.

Villalobos-Figueroa, A., V. R. De la Parra, P. B. E. Galván, R. O. J. Cacho, P. M. A. Izaguirre. 1984. Estudio hidrobiologico en la Laguna de la Mancha, Municipio de Actopan, Veracruz, 1979-1980. *INIREB* **15**:9-51.

Wium-Andersen, S., U. Anthoni, C. Christophersen, G. Houen. 1982. Allelopathic effects on phytoplankton by substances isolated from aquatic macrophytes (Charales). *OIKOS*, **39**: 187-190.

Puerto Morelos, Quintana Roo, Mexico[1]

Francisco Ruíz-Rentería, Brigitta I. van Tussenbroek, and Eric Jordán-Dahlgren
Estación Puerto Morelos, Instituto de Ciencias del Mar y Limnología
Universidad Nacional Autónoma de México
Ap. Postal 1152
Cancún 77500, Q.R., Mexico

Puerto Morelos is located on the northeastern coast of the Yucatán Peninsula. This rapidly growing village depends on fishing and tourism. The climate is typically Caribbean, with a warm rainy season and a slightly cooler dry season. Carbonate rocks and sediments of Tertiary to Holocene origin cover most of the peninsula. The limestone is heavily karstified which, together with the lack of soil, accounts for the scarcity of rivers. Thus, coastal zone processes are influenced primarily by oceanic rather than terrestrial inputs. The dominant ecosystems are coral reefs, seagrass meadows, and inland wetlands that are partially colonized by mangroves. While continuous interactions exist between the coral reef and seagrass ecosystems, the wetlands are isolated by a sand bar, limiting exchanges to underground brackish water seepage and occasional storm wave intrusions.

Introduction

Puerto Morelos is located on the northeastern coast of the Yucatan Peninsula, Mexico (Fig. 1). The peninsula is a large, mostly flat, heavily karstified limestone platform formed by the deposition of Tertiary-Holocene carbonates and evaporites upon Jurassic-Cretaceous red beds (Ward, 1985). Rainwater filters rapidly through the limestone into the aquifer and there is very little surface drainage. Above 20°N latitude, the average annual underground freshwater discharge from the peninsula is estimated to be 8.6 million m^3 per year per km of coastline (Back, 1985).

At Puerto Morelos, the coastal zone is delimited on the landward side by 10 m high Pleistocene berms, which limit the inland extension of shallow and almost closed coastal lagoons colonized by wetland flora (Fig. 1). The wetland lagoons are isolated from the adjacent sea by a 2-3 m high, 100-200 m wide sand bar that constitutes the present shoreline. *Rhizophora mangle* stands occur as narrow belts along the edges of the lagoons or as small isolated patches in the central parts. Except for seawater input during major storms, which are rare events in this area, oceanic influence on the wetlands is small. Small-scale discharge of fresh or brackish wetland waters occurs through submarine springs and by

[1] *CARICOMP — Caribbean Coral Reef, Seagrass and Mangrove Sites* (edited by B. Kjerfve), pp 57-66.
UNESCO, Paris, 1998, 347 pp.

overflow through small canals during the rainy season. Seaward from the sand bar, the typical environment is a coast fringed by a reef. The reef lagoon (or reef channel) is several hundred meters wide and 3 to 4 m in average depth; the bottom is covered by calcareous sand, which is stabilized by seagrass meadows. In certain areas, however, the underlying calcareous pavement is exposed and is colonized by coral reef communities typical of hardgrounds or is covered by unconsolidated carbonate sediments. The reef is a shallow barrier with little Holocene accretion and morphology determined primarily by events of the middle and late Pleistocene (Ward, 1985). Seaward from the crest, the reef gently slopes to depths of 20-25 m, giving way to a mostly barren sand platform, which slopes gently for several kilometers. The shelf edge occurs at a depth of 40-60 m, followed by a drop-off to more than 400 m.

Puerto Morelos is a small fishing and tourist village with a permanent population of *ca.* 3000 people, plus a seasonal population of 100 to 200 (Gobierno del estado de Q.R., Mexico, 1996). Half of the inhabitants live in the coastal zone on the sandbar, the remainder live landward on the Pleistocene berms (Fig. 1). Commercial fishing principally comprises lobsters *Panulirus argus* and *P. gutattus* (Lozano *et al.*, 1991) and fishes such as barracuda, snapper, grouper, hogfish and, to a certain extent, triggerfish. The average fish size and population size of these species seem to have decreased considerably in recent years, but other reef fish species are still relatively untouched. Both commercial and subsistence fishing employ lobsterpots, spearguns, gill nets, and line and hook. In recent years, tourism has increased and, at present, an average of six boats (with about ten people per boat) make daily trips to the coral reef. The impact of these activities on the reefs has not yet been assessed.

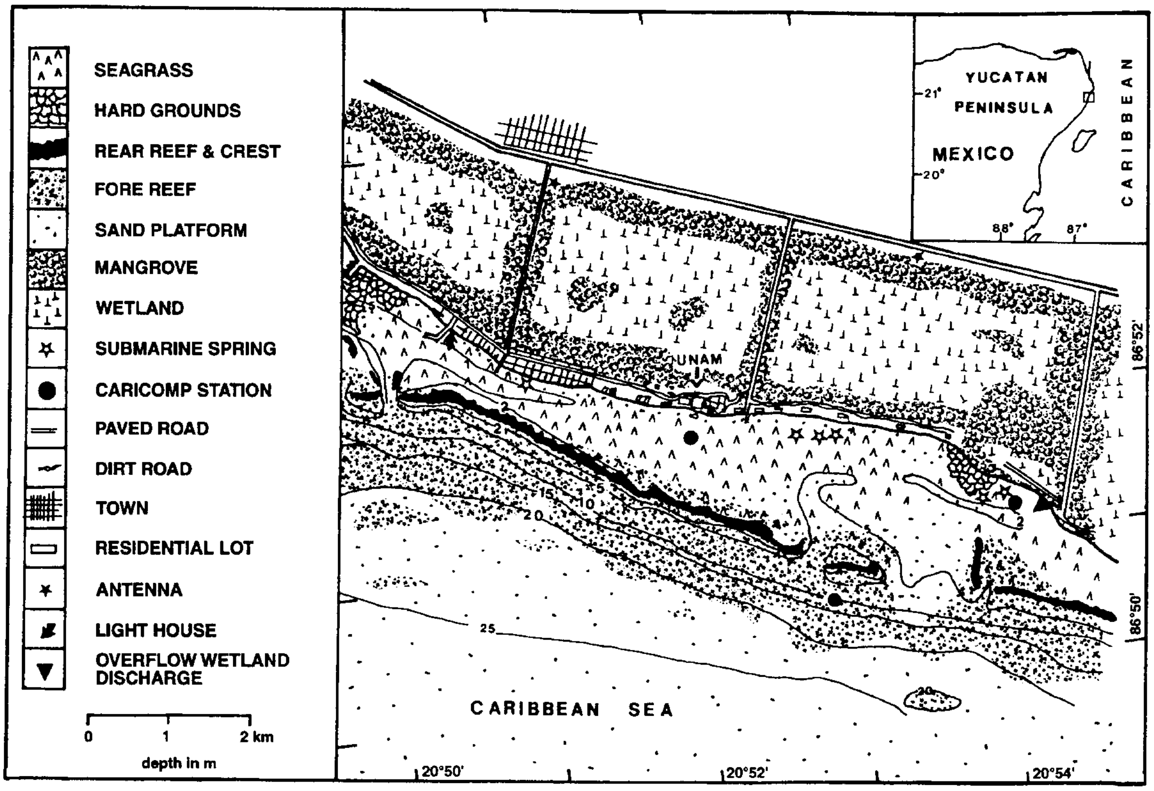

Fig. 1. Feature map of the Puerto Morelos CARICOMP site; isobaths modified from Merino and Otero (1991).

Urbanization for tourism development and residential housing is rapidly increasing, resulting in landfill and deforestation in the wetland areas. Puerto Morelos is not yet equipped with a central sewer system, and wastes are discharged either into septic systems or directly, without any treatment, into holes in the ground. Urbanization is expected to increase in the near future, as the government considers development of a tourist resort in the coastal area and an industrial zone landward. At present, however, the Puerto Morelos area is still relatively pristine.

Atmostpheric and Oceanic Characteristics

According to the official climate charts (Secretaría de la Presidencia, 1970a), the climate in the region is warm, sub-humid with marked rainy seasons. Merino and Otero (1991) reported an average yearly air temperature of 26.3°C, with a summer high of 32.5°C and a winter low of 13.0°C for the period 1982-1983. CARICOMP data collected from 1992 show a similar seasonal distribution of air temperature. The highest temperature of 34.5°C was recorded once in summer and once in autumn. The lowest temperature was 12.5°C, in the winter. According to Merino and Otero (1991), average yearly rainfall is 1,123 mm. However, rain can be quite variable in Puerto Morelos. During the period 1982-1983 there was more rain during the dry season (January-May) than during the rainy season (June-November). CARICOMP meteorological data are collected 6 m above sea level. Rain data from 25 November 1992 through 25 November 1993 show rainfall throughout the year, with a yearly total of 1,804 mm; the driest month was April. The site is under the influence of trade winds in the summer, with velocities averaging 5 m s^{-1} (Merino and Otero, 1991), which are interrupted for periods of 3 to 10 days in winter by intense cold winds from the north. Tropical storms and hurricanes occur from time to time along the eastern coast of Yucatan. In the last 30 years, three hurricanes have passed over Puerto Morelos: Beulah, a Force 3 hurricane in 1965; Allen, a Force 5 hurricane in 1980; and Gilbert, a Force 5 hurricane in 1988. Shortly after Gilbert, a tropical storm-hurricane named Keith also struck the area. In October 1995, Hurricane Roxanne crossed the coast *ca.* 100 km south of Puerto Morelos; not much damage was done.

On oceanic scale, the principal feature is the Yucatan Current (precursor of the Gulf Stream), which parallels the edge of the continental shelf off Puerto Morelos. GEK measurements of northward flow in the Yucatan Strait indicated maximum velocities of 4-5 knots (Molinari and Cochrane, 1970). Nowlin and Hubertz (1970) obtained more moderate values, 1-2 knots. Cochrane (1966) and Ruiz (1979) suggested that the direction and intensity of the current changes with seasons. Tides in this region of the Caribbean are mixed semi-diurnal, with a small range of 0.24 m, as shown by tide tables for Cozumel Island situated 60 km south of Puerto Morelos (Instituto de Geofísica, 1992).

Oceanographic data are sparse for Puerto Morelos. Circulation in the reef lagoon is mostly parallel to the coast (unpublished data). Currents change in speed and direction, due to a combination of variables: influence of the Yucatan Current, winds, wave spillage over the reef, and the location of surge channels. Waves in the reef lagoon are low; Merino and Otero (1991) measured a height of 0.14 m. No data are available for open ocean wave height, but from personal observation, 1 m is the average. Table 1 shows the average values of several water quality parameters at Puerto Morelos 1982-1983 by

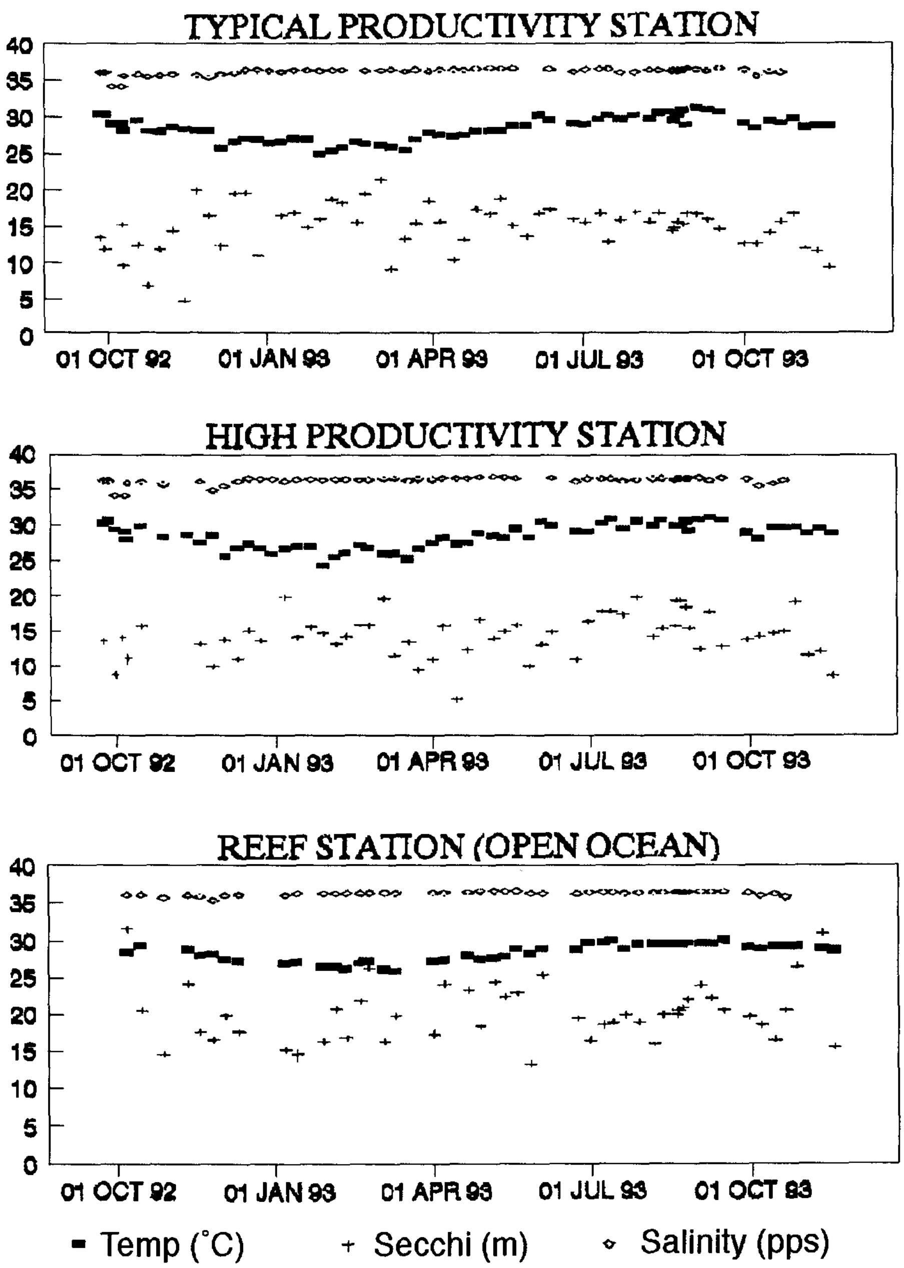

Fig. 2. Temperature, salinity and Secchi disk measurements at seagrass and coral reef stations. Secchi measures were taken horizontally at the lagoon stations, vertically in open ocean close to the reef station.

Merino and Otero (1991). CARICOMP weekly data during 1992-1993 (Fig. 2) at three sampling locations show similar mean water temperature and salinity as those in Table 1. Salinity and temperature appear to be almost the same for the three CARICOMP locations. However, slight differences are appreciable in transparency data between the sampling stations.

Table 1. Water quality parameters at Puerto Morelos, sampled monthly from March 1982 through July 1983 (Merino and Otero, 1991).

	Average Values
Temperature	27.74°C
Wave height	0.14 m
Salinity	35.7‰
Max sea level variability	0.68 m
Dissolved oxygen	4.99 mg l^{-1}
pH	8.3
Alkalinity	2.5 meq l^{-1}
Nitrite	0.06 µg-at l^{-1}
Nitrate	13.9 µg-at l^{-1}
Silicate	5.8 µg-at l^{-1}
Ammonia	0.08 µg-at l^{-1}
Phosphorus	5.04 µg-at l^{-1}
Particulate carbon	99.1 mg l^{-1}

Mangrove Wetlands

The mangrove wetlands in the shallow coastal lagoon are isolated from the sea by the sand bar, and interaction between seagrass beds and coral reef is thus virtually absent. The wetland lagoon is heavily perturbed by deforestation for urbanization and most of the mangrove area bordering the sandbar is privately owned. Additionally, water circulation in the lagoon has been interrupted by the construction of roads running from the sand bar to the highway (Fig. 1). Due to the absence of an untouched area near the other CARICOMP sampling stations, a suitable mangrove sampling station has not been located to date.

Seagrass Beds

Lagoon vegetation can roughly be divided into three distinct zones: (1) a narrow coastal fringe, (2) a broad mid-lagoon zone, and (3) an area of backreef vegetation (Table 2). The abundant vegetation

Table 2. Characteristics of vegetation zones in the Puerto Morelos reef lagoon (van Tussenbroek, unpub. data).

		Standing Crop (g m^{-2} dry weight)		Algae
Vegetation Zone	Characteristics	*T. testudinum*	*S. filiforme*	Abundance
Coastal Fringe	20-50 m wide			
	well-developed vegetation			
	T. testudinum dominated	25-45	20-30	± or +
	S. filiforme dominated	5-20	100-160	
Mid-Lagoon Zone	200-1,000 m wide			
Typical	*T. testudinum* dominated	20-35	2-12	±
High density	*T. testudinum* dominated	50-80	2-5	–
Low density	algae dominated	20-20	10-30	+
Backreef Zone*	100-400 m wide			
Short *T. testudinum*	leaf length 9-10 cm	15-30	virt. absent	–
Long *T. testudinum*	leaf length 13-15 cm	30-55	virt. absent	±

*Length of *T. testudinum* in the backreef zone is the average length of the largest leaves.
Key to algae abundance: –, few; ±, more or less abundant; +, dominant.

of the coastal fringes is dominated by either *Thalassia testudinum* or *Syringodium filiforme*, which are accompanied by rhizophytic algae. Occasionally mats of *Halodule wrightii* or *Caulerpa* spp. are found close to the beach in front of this well-developed fringe.

The mid-lagoon zone covers the greater part of the lagoon. Denuded sandy areas, from 10 m^2 to 100 m^2, can be found throughout this zone. Bottom vegetation typically consists of a moderate density of *Thalassia testudinum*, with *Syringodium filiforme*, accompanied by rhizophytic algae; the sampling site off the UNAM research station is considered to be representative of this vegetation (Fig. 1). *Thalassia testudinum* reaches a high density in an area in front of a mangrove discharge; the high productivity sampling station is located here (Fig. 1). Off the village, in contrast, the mid-lagoon seagrass density is low, and rhizophytic algae and floating forms of *Lobophora variegata* (max. standing crop: 100 g m^{-2} dry weight) or *Laurencia intricata* (max. standing crop: 20 g m^{-2}) generally dominate.

In the backreef zone, *T. testudinum* has generally very short leaves. *Syringodium filiforme* and rhizophytic algae are virtually absent. Only in front of the village, where the backreef area is more protected due to a broad reef crest, *T. testudinum* leaves tend to be larger than in the rest of this zone.

In the reef lagoon,*Thalassia testudinum* shows seasonal fluctuations in leaf biomass and productivity: maximal in the summer and minimal in the winter months (Fig. 3). It is possible that the present coral reef lagoon vegetation is still in an intermediate state of recovery from the disturbance caused by Hurricane Gilbert in 1988. Population analysis from *Thalassia testudinum* short-shoots sampled in two transects from the coast to the coral reef suggest that *T. testudinum* was not removed in the backreef areas. *T. testudinum* lagoon and coastal populations, however, showed a sharp decline in pre-hurricane short-shoots, suggesting that these turtle grass populations were affected by the storm (van Tussenbroek, 1994).

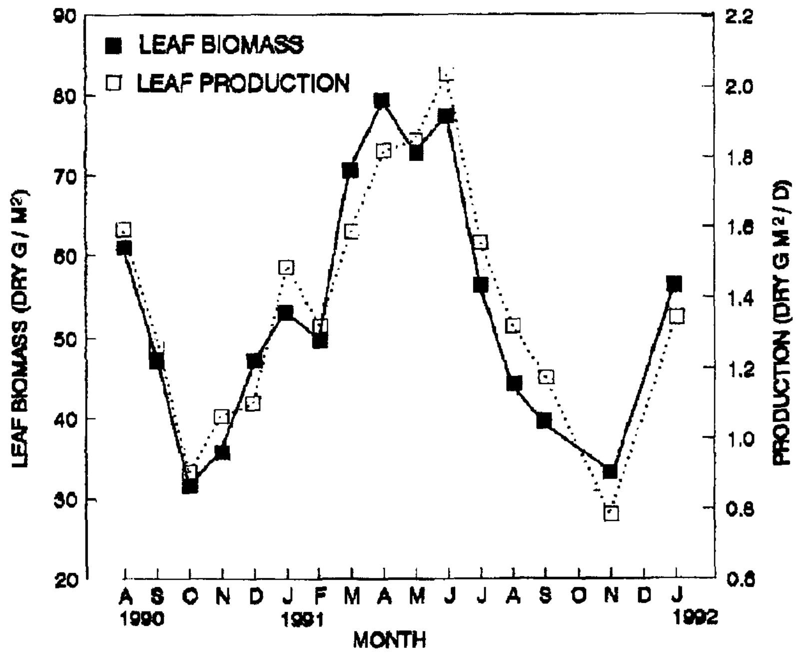

Fig. 3. *T. testudinum* leaf standing crop and productivity measured from August 1990 through January 1992 at the high productivity sampling station in the Puerto Morelos reef lagoon (van Tussenbroek, 1995).

No *T. testudinum* was apparently removed from the high density CARICOMP station in front of the wetlands discharge. The most common rhizophytic algae found throughout the lagoon are *Penicillus capitatus*, *Rhipocephalus phoenix*, *R. oblongus*, *Udotea flabellum*, U. spinulosa, and *Halimeda incrasata*; *Avrainvillea* spp. are abundant in some coastal areas.

Coral Reefs

Puerto Morelos is situated in the northern part of an extensive barrier-fringing reef tract that extends from Belize to the Yucatan Strait. In contrast to the southern reefs, however, reef development in the northern part of the tract tends to be limited to reef crests and backreef zones (Jordán-Dahlgren *et al.*, 1981). The Puerto Morelos reef consists of an extensive calcareous platform that is bevelled on the seaward side, probably by eustatic changes during the Pleistocene. Primarily oceanic forces influence this reef: the Yucatan Current and the large fetch of the waves at this latitude. Five main zones are recognized along the reef profile (Fig. 4), based upon scleractinian composition and reef topography (Table 3). This pattern is similar to that of other areas with a similar geomorphological setting along the Eastern Yucatan reef tract (Jordán-Dahlgren *et al.*, 1981; Jordán-Dahlgren, 1989). A sloping forereef with few high relief features is characteristic of these reefs. Perhaps in part due to this reef morphology, which favors sand accumulation and its resuspension and transport during storms, live scleratinean coral cover on the forereef zone is typically sparse. In contrast, coral cover tends to be dense at the reef crest (*Acropora palmata* and *Millepora complanta*) and in the backreef zone (*A. palmata* and *Montastraea annularis*). In the forereef zone, the most conspicuous components of the biota are gorgonians, macroalgae, and small hemispherical coral heads of *Diploria strigosa*, *Montastraea cavernosa*, and *dichocoenia stokesii*, among many others. The algae seldom exhibit significant vertical growth, except for seasonally occurring *Sargassum* spp. and *Turbinaria* spp. In the few places where

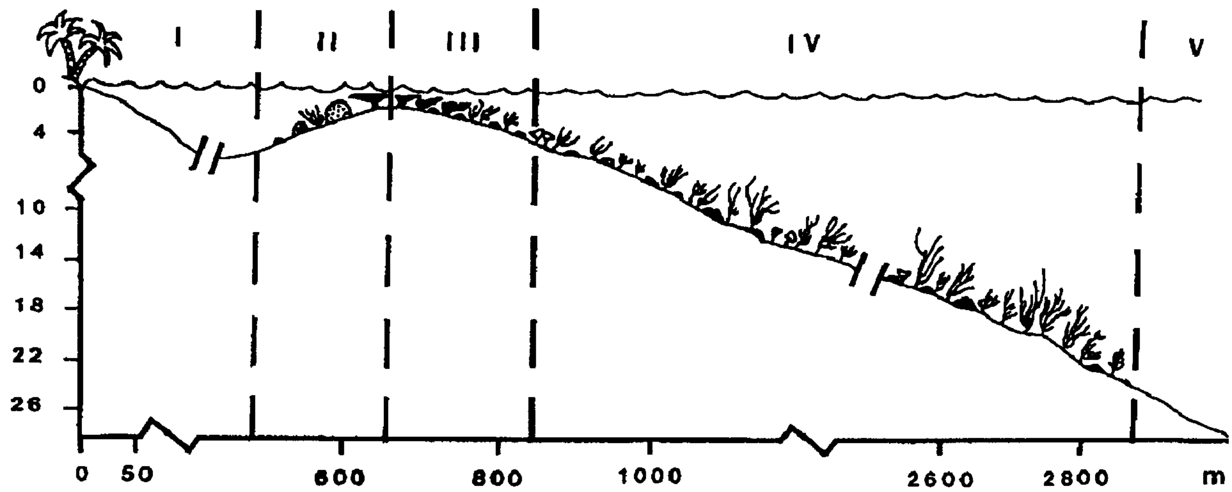

Fig. 4. Reef profile at the Puerto Morelos CARICOMP site. Zonation is based on scleractinian species composition and bottom relief (modified from Jordán-Dahlgren *et al.*, 1981): I, lagoon zone; II, backreef zone; III, breaker zone; IV, forereef zone; V, sand platform zone.

high relief reef features exist, the coral community tends to be strongly dominated by large scleractinian colonies, as in any other well developed coral reef.

The CARICOMP reef sampling station is located on a typical low-relief forereef (Fig. 1). The overall condition of the coral communities of this reef seems good; no extreme situations of bleaching, algal growth, or fish kill have been recorded in the area. At present, the reef is still recovering from the devastating effects of Hurricane Gilbert in 1988 (Table 3). Natural regrowth and recolonization are proceeding at an also variable rate, both between and within the reef zones. Additionally, *Diadema antillarum* urchins, which almost disappeared after the pan-Caribbean demise and which were further affected by Gilbert in 1988, are gradually becoming abundant again. The reef has undergone, and is recovering from, the effects of a major bleaching event that affected most of the Caribbean Sea during the last months of 1995. No evaluation of its effects has been done.

Table 3. Coral reef zonation and dominant scleractinian fauna at Puerto Morelos.

	Range		Bottom Type and	Scleractinian Fauna					
				Jordán-Dahlgren *et al.*, 1981			Rodriguez-Martinez, 1993		
Reef Zones	Width (m)	Depth (m)	Dominant Biota	Spp #	Cov %	Dominant Species	Spp #	Cov %	Dominant Species
Lagoon	400-500	0.1-6.0	seagrass, sand, hardground	14	2.0	*M. aereolata* *A. agaricites* *M. annularis*	12	1.0	*M. aerolata* *M. annularis*
Backreef	30-300	1.0-3.0	seagrass, coral, macro-algae, sand, hardground	27	28.4	*M. annularis* *A.. palmata*	19	4.6	*M. annularis* *P. astreoides*
Reef Crest									
A. millipora	25-75	0.4-1.2	hardground, coral, coral rubble	14	27.1	*M. complanata* *A. palmata*	8	6.4	*A. palmata* *P. astreoides*
Barren	50-100	1.3-3.5	hardground, macroalgae, sponges	7	3.1	*A. palmata*	3	1.0	*M. complanata*
Forereef									
at 5 m	100-150	3.6-7.5	hardground, macroalgae, sponges	17	7.4	*S. siderea* *D. strigosa* *A. palmata*	11	2.7	*S. siderea* *D. clivosa* *D. strigosa*
at 10 m	100-200	7.5-12.5	hardground, gorgonians, macroalgae	17	7.1	*D. strigosa* *S. siderea* *M. cavernosa*	12	3.1	*M. cavernosa* *S. siderea* *M. annularis*
at 15 m	100-200	12.6-17.5	hardground, gorgonians, macroalgae	14	4.6	*M. cavernosa* *S. Siderea* *D. Stokesii*	12	1.4	*M. carvernosa* *S. siderea* *M. annularis*
at 20 m	150-300	17.6-22.5	hardground, gorgonians, macroalgae, sponges	12	1.9	*S. siderea* *D. strigosa* *D. stokesii*	14	2.1	*M. cavernosa* *m. annularis* *S. siderea*
Sand Platform	> 500	20.0-40.0	sand, macro-algae						

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References

Back, W. 1985. Hydrogeology of the Yucatán. **In:** *Geology and Hydrogeology of Northeastern Yucatán and Quaternary Geology of Northeastern Yucatan* (edited by W. C. Ward, A. E. Weidie, W. Back), pp 99-124. New Orleans Geological Society. New Orleans LA, USA, 153 pp.

Cochrane, J. D. 1966. The Yucatan Current, upwelling off northeastern Yucatan, and currents and waters of the western equatorial Atlantic. **In:** *Oceanography of the Gulf of Mexico*, pp 14-32. Progress Report No. 66-23T, Department of Oceanography, Texas A&M University, Galveston TX, USA.

Gobierno del Estado de Q.R., Mexico. 1996. *SEDESOL: Plan Director de Desarrollo Urbano de Puerto Morelos*, 95 pp.

Instituto de Geofísica. 1992. *Tablas de Predicción de Mareas — Puertos del Golfo de México y Mar Caribe, Datos Geofísicos Serie A: Oceanografía*. Universidad Nacional Autónoma de México, 191 pp.

Jordán-Dahlgren, E., M. Merino, M. Moreno, E. Martín. 1981. Community structure of coral reefs in the Mexican Caribbean. **In:** *Proceedings of the IV International Coral Reef Symposium (Manila)* (edited by E. D. Gomez, C. E. Birkeland, R. W. Buddemeier, R. E. Johanes, J. A. Marsh, R. T. Tsuda), Vol. 2, pp 303-308. Marine Sciences Center, University of the Philippines, Quezon, The Philippines, 785 pp.

Jordán-Dahlgren, E. 1989. Efecto de la morfología del sustrato en el desarrollo de la comunidad coralina. *Anales del Instituto de Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México*, **16**:105-118.

Jordán-Dahlgren and Rodriguez-Martinez, 1998. Post-hurricane initial recovery of acropora palmata. *Bulletin of Marine Science*, in press.

Lozano-Alvarez, E., P. Briones-Fourzán, J. González-Cano. 1991. Pesca exploratoria de langostas con nasas en la plataforma continental del área de Puerto Morelos, Q.R., México. *Anales del Instituto de Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México*, **18**:49-58.

Merino, M., L. Otero. 1991. *Atlas Ambiental Costero, Puerto Morelos – Quintana Roo*. Ferrandiz SA, México DF 14640, 80 pp.

Molinari, R. L., J. D. Cochrane. 1970. The effect of topography in the Yucatan Current. **In:** *Contributions on the Physical Oceanography of the Gulf of Mexico* (edited by L. R. A. Capurro, J. L. Reid), pp 149-155. Texas A&M University Oceanographic Studies, Galveston TX, USA, 288 pp.

Nowlin, D. W., J. M. Hubertz. 1970. Contrasting summer circulation patterns for the eastern Gulf of Mexico. **In:** *Contributions on the Physical Oceanography of the Gulf of Mexico* (edited by L. R. A. Capurro, J. L. Reid), pp 119-137. Texas A&M University Oceanographic Studies, Galveston TX, USA, 288 pp.

Rodríguez-Martinez, R. 1993. *Efectos de un Ciclón en la Estructura Comunitaria de Corales Escleractinios*. Bachelor Thesis, ENEP Iztacala, Universidad Nacional Autónoma de México, 64 pp.

Ruiz, F. 1979. *Upwelling North of the Yucatan Peninsula*. MSc Thesis, Texas A&M University, Galveston TX, USA, 86 pp.

Secretaría de la Presidencia, 1970a. *Carta de Climas Cozumel 16 Q-IV*. Comisión de Estudios del Territorio Nacional, Dirección de Planeación de la Secretaría de la Presidencia e Instituto de Geografía de la Universidad Nacional Autónoma de México.

van Tussenbroek, B. I. 1994. The impact of Hurricane Gilbert on *Thalassia testudinum* in Puerto Morelos reef lagoon, Mexico: A retrospective study. *Botanica Marina,* **37**:421-428.

van Tussenbroek, B. I. 1995. *Thalassia testudinum* leaf dynamics in a Mexican Caribbean coral reef lagoon. *Marine Biology,* **122**:33-40.

Ward, W. C. 1985. Quaternary geology of northeastern Yucatán Peninsula. **In:** *Geology and Hydrogeology of Northeastern Yucatán and Quaternary Geology of Northeastern Yucatan* (edited by W. C. Ward, A. E. Weidie, W. Back), pp 23-95. New Orleans Geological Society. New Orleans, LA, USA, 153 pp.

Calabash Caye, Turneffe Islands Atoll, Belize[1]

Eden Garcia and Karie Holtermann
University College of Belize Marine Research Centre
Calabash Caye, Turneff Islands Atoll, Belize

Turneffe Islands Atoll is located 51 km off the coast of Belize. Calabash Caye, on the eastern rim of the atoll, is a CARICOMP site maintained by the University College of Belize Marine Research Centre. There are several subtidal mangrove cayes on the western edge of the atoll, sandy cayes on the eastern edge, and an extensive fringing reef surrounding the atoll. The chain of islands forming the atoll partially encloses two lagoons, the North Lagoon and the South Lagoon, which are dominated by seagrass beds. The mangroves, seagrass beds, and coral reefs enhance the diversity of the marine and terrestrial organisms at Calabash Caye. Over the past decade, only a few studies concerning marine resources have been carried out on the atoll.

Introduction

Belize is a small (46,620 km^2) English-speaking country in Central America, bordered by Mexico to the north, Guatemala to the west and south, and the Caribbean to the east (Fig. 1; 17°09'00" to 17°38' 00"N, 87°44'30" to 87°57'30"W). It is a tropical country with two principal ecosystems, rain forest and barrier reef, linked by rivers, coastal waters, and seagrass and mangrove communities. Off the eastern coast of Belize is the second longest barrier reef in the world (more than 27 km long), which extends from the Mexican border to the Gulf of Honduras. Three of the four existing atolls in the western hemisphere are located east of the barrier reef: Glover's Reef, Lighthouse Reef, and the Turneffe Islands Atoll (Fig. 1). The University College of Belize Marine Research Centre (UCBMRC), which was established in 1994, is located on a 2.025 ha plot on Calabash Caye, a sandy caye on the eastern rim of the Turneffe Islands Atoll. Vegetation consists of dense cocal, caye, and mangrove forests. The CARICOMP protocols have been implemented at the Calabash Caye Field Station.

Geology of Belize

Belize is located on the Yucatan continental block, one of two Paleozoic blocks forming northern Central America. The splitting of the Yucatan Block from the Nicaragua-Honduras Block to the south occurred along an east-west fracture zone, what is now the Cayman Trench (Wantland and Pusey, 1971).

[1] *CARICOMP — Caribbean Coral Reef, Seagrass and Mangrove Sites* (edited by B. Kjerfve), pp 67-77.
UNESCO, Paris, 1998, 347 pp.

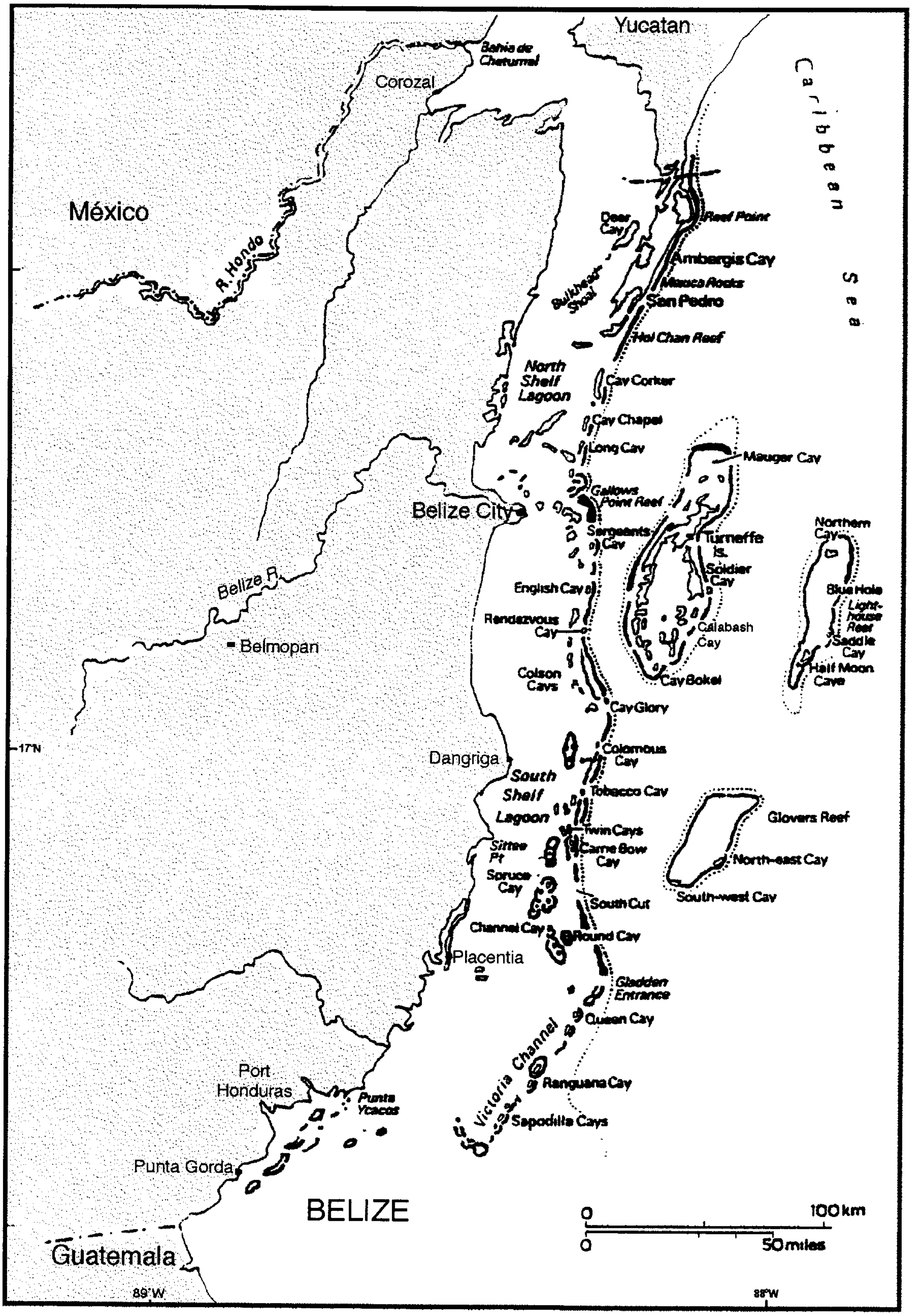

Fig. 1. Map of Belize, showing the barrier reef and the three atolls: Glover's Reef, Lighthouse Reef, and the Turneffe Islands Atoll.

Plate movement reconstruction shows that, by the Late Eocene, both blocks had rotated from their pre-drift location on Pangaea during the Early Triassic to their position. From Cretaceous to Pliocene time, the Yucatan Block subsided and tilted northward; the submerged part is now the Campeche Bank (Wantland and Pusey, 1971). A prominent series of five parallel submarine ridges and scarps formed along the eastern edge of the Yucatan Block. These north-northeast oriented ridges characterize the present continental shelf margin of Belize. They have been modified by erosion, sedimentation, and reef growth during Pleistocene sea-level changes. Evidence suggests that the continental margin is still in the process of tectonic development (James and Ginsburg, 1979).

The five submarine ridges are the most distinctive features of the Belizean continental margin; they parallel the major rivers in northern Belize and are thought to be fault controlled (James and Ginsburg, 1979). The best-developed ridge forms the southern edge of the continental shelf and extends north, becoming the foundation for Glover's Reef and Lighthouse Reef; the depth reaches 3,000 m on the east side. The most poorly defined ridge makes up the northern part of the barrier reef in Belize and Ambergris Caye. The bases of the ridges are believed to be of continental origin as they are thought to consist of material very similar to that of the Maya Mountains. Drilling has shown that much of the relief on these ridges is due to coral growth (Dillon and Vedder, 1973). Three of the five ridges form the foundation for the barrier reef platform.

The Belize barrier reef consists of three biogeomorphic provinces: the northern province has 46 km of shallow-water reefs, the central has 91 km of shallow-water reefs, and the southern has 10 km of shallow-water reefs (Burke, 1993). The central province is the most well developed, with continuous wide reefs. The northern and southern reefs are discontinuous, except along Ambergris Caye. Researchers believe the limited reef development in the south is due to rapid sea-level rise, high-energy waves, and high turbidity. The development of the northern reef was hindered by heavy terrestrial run-off, high turbidity, variable salinity, and prevalence of winds (Burke, 1993). The central province was protected from wave energy by the outer atolls and had a slower sea-level rise (Burke, 1993).

The shelf in Belize extends east from the mainland to a seaward boundary at a depth of 180 m just beyond the barrier reef, where the slope dips 40° into abyssal waters. The shelf is 195 km long and lies between 15°50'N and 17°55'N. The shelf has two main hydrographic provinces: the barrier platform, which consists of the barrier reef, backreef lagoon, and caye complex, and the shelf lagoon, which at the latitude of Belize City consists of bathymetrically different northern and southern sections. The northern part of the shelf is bordered by a low karsted surface of flat-lying Cenozoic and Cretaceous carbonates with a few small rivers draining onto the shelf (James and Ginsburg, 1979). The inner shelf is generally flat, extending to a depth of only 8 m. The southern continental shelf is bordered by the Maya Mountains, through which many rivers flow onto the shelf. The depth of the shelf lagoon ranges from 25 m near Belize City to 200 m near Honduras (James and Ginsburg, 1979).

Geography of the Turneffe Islands Atoll and Calabash Caye

The Turneffe Islands Atoll is roughly lens-shaped, with a maximum length of 50 km and a width of 16 km at its widest point (Fig. 2). The atoll developed along one of the fault-controlled submarine ridges that occur off the coast of Belize along with the Cinchorro Bank Atoll in Mexico. Turneffe is separated from the barrier reef by a 10-16 km wide, 275-300 m deep channel (Gibson, 1990). It is bounded by a drying reef to the north and by Bokel Caye to the south. There is a well-defined narrow reef on the windward, eastern side. The reef crest is narrow and fringes the outer edge of a reef-flat less than 400 m wide. The reef is highly segmented, with about 23 gaps, or channels, most of which are less than 50 m wide and 6 m deep. Small sandy cayes are located between the channels on the inner edge of the eastern side of the reef flat; one of these is Calabash Caye.

Calabash Caye, home to the UCB Marine Research Centre, is a sandy caye located on the eastern rim of the atoll, aligned NNE-SSW, parallel to the reef (Fig. 3). In 1962, Stoddart reported Calabash Caye (which is now the eastern portion of the island) to be 43 m long and 32-50 m wide; the caye has grown considerably since then.

The caye has a dense cover of cocal, caye, mangrove forests, and other low cover vegetation. A 500-m long interior lagoon, referred to as the "back lagoon," is located in the middle of the caye and has been isolated for a long time. The back lagoon has an average salinity of 36‰ and there is little flushing. The back lagoon supports a unique ecosystem of sponges, upside-down jellyfish (*Cassiopea fondosa*), and tunicates (Catterall, 1996). A sandy beach and an extensive fringing reef with diverse species of fish, coral, algae, and other marine invertebrates extend along the entire east coast of Calabash Caye. Turtle grass (*Thalassia testidinum*), which is the dominant species, and manatee grass (*Syringodium filiforme*) are found in the shallow waters surrounding the caye.

Calabash Caye has been inhabited since the beginning of the 20th century, based first on the sponge industry and later the coconut industry, but was completely devastated by Hurricane Hattie in 1962. Currently, there is a camp south of the Marine Research Centre, which houses persons engaged in the coconut business.

Climate and Oceanographic Conditions

Few climatic and oceanographic measurements have been recorded in the Turneffe Islands Atoll; data are available primarily from coastal stations and pertain to the mainland. The rainy season in Belize occurs from June through December, with variable patterns of rainfall in the north and north-central areas. There is a wide range of rainfall, from less than 2,000 mm per year in the north, more than 4,500 mm per year in the south, and over 10,000 mm per year in the Maya Mountains (Perkins, 1995). Turneffe lies between the latitudes of the Belize and Stann Creek districts, but rainfall in significantly lower than on the mainland (Stoddart, 1962). Over the shelf, rainfall is less than at the corresponding mainland sites (Perkins, 1995). The only rainfall figures for Turneffe were recorded during the summer months of 1937-1939 and show considerable variation: 558 mm in 1937, 379 mm in 1938, and 121 mm in 1939 (Stoddart, 1962). Occasional heavy rains are associated with winter storms (northers).

Along the coast of Belize, winds are steady from the northeast, east, and southeast at 3-8 m s^{-1} (Stoddart, 1962), with easterly winds in the atoll area for most of the year. From November through March, cold fronts moving through from southern North America bring northers, with winds gusting to

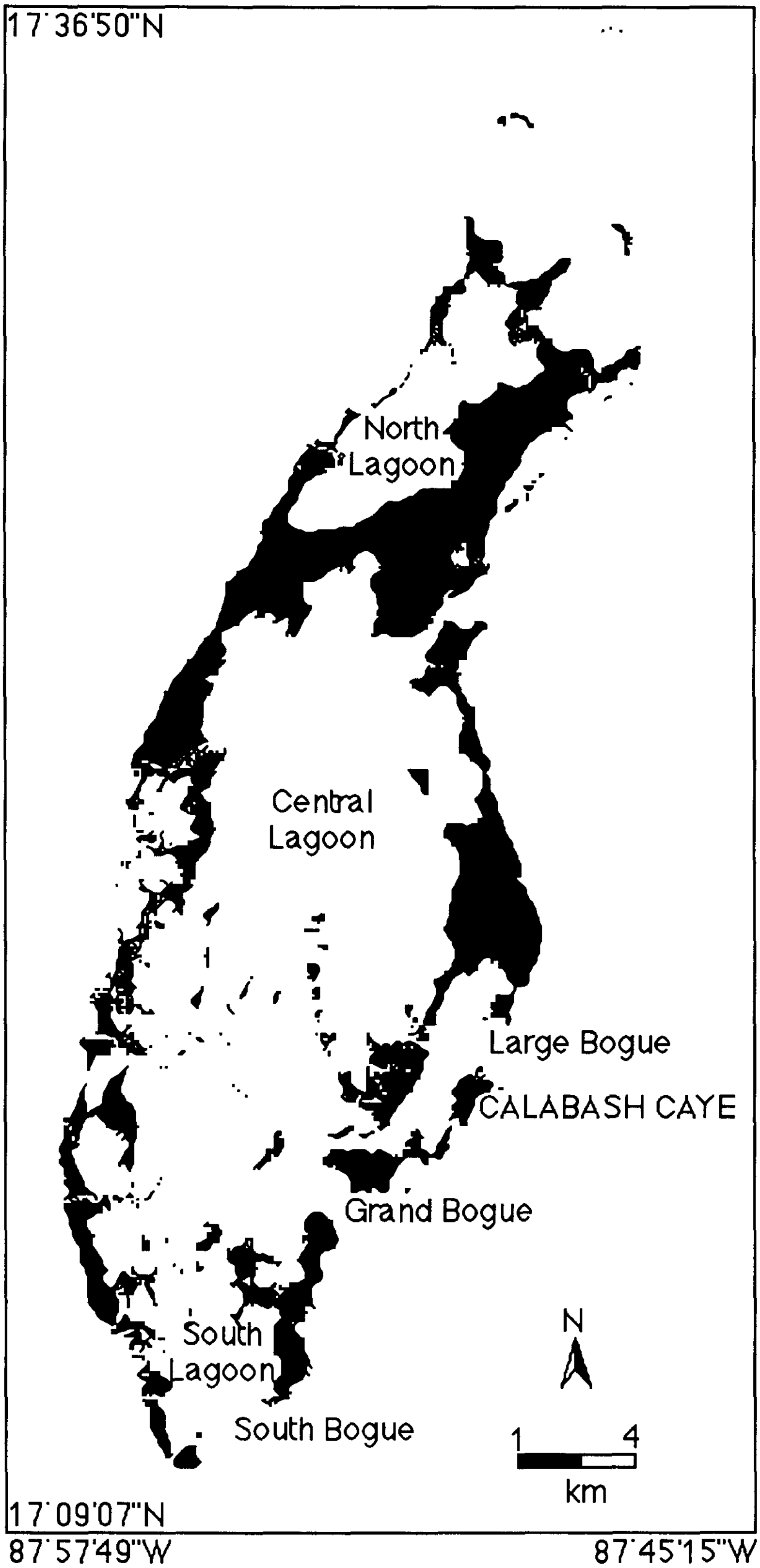

Fig. 2. Map of the Turneffe Islands Atoll showing Calabash Caye.

31 m s^{-1}. The Turneffe Islands Atoll is also affected by hurricanes moving through the western Caribbean, with strong easterly winds and high meteorological tides. The normal tidal range on the coast of Belize is 0.5 m but may reach 0.8 m during northers.

Air temperature data are sparse for Turneffe and surrounding environment. During northers, temperatures sharply fall 5-7°C and remain cooler than normal for several days. Surface water temperatures were recorded in the shelf lagoon near the barrier reef in July and August 1991 (29°C and 30°C), and the bottom temperature was 0.5-1.0° colder. Average oceanic surface temperature off the coast of Belize ranges from 25.5°C in February to 28.5°C in August. No cold-water upwellings, which may alter seawater temperature, are known to occur in Belizean waters, although there are some farther north, off the Yucatan Peninsula (Stoddart, 1962). Normal seawater salinities of 35-37‰ have been recorded offshore, approaching the barrier platform (Perkins, 1995).

Along the coast of Belize, wind-generated currents are more influential than tidal currents. Inside the barrier reef, the prevailing currents are southerly. Seaward of the Turneffe Islands Atoll, winds are northerly (1 m s^{-1}), but part of the current flows westward around the northern part of the atoll, creating a southerly drift along the leeward side. Inside the atoll lagoons, water currents flow west, creating a westward drift. Stoddart (1962) observed a large N/S-oriented drift on the eastern side of Calabash Caye, between the sandy ridge shoreline and the fringing reef at the front.

CARICOMP climate data (air temperature, minimum and maximum temperatures, and cumulative rainfall) are now being recorded daily at the Marine Research Centre Field Station; oceanographic data are collected weekly at the secondary seagrass site and at the mangrove site east of the inner lagoon (Fig. 3).

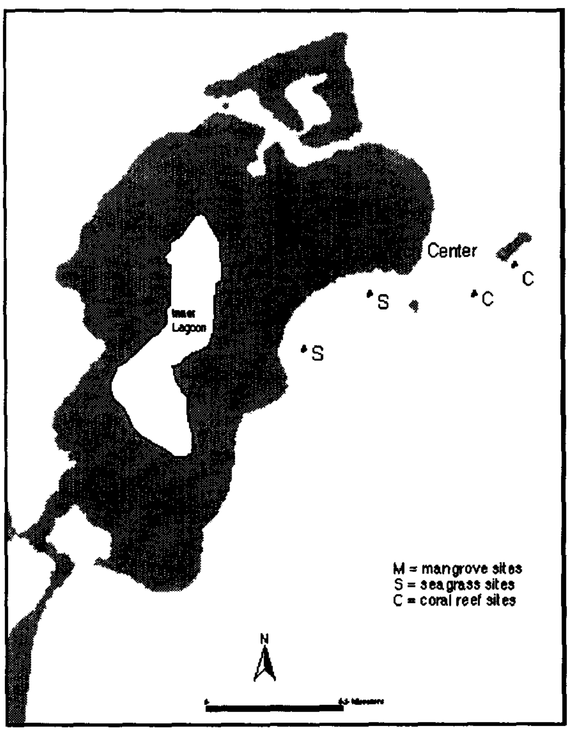

Fig. 3. Map of Calabash Caye, showing location of the mangrove, seagrass, and coral reef sites.

Vegetation and Soil Type Classification at Calabash Caye

Three major land systems (defined as an area, or group of areas, throughout which there is a recurring pattern of topography, soils, and vegetation) have been identified in Turneffe (Minty *et al.*, 1995). The two most dominant types at Calabash Caye are the strand-plain land system and the saline-swamp land system. The strand-plain system consists of wave- and storm-built ridges of sand, coral rubble, a mixture of both materials. The characteristic natural vegetation in this system on Calabash Caye is caye forest and cocal forest on an organic sand soil (Minty *et al.*, 1995). The saline-swamp system occupies the low tidal flat, with characteristic mangrove vegetation on waterlogged saline peat soil (Minty *et al.*, 1995), which may extend to a depth of 10 m (Stevely and Sweat, 1994).

Minty *et al.* (1995) described caye forests as the climax association of the higher cayes, where saline influence is minimal or absent and is restricted to sand ridge areas on organic sands. This type of forest consists of broadleaf trees generally 7-15 m tall: *Bursera simaruba, Metopium brownei, Cardia sebestena, Ponteria campechiana, Bumelia retusa,* and occasionally *Coccoloba uvifera.* The understory is dominated by *Ficus* sp. and young trees of the above species. The shrub layer is mostly *Pithecellobium keyense.* There is no information on the herb layer in this type of forest at Calabash Caye.

The cocal forest at Calabash Caye consists of *Cocos nucifera,* the canopy of which ranges from 7 to 15 m and is usually continuous. Little vegetation is present in the understory and shrub layer, and there is either bare ground or palm frond litter at the base. A herb layer of *Stachytarpheta jamaicensis, Ambrosia hispida, Cakile lanceolata,* and *Wedelia* is present under moderately discontinuous canopies (Minty *et al.*, 1995).

Mangrove forests, predominantly *Rhizophora mangle,* dominate the western side and northern tip of Calabash Caye, and *R. mangle* forms monospecific stands on the periphery of the inner lagoon. Mangrove zonation patterns are observed in certain areas of the caye. The canopy consists of mixed stands of *R. mangle, Avicennia germinans,* and *Laguncularia racemosa,* with occasional *Conocarpus erectus.* Young trees of these species, plus *Batis maritima,* consititute the shrub and herb layers of the cocal forest. The ground layer consists of leaf litter and twigs.

Mangrove Ecosystems

Mangroves border most of the coastline of Belize and extend upstream from numerous river mouths; they fringe or cover most lagoon cayes. Red mangrove stilt roots line all channels, creeks, and lagoons; below tide level, they support spectacularly colored clusters of algae, sponges, tunicates, anemones, and associated species. They also provide hiding or feeding places for fish and shellfish (Rützler and Feller, 1987). According to Stevely and Seat (1994), the mangrove ecosystems in the Turneffe Islands Atoll have kept pace with seamount subsidence and sea-level rise.

The red mangrove (*R. mangle*) typically forms monospecific stands along shorelines, creeks, and lagoon banks where tidal inundation is frequent. At more interior, less frequently inundated sites, the black mangrove (*A. germinans*) dominates. The white mangrove (*L. racemosa*) forms extensive stands at high elevations where flooding and salinity stresses are minimal, but also occurs occasionally at lower elevations (McKee, 1995). On cayes with slightly higher elevations, additional woody and herbaceous (soft-stemmed) halophytes are associated with the mangove ecosystem, such as buttonwood (*C. erectus*), salt wort (*B. maritima*), and sea pulsane (*Sesuvium* sp.) (Rützler and Feller, 1987/1988).

A perpendicular transect from the eastern shoreline of the inner lagoon traverses three zones: a shore zone dominated by *R. mangle*, a transition zone with a mixed canopy of all three species, and a landward zone dominated by *A. germinans*. A few *L. racemosa* and *C. erectus* can also be found in the landward zone that is dominated by *A. germinans* (McKee, 1995).

The CARICOMP mangrove site at Calabash Caye was inventoried by August 1996. It consists of three 10 × 10 m study plots located on the eastern shoreline of the inner lagoon (17°16'52.6"N, 87°48' 50.9"W; Fig. 3). All three plots contain a few *A. germinans* and *L. racemosa*, but *R. mangle* is dominant. Total tree height for *R. mangle* ranges from 1.2 m to 7.2 m; *A. germinans* 2.4-10.7 m, and *L. racemosa* 4.5-9.4 m. Interstitial soil-water salinity tests are carried out on each study plot on a monthly basis; average salinity in the area is 37‰. Seedlings, leaf litter, and algal mats cover the ground surface of the study plots. Leaf litter has been collected but the data are insufficient to determine growth or biomass production patterns in the area.

Seagrass Ecosystems

The seagrass ecosystem is frequently connected to mangrove forests on the landward side and to the coral reefs on the seaward side. These marine grasses bind sediments and provide a stable substrate for benthic organisms. Seagrass beds also provide food and shelter to commercially important species. Shrimp, lobster (*Panulirus argus*), and conch (*Strombus gigas*) depend on the seagrass areas as a foraging area for food (Hain, 1987/1988). Seagrass beds within the Turneffe Islands Atoll are intact and are not greatly disturbed except by dolphins (*Tursiops turncatus*) and crocodiles (*Corcodylus acutus*) that inhabit the lagoons, and by fishermen harvesting conch, lobster, and fish in the area.

The CARICOMP seagrass sites are located on the eastern side of Calabash Caye. The primary site is on the northeastern side (17°16'54.0"N, 87°48'31.2"W; Fig. 3), in a red mangrove-fringed channel between the northeastern edge of Calabash Caye and a small island called Little Calabash. The primary site (in water depth 0.5-1.0 m) is densely covered with *Thalassia testudinum*, with leaves up to 30 cm long, along with a few *Syringodium filiforme* and *Halimeda* algae. The bottom substrate consists of soft muddy sediments with dead *Halimeda*. The secondary site is located 40 m to the south, in water depth 2-3 m, and has a compact sandy bottom substrate mixed with some dead *Halimeda* and shells. The secondary site contains the same species as the primary site but with less dense *Thalassia* cover.

Coral Reef Ecosystem

There are no data as yet from the newly set up CARICOMP reef site at Calabash Reef. Previous researchers established two transects in the area, but these are no longer in use. The previous findings will be compared with CARICOMP surveys now being carried out.

Stoddart (1962) established a reef transect from Little Calabash Island into deeper water, which showed reef zonation east of Calabash Caye after Hurricane Hattie (Table 1). A more recent study of coral distribution was conducted by the Planetary Coral Reef Foundation in 1992, using a chain transect and video. The study site was on Calabash Reef 2 km south of the channel separating Calabash Caye from Blackbird Caye, an area representative of the most well-developed region on the windward reef. Their 900 m transects extended from behind the reef crest seaward to a depth of 45 m. The results of these two surveys found Calabash Reefs having a clear zonation pattern of a windward West Indian coral reef with a backreef, reef crest, spur-and-groove zone, mixed zone, forereef terrace, escarpment, forereef, and deep forereef. The coral coverage varied, with the highest coverage in the spur-and-groove zone. Approximately 29 sceractinian species were found, not including separation of *Montastraea annularis* into subgroups; this was 69% of the hermatypic species in the area. Algal cover exhibited a pattern of increasing abundance with increasing depth. The cover was 30% in the spur-and-groove zone and increased with depth. Sea urchin abundance decreased with depth, with a mean of 83 urchins per search period in the spur-and-groove zone to a low of 3 urchins on the forereef slope. Urchins larger than 10 cm on the reef crest were *Diadema antillarum;* the dominant species in the spur-and-groove zone was *Echinometra viridis* (Dustan *et al.*, 1992).

The results of both these previous studies show that Calabash Reef is a thriving windward West Indian coral reef community with signs of hurricane damage on the populations of some coral species. In the early 1990s, coral bleaching was found throughout the Caribbean but Belize was seemingly spared. However, from August to October of 1995, NOAA satellites detected elevated sea temperatures spanning much of the Gulf of Mexico and the western Caribbean basin from Belize to Jamaica, Honduras, and Venezuela. It was at this time that coral bleaching was reported for the first time in Belize (Stout, 1995).

Table 1. Reef transect seaward from Little Calabash Island just after Hurricane Hattie.

Zone	Description from Stoddart (1962)
Sand and rubble platform adjacent to the caye	There is about 12 inches of water on this platform and it is about 200 feet wide. It is carpeted with *Thalassia* and other green algae, including *Halimedia*. Near the outer edge of the platform *Porites* rubble becomes prominent.
Reef flat	A sandy area under 18 inches of water 20-30 feet wide. Small corals (*Favia fragusm* and *Porites divaricata*) and sea-urchins (*Diadema*) are scattered in the turtle grass.
Inner reef zone	A sandy area under 2 feet of water, with scattered colonies of *Montastraea annularis*, *Porites asteroides*, and *Dendrogyra cylindrus* about a foot high, with small colonies of *Siderastrea siderea*. Also, sea fans and sea whips are found here.
Cervicornis zone	The ground is covered by *Acropora cervicornis*, much of which is dead. The *Montastraea* and *Porites* colonies are larger.
Annularis zone	Large blocks of *Montastraea annularis*, *Porites asteroides*, *Dendrogyra cylindrus*, and *Siderastrea siderea*. Also present are encrusting and foliaceous *Agaricia* with *Acropora cervicornis* and *Acropora palmata*. This zone is approximately 8 feet deep and 15 yards wide.
Reef crest (*Agaricia*)	This is made up of massive blocks of mostly dead corals covered with *Agaricia agaricites*. Channels between the blocks are 10 feet deep. This area is only a few yards wide.
Outer slope	A platform from 10 to 15 feet deep and deepening toward the sea. Colonies of *Montastraea*, *Porites*, and *Siderastra* are 2 feet in average. Low colonies of *Acropora palmata* are also found in this area.

Conclusions

Tourism is now Belize's largest industry. The Tourist Board estimates Bz$150 million (US$7.5 million) were generated by tourism in 1994 (Gibson *et al.*, 1995). Tourism has traditionally been based on visits to the cayes, with 78% of hotels located in the coastal zone. Additionally, 1995 fishing exports totalled an estimated Bz$20 million (Gibson *et al.*, 1995). Two resorts focusing on dive tourism already exist on the Turneffe Islands Atoll, and fishing pressures are not well documented but seem to have increased in recent years; the atoll remains an unprotected area. The Marine Research Centre is focused on collecting baseline data to contribute to the understanding of these pressures and marine processes in the area as well as throughout the Caribbean. The MRC joined CARICOMP in November 1996.

Acknowledgements

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References

Burke, R. B. 1993. *How Have Holocene Sea Level Rise and Antecedent Topography Influenced Belize Barrier Reef Development?* Proceedings of the Colloquium on Global Aspects of Coral Reef Health, Hazards, and History. Rosenstiel School of Marine and Atmospheric Science, University of Miami (with the cooperation of the International Society for Reef Studies), Miami FL, USA.

Catterall, D. P. 1996. *A Strategic Environmental Assessment of Tourism Development on Turneffe Atoll, Belize.* DIC dissertation, Imperial College of Science, Technology and Medicine, London, UK.

Chamberlain, T. L. 1995. *Coastal and Reef Dynamics of Belize: Field Manual.* College of Natural Resources, Colorado State University, Fort Collins CO, USA, 16 pp.

Dillon, W. P., J. G. Vedder. 1973. Structure and development of the continental margin of British Honduras. *Bulletin of the Geological Society (London)*, **84**:2713-2731.

Dustan, P., A. King, E. Treml, C. Handte. 1992. *Hard Coral Species Population Survey, Turneffe Atoll, Belize.* Planetary Coral Reef Foundation, 12 pp.

Gibson, J. 1990. *Status Report on Turneffe Islands.* Coastal Zone Management Project, Belize, 7 pp.

Gibson, J., M. McField, S. Well. 1995. *State of the Coastal Zone Report, Belize,* 254 pp.

Hain, J. S. 1987/1988. Belize. *Oceanus,* **30**(4):74-76.

James, N. P., R. N. Ginsburg. 1979. *The Seaward Margin of Belize Barrier and Atoll Reefs: Morphology, Sedimentology, Organism Distribution and Late Quaternary History.* Publication 3, International Association of Sedimentologists, 191 pp.

McKee, K. L. 1995. Seedling recruitment patterns in a Belize mangrove forest: Effects of establishment ability and physico-chemical factors. *Oecologia,* **101**:448-460.

Minty, C., M. Murray, S. Zisman. 1995. *Turneffe Terrestrial Resource Reconnaissance Report to Coral Caye Conservation Ltd.* Marine Research Centre, University College of Belize, Technical Report Series No. 2, 35 pp.

Ogden, J. C. 1987/88. Cooperative coastal ecology at Caribbean marine laboratories. *Oceanus,* **30**(4): 10-14.

Platt, S. G. 1995. *Preliminary Assessment of the Status of the American crocodile (Crocodylus acutus) in the Turneffe Atoll, Belize.* Marine Research Centre, University College of Belize, Technical Report Series No. 3, 14 pp.

Perkins, J. S. 1995. *Belize Barrier Reef Ecosystem: An Assessment of Resources.* The New York Zoological Society, New York NY, USA, 215 pp.

Raines, P., A. Gill, 1994. *The Belize Marine Research Centre, Turneffe Atoll, Belize.* Coral Caye Conservation Ltd., London, UK, 24 pp.

Rützler, K., I. C. Feller. 1987/1988. Mangrove swamp communities. *Oceanus,* **30**(4):17-21.

Rützler, K., I. C. Feller. 1996. Caribbean mangrove swamps. *Scientific American,* **274**(3):94-99.

Stevely, J. M., D. E. Sweat. 1994. A Preliminary Evaluation of the Commercial Sponge Resources of Belize, with Reference to the Location of the Turneffe Islands Sponge Farm. *Atoll Research Bulletin,* **424**:14.

Stoddart, D. R. 1962. Three Caribbean atolls: Turneffe Islands, Lighthouse Reef and Glover's Reef, British Honduras. *Atoll Research Bulletin,* **87**:31-49.

Stout, M. 1995. *Coral Reef Bleaching Found in Belize for the First Time.* US National Oceanic and Atmospheric Administration, Internet homepage.

Wantland, K. F., W. C. Pusey III. 1971. *A Guidebook for the Field: The Southern Shelf of British Honduras.* 21st Annual Meeting of the Gulf Coast Association of Geological Societies, 87 pp.

Carrie Bow Cay, Belize[1]

Karen H. Koltes[1], John J. Tschirky[2], and Ilka C. Feller[3]

[1]*Biological Resources Division, U.S. Geological Survey, Department of the Interior, MS-301, 12201 Sunrise Valley Drive, Reston VA 20192 USA*

[2]*The Nature Conservancy, Latin American and Caribbean Division, 1815 North Lynn. Arlington VA 22209 USA*

[3]*Smithsonian Environmental Research Center, PO Box 28, Edgewater MD 21037 USA*

Carrie Bow Cay is located 18 km offshore in the central province of the Belize Barrier Reef complex. Although the reef-seagrass-mangrove complex near Carrie Bow Cay is representative of the entire barrier reef complex, the central province contains the most spectacular reef development. The climate in this region is subtropical, with a wet season from June to October. The present-day barrier reef seaward of Carrie Bow Cay is characterized by distinctive zones, with biological and geological development controlled primarily by water movement and depth. Coral cover along the CARICOMP transects is currently in the range of about 12-20%, down from an estimated 30-35% in the 1970s. The decline in coral cover appears to have resulted from die-off of *Acropora cervicornis*, one of the dominant hard corals in the 1970s, and an accompanying increase in macroalgae. The seagrass community is dominated by *Thalassia testudinum*, with an estimated total biomass at the CARICOMP sites varying seasonally from approximately 3,766 to 4,159 g m^{-2} dry weight, among the highest reported for the Caribbean. The mangrove community is dominated by *Rhizophora mangle* L., which forms a monospecific fringe around the peripheries of the islands. In 1995, widespread bleaching was reported in Belize for the first time. At Carrie Bow Cay, bleaching was preceded by unusually calm water conditions, high light transmittance, and high sea surface temperatures. Although the area in the vicinity of Carrie Bow Cay is generally considered pristine at present, increasing pressure from development and the rapidly expanding tourism industry pose significant threats.

Introduction

The Smithsonian Institution's National Museum of Natural History Field Station on Carrie Bow Cay (16°48'N and 88°05'W) is one of three CARICOMP sites established in Belize (Fig. 1). Carrie Bow

[1] *CARICOMP — Caribbean Coral Reef, Seagrass and Mangrove Sites* (edited by B. Kjerfve), pp 79-94. UNESCO, Paris, 1998, 347 pp.

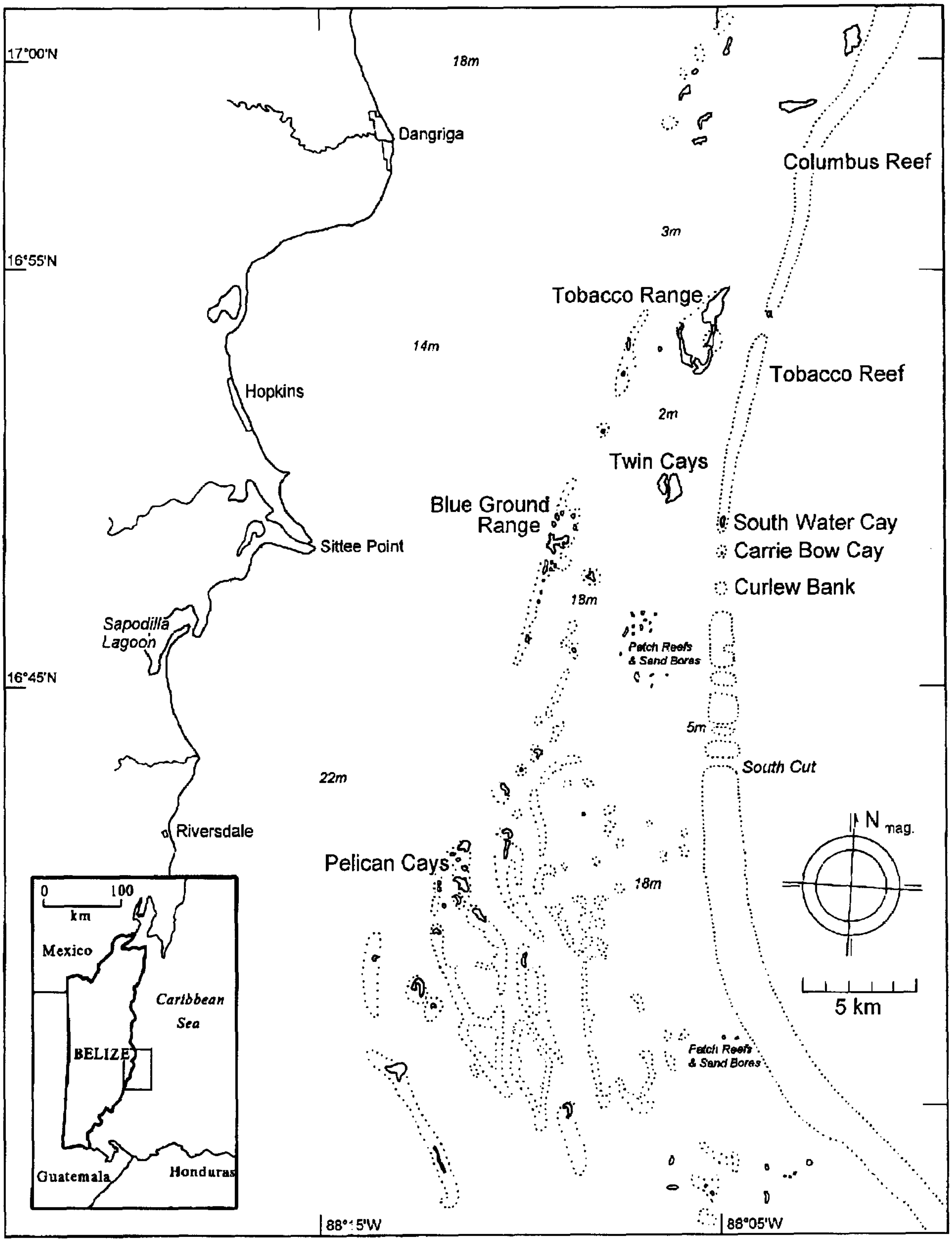

Fig. 1. Map of the central province, Belize Barrier Reef complex, showing Carrie Bow Cay (coral reef sites) and Twin Cays (seagrass and mangrove sites).

Cay is situated 18 km offshore on top of the barrier reef proper. Twin Cays, site of the CARICOMP mangrove and seagrass studies, is located approximately 2.3 km leeward of Carrie Bow Cay in the outer lagoon. The Smithsonian Institution established the research station at Carrie Bow Cay in 1972 and has sponsored extensive multidisciplinary investigations of the coral reef, seagrass, and mangrove communities of the region, resulting in more than 500 publications.

The Belize Barrier Reef is the largest continuous reef system in the western Atlantic, extending 257 km from Ambergris Cay to the Gulf of Honduras (Burke, 1982). The barrier reef complex varies in width from 10 to 32 km and contains hundreds of mangrove islands, diverse intertidal and subtidal barrier and patch reef zones, three large atolls, and vast lagoonal seagrass beds. The present shape and bathymetry of this system are the outcome principally of faulting along a NNE trend during the Pliocene (Macintyre and Aronson, 1997). The resultant series of multiple fault-block ridges parallel the coastline and, in combination with reef growth and karstification associated with glacio-eustatic fluctuations in Pleistocene sea levels, produce the present-day patterns of parallel shoals, reefs, and mangrove islands (Burke, 1993; Macintyre *et al.*, 1995).

On the basis of biogeomorphic characteristics, Burke (1982, 1993) divided the barrier reef complex into three provinces: northern, central, and southern. The central province, in which Carrie Bow Cay and Twin Cays are located, contains the most spectacular reef development, with 91 km of almost continuous well-developed barrier reef, sand cays on the inner edge of the reef rims, and numerous mangrove islands, patch reefs, and seagrass beds in the center and landward edge of the barrier platform (Burke, 1982; Macintyre and Aronson, 1997). Detailed descriptions of the topography, geology, ecology, and biology of this portion of the Belize Barrier Reef are provided by Rützler and Macintyre (1982a).

Although no data have been collected on water quality, the area around Carrie Bow Cay is generally considered pristine and removed from any potential anthropogenic threats associated with Belize's small coastal towns and intensive citrus production. Fishing for finfish (primarily snapper and grouper) is conducted by handline and speargun, with little or no trap fishing. Beginning in the 1970s, increased fishing pressure by local fishermen on queen conch and spiny lobster depleted these formerly common species from shallow-water areas around Carrie Bow Cay (Rützler and Macintyre, 1982b). These target species continue to be overfished.

Atmospheric and Oceanographic Climates

Belize has a subtropical climate, with an average minimum temperature of 20°C in December and January and an average maximum temperature of 31.1°C in August (Stoddart *et al.*, 1982). Temperatures on the barrier reef at Carrie Bow Cay are comparable to those reported on the mainland (Rützler and Ferraris, 1982). Air temperatures recorded from 1993 through 1996 as part of the CARICOMP project at Carrie Bow Cay ranged from a mean monthly maximum of 34.6°C (August 1995) to a minimum of 22.5°C (January 1996; Fig. 2). Northeast tradewinds prevail for about 70% of the year, interrupted during November-February by "northers." These 4-5 day periods of northerly winds and low temperatures are associated with the southerly extension of the North American high pressure system (Stoddart *et al.*,

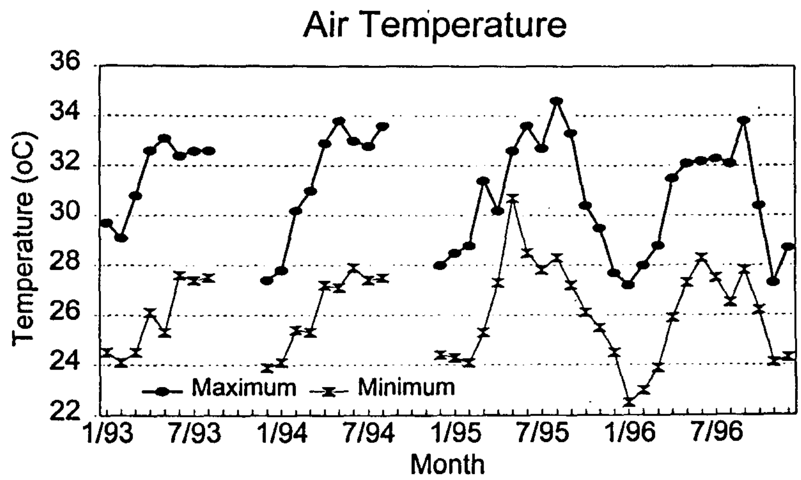

Fig. 2. Monthly means of the maximum and minimum air temperatures recorded daily at Carrie Bow Cay, Belize, from January 1993 to December 1996. No data were recorded September-November in 1993 and 1994 while the station was closed.

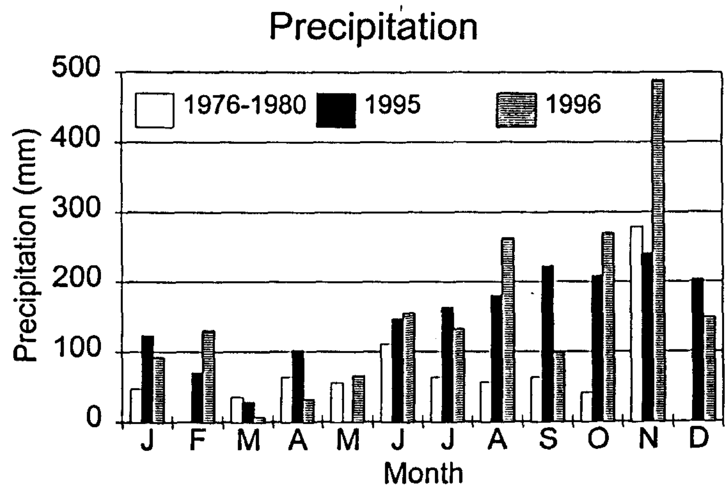

Fig. 3. Precipitation at Carrie Bow Cay; monthly mean (in mm) for 1995 and 1996 (CARICOMP) compared to monthly mean from 1976-1980 (Rützler and Ferraris, 1982). Note precipitation during May 1995 = 0 mm; no data were collected in February and December 1976-1980.

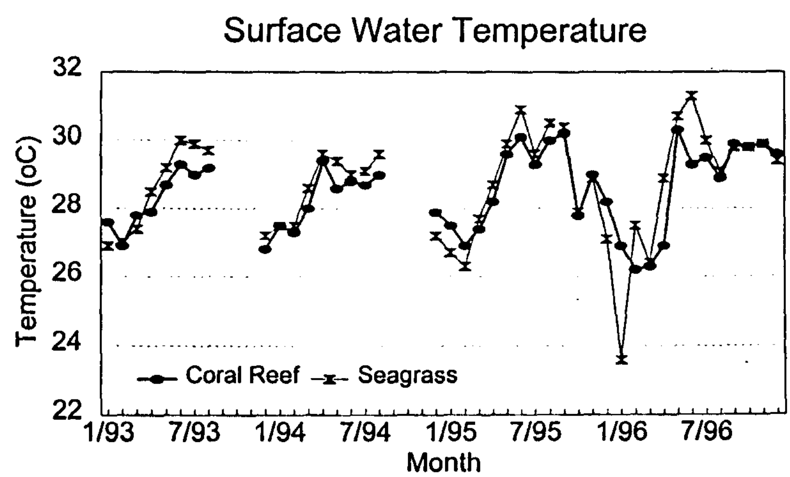

Fig. 4. Surface (0.5 m depth) water temperature over the drop-off seaward of Carrie Bow Cay and at CARICOMP Seagrass Site II; monthly mean from January 1993 to December 1996.

1982) and are often accompanied by strong swells (Perkins, 1983). Hurricanes occur during the months of July through October. During the 20th century, nine hurricanes and seven tropical storms have passed within a 50-km radius of Carrie Bow Cay. Most of these storms have occurred since 1960.

Rainfall is highly variable in Belize, increasing markedly from north to south (Stoddart *et al.*, 1982). The average annual rainfall in the Dangriga (Stann Creek) area is 2,218 mm, with a maximum of 312 mm in September and a wet season from June to October. The climate on the central barrier reef is drier; the cays get approximately 42% of the mainland rainfall based on measurements at Carrie Bow Cay from 1976 through 1980 (Rützler and Ferraris, 1982; Fig. 3). On average, maximum monthly rainfall for Carrie Bow Cay occurs in November (mean = 336 mm), with a minimum in March (mean = 23 mm). In 1995 and 1996, the only years for which there are complete CARICOMP records, cumulative rainfall at Carrie Bow Cay was 1,691 mm and 1,883 mm, respectively. Maximum monthly rainfall (488 mm) occurred in November 1996, whereas no rain fell in May 1995 (Fig. 3). Humidity ranges from 58% to 96%, with an average of 78% (Rützler and Ferraris, 1982).

In addition to daily monitoring of precipitation and air temperature as part of the CARICOMP program, weekly monitoring of water temperature (0.5 m below the surface), salinity (0.5 m below the surface), and light attenuation (vertical distance) at the drop-off seaward of the coral reef sites (Carrie Bow Cay) and at the seagrass sites (horizontal distance 0.5 m below the surface; Twin Cays) has been conducted since January 1993 (except during seasonal closure of the field station from September through November in 1993 and 1994). Interstitial salinity measurements have been recorded at the Twin Cays mangrove plots since mid-1995. Bottom water temperatures were recorded from 12 August to 22 December 1994, and continuously since 25 August 1995, using remote data loggers at the coral reef (13 m) and seagrass (1.2 m) monitoring sites. Mean monthly surface water temperatures over the drop-off ranged from 26.2°C (February 1996) to 30.3°C (May 1996; Fig. 4). Daily means of bottom water temperatures at the coral reef site (13 m) ranged from 25.4°C (25 February 1996) to 30.3°C (27 August 1995; Fig. 5). During 1994, bottom water temperatures exhibited a low-frequency oscillation of approximately 1°C, with a cycle of 21 days (Fig. 5). Water temperatures recorded weekly at Seagrass Site II ranged from a monthly mean of 23.6°C (January 1996) to 31.3°C (June 1996; Fig. 4). Salinity ranged from a monthly mean of 33.0‰ (August 1996) to 37.4‰ (March 1996) over the drop-off and 33.3‰ (August 1996) to 37.3‰ (August 1996) over the seagrass sites. Secchi disk readings ranged from 11.0 m (May

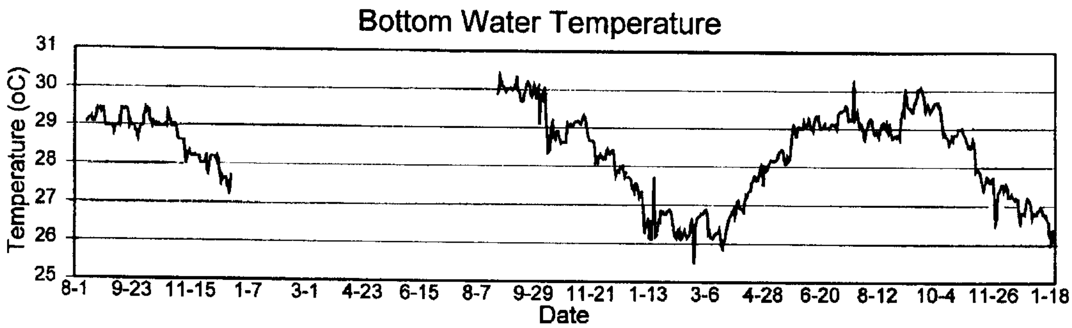

Fig. 5. Daily mean of bottom water temperatures (13 m depth) recorded 08/12/94-12/22/94 and 08/25/95-01/22/97 using a remote data logger deployed at CARICOMP Coral Reef Site I. Note the 21-day temperature cycle in 1994 and the signatures of Hurricanes Opal and Roxanne in early October 1995.

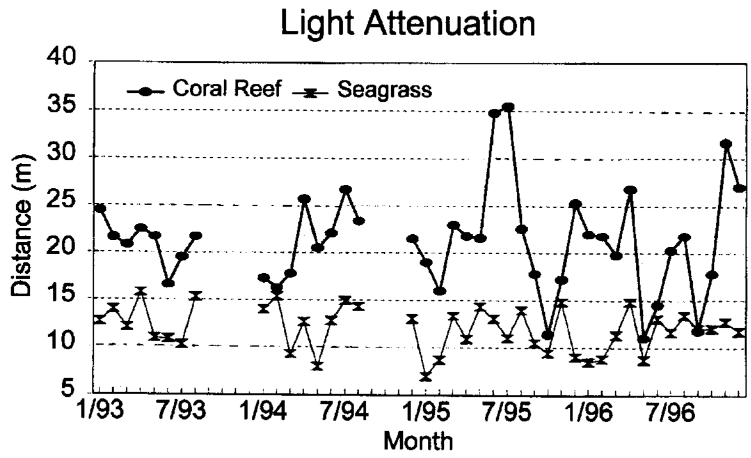

Fig. 6. Light attenuation (monthly mean Secchi disk readings in m) measured vertically over the drop-off and horizontally at 0.5 m below the surface over the seagrass beds.

1996) to 35.5 m (July 1995) over the drop-off (vertical distance), and 7.0 m (January 1995) to 15.8 m (March 1993) at Seagrass Site II (horizontal distance; Fig. 6).

The tide in this region of the Caribbean is microtidal and mixed semi-diurnal; the mean range is 15 cm at Carrie Bow Cay (Kjerfve *et al.*, 1982) and 21 cm at Twin Cays (Wright *et al.*, 1991).

Barrier Reef Environment

The western Caribbean is characterized by thick late Holocene shelf and shelf-edge reef accumulations which reach their maximum extent along the Belize Barrier Reef (Macintyre, 1988). Sediments accumulate more rapidly here because lower wave energy (relative to the eastern Caribbean) has allowed fragile branching *Acropora cervicornis* and other communities to flourish at depths of 20 m or more. Cores taken near Carrie Bow Cay indicate that the barrier reef consists of at least 16 m of unlithified late Holocene sediments in the back reef and more than 18 m of a mixed coral and deeper water coral-head facies in the shallow and deep forereef, with a maximum age of 7,175 ± 100 years BP. *A. cervicornis* is present but appears to play a minor role in the construction of this outer reef complex (Macintyre, 1988).

On the basis of dominant biological and geological characteristics, Rützler and Macintyre (1982b) divided the present-day barrier reef seaward of Carrie Bow Cay into four major zones: backreef, reef crest, inner forereef, and outer forereef. These zones were further divided into zones, the biological and geological characteristics of which are controlled primarily by water movement and depth (Rützler and Macintyre, 1982b). Site I of the CARICOMP reef transects was established on the study transect set up by Rützler and Macintyre (1982b), approximately 200 m north of Carrie Bow Cay. Site II was established approximately 100 m south of Site I at the same depth (13 m). Both sites are located on the upper edge of the inner reef slope that marks the transition from the inner to the outer forereef habitats (Fig. 7).

The inner forereef zone at Carrie Bow Cay begins seaward of the reef crest with the high-relief spur and groove zone. This zone is characterized by large, well-developed buttresses separated by sand channels (Rützler and Macintyre, 1982b). Percent coral cover ranges from near zero to >60%, and topographic complexity ranges from <0.20 to >0.80 (Aronson and Precht, 1995). In a 1980 survey, algal abundance was low (about 4.5%) and consisted primarily of *Porolithon* and *Halimeda opuntia* (Littler *et al.*, 1987). This zone is composed of two overlapping subzones: a shallower set of spurs (0-3 m depth) dominated by *Acropora palmata* and *Millepora* spp., and a slightly deeper set of spurs (3-6 m depth) dominated by *Agaricia tenuifolia* (Rützler and Macintyre, 1982b; Aronson and Precht, 1995). Dominance of the high-relief spur and groove subzone by *A. tenuifolia* contrasts with many Caribbean reefs in which reef buttresses are constructed primarily by massive corals such as *Montastraea annularis*. Chornesky (1991) showed that this results from the ability of *A. tenuifolia* to modify its skeleton so that contiguous, genetically distinct colonies become anchored against each other to form a relatively stable honeycomb of coral skeleton that monopolizes space on the spurs. Other abundant species in this zone include *Acropora cervicornis, Porites porites*, and *P. astreoides*. Prior to the major die-off of *Diadema antillarum* throughout the Caribbean (Lessios *et al.*, 1984), this zone also contained the highest density (4.3 individuals/m^{-2}) of *D. antillarum* (Lewis and Wainwright, 1985).

The low-relief spur and groove zone (10 m depth) of the inner forereef is a broad shallow slope best described as a hardground that is regularly interrupted by shallow sand channels. The low (about 1 m relief) coral ridges are formed primarily of *Montastraea annularis, M. cavernosa* and *Diploria strigosa* (Rützler and Macintyre, 1982b). Much of this area is densely covered with gorgonians dominated by

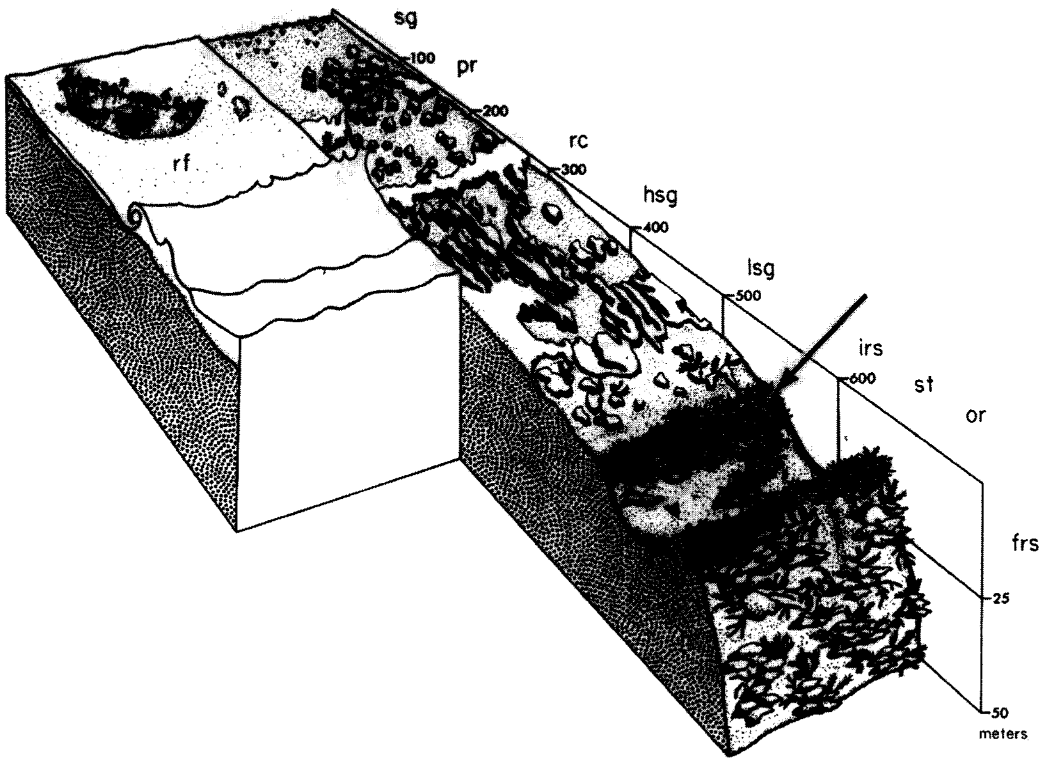

Fig. 7. Study transect of Rützler and Macintyre (1982b) showing biogeological zones from lagoon to outer forereef (frs = forereef slope; hsg = high spur and groove; irs = inner reef slope; lsg = low spur and groove; or = outer reef; pr = patch reefs; rc = reef crest; rf = reef flat; sg = seagrass; st = sand trough). Location of CARICOMP Site I reef transects is indicated by an arrow. CARICOMP Site II is approximately 100 m south at the same water depth (13 m). Note that *Acropora cervicornis*, depicted on the inner reef slope in this diagram from the late 1970s, has disappeared.

Pseudopterogorgia species (Lasker and Coffroth, 1983). *Briareum asbestinum* and *Muriceopsis flavida* are the two most abundant octocorals on the CARICOMP transects. Demospongea and scattered coral heads, primarily *M. annularis,* also dominate this area (Lewis and Wainwright, 1985). Littler *et al.* (1987) found that macroalgal abundance in 1980 was extremely low (about 2.5%) in this zone and composed of epilithic forms on the reef rock and scattered rubble. Spatial heterogeneity (3D structure) is high (mean rugosity on CARICOMP Coral Reef Site I ≈ 1.71) and herbivorous fish are abundant, reaching their maximum density in this zone (Lewis and Wainwright, 1985).

The transition from the inner forereef to the outer forereef zones occurs at the seaward edge of the low-relief spur and groove where the gradual slope of the inner forereef abruptly changes to a steeply sloping (25°) zone of hard corals and sponges. Columnar colonies of *Montastraea annularis* at the top of the slope give way to large platy colonies toward the base that are accompanied by *Porites astreoides, Siderastrea siderea,* and *Agaricia* spp. (Rützler and Macintyre, 1982b). Until the late 1970s, this zone was dominated by *Acropora cervicornis* (Rützler and Macintyre, 1982b; Burke, 1993). By 1984, most of the *A. cervicornis* had died off, apparently from white-band disease (Peters, 1993; Aronson and Precht, 1997; Macintyre and Aronson, 1997). At some Belizean reef sites, *A. cervicornis* has been replaced in the interim by *Agaricia* spp., possibly due to high levels of herbivory by the echinoid *Echinometra viridis* (Aronson and Precht, 1997). In the shallow backreef zone at Carrie Bow Cay, the disappearance of *A. cervicornis* has been accompanied by a proliferation of *Porites porites,* an opportunistic species that is starting to overgrow some of the slower growing massive corals (Macintyre and Aronson, 1997). However, in the deeper forereef areas at Carrie Bow Cay, most of the *A. cervicornis* has been replaced primarily by macroalgae (principally *Lobophora variegata, Dictyota* spp., and *Halimeda* spp.). The faunal transition from dominance of hard corals to macroalgae accompanying the demise of *A. cervicornis* is reflected in the relatively low percent coral cover and high algal (macrophyte) cover presently observed at the CARICOMP sites (Table 1). This is particularly evident at Site I, where macroalgal cover has increased from approximately 3.4% in 1980 (Littler *et al.,* 1987) to about 45% at present, while coral cover has dropped from an estimated 30-35% in the late 1970s (Rützler and Macintyre, 1982b) to around 12% today. A similar decline in coral cover from the 1970s to the 1990s from natural disturbances has been noted in the Gulf of San Blas, Panama (Ogden and Ogden, 1993).

Table 1. Percent cover of benthic organisms at CARICOMP Coral Reef Sites I and II, Carrie Bow Cay, Belize; August 1995.

	% Cover				
Site	Hermatypic Corals	Gorgonacea	Algae	Sponges	Abiotic
I	12.3	2.3	65.8	1.4	18.2
II	20.9	1.0	52.7	3.3	22.2

Mean of five 10-m transects per site surveyed as part of semi-annual CARICOMP monitoring (see CARICOMP, 1994, for description of methods). Algae include macrophytes (fleshy and calcareous), turf algae, and cyanophytes.

The inner forereef slope ends at about 24 m in a broad, flat sand trough consisting of poorly-sorted *Halimeda*-rich sand. From there, the slope rises sharply (45°) to the outer ridge at about 12-14 m below the surface. The narrow outer ridge (about 20 m wide at this point on the Rützler-Macintyre transect) parallels the intertidal reef crest and delineates the continental shelf (Rützler and Macintyre, 1982b). Prior to 1984, this area was also dominated by *Acropora cervicornis*, but it now consists mainly of *A. cervicornis* rubble covered by *Lobophora* spp. (Macintyre and Aronson, 1997), with local accumulations of *Montastraea annularis, Agaricia agaricites, A. tenuifolia*, and *Madracis mirabilis* (Rützler and Macintyre, 1982b). The outer forereef slope drops steeply (50-70°) and is dominated in the upper reaches by platy *Montastraea cavernosa, M. annularis*, Gorgonacea, *Agaricia fragilis, Leptoseris cucullata*, and Demospongea (Rützler and Macintyre, 1982b).

There was widespread coral bleaching in Belize in 1995, an area from which there had been no previous reports of bleaching (Glynn, 1993; Williams and Bunkley-Williams, 1990). We observed some bleaching of hard corals, especially *Montastraea annularis*, on the CARICOMP transects during the August 1995 survey. By October 1995, up to 90% of *M. annularis* colonies were bleached, particularly on the shallow (<10 m depth) forereef off South Water Cay. Extensive bleaching was also reported for *Agaricia agaricites, A. tenuifolia, Madracis* spp., and *Porites porites*. Our surveys of the forereef at Carrie Bow Cay in December 1995 showed that bleaching was still widespread. The incidence of bleaching varied among species and appeared, in some species, to be related to water depth. Heavily affected species included *Montastraea annularis, Agaricia lamarcki, A. grahamae, Siderastrea siderea*, and *Diploria labyrinthiformis*. Bleaching at Carrie Bow Cay was preceded in June and July 1995 by unusually calm water conditions and high light transmittance (Fig. 6), as well as high sea surface temperatures (SSTs) in the Gulf of Mexico and western Caribbean (Strong *et al.*, in press). As determined by satellite imagery (Gleeson and Strong, 1995), SSTs reached a 12-year high of 29.9°C at Glovers Reef, Belize, in September 1995. Surface water temperatures over the drop-off at Carrie Bow Cay were the highest recorded since CARICOMP monitoring began in January 1993, reaching a peak of 30.4°C during the first two weeks of June 1995 (Fig. 4). Bottom water temperatures at CARICOMP Coral Reef Site I (13 m water depth) averaged 29.8°C (±0.16) during the last week of August (Fig. 5). By December 1995, temperatures had fallen to a monthly average of 27.7°C. The rapid decline in water temperatures was due partly to the passages of Hurricanes Opal and Roxanne across the Yucatan Peninsula in late September and early October 1995, respectively (Figs. 4 and 5). Follow-up surveys of coral bleaching in August 1996 and January 1997 indicated that most of the coral had recovered.

Seagrasses

More than 90% of the lagoon leeward of Carrie Bow Cay is shallow (<6.5 m) soft bottom dominated by *Thalassia testudinum*; the remainder consists of rubble, reef patches, and large sponges (Rützler and Macintyre, 1982b). As previously noted, overfishing of queen conch, *Strombus gigas*, has left the lagoon largely devoid of this herbivore. The seagrass beds are crisscrossed by a series of uncolonized sand holes from seismic surveys for petroleum exploration during the 1960s. Recolonization of disturbed areas by *Thalassia* is slow, often taking years (Zieman and Zieman, 1989; Williams, 1988), possibly due to nutrient accumulation in the sediments (Williams, 1990).

TWIN CAYS, BELIZE
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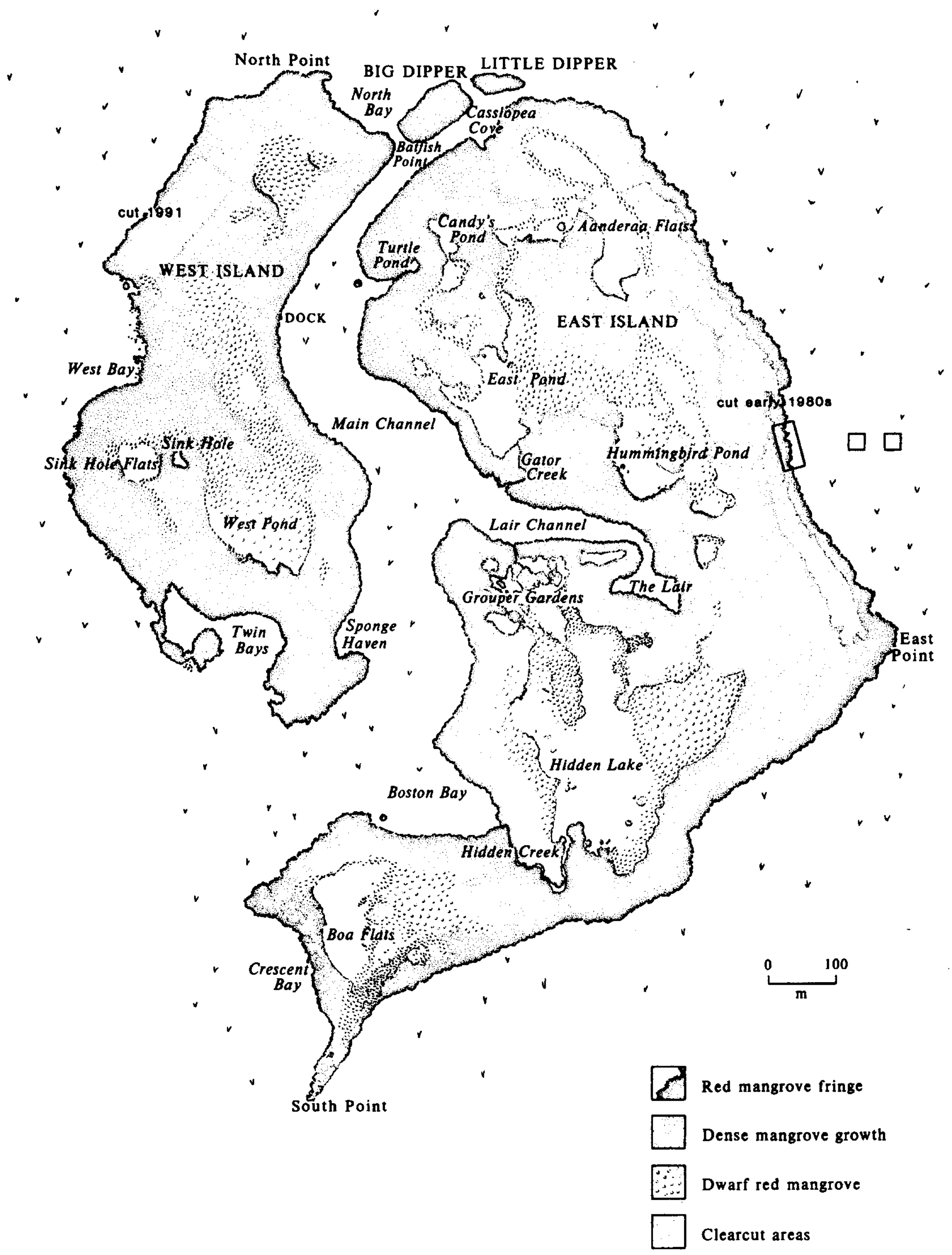

Fig. 8. Twin Cays, Belize, showing the location of CARICOMP Seagrass Sites I and II (open squares off eastern shoreline) and the three contiguous mangrove plots along the eastern shoreline.

Two permanent monitoring plots were established in the seagrass beds approximately 100 and 150 m east of the CARICOMP mangrove plot at Twin Cays (Fig. 8). Site I was established in what was judged to be a "high productivity" area (100 m offshore), while Site II was established in a "representative" or "average" area (150 m offshore). However, after semi-annual sampling over three years (1993-1995), no difference has been observed between the sites and data on biomass and productivity are pooled in subsequent analyses.

The seagrass beds adjacent to Twin Cays lie on a shallow shelf that increases gradually in depth from the shoreline to approximately 1.2-1.5 m at the CARICOMP sites, before dropping more steeply to the lagoon bottom (approximately 7 m) about 300 m offshore. Bottom sediments (to at least 1 m) consist primarily of *Halimeda* sand mixed with fine clay. *Thalassia testudinum* grows profusely in this area (short shoot density = 960 ± 250 m^{-2}), interspersed with sparse stands of *Syringodium filiforme* and *Halimeda* spp. As noted by Young and Young (1982), *Thalassia* blades in the lagoon are heavily encrusted with coralline algae and are conspicuously devoid of epizoans, except Foraminifera.

Seagrass biomass shows slight seasonal variations (Table 2), somewhat higher in August (4116 ± 681 g m^{-2} dry wt) than in December (3795 ± 741 gm^{-2} dry wt). Seagrass biomass estimates for this area are among the highest within the network of sites and among the highest reported in the Caribbean (Zieman and Zieman, 1989). The biomass of these beds appears to be related to greater sediment depth (Tomasko and Lapointe, 1991) or nutrient enrichment from the adjacent mangrove community where turtle grass is more dense and grows three times faster than *Thalassia* in the nearby open lagoon (Rützler and Feller, 1988). Areal productivity also varies seasonally, with higher productivity during August compared to December (Table 3). The turnover rate for *Thalassia* leaves does not show signifi-

Table 2. Biomass (g m^{-2} dry weight) of seagrass fractions at CARICOMP Seagrass Sites I and II, Twin Cays, Belize; monthly mean and standard deviation of pooled Site I and Site II samples (12/93-07/97).

	Thalassia		Other Grass			Calcareous Algae		
Month	Above	Below	Green	Non-Green	Fleshy Algae	Above	Below	Total
Aug, n = 28	883	3251	5	19	1.3	49	14	4116*
(std dev)	*(254)*	*(600)*	*(9)*	*(26)*	*(8)*	*(92)*	*(16)*	*(681)*
Dec, n = 28	731	2914	5	31	9	53	60	3795*
(std dev)	*(211)*	*(625)*	*(7)*	*(44)*	*(25)*	*(63)*	*(118)*	*(741)*

*significantly different, $p < 0.05$; two-tailed t-test with 54 df.

Table 3. *Thalassia testudinum*: areal productivity and turnover (% of the plant present that is replaced each day); mean and standard deviation of pooled Site I and Site II by month (08/93-07/97).

Month	Areal Productivity (g dry weight m^{-2} d^{-1})	Turnover (% per day)
Aug, n = 54	2.86*	2.44**
(std dev)	*(0.96)*	*(0.39)*
Dec, n = 42	2.30*	2.36**
(std dev)	*(0.88)*	*(0.59)*

*significantly different, $p < 0.05$; two-tailed t-test with 94 df.; **no significant difference.

cant seasonal variation, averaging about 2.4% per plant per day. Blade turnover rates for this community are comparable to others in the Caribbean and elsewhere in Belize, where they have been observed to remain at near-constant rates (Tomasko and Lapointe, 1991).

Mangrove Forests

Mangroves of the central barrier reef complex occur on both isolated islands and elliptical groups of islands (ranges) several hundred meters leeward of the reef crest. Most of the mangrove communities in this region, including the Twin Cays complex, are built on a limestone platform (fossil patch reef) that was topographically high during the Late Pleistocene (Rützler and Feller, 1988, 1996; Littler *et al.*, 1995; Woodroffe, 1995). Beyond the influence of the terrestrially-derived sediments that underlie mangrove forests of the mainland, the mangrove forests of the central barrier reef are underlain by mangrove-derived peat which accumulated to thicknesses of as much as 10 m during the rising seas of the Holocene transgression (Woodroffe, 1995; Macintyre *et al.*, 1995). Like many mangrove systems of the Caribbean, they are dominated by red mangroves, *Rhizophora mangle* L., which form a fringe around the periphery of the islands. The interiors have extensive stands of black mangroves, *Avicennia germinans* (L.) Stearn, which are exposed on the shore in some areas such as Tobacco Range as a result of shoreline erosion (Woodroffe, 1995). There are scattered individuals of white mangroves, *Laguncularia racemosa* (L.) Gaertn.f., but these do not form the thickets common on other West Indian islands where there has been considerable disturbance to the mangrove vegetation (Woodroffe, 1995).

Twin Cays is a 91.5-ha range of two large and four small intertidal islands (Fig. 8). The two large islands, East Island and West Island, are separated by a 0.5-2.0 m deep, S-shaped navigable channel. Except for sand spits at South Point and just north of West Bay (which flooded prior to being filled for development in the 1980s), Twin Cays lies within the intertidal zone and is overwashed by spring tides. In 1980, Twin Cays became one of the primary study sites for long-term ecological studies by Smithsonian Institution scientists and their collaborators at Carrie Bow Cay.

Although its topographic shoreline is within the intertidal zone, Twin Cays' vegetation is physiognomically varied and interrupted by tidal creeks, open flats and shallow interior ponds (Fig. 8). Red mangrove forms a dense, monospecific fringe around the island peripheries and along creek banks, and its height generally decreases with distance from the shoreline. *Avicennia germinans* and *L. racemosa* occur primarily in the interior of Twin Cays, typically intermixed in a transition zone with *R. mangle* just landward of the fringe forest. *Avicennia germinans* also forms monospecific stands in some areas in the interior. However, *L. racemosa* does not form extensive stands. Ponded areas in the interior are dominated by extensive stands of dwarf *R. mangle*. (McKee, 1993a). The zonation pattern of mangroves at Twin Cays varies not only with spatial position relative to the shoreline but also with hydroedaphic conditions (McKee, 1993b). Fertilization studies have shown that phosphorus deficiency is a primary factor limiting the growth of dwarf trees in the interior of Twin Cays (Feller, 1995).

Based on surveys and transects across Twin Cays, Woodroffe (1995) compiled a vegetation map of the occurrence of mangrove species and the structure of mangrove vegetation that includes seven types: *R. mangle* scrub (<2 m); *R. mangle* thicket (2-4 m); *R. mangle* woodland (>4 m); *A. germinans* woodland;

A. germinans open woodland with *R. mangle* scrub; and dead *R. mangle*. The mangrove community of Twin Cays is similar to the basin mangrove in Rookery Bay, Florida, and a fringe mangrove in Ceiba, Puerto Rico (Woodroffe, 1995). Woodroffe also noted that the ranges are undergoing disintegration, and there is abundant evidence (extensive unvegetated flats in the interiors and dead mangrove stumps throughout the range) that the pattern of mangrove distribution is changing. Woodroffe suggested that shoreline erosion and the anomalous mangrove distribution patterns on Twin Cays, as well as in other nearby mangrove ranges, may be the result of abiotic stresses in the environment, including hurricane damage, reduced tidal flushing, salinity, and soil chemistry, as well as clearing of mangroves by humans.

In December 1993, five 10 m x 10 m (0.1 ha) plots were established 5 m apart along a 70-m transect perpendicular to the shoreline on the eastern (windward) shore of Twin Cays. Plots 1 and 2 (closest to the shoreline), consisted almost entirely of *R. mangle*, Plots 3 and 4 consisted of *A. germinans* and a few *L. racemosa*, while Plot 5 (interior) consisted primarily of dwarf *R. mangle*. To establish seasonal patterns of productivity, leaf litter was collected monthly in 10 mesh-lined traps deployed within each plot (CARICOMP, 1994). In 1994, productivity showed peaks in spring and fall (Fig. 9). In 1995, the CARICOMP protocol was revised to three 10 m x 10 m plots set up parallel to the shoreline in the red mangrove fringe, with semi-annual sampling of litter fall.

Historically, fishermen used Twin Cays as a base for seasonal fishing camps, for bait collecting, and for storm shelter. Since the early 1980s, local developers have tried repeatedly to establish resorts and vacation homes on Twin Cays. Several areas have been clear-cut and later abandoned. Although Belize's regulations regarding mangrove protection should protect Twin Cays from future threats of development, attempts by the Forestry Department to enforce these regulations have been only moderately successful. Indeed, in 1995, several hectares along the shoreline immediately north of the CARI-

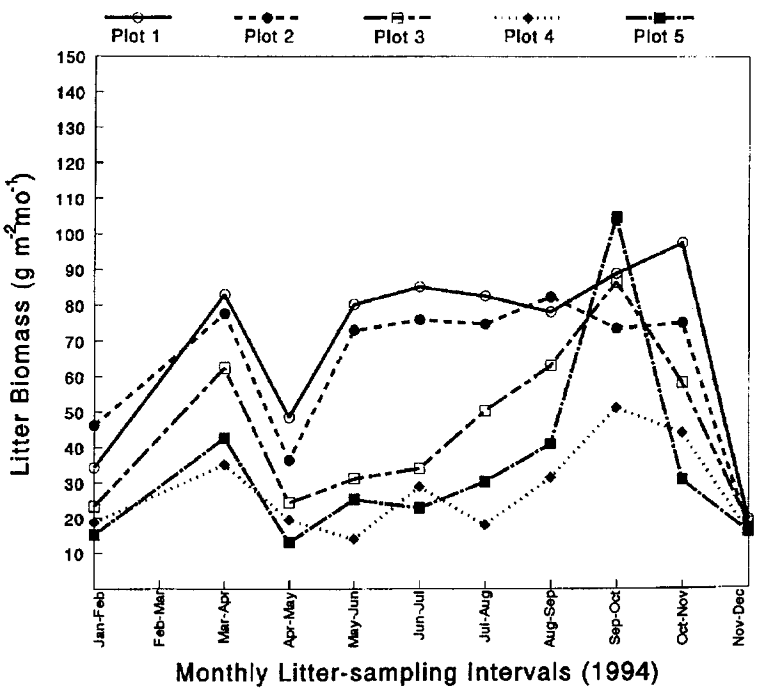

Fig. 9. Mean biomass (g m^{-2} mo^{-1}) of leaf litter from mangrove plots at Twin Cays, Belize. Plot 1 = shoreline; Plot 5 = interior.

COMP site were cleared of mangroves and filled with sediment dredged from the sub-tidal area adjacent to the development site. The developer is proposing to establish a marina and resort on the site. Other threats are also increasing, particularly from the rapidly expanding tourism industry. Substantial quantities of trash have been dumped into several small bays by operators of nearby resorts and sailing yachts that use Twin Cays as an anchorage. Beginning in the late 1980s, boat traffic from tourism began to increase dramatically in the Main Channel. Wakes created from boats driven at high speed have broken mangrove roots and dislodged sessile organisms in the bostrychietum communities. Unfortunately, rapidly rising rates of inadequately managed tourism will likely exert increasing pressure on this and other mangrove communities in Belize.

Acknowledgments

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References

Aronson, R. B., R. F. Precht. 1995. Landscape patterns of reef coral diversity: A test of the intermediate disturbance hypothesis. *Journal of Experimental Marine Biology and Ecology*, **192**:1-14.

Aronson, R. B., R. F. Precht. 1997. Stasis, biological disturbance, and community structure of a Holocene coral reef. *Paleobiology*, **238**:326-346.

Burke, R. B. 1982. Reconnaissance study of the geomorphology and benthic communities of the outer barrier reef platform, Belize. **In:** *The Atlantic Barrier Reef Ecosystem at Carrie Bow Cay, Belize, 1: Structure and Communities [Smithsonian Contributions to Marine Sciences, Vol. 12]* (edited by K. Rützler and I. G. Macintyre), pp 509-526. Smithsonian Institution, Washington DC, USA, 539 pp.

Burke, R .B. 1993. How have Holocene sea level rise and antecedent topography influenced Belize Barrier Reef development? **In:** *Proceedings of the Colloquium on Global Aspects of Coral Reefs: Health, Hazards, and History* (compiled by R. N. Ginsburg), pp 14-21. University of Miami, Miami FL, USA, 420 pp.

CARICOMP. 1994. *Level I Manual of Methods for Mapping and Monitoring of Physical and Biological Parameters in the Coastal Zone of the Caribbean.* University of the West Indies, Kingston, Jamaica, 54 pp.

CARICOMP. 1997. Meteorological and oceanographic characterization of coral reef, seagrass and mangrove habitats in the wider Caribbean. **In:** *Proceedings of the Eighth International Coral Reef Symposium (Panama, June 1996)* (edited by H. A. Lessios and I. G. Macintyre), Vol. I, pp 657-662. Smithsonian Tropical Research Institute, Balboa, Republic of Panama.

CARICOMP. 1997. Variation in ecological parameters of *Thalassia testudinum* across the CARICOMP network. **In:** *Proceedings of the Eighth International Coral Reef Symposium (Panama, June*

1996) (edited by H. A. Lessios and I. G. Macintyre), Vol. I, pp 663-668. Smithsonian Tropical Research Institute, Balboa, Republic of Panama.

Chornesky, E. A. 1991. The ties that bind: Inter-clonal cooperation may help a fragile coral dominate shallow high-energy reefs. *Marine Biology,* **109**:41-51.

Feller, I. C. 1995. Effects of nutrient enrichment on growth and herbivory of dwarf red mangrove (*Rhizophora mangle*). *Ecological Monographs,* **65**:477-505.

Gleeson, M. W., A. E. Strong. 1995. Applying MCSST to coral reef bleaching. *Advances in Space Research,* **16**(10):151-154.

Glynn, P. W. 1993. Coral reef bleaching: ecological perspectives. *Coral Reefs,* **12**:1-17.

Kjerfve, B., K. Rützler, G. H. Kierspe. 1982. Tides at Carrie Bow Cay, Belize. **In:** *The Atlantic Barrier Reef Ecosystem at Carrie Bow Cay, Belize [Smithsonian Contributions to Marine Sciences, Vol. 12]* (edited by K. Rützler and I. G. Macintyre), pp 47-51. The Smithsonian Institution, Washington DC, USA, 539 pp.

Lasker, H., M.-A. Coffroth. 1983. Octocoral distribution at Carrie Bow Cay, Belize. *Marine Ecology Progress Series,* **13**:21-28.

Lessios, H. A., D. R. Robertson, J. D. Cubrit. 1984. Spread of *Diadema* mass mortality through the Caribbean. *Science,* **226**:335-337.

Lewis, S. M., P.C. Wainwright. 1985. Herbivore abundance and grazing intensity on a Caribbean coral reef. *Journal of Experimental Marine Biology and Ecology,* **87**:215-228.

Littler, M. M., P. R. Taylor, D. S. Littler, R. H. Sims, J. N. Norris. 1987. *Dominant Macrophyte Standing Stocks, Productivity and Community Structure on a Belizean Barrier Reef [Atoll Research Bulletin 302].* Smithsonian Institution, Washington DC, USA, 18 pp.

Littler, M. M., D. S. Littler, I. G. Macintyre. 1995. *Introduction to the Biology and Geology of Tobacco Range, Belize, C.A. [Atoll Research Bulletin 426].* Smithsonian Institution, Washington DC, USA, 6 pp.

Macintyre, I. G. 1988. Modern coral reefs of Western Atlantic: New geological perspective. *AAPG Bulletin,* **72**(11):1360-1369.

Macintyre, I. G., R. B. Aronson. 1997. Field guidebook to the reefs of Belize. **In:** *Proceedings of the Eighth International Coral Reef Symposium (Panama, June 1996)* (edited by H. A. Lessios and I. G. Macintyre), Vol. I, pp 203. Smithsonian Tropical Research Institute, Balboa, Republic of Panama.

Macintyre, I. G., M. M. Littler, D. S. Littler. 1995. *Holocene History of Tobacco Range, Belize, Central America [Atoll Research Bulletin 430].* Smithsonian Institution, Washington DC, USA, 18 pp.

McKee, K. L. 1993a. *Determinants of Mangrove Species Distribution in Neotropical Forests: Biotic and Abiotic Factors Affecting Seedling Survival and Growth.* Ph.D. Dissertation, Louisiana State University, Shreveport LA, USA, 234 pp.

McKee, K. L. 1993b. Soil physiochemical patterns and mangrove species distribution: Reciprocal effects? *Journal of Ecology,* **81**:477-487.

Ogden, J. C., N. B. Ogden. 1993. The coral reefs of the San Blas Islands: Revisited after 20 years. **In:** *Proceedings of the Colloquium on Global Aspects of Coral Reefs: Health, Hazards, and History* (compiled by R. N. Ginsburg), pp 267-272. University of Miami, Miami FL, 420 pp.

Peters, E. C. 1993. Diseases of other invertebrate Phyla: Porifera, Cnidaria, Ctenophora, Annelida, Echinodermata. **In:** *Pathobiology of Marine and Estuarine Organisms [Advances in Fisheries Science]* (edited by J. A. Couch and J. W. Fournie), pp 393-449. CRC Press, Boca Raton FL USA, 552 pp.

Perkins, J. S. 1983. *The Belize Barrier Reef Ecosystem: An Assessment of its Resources, Conservation Status and Management.* New York Zoological Society, New York NY, USA, 189 pp.

Rützler, K., I. C. Feller. 1988. Mangrove swamp communities. *Oceanus,* **30**(4):16-24.

Rützler, K., I. C. Feller. 1996. Caribbean mangrove swamps. *Scientific American,* **274**(3):94-99.

Rützler, K., J. D. Ferraris. 1982. Terrestrial environments and climate, Carrie Bow Cay, Belize. **In:** *The Atlantic Barrier Reef Ecosystem at Carrie Bow Cay, Belize, 1: Structure and Communities [Smithsonian Contributions to Marine Sciences, Vol. 12]* (edited by K. Rützler and I. G. Macintyre), pp 77-91. Smithsonian Institution, Washington DC, USA, 539 pp.

Rützler, K., I. G. Macintyre (Editors). 1982a. *The Atlantic Barrier Ecosystems at Carrie Bow Cay, Belize, 1: Structure and Communities [Smithsonian Contributions to Marine Sciences, Vol. 12].* Smithsonian Institution, Washington DC, USA, 539 pp.

Rützler, K., I. G. Macintyre. 1982b. The habitat distribution and community structure of the barrier reef complex at Carrie Bow Cay, Belize. **In:** *The Atlantic Barrier Reef Ecosystem at Carrie Bow Cay, Belize, 1: Structure and Communities [Smithsonian Contributions to Marine Sciences, Vol. 12]* (edited by K. Rützler and I. G. Macintyre), pp 9-45. Smithsonian Institution, Washington DC, USA, 539 pp.

Stoddart, D. R., F. R. Fosberg, D. L. Spellman. 1982. *Cays of the Belize Barrier Reef and Lagoon [Atoll Research Bulletin 256].* Smithsonian Institution, Washington DC, USA, 76 pp.

Strong, A. E., C. S. Barrientos, C. Duda, J. Sapper. 1997. Improved satellite techniques for monitoring coral reef bleaching. **In:** *Proceedings of the Eighth International Coral Reef Symposium (Panama, June 1996)* (edited by H. A. Lessios and I. G. Macintyre), Vol. II, pp 1495. Smithsonian Tropical Research Institute, Balboa, Republic of Panama.

Tomasko, D. A., B. E. Lapointe. 1991. Productivity and biomass of *Thalassia testudinum* as related to water column nutrient availability: Field observations and experimental studies. *Marine Ecology Progress Series,* **75**:9-17.

Williams, E. H., L. Bunkley-Williams. 1990. *The World-Wide Coral Reef Bleaching Cycle and Related Sources of Coral Mortality [Atoll Research Bulletin 335].* Smithsonian Institution, Washington DC, 76 pp.

Williams, S. L. 1988. *Thalassia testudinum* productivity and grazing by green turtles in a highly disturbed seagrass bed. *Marine Biology,* **98**:447-455.

Williams, S. L. 1990. Experimental studies of Caribbean seagrass bed development. *Ecological Monographs,* **60**(4):449-469.

Woodroffe, C. D. 1995. *Mangrove Vegetation of Tobacco Range and Nearby Mangrove Ranges, Central Belize Barrier Reef [Atoll Research Bulletin 427].* Smithsonian Institution, Washington DC, USA, 35 pp.

Wright, R. M., D. W. Urish, I. Runge. 1991. The hydrology of a Caribbean mangrove island. In *Coastlines of the Caribbean: ASCE Coastal Zone 1991 Conference* (edited by G. Cambers and O. T. Magoon), pp 170-184. American Society of Civil Engineers, New York NY, USA, 180 pp.

Young, D. K., M. W. Young. 1982. Macrobenthic invertebrates in bare sand and seagrass (*Thalassia testudinum*) at Carrie Bow Cay, Belize. **In:** *The Atlantic Barrier Reef Ecosystem at Carrie Bow Cay, Belize, 1: Structure and Communities [Smithsonian Contributions to Marine Sciences, Vol. 12]* (edited by K. Rützler and I. G. Macintyre), pp 115-126. Smithsonian Institution, Washington DC, USA, 539 p.

Zieman, J. C., R. T. Zieman. 1989. The Ecology of the Seagrass Meadows of the West Coast of Florida: A Community Profile. Biological Report 85(7.25), U.S. Fish and Wildlife Service, Washington DC, USA, 155 p.

Great Corn Island, Nicaragua[1]

Joseph D. Ryan[1,2,5], Leanne J. Miller[3,5], Yamil Zapata[2,4,5], Oliver Downs[5], and Rodolfo Chan[2,6]

[1]*AEL/CEES, The University of Maryland System, Gunter Hall, Frostburg MD 21532 USA*

[2]*Centro de Investigación y Documentación de la Costa Atlántica, Apartado 42, Bluefields, Nicaragua*

[3]*Marine Research Institute, Florida Department of Environmental Protection, 100 8th Avenue SE, St. Petersburg FL 33701-5095 USA*

[4]*Marine Biology Department, Universidad de las Regiones Autónomas de la Costa Caribe Nicaraguense, Bluefields, Nicaragua*

[5]*Corn Islands Environmental Education Foundation, Office of the Mayor, Corn Island, Nicaragua*

[6]*Marine Sciences Department, Bluefields Indian Caribbean University, Bluefields, Nicaragua*

Mangrove wetlands, seagrass beds, and coral reefs are found throughout Nicaragua's Caribbean coastal zone, but few scientific studies have been carried out to identify their distribution, productivity, or general physical condition. Preliminary data indicate that live coral coverage of several large coral reefs on the Nicaraguan shelf is declining. In view of the ecological importance of these habitats in sustaining east coast fisheries, Nicaragua joined the CARICOMP program in 1992. Great Corn Island was selected as the site for carrying out coral reef and seagrass monitoring. Although mangrove forests occur on the island, they are cut off from the sea except during short periods during the rainy season. To date, work at Great Corn Island has been limited to the coral reef site, which has been monitored for four years (1993-1997).

Introduction

Nicaragua's humid Caribbean coastal zone (Fig. 1) traverses a broad range of environments that include brackish wetlands on the land, and nearshore and offshore benthic communities in the sea (Ryan, 1995). On the land, 90% of Nicaragua's watersheds drain towards the east coast through eleven major rivers. The nutrient loads and freshwater pulsed by these rivers provide the basis for many of the environmental functions characteristic of the Miskito lowlands and the nearshore coastal boundary

[1] *CARICOMP — Caribbean Coral Reef, Seagrass and Mangrove Sites* (edited by B. Kjerfve), pp 95-105. UNESCO, Paris, 1998, 347 pp.

layer (Murray and Young, 1985; Ryan, 1992a). However, increased deforestation has led to high erosion along many of the watersheds. This has resulted in higher sediment loads that are believed to have killed several of the large nearshore reef complexes on the central Nicaraguan shelf (Ryan, 1992a). The dynamics of marine environments on the continental shelf, the largest in the wider Caribbean, are primarily influenced by tropical storms, the westward flowing Caribbean Current, tradewinds (Roberts and Murray, 1983; Murray *et al.*, 1982; Ryan 1992a, 1994), and ecological processes.

Mangroves, seagrasses, and coral reefs are found throughout this coastal zone. With the exception of their co-occurrence on the shallow Miskito Cays bank, they are not distributed according to the classical paradigm in which three habitats are tightly linked through physico-ecological processes over space and time (Ogden and Gladfelter 1983). This notwithstanding, the environmental functions of these three habitats provide resources and ecological services that contribute to the welfare of Nicaragua's diverse coastal population (Ryan, 1995). For example, coral reefs and seagrasses produce scale-fish, lobster, and shrimp that account for more than 70% of the country's seafood exports. This production provides jobs (artisanal and industrial fisheries) and subsistence incomes for local communities. Additionally, the habitats provide food and refuge for more than half of the remaining endangered green sea turtles (*Chelonia mydas*) that remain in the Atlantic Ocean (Carr, *et al.*, 1978; Mortimer, 1983).

While most of the estimated 600 km^2 of mangrove forests (Robinson, 1991) are largely confined to ten coastal lagoons and along river banks, they are also found in nearshore (Pearl Cays) and offshore (Miskito Cays, Corn Islands) marine environments. Seagrass meadows and coral reefs occur both nearshore and offshore across the Nicaraguan shelf. Although the areal coverage of these latter habitats is unknown, the seagrasses are among the most extensive in the world (Roberts and Murray, 1983). Most of the available data for coral reefs come from studies on the Corn Islands (Geister, 1983; Roberts and Suhayda, 1983; Ryan, 1994). The few coral data that have been collected for the important reef system in the Miskito Cays provide no scientific basis for quantifying coral abundance nor for evaluating their environmental condition, even though this progam has been operational for four years. Seagrass surveys have been carried out in the Miskito Cays by Ogden and Gladfelter (1983), Phillips *et al.* (1982), and Marshall (1994), and in the Pearl Cays and Corn Islands by Ryan (1992b, 1994).

Because of its remoteness from the rest of the country and a long history of civil war, the Caribbean coast of Nicaragua has remained relatively undeveloped. Less than 10% of the total population lives on that coast, and population densities are low. Approximately six inhabitants per km^2 live in an area that comprises nearly half of the national territory (Robinson, 1991). The exception is Great Corn Island, one of only two inhabitated islands on the shelf, which has a population density of nearly 500 inhabitants per km^2. Virtually all travel within the Caribbean coastal region is by water, due to the lack of roads. Human activities represent the greatest current threats to seagrasses and coral reefs. Habitat degradation (sedimentation and damaging fishing practices) and overfishing are common in nearshore environments, whereas high nutrient concentrations threaten the reefs offshore the Corn Islands. In nearshore areas, increased sediment loads are hypothesized to be responsible for an average living coral cover of 10% for corals found within 25 km^2 of the mainland (Ryan, 1992a,b). The effects of overfishing of these habitats is unknown, but the decline in reef fish populations may be related to in-

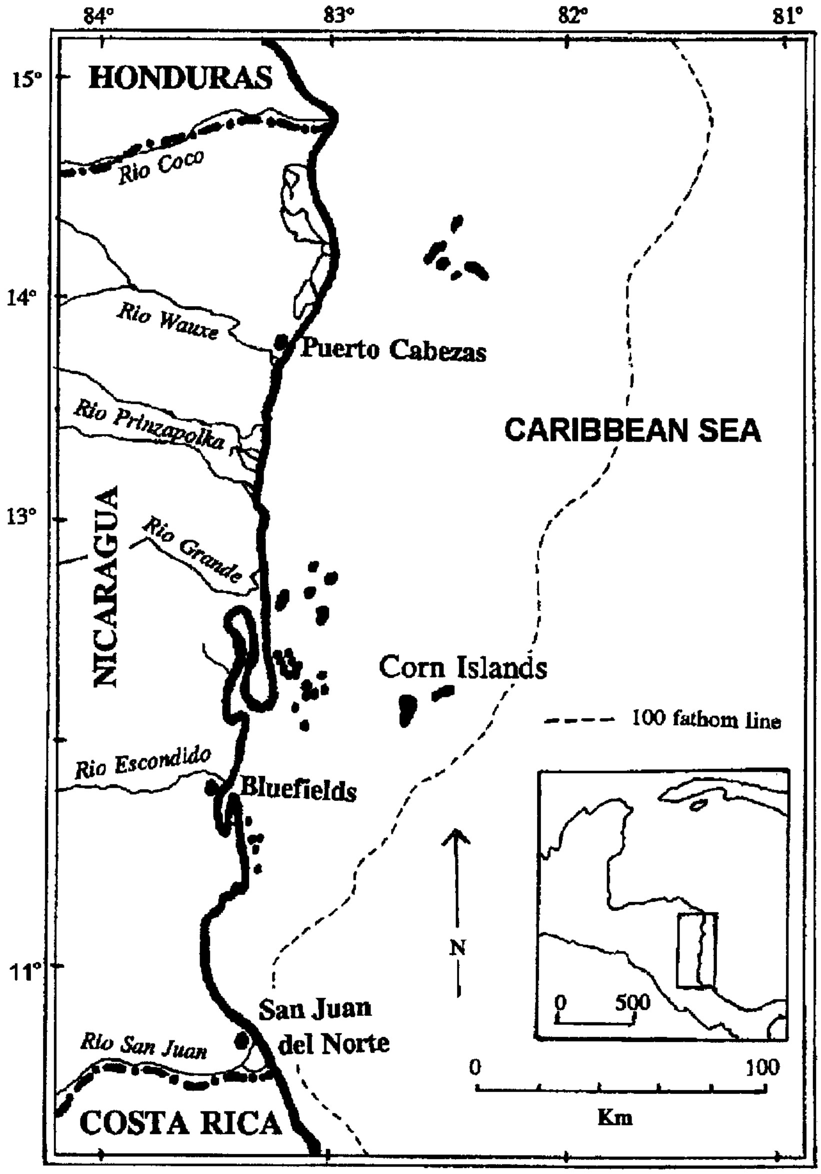

Fig. 1. Map of Nicaragua's Caribbean coast and study area.

creased use of Jamaican-type fish traps and by-catch of reef fishes in shrimp trawlers (Ryan 1995). In offshore environments, many of the fringing reefs on Great Corn Island are believed to be declining as a result of sewage (Ryan, 1993; Broegaard, 1995).

Nicaragua joined the CARICOMP Program in 1992 and, after a careful search, decided to select Great Corn Island as its coral and seagrass monitoring location. The Corn Island site was selected for three reasons. First, it is outside the influence of terrestrial erosion that has led to river-borne sedimentation impacts on nearshore coral reefs and seagrasses. Second, both the island and its underwater environments are more accessible than at either of the other sites that were considered (Miskito and Pearl Cays). Finally, the lack of a close physico-ecological coupling between terrestrial mangroves and marine seagrasses and corals favored the selection of an offshore site.

The Setting at Great Corn Island

The two Corn Islands rise above the central Nicaraguan shelf to form the only inhabited islands along the Caribbean coast of Nicaragua (Figs. 1 and 2). Great Corn Island is located between latitudes 12°08'40"N and 12°11'83"N, and longitudes 83°04'24"W and 83°01'38"W. The island's area is 10.3 km^2 and it is inhabited by about 5,000 people. Lesser Corn Island, located 15 km to the northeast, is approximately half the size and has a population of about 500. A lobster and scale-fish fishery and two seafood processing plants, which produce over 40% of Nicaragua's total seafood exports, provide the primary sources of income for the two islands.

General descriptions of physiographic features have been published (Conzenius, 1929; McBirney and Williams, 1965), as have descriptions of underwater environments (Geister, 1983; Roberts and Suhayda, 1983; Ryan, 1992b, 1994). The geological and hydrological forces in operation on the island have been summarized by Ruden (1993), who calculated that approximately one-half of the big island lies beneath the 2-m contour line, and that a sea level rise of only 0.5 m would innundate about one-

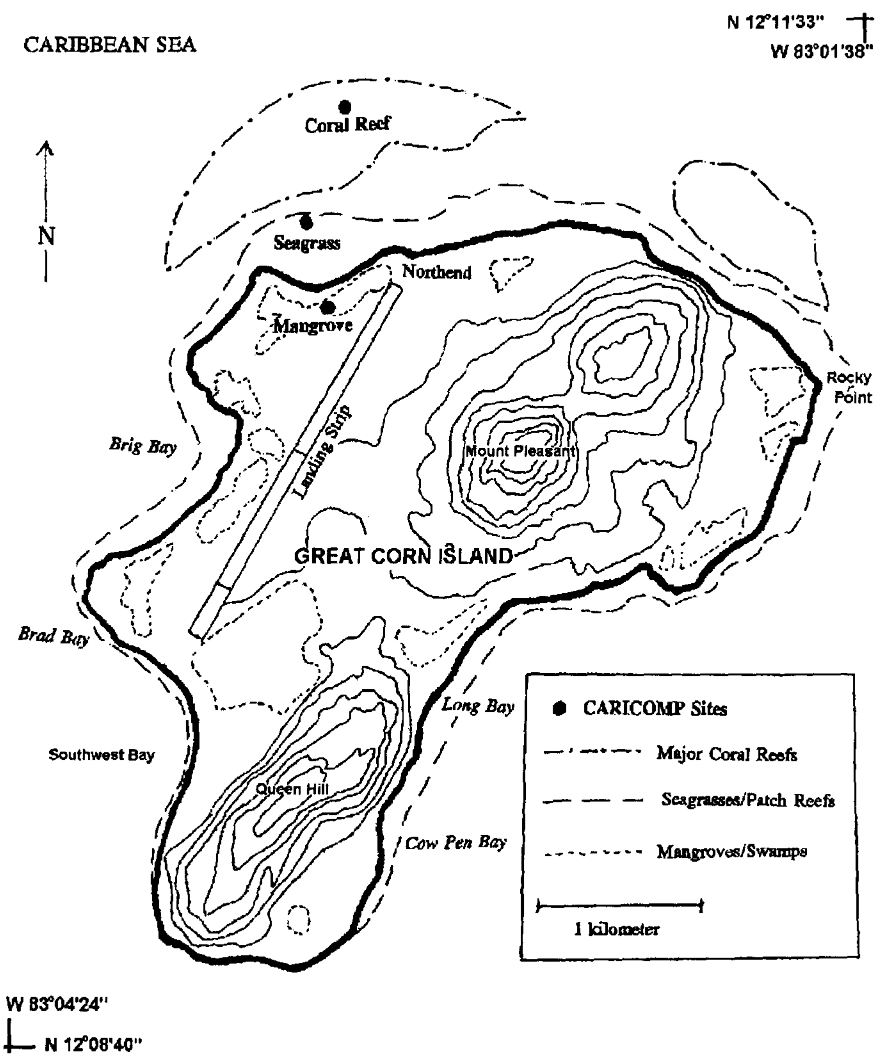

Fig.2. Map of Great Corn Island showing major features and the location of the CARICOMP monitoring sites.

third of the island. The island is made up of Tertiary (Miocene-Pliocene) basalts that protrude through late Tertiary carbonates. These basalt formations extend offshore, covering an area of approximately 10 km^2 beneath the coral reefs. It has been hypothesized (Broegaard, 1995) that the island's fresh-water aquifer is geologically connected to the nearshore reefs (<1 km from the island) and that sewage may be seeping through fractures in the geological formations connecting the island and the nearshore reefs.

Climate and Oceanic Conditions

Tradewinds are the dominant force that controls processes such as erosion, groundwater movement, and wave energy around the Corn Islands. Winds blow steadily from the ENE at 7-10 m s^{-1}, with a steadiness factor of 90% (Roberts and Suhayda, 1983). These and other physical forces (storms and currents) have sculptured the existing shape of the Corn Islands and the underwater reef formations.

There are no continuous air temperature or rainfall records for the Corn Islands, and logistical difficulties made it impossible to collect *in situ* data for more than six months. Hobo-temperature readings in 1994-1995 were consistent with long-term data for nearby San Andrés in 1959-1981. Given the absence of more recent long-term data, we present temperature recordings from the San Andrés data-set. Average air temperatures had an annual mean value of 27.4°C and a relative humidity of 81%. The coolest months are December-March, with an average of 27°C or lower. The warmest months are May-September (28°C). Extreme temperatures occurred in March 1973 (17°C) and July 1971 (34.4°C); these cannot be ruled out as factors in the observed coral degradation patterns. Average monthly rainfall is 50 mm; the rainy season is July-December (150-300 mm), with the highest rate in November.

Solar radiation is a critical parameter for coral and seagrass growth. López de la Fuente (1994) collected solar radiation data from Bluefields and found that the highest global radiation occurs in April, the lowest in December. The quantities of photosynthetically active radiation (PAR), which represents the amount of solar radiation available to perform photosynthesis, is proportional to solar radiation values.

Nicaragua's Caribbean coast is characterized by one of the highest rainfall rates in the world, 3 m per year in the north and nearly 7 m per year near the Costa Rica border. An average of 3.5 m per year is assumed until more data can be collected. A relatively dry season occurs between January and April, and this period coincides with the strongest tradewinds. Peak rainfall is delivered between May and September. Annual evaporation has been estimated at 1.3×10^{-1} mm. The highest evaporation rates (154 mm) occur during the months of April and May, the lowest (86.9 mm) during November (Peralta-Williams, 1991).

Tropical storms impact the Corn Islands once a year on average, although three storms and a hurricane pounded the island in 1996. Hurricanes can be expected to strike the Nicaraguan coast once every 50 years, but three hurricanes have struck Corn Island in the past eight years. Joan (October 1988) was the most severe. Winds gusting up to 70 m s^{-1} struck Great Corn Island directly from the southeast, blasted across the island, and devastated 95% of all standing structures on the island. In the sea, the wave surge lasted for nearly one week, and wave heights >15 m were observed on the southeast side of the island during the peak of the storm. Bottom surges resuspended large sand banks and shifted them so that they spread over several extensive coral formations on the fringing reef in 1-7 m depth, and shallow (<7 m) *Acropora* formations were badly damaged. However, the most recent hurricane, Cesar, did very little damage to the reefs when it hit in 1996.

Few data exist on physical-chemical seawater conditions on the Nicaraguan shelf, and historical data for the Corn Islands are nonexistent. Tides are semi-diurnal and average less than 1 m in range. Average salinity during the initial phase of the monitoring program was 34.5‰; seawater temperatures averaged 28.5°C (Fig. 3). These measurements were made at the CARICOMP site.

Coastal Habitats on Corn Island

Approximately 15 percent of the island's wetlands are composed of freshwater (*Raphia taedigera*) and mangrove (*Rhizophora mangle*) vegetation located in three different sections of the island (Fig. 2). Direct connection to the sea is blocked during most of the year by a beach dune system surrounding most of the island. However, during the wet season, heavy rains fill the wetlands until hydrostatic pressure builds up and breaks open the dune system. This allows for a temporary interaction, release of tannin-rich fresh waters, migration of crustaceans and scale-fish, between the wetlands and the offshore ecosystems. Many of the mangroves on Great Corn Island have been degraded by sewage discharge.

Marine environments surrounding Great Corn Island include numerous seagrass meadows. Dense mixtures of *Syringodium filiforme, Thalassia testudinum, Halophila* spp., and *Halodule wrightii* are commonly found in the nearshore backreef lagoon, whereas *Thalassia testudinum* and *Syringodium filiforme* dominate deeper offshore environments (6-8 m depth).

Fig.3. Summary of water temperature data at the CARICOMP reef site, Great Corn Island, Nicaragua.

The largest coral reef system associated with Great Corn Island is the Cana Reef, a complex composed of fringing and patch reefs located on the northeast corner (windward side) of the island, which extends seaward 2 km and then curves towards the south. This system, which is 4 km long, consists of three separate reef formations (Fig. 2). Historically, the reef complex appears to have been best developed on the nearshore eastern and western borders (Geister, 1983), but the continuity essentially disappears in the center, where isolated patch reefs rise from the bottom. In general, there is little reef development on the leeward side of the island, presumably due to an island wave "shadow" effect that reduces current and wave activity behind Cana Reef (White, 1977).

On the offshore reefs, the coral is generally in good condition but many nearshore (<1 km from the island) corals are dead and covered by algae and encrusting sponges (Ryan, 1994). The most frequently observed encrusting sponges are *Clathria* spp., *Cliona* sp., and *Agnanthosigmella varians*, the latter covering most of the dead corals. Many of the nearshore corals appear to be declining due to subterranean discharges of sewage-contaminated groundwater originating from the island (Ruden, 1993; Ryan, 1994; Broegaard, 1995). Farther offshore, beyond the Cana Reef, patchy seagrass meadows and more robust corals abound. The outer coral reefs receive most of the incoming wave energy directed at the island; *Acropora palmata* and *Montastraea annularis* are the dominant frame-building corals throughout the fringing reef system.

The CARICOMP Reef Site

In 1993, a set of five permanent transects was established on the CARICOMP monitoring site. The site is located at latitude 12°11'59.4"N and longitude 83° 03'28.5"W, within the offshore reef system in an area in which the reef is part of the fringing reef that is found at a depth of 12-15 m. The reef terminates at 20 m, where extensive sand pools extend seaward (Roberts and Suhayda, 1983; Geister, 1983; Ryan, 1994). The site is in the path of the predominant trade winds and wave energy (Fig. 2) and sand is frequently resuspended in the water column. The only human influence near the monitoring site is sporadic fishing by lobster divers, occasional fish trapping, and occasional hook-and-line fishing.

Based on chain transect surveys over the three year sampling period 1993-1995, mean substrate rugosity measured 1.91 (sd=0.132). Live cover at the site was dominated by algae (43.9%) and scleractinian corals (25.2%). Non-living substrate (e.g., gaps, holes, dead coral) made up 27% of the reef cover.

Data on the abundance of hard, soft, and hydrocorals were collected using a combination of chain transect and meter-square methods in order to make a more representative species characterization of the site. A total of 28 coral species was found using the two different methods (Table 2). Chain transects appeared to be more sensitive for finding smaller species (e.g., *Scolymia*, *Mycetophyllia*). Results indicated that a small group of coral taxa (*Montastraea annularis*, *Agaricia* spp., *Porites* spp., *Millepora alcicornis*, and *Pseudopterogorgia* spp.) represented over 90% of the corals sampled at the site (Table 2). Algae were dominated by the "fleshy" species, *Dictyota* spp. and *Padina* spp. Abiotic substrate made up nearly one-quarter (23%) of the site. Sponges and soft corals represented less than 5% of the total cover (Table 3). Video archives (8 mm video camera) were made by swimming 1 m above each of the 5 transects during each year from 1994 through 1996.

Table 2. Coral species composition comparing meter-square quadrats and chain transects, August 1994.

Coral Species Composition	Quadrat Percent	Quadrat Rank	Chain Percent	Chain Rank
Montastraea annularis	48.5	1	4.93	1
Agaricia spp.	21.1	2	8.3	3.5
Porites astreoides	6.9	3	11.6	2
Agaricia agaracites	6.6	4	8.3	3.5
Pseudopterogorgia spp.	5.6	5	2.8	6.5
Millepora alcicornis	3.2	6	0.2	16
Porites porites furcata	1.6	7	1.5	9
Muriceopsis flavida	1.2	8	0	—
Porties porites	1.0	9	6.2	5
Montastraea cavernosa	1.0	10	0	—
Porites colenensis	0.9	11	0.9	12.5
Agaricia humilis	0.4	12	0	—
Mycetophyllia spp.	0.4	13	0.6	15
Pseudopterogorgia bipinnata	0.3	14	2.8	6.5
Pseudopterogorgiaamericana	0.3	15	0	—
Siderastrea siderea	0.1	16	0	—
Porites porites divarcata	0.1	17	1.0	11
Gorgonia mariae	0.1	18	0	—
Eunicea spp.	0.1	19	0	—
Colpophyllia natans	0.1	20	0.7	14
Manicina areolata	0.1	21	0	—
Dichoenia stokesii	0.1	22	0	—
Agaricia aagarites danae	0	—	1.7	6
Leptoseris cucullata	0	—	1.1	10
Meandrine meandrites	0	—	0.9	12.5
Mycetophylia aliciae	0	—	0.5	15
Scolymia sp.	0	—	0.1	17.5
Acropora cervicornis	0	—	0.1	17.5
Species Number by Method		S = 22		S = 19
Total Species Number = 28				

Table 3. Mean percent cover and standard deviation (sd) of cover by different benthic categories, by transect and overall, 1993-1995.

Benthic Category		Transect 1	2	3	4	5	Overall Mean
Algae	mean	0.71	0.73	2.4	2.9	1.7	1.7
	sd	0.41	0.52	3.5	2.5	1.5	1.0
Stony Corals	mean	18.9	30.7	20.2	24.4	32.0	25.2
	sd	4.0	5.4	3.9	1.1	5.6	6.0
Soft Corals	mean	0.70	0.72	6.4	2.9	1.7	1.7
	sd	0.41	0.52	2.4	2.5	1.5	1.0
Sponges	mean	1.8	1.3	3.1	0.81	1.9	1.8
	sd	0.65	1.3	1.3	0.91	2.3	0.86
Non-Living	mean	34.4	22.2	23.8	32.1	25.2	27.5
	sd	11.0	4.6	18.4	7.2	7.4	5.4

The seagrass monitoring site is located in a wave-exposed environment 200 m seaward of two sites on the north coastline (Fig. 2). Each of the two sites consists of a meadow of mixed *Thalassia* and *Syringodium* located at <2 m depth. Seagrass sampling data are still unavailable due to a lack of equipment.

No mangroves were monitored at Corn Island due to lack of human resources during the first three years, but a site for future measurements has been selected in nearby Pearl Lagoon on the mainland.

Black sea urchins (*Diadema antillarum*) were not observed at the reef site. Densities in some of the shallow (<5 m) nearshore reefs around Great and Lesser Corn Islands were below 4 urchins m^{-2}. Surveys of other urchins at the 5 transects (1 m on either side of each transect line) in October 1995 found a mean density of 29.2 (sd=25.2) *Echinometra viridis*. No correlation was found between urchin abundance and any of the six benthic categories nor substrate rugosity.

No bleaching was observed at the site during any of the three sampling periods. Sea fan surveys were carried out at both the CARICOMP site and at different locations around the Corn Islands. A total of 34 sea fans was examined. None of the sea fans examined on the reef (*Gorgonia ventalina* and *Gorgonia flabellum*) showed any evidence of disease, as reported for reefs in the eastern Caribbean by Nagelkerken *et al.* (1997). Along with the negative findings reported in nearby San Andrés Island and the Bay Islands, our results provide support for the finding that the disease is not widespread in the western Caribbean.

While most of the nearshore coral reefs at Great Corn Island (<1 km from the island) have undergone a major decline (<10% live coral cover) over the last decade, the percent live coral coverage (25.2%) at the deeper CARICOMP site is within the range of values reported for other Caribbean sites (CARICOMP, 1997). The annual variability of live coral cover was not significant over the three years, although standard deviations for the 5 transects at the CARICOMP reef site was high. This appears to be due to two problems. First, the failure to place permanent markers along the transects allowed for high variability in the placement of the chain each year. This problem has been overcome by hammering nails into dead coral along each of the transects. Second, the use of different divers to collect data each year was undoubtedly another source of variabililty. This problem has also been rectified by establishing a permanent sampling team of three divers from the region. Continuously recording temperature probes are now installed permanently at the reef, seagrass, and land sites.

Acknowledgments

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References

Broegaard, J. R. 1995. Corn Island: Las aguas oscuras bajo el paraíso. *WANI*, **18**:45-49.

Carr, A., M. Carr, A. Meylan. 1978. The ecology and migrations of sea turtles: 7, The West Caribbean green turtle colony. *American Museum of Natural History*, **162**:1-42.

CARICOMP. 1997. CARICOMP monitoring of coral reefs. **In:** *Proceedings of the Eighth International Coral Reef Symposium (Panama, June 1996)* (edited by H. A. Lessios and I. G. Macintyre), Vol. I, pp 651-656. Smithsonian Tropical Research Institute, Balboa, Republic of Panama.

Conzenius, E. 1929. Les îles Corn du Nicaragua. *La Géographie, Paris*, **52**: 346-352.

Crout, R. L., S. P. Murray. 1978. Shelf and coastal boundary layer currents, Miskito Bank of Nicaragua. **In:** *Proceedings of the 16th Coastal Engineering Conference.* ASCE/Hamburg, West Germany.

Geister, J. 1983. Holocene West Indian coral reefs: Geomorphology, ecology and facies. *Facies*, **9**:173-284.

López de la Fuente, J. 1994. *Atlas of Solar Radiation in Nicaragua.* Report to the Swedish Development Assistance Program, Stockholm, Sweden, 56 pp.

Marshall, M. 1994. *Seagrasses of the Miskito Cays Biological Reserve.* Preliminary Report to USAID, 16 pp.

McBirney, A., H. Williams. 1965. Volcanic history of Nicaragua. *University of California Publications in Geological Sciences*, **55**:1-75.

Mortimer, J. 1983. The feeding ecology of the West Caribbean Green Turtle (*Chelonia mydas*) in Nicaragua. *Biotropica*, **13**: 49-58.

Murray, S. P., M. Young. 1985. The nearshore current along a high-rainfall, trade-wind coast — Nicaragua. *Estuarine, Coastal, and Shelf Science*, **21**: 687-699.

Murray, S. P., A. S. Hsu, H. H. Roberts, E. H. Owens, R. L. Crout. 1982. Physical Processes and Sedimentation on a Broad, Shallow Bank. *Estuarine and Coastal Marine Science*, **14**:135-157.

Nagelkerken, I., K. Buchan, G. W. Smith, K. Bonair, P. Bush, J. Garzón-Ferreira, L. Botero, P. Gayle, C. Herberer, C. Petrovic, L. Pors, P. Yoshioka. 1997. Widespread disease in Caribbean fans: I. Spreading and general characteristics. **In:** *Proceedings of the Eighth International Coral Reef Symposium (Panama, June 1996)* (edited by H. A. Lessios and I. G. Macintyre), Vol. I, p 659. Smithsonian Tropical Research Institute, Balboa, Republic of Panama.

Ogden, J. C., E.H. Gladfelter. 1983. *Coral Reefs, Seagrass Beds and Mangroves: Their Interaction in Coastal Zones of the Caribbean.* UNESCO Reports in Marine Science No. 23.

Peralta-Willimas, L. 1991. *Diagnóstico de los Recursos Pesqueros.* Instituto Nicaraguense de las Regiones Autónomas (Indera) , 52 pp.

Phillips, R. C., R. L. Vadas, N. Ogden. 1982. The marine algae and seagrasses of the Miskito Bank, Nicaragua. *Aquatic Botany*, **13**:187-195.

Roberts, H. H., S. P. Murray. 1983. Controls on reef development and the terrigenous-carbonate interface on a shallow shelf, Nicaragua (Central America). *Coral Reefs*, **2**:71-80.

Roberts, H. H., J. N. Suhayda. 1983. Wave-current interactions on a shallow reef (Nicaragua, Central America). *Coral Reefs*, **1**: 209-214.

Robinson, S. 1991. *Diagnóstico Preliminar de la Situación Actual de Medio Ambiente en la Region Autónoma Atlántica Sur: Parte I, Volume VI-A.* Report by Instituto Nicaraguense de las Regiones Autónomas (Indera), 76 pp.

Ruden, F. 1993. The hydrogeologic environment of an oceanic basaltic island. **In:** *Memoirs of the 24th Congress of the International Association of Hydrogeologists (Oslo, Norway)*, pp 166-1182.

Ryan, J. D. 1992a. *Ecosistemas Marinas y el Manejo Sostenible en la Costa Central del Caribe Nicaraguense.* WANI 13, Universidad Centroamericana Press, 15 pp.

Ryan, J. 1992b. *Ecosistemas de Arrecifes Coralinos en la Plataforma Central de Nicaragua.* WANI 14, Universidad Centroamericana Press, 13 pp.

Ryan, J. 1993. *Pastos Marinos del Caribe Nicaragüense.* WANI 15, Universidad Centroamericana Press, 12 pp.

Ryan, J. 1994. *The Corn Island Reef Survey: Coral Degradation Patterns and Recommended Actions.* Report to NORAD and IRENA (April), 42 pp.

Ryan, J. 1995. *Fisheries Resources and Their Sustainable Use on the Nicaraguan Caribbean Coast* [in Spanish], WANI 16, Universidad Centroamericana Press, 13 pp.

White, M. L. 1977. *Analysis of Island Wave Shadows.* MS Thesis, Louisiana State University, Baton Rouge, LA, 55 pp.

Cahuita and Laguna Gandoca, Costa Rica[1]

Jorge Cortés
Centro de Investigación en Ciencias del Mar y Limnología
Escuela de Biología, Universidad de Costa Rica
San Pedro, Costa Rica

The Costa Rican CARICOMP sites are located in two protected areas in the southern portion of the Caribbean coast near the border with Panama: the Refugio Nacional de Vida Silvestre Gandoca-Manzanillo (mangrove site) and the Parque Nacional Cahuita (seagrass and coral reef sites). This tectonically active area is characterized by rocky headlands, extensive wetlands, and beaches. The climate is hot and humid. This region hosts over 150,000 tourists per year. The mangrove swamp in Laguna Gandoca, which is about 250 ha in area, harbors the country's only natural population of mangrove oysters, contains the largest patch of red mangrove, and is one of the main nursery grounds for the Atlantic tarpon. In the Parque Nacional Cahuita, the seagrass bed is one of the largest in the country, about 20 ha in area; the coral reef is the longest continuous coral reef in the country, with the outer crest extending 5 km, and contains the most number of species.

Introduction

The Costa Rican CARICOMP sites are located in two protected areas on the southern portion of the Caribbean coast of Costa Rica near the Panamanian border (Fig. 1). The mangrove site is located at Laguna Gandoca, within the Refugio Nacional de Vida Silvestre Gandoca-Manzanillo (9°35'N, 82° 36'W). The seagrass and coral reef sites are located in the Parque Nacional Cahuita (9°45'N, 82°48'W), about 30 km northwest of Gandoca-Manzanillo.

The extensive wetlands of this portion of Costa Rica consist mainly of freshwater *Raphia* palm swamps, known locally as "yolilalles." The coastal lagoon, Laguna Gandoca, harbors a mangrove forest. Land use in adjacent areas includes banana and forestry plantations. On the coast itself, sandy pocket beaches alternate with rocky headlands. These promontories are uplifted Pleistocene and Holocene fossil coral reefs and beach rocks. The present-day coral reefs grow on the bathymetric highs seaward of the promontories, as at the Parque Nacional Cahuita.

[1] *CARICOMP — Caribbean Coral Reef, Seagrass and Mangrove Sites* (edited by B. Kjerfve), pp 107-113. UNESCO, Paris, 1998, 347 pp.

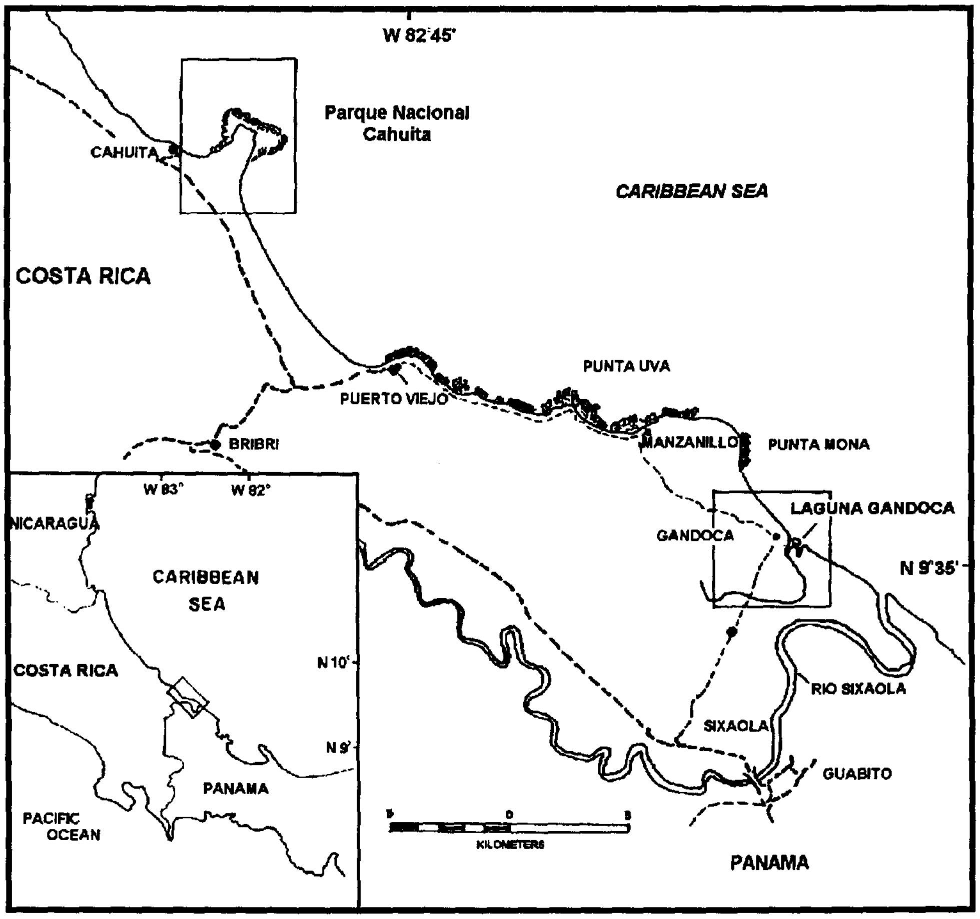

Fig. 1. Location of the study areas on the Caribbean coast of Costa Rica.

The town of Cahuita, from which the park was named, has a population of 3,000 (Bermúdez, 1992). Tourism has grown rapidly over the past decade and, together, Cahuita and Gandoca-Manzanillo host more than 150,000 tourists per year (Bermúdez, 1992).

Atmospheric and Oceanic Climates

The hot and humid climate of the Caribbean coast of Costa Rica consists of two rainy seasons, November-March and June-August. Average precipitation decreases from north to south along the coast, from about 5,000 mm near the Nicaraguan border to less than 2,500 mm near the Panamanian border (Coen, 1983). In the study area, average rainfall varies from 3,000 mm at Cahuita to 2,500 mm at Gandoca. Air temperature ranges from 24°C to 27°C (Herrera, 1984).

The main marine current along the coast is from northwest to southeast, with small eddies in the opposite direction. These eddies transport terrigenous sediments derived from the larger rivers along the coast into coral reef areas (Cortés, 1981, 1992a).

The tidal range is 30-50 cm, but the area is also greatly affected by local winds. Tides are mixed, mainly diurnal. Waves are mainly from the northeast January-June and from the east July-December, depending on the position of the Intertropical Convergence Zone.

Mangrove Forest

The mangrove site is located at Laguna Gandoca and covers an area of 250 ha. It is the least altered by human activities of any mangrove forest on the Caribbean coast of Costa Rica. The lagoon is a topographic depression at the land-sea interface created by fluvial-tidal interactions. Long-shore currents here built a sandy bar or spit across the confluence to create a coastal lagoon. Exchange between the lagoon and the ocean depends on precipitation and run-off. More freshwater exits the system than marine water enters. The outlet varies in size, from occasionally being closed to being several meters wide.

The lower section of the mangrove forest is dominated by large *Rhizophora racemosa* G.F.W.Meyer and *Avicennia germinans* (Linnaeus); other species include *R. harrisonii* Leechman, *Conocarpus erecta* Linnaeus, and *R. mangle* Linnaeus. The upper reaches of the forest are dominated by the fern *Acrosticum aureum* Linnaeus and the palm *Raphia taedigera* Martius.

Laguna Gandoca has the only natural populations of the mangrove osyter, *Crassostrea rhizophorae* (Guilding) in Costa Rica, and the largest patch of red mangrove, *R. mangle*. This lagoon is one of the main nursery sites for the Atlantic tarpon, *Megalops atlanticus* Valenciennes, and other species of economic importance (Chacón, 1994).

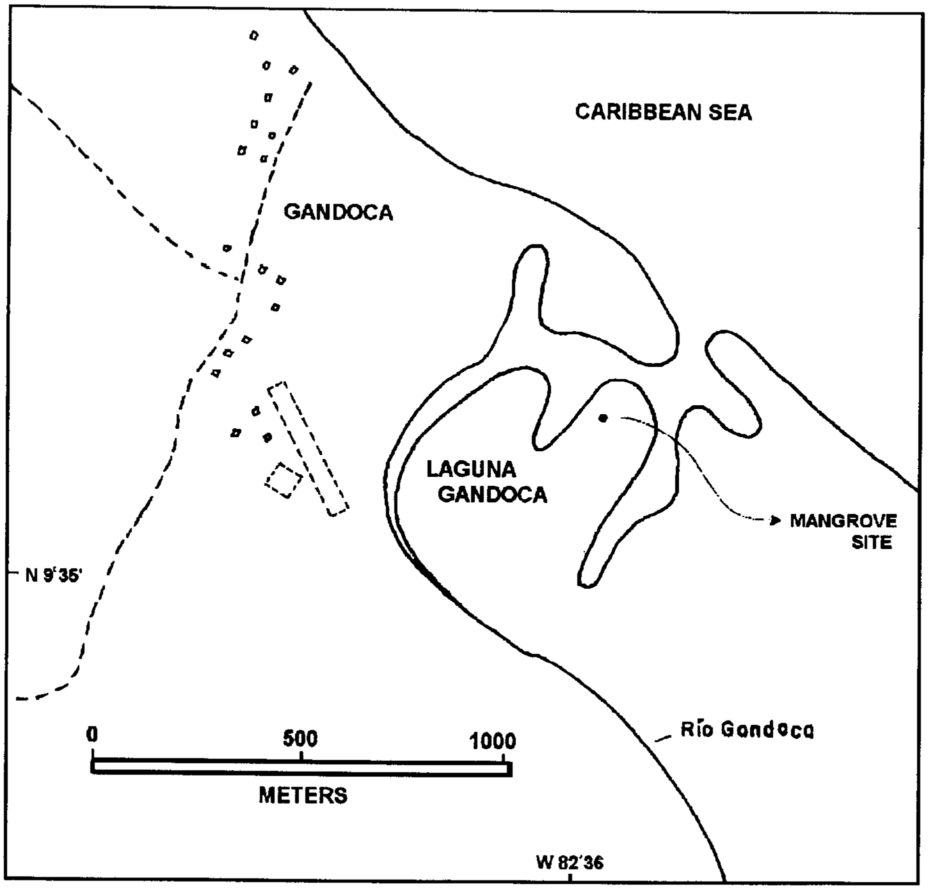

Fig. 2. Mangrove site at Laguna Gandoca within the Refugio Nacional de Vida Silvestre, Gandoca-Manzanillo, Costa Rica.

Seagrass Beds

The seagrass site is located in a shallow (<1 m) lagoon in the Parque Nacional Cahuita (Fig. 3). The lagoon covers an area of 250 ha, and the seagrass beds cover 20 ha behind the reef crests. The predominant species is turtle grass, *Thalassia testudinum* Banks ex König, with intermixed manatee grass, *Syringodium filiformis* Kütz. *Haloodule wrightii* Ascherson is also found mixed with the other seagrasses or alone in protected areas. This seagrass site was affected by the 1991 Limón earthquake (7.5 on the Richter scale), as a result of co-seismic uplift of about 50 cm (Cortés *et al.*, 1992). One year after the earthquake, *Thalassia* had completely overgrown the lagoon, but the populations of algae and seagrasses had returned to pre-earthquake levels two years after the quake.

At the site in the middle of the lagoon, the ratio of *Thalassia* to *Syringodium* is about three to four. Several coral species and many algae are present, especially *Dictyota, Amphiroa, Laurencia,* and *Halimeda.* In early 1995, the density of *Thalassia* was 1,035 ± 38 short shoots m^{-2}, and the density of *Syringodium* was 771 ± 365 short shoots m^{-2}. Between April and May 1995, the growth rate of *Thalassia* was 300 ± 320 mg m^{-2} d^{-1}.

Coral Reefs

The coral reefs are the most studied marine ecosystems on the Caribbean coast of Costa Rica. Of these, the one at the Parque Nacional Cahuita has been studied longer and in greater detail (Fig. 3). The reef was described first by Wellington (1974a); since then, high levels of siltation and turbidity have been investigated. Studies have suggested that the high levels of terrigenous sediments are responsible for the siltation and turbidity as well as being the main stressor on the reef (Risk *et al.*, 1980; Cortés, 1981; Cortés and Risk, 1984, 1985; Cortés and Guzmán, 1985a). A study conducted 15 years after these initial observations indicates a continuous deterioration of the coral reef (Cortés, 1994).

Descriptions have been published of coral species (Cortés and Guzmán, 1985b; Cortés, 1992b), octocorals (Guzmán and Cortés, 1985), algae (Wellington, 1974b; Soto and Ballentine, 1986), microcrustaceans (Breedy, 1986; Breedy and Murillo, 1995), sponges (Loaiza, 1991), densities of *Diadema* (Valdez and Villalobos, 1978), and primary productivity (Silva, 1986). Pollution on the reef has been documented by Mata *et al.* (1987), Rojas (1990), Sandí (1990), and Guzmán and Jiménez (1992). The death of corals and other reef organisms due to high temperatures in 1983 was reported by Cortés *et al.* (1984), while that resulting from the 1991 earthquake was reported by Cortés *et al.* (1992). The massive 1983 die-off of *Gorgonia* was described by Guzmán and Cortés (1984), that of *Diadema* by Murillo and Cortés (1984).

The coral reef is characterized by an outer crest extending for 5 km around Punta Cahuita; the forereef base is at a depth of 15 m. The reef crest is dominated by *Millepora complanata* Lamarck and coralline algae. A smaller inner crest extends for 500 m around Puerto Vargas; the base of the forereef is at 5-6 m and is built mainly of *Agaricia agaricites* (Linnaeus) and *Porites* spp. on the eastern end, and of massive corals in other sections. The reef crest had *Acropora palmata* (Lamarck), but the species died off in 1983 (Cortés *et al.*, 1984) with little recovery since then. The backreef has *Diploria clivosa* (Ellis & Solander) and *Millepora complanata*; the lagoon is mainly rubble, with a few seagrasses and algae.

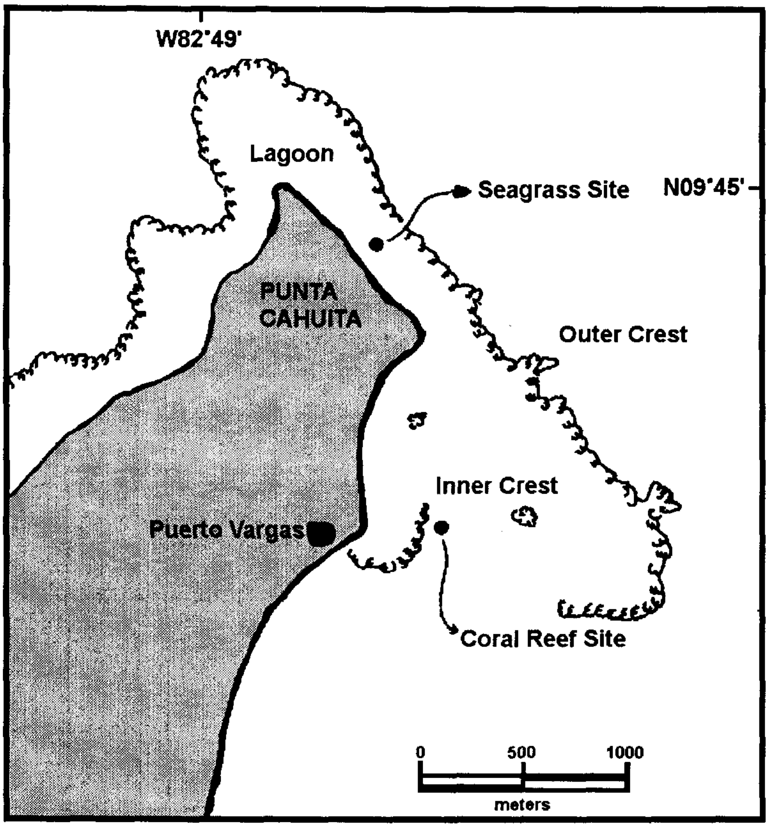

Fig. 3. Seagrass and coral reef sites at Parque Nacional Cahuita, Costa Rica.

The CARICOMP site is located on the inner crest at the base of the reef at a depth of 5 m. The main coral is *Siderastrea siderea* (Ellis & Solander), together with *Diploria strigosa* Dana and a few *Montastraea franksi* Gregory. Average live coral coverage is 28.8 ± 2.8% (n = 5 × 10-m-long transects).

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References

Bermúdez, F. 1992. *Evolución del Turismo en las Áreas Silvestres: Período 1982-1991.* Unpublished report, Servicio de Parques Nacionales, Ministerio de Recursos Naturales, San José, Costa Rica.

Breedy, O. 1986. *Contribución al Estudio de los Microcrustaceos Bénticos (Isopoda y Tanaidacea) en el Arrecife Coralino del Parque Nacional Cahuita, Limón, Costa Rica.* Thesis, Escuela de Biología, Universidad de Costa Rica, 46 pp.

Breedy, O., U. M. Murillo. 1995. Isópodas (Crustacea: Peracarida) de un arrecife del Caribe de Costa Rica. *Revista de Biología Tropical,* **43**:219-229.

Chacón Ch., D. 1994. Ecología básica y alimentación del sábalo *Megalops atlanticus* (Pisces: Megalopidae). *Revista de Biología Tropical,* **42**:225-232.

Coen, E. 1983. Climate. **In**: *Costa Rican Natural History, Vol. 35* (edited by D. H. Janzen), p 46. University of Chicago Press, Chicago IL, USA, 816 pp.

Cortés, J. 1981. *The Coral Reef at Cahuita, Costa Rica: A Reef Under Stress.* M.Sc. thesis, McMaster University, Hamilton, Ontario, Canada, 176 pp.

Cortés, J. 1992a. Los arrecifes coralinos del Refugio Nacional de Vida Silvestre Gandoca-Manzanillo, Limón, Costa Rica. *Revista de Biología Tropical,* **40**:325-333.

Cortés, J. 1992b. Organismos de los arrecifes coralinos de Costa Rica: V. Descripción y distribución geográfica de hydrocorales (Cnidaria; Hydrozoa: Milleporina & Stylasterina) de la costa Caribe. *Brenesia,* **38**:45-50.

Cortés, J. 1994. A reef under siltation stress: A decade of degradation. **In**: *Proceedings of the Colloquium on Global Aspects of Coral Reefs: Health, Hazards and History, 1993* (compiled by R. N. Ginsburg), pp 240-246. Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami FL, USA, 420 pp.

Cortés, J., H. M. Guzmán. 1985a. Arrecifes coralinos de la costa Atlántica de Costa Rica. *Brenesia,* **23**:275-292.

Cortés, J., H. M. Guzmán. 1985b. Organismos de los arrecifes coralinos de Costa Rica. III: Descripción y distribución geográfica de corales escleractinios (Cnidaria: Anthozoa: Scleractinia) de la costa Caribe. *Brenesia,* **24**:63-124.

Cortés, J., M. J. Risk. 1984. El arrecife coralino del Parque Nacional Cahuita, Costa Rica. *Revista de Biología Tropical,* **32**:198-121.

Cortés, J., M. J. Risk. 1985. A reef under siltation stress: Cahuita, Costa Rica. *Bulletin of Marine Science,* **36**:339-356.

Cortés, J., M. M. Murillo, H. M. Guzmán, H. Acuña. 1984. Pérdida de zooxantelas y muerte de corales y otros organismos arrecifales en el Atlántico y Pacífico de Costa Rica. *Revista de Biología Tropical,* **32**:227-231.

Cortés, J., R. Soto, C. Jiménez, A. Astorga. 1992. Earthquake associated mortality of intertidal and coral reef organisms (Caribbean of Costa Rica). *Proceedings of the 7th International Coral Reef Symposium (Guam),* **1**:235-240.

Guzmán, H. M., J. Cortés. 1984. Mortalidad de *Gorgonia flabellum* en la costa Caribe de Costa Rica. *Revista de Biología Tropical,* **32**:305-308.

Guzmán, H. M., J. Cortés. 1985. Organismos de los arrecifes coralinos de Costa Rica. IV: Descripción y distribución geográfica de octocoralarios escleractinios de la costa Caribe. *Brenesia,* **24**:125-174.

Guzmán, H. M., C. E. Jiménez. 1992. Contamination of coral reefs by heavy metals along the Caribbean coast of Central America (Costa Rica and Panama). *Bulletin of Marine Pollution,* **24**:554-561.

Herrera, W. 1984. *Clima de Costa Rica.* Editorial Universidad Estatal a Distancia (UNED), San José, Costa Rica, 118 pp.

Loaiza, B. 1991. Estudio taxonómico de las esponjas del Parque Nacional Cahuita, sector Puerto Vargas e Isla Uvita, Limón, Costa Rica. *Brenesia,* **36**:21-62.

Mata, A., J. A. Acuña, M. M. Murillo, J. Cortés. 1987. La contaminación por petróleo en el Caribe de Costa Rica: 1981-1985. *Caribbean Journal of Science,* **23**:41-49.

Murillo, M. M., J. Cortés. 1984. Alta mortalidad en la población del erizo de mar *Diadema antillarum* Philippi (Echinodermata: Echinoidea), en el Parque Nacional Cahuita, Limón, Costa Rica. *Revista de Biología Tropical,* **32**:167-169.

Risk, M. J., M. M. Murillo, J. Cortés. 1980. Observaciones biológicas preliminares sobre el arrecife coralino en el Parque Nacional Cahuita, Costa Rica. *Revista de Biología Tropical,* **28**:361-382.

Rojas Guitart, M. T. 1990. *Determinación de Cadmio, Cromo, Cobre, Hierro, Manganeso, Plomo y Zinc en el Pepino de Mar Holothuria sp. (Echinodermata) del Arrecife Coralino del Parque Nacional Cahuita, Costa Caribe, Costa Rica.* Tesis de Licenciatura en Química, Universidad de Costa Rica, 69 pp.

Sandí, G. 1990. *Determinación de Zn, Cd, Pb, Cu, Fe, Mn, Cr en Aguas del Arrecife Coralino del Parque Nacional Cahuita, Costa Rica.* Tesis de Licenciatura, Escuela de Química, Universidad de Costa Rica, 72 pp.

Silva Benavides, A. M. 1986. *Productividad Primaria, Biomasa del Fitoplancton y la Relación con Parámetros Físico-Químicos en el Arrecife Coralino del Parque Nacional Cahuita.* Tesis de Licenciatura en Biología, Universidad de Costa Rica, 72 pp.

Soto, R., D. L. Ballentine. 1986. La flora bentónica del Caribe de Costa Rica (Notas preliminares). *Brenesia,* **25/26**:123-162.

Valdez, M. F., C. R. Villalobos. 1978. Distribución espacial, correlación con el substrato y grado de agregación en *Diadema antillarum* Phillipi (Echinodermata: Echinoidea). *Revista de Biología Tropical,* **26**:237-245.

Wellington, G. M. 1974a. *An Ecological Description of the Marine and Associated Environments at Monumento Nacional Cahuita.* Subdirección de Parques Nacionales, Ministerio de Agricultura y Ganadería, San José, Costa Rica, 86 pp.

Wellington, G. M. 1974b. The benthic flora of Punta Cahuita: Annotated list of species with additions to the Costa Rican Atlantic flora. *Brenesia,* **3**:19-30.

Bahía de Chengue, Parque Natural Tayrona, Colombia[1]

Jaime Garzón-Ferreira
Instituto de Investigaciones Marinas y Costeras (INVEMAR)
Apartado 1016
Santa Marta, Colombia

Bahía de Chengue is a small bay located on the Caribbean coast of Colombia. The shores are mainly steep and rocky and support poorly developed but diverse coral reef communities. At the inner portion of the bay there are sedimentary shallow bottoms with seagrass beds dominated by *Thalassia* and narrow but dense coastal fringes of small *Rhizophora* trees. Regional climate and oceanography are strongly determined by high coastal topography and trade wind incidence. There are two clearly distinct seasons: (1) a dry season (from December to April), when strong NE trade winds (mean 3.5 m s^{-1}) reduce precipitation and generate an upwelling that transports water with low temperature (mean 25.5°C) from 100-200 m depth to the surface; and (2) a rainy season (from May to November), with low trade wind incidence (mean 1.5 m s^{-1}), more than 80% of the total annual rain, reduced upwelling occurrence, and higher seawater temperature at surface (mean 28.0°C). Turbid currents of reduced salinity commonly enter the bay from the southwest during the rainy season. Chengue is part of a Natural Park but human activities in the area, although not extensive, have an impact on the marine ecosystem.

Introduction

The CARICOMP site in Colombia is Bahía de Chengue (11°20'N and 74°08'W), a small bay (surface area 3.3 km^2) in the Parque Natural Tayrona, located 14 km northeast of the city of Santa Marta on the Caribbean coast of Colombia (Fig. 1). The coastal topography is heterogeneous, with a steep relief due to the closeness of the Sierra Nevada de Santa Marta, the highest mountain system of Colombia (5,800 m above sea level). Consequently, the shore is basically a cliff composed of several types of metamorphic rocks (Doolan and McDonald, 1976), with numerous rocky headlands, islets, bays, and inlets. Also, the continental shelf is very narrow, and depths of 200 m are found only 2 km from shore. At the inner portion of area bays, there are sedimentary beaches, small coastal lagoons and, intermittently, the mouths of small rivers (Garzón-Ferreira and Cano, 1991).

[1] *CARICOMP — Caribbean Coral Reef, Seagrass and Mangrove Sites* (edited by B. Kjerfve), pp 115-125. UNESCO, Paris, 1998, 347 pp.

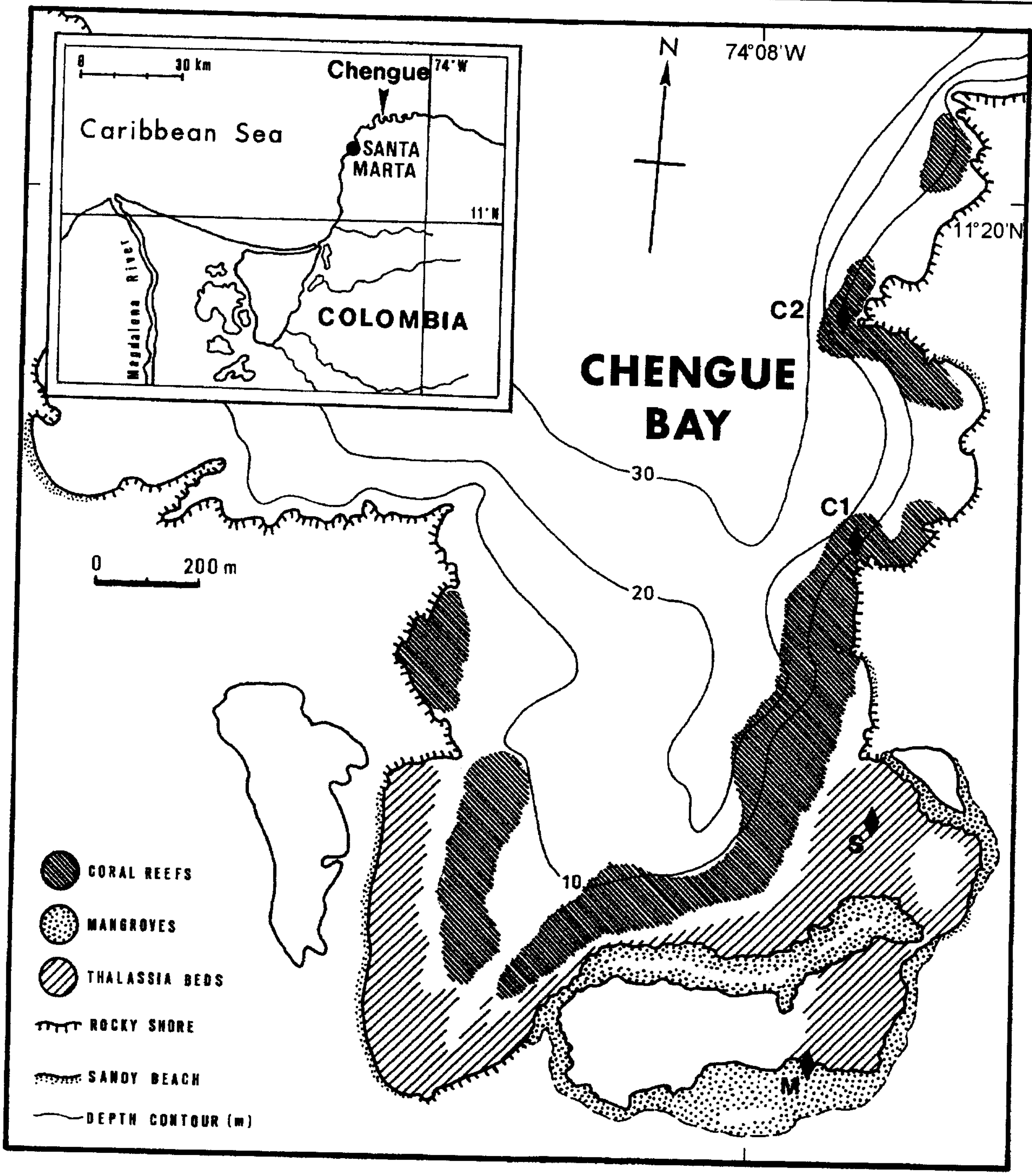

Fig. 1. Map of Bahía de Chengue, indicating bathymetry, distribution of principal coastal marine ecosystems, location of CARICOMP sampling sites (black diamonds): mangrove wetlands (M), seagrass beds (S), and coral reefs (C1 and C2). Coral reef physical measurements were taken at site C1. Inset map includes a section of the Caribbean coast of Colombia, showing the locations of Bahía de Chengue, Santa Marta, and the mouth of the Magdalena River.

The submarine topography and distribution of the major shallow marine ecosystems of Bahía de Chengue are shown in Fig. 1. Most of the bottom is sandy and deeper than 10 m. Coastal lagoons, mangroves, seagrass beds, and coral reefs have developed at the eastern and southern shores of the bay,

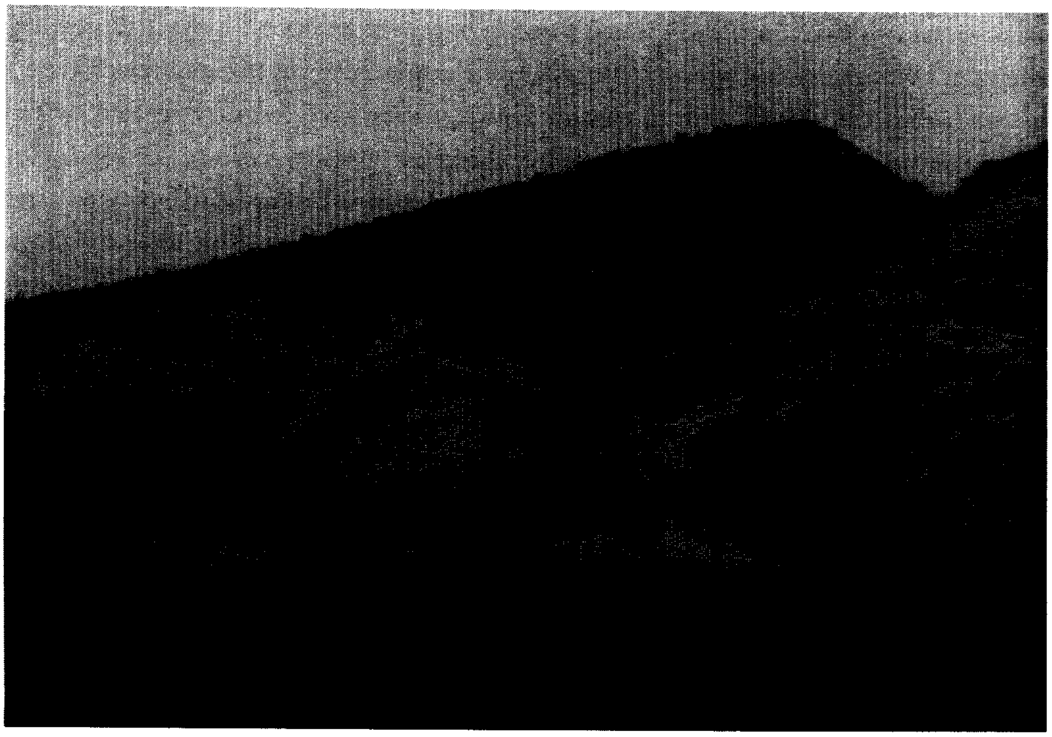

Photo 1. Northwestern shore of Bahía de Chengue showing exposed metamorphic rocks and strong wave action.

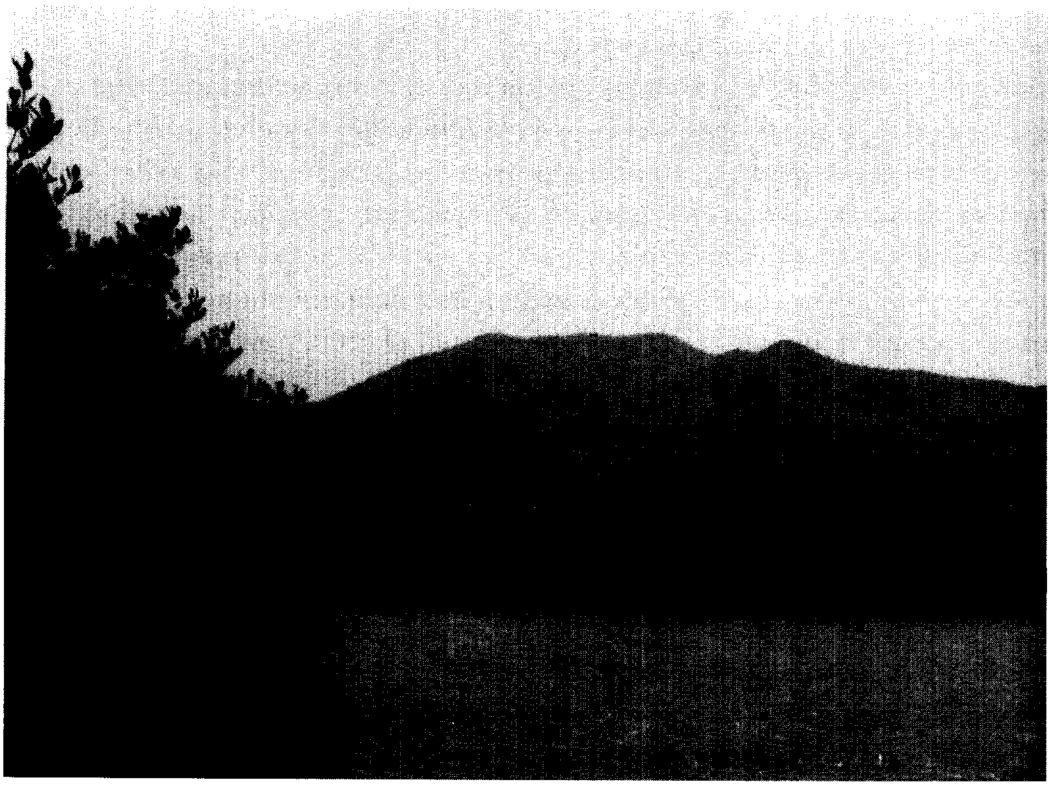

Photo 2. Fringes of *Rhizophora mangle* (red mangrove) in the southern lagoon of Bahía de Chengue.

where trade wind-induced wave action from the northeast is low, while rocky bottoms are the dominant ecosystem near shore in high wave energy zones, as in the NW shore of the bay. A detailed description of the sediments, hydrography, and biotic communities of the southern lagoon was provided by Alvarez-León *et al.* (1995). Due to coastal heterogeneity and the occurrence of wide gradients of exposure to prevailing waves from the northeast, there are extensive benthic communities and species. Therefore, marine biodiversity in Chengue is high, as suggested by the results of Velásquez (1987) who found 500 mollusk species when surveying less than 3 km^2 of the bay. The work by Brattstrom (1980) may also be indicative of high marine biodiversity in the area of Santa Marta. He described nine stations in the rocky littoral zone (to 1 m depth) and reported at least 246 species (67 of algae and 179 of benthic invertebrates). Acero and Garzón (1987) recorded 372 species of reef fishes in the Santa Marta area.

A single family of eight persons (five adults and three children) constitutes the permanent human population of Chengue, accompanied by six cows, one pig, two dogs, and two geese. This family subsists mainly on salt mining from the western lagoon, but also on fishing in the bay. Although they use wood for cooking, no major modification of the terrestrial vegetation cover around the bay is evident. At the end of March each year, an additional group of ten persons arrives at Chengue to work the salt mines for one and one-half months. Fishermen from nearby areas regularly work in Bahía de Chengue; unfortunately, they sometimes use dynamite. Each night, the lights of approximately six hook-and-line fishing boats are visible near the reefs. In daylight hours, the fishermen sometimes use gill nets or beach seines across the seagrasses and in the southern lagoon. Commercial reef fish populations are clearly overfished; thus, only small groupers, snappers, or grunts are observed. As no road has been opened to the bay, tourist visits are infrequent.

Locations of the CARICOMP sampling stations in Bahía de Chengue are shown in Fig. 1. Physical measurements of the coral reef environment are being made 50 m to the west of site C1, and a Hobo data logger for permanent temperature recording was placed at a depth of 9 m (under a coral head) in this site. Two additional Hobos have been installed: one at a depth of 1.5 m in the seagrass bed site, and one buried 10 cm below the sediment surface (exposed at low tide) at the mangrove site (20 m behind the outer margin of the *Rhizophora* fringe). Sampling procedures for physical weekly measurements at seagrass and mangrove stations are as described in the CARICOMP methods manual. Daily site measurements are made at the Instituto de Investigaciones Marinas (INVEMAR), which is located 30 m above sea level on a coastal rocky cliff at Punta de Betín, Santa Marta.

Climate and Oceanography

There exist no meteorological data from Chengue, but climatological data are available from Santa Marta (Salzwedel and Muller, 1983) (Table 1). Personal observations during 13 years in the area indicate that the general climate as well as oceanographic conditions are similar at both locations, being strongly dominated by the trade winds that blow from the northeast (known locally as "brisa"). There is a dry season from December to April, when the trade winds are strong (mean wind velocity 3.5 m s^{-1}, maximum up to >30 m s^{-1}) and precipitation is low (<20% of the annual total). The rest of the year (May-November) is known as the rainy season, characterized by lower trade wind incidence (mean wind velocity 1.5 m s^{-1}) and higher precipitation (52% of total annual rainfall during September-November). There usually is an intermediate, weak dry season during June and July. If the wind does not blow from the northeast, calm conditions prevail. A strong southwest wind, the "vendaval," occurs occasionally, principally during the rainy season. Seasonally, air temperature varies insignificantly (Table 1). The annual mean is 28°C. Between 1976 and 1981, the mean annual precipitation was 347 mm; the range was 169 to 676 mm. The total number of sunshine hours per year has been estimated at 2,900 (Salzwedel and Muller, 1983). Total precipitation in 1993 was 318 mm at Punta de Betín, Santa Marta, of which more than 50% fell in May (Fig. 2).

Table 1. Summary of meteorological and hydrological conditions in Santa Marta, Colombia.

	Dry Season (Dec-Apr)		Rainy Season (May-Nov)	
	Range	Mean	Range	Mean
Air temperature (°C)	27.6 – 28.1	27.9	26.7 – 28.5	27.7
Wind direction NE (%)	72 – 93	85	62 – 87	70
Calm (%)	6 – 25	14	12 – 37	27
Mean wind velocity (m s^{-1})	2.1 – 5.1	3.5	0.8 – 2.9	1.5
Max wind velocity (m s^{-1})	12 – 22	16.7	6 – 18	9.9
Sunshine (hr d^{-1})	7.1 – 9.7	8.8	5.8 – 8.8	7.6
Precipitation (mm)	9 – 174	64	121 – 523	283
Number of rainy days	1 – 6	3.0	16 – 40	27.5
Water temperature (°C)	24.8 – 26.4	25.5	27.4 – 28.6	28.0
Salinity (‰)	36.1 – 37.4	36.7	25.1 – 36.4	35.7
Oxygen content (ppm)	4.4 –4.6	4.5	4.4 – 4.8	4.6
Oxygen saturation (%)	94 – 101	97	99 – 109	103
pH	8.15 – 8.26	8.20	8.18 – 8.33	8.25

Mean values and their respective ranges given for each season are calculated from monthly means — except for precipitation, which result from sums; compiled from several sources and years (between 1966 and 1983) by Salzwedel and Muller (1983).

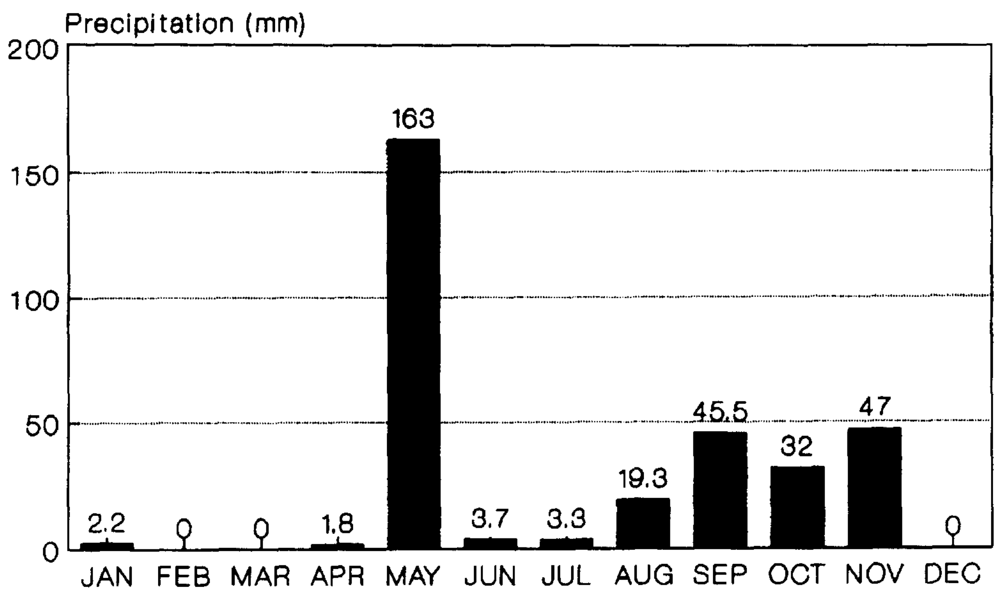

Fig. 2. Monthly precipitation at Punta de Betín, Santa Marta, during 1993.

Coastal oceanographic conditions also show some seasonal variation. During the dry season, upwelling occurs nearshore due to currents transporting waters from depths of 100-200 m to the surface (Bula-Meyer, 1977; Ramírez, 1983). As a result, typical water temperatures are considerably lower and salinity higher from December to April (Table 1; Fig. 3). Also, a slight increase in dissolved inorganic nutrients in surface waters during the dry season has been reported. Ramírez (1990) recorded nitrate concentrations four times greater for December-April in two bays in the Santa Marta area. At Bahía de Chengue, surface water temperature and salinity were measured weekly at three CARICOMP stations (Fig. 3) during 1993. Except for December, mean monthly temperature was highest at the inner station (mangrove lagoon), intermediate at the seagrass station, and lowest at the outer station (coral reef), ranging from 25.5°C in January to 28.8°C in May at the coral reef (annual mean 27.2°C). With respect to salinity, the highest values were found in the lagoon during all months except May (which was the rainiest month in 1993; Fig. 2) when salinity dropped to a minimum and was almost identical at the three stations (33.3-34.0‰). Solano (1987) recorded colder waters in Chengue during the dry season of 1985 when the mean monthly temperature reached a minimum of 24.1°C in March, and also lower salinity (31.4‰ in November).

Water transparency was measured weekly at Chengue as part of CARICOMP sampling during 1993. A Secchi disk (30 cm in diameter, 50% black and 50% white on the upper surface) was used, vertically at the coral reef and horizontally above the seagrass bed. Disk visibility distance (at which the disk no longer can be seen) varied irregularly, indicating low values in both seasons (Fig. 3). Monthly means ranged from less than 8 m in January and May to more than 15 m in March and October at the coral reef, and from less than 4 m in January and May to more than 7 m in September at the seagrass site.

Turbidity, which is notably higher in the southeastern part of the bay, increases because of local drainage from the southwest during the rainy season, resuspension of sediments due to wind-induced wave action during the dry season, and daily tidal currents from the southern lagoon. Sedimentation rates have been estimated from six traps (PVC tubes 25 cm long, 5 cm in diameter) placed for two-month periods at depths of 9-11 m, 0.5 m above the coral surface at the reef site. Mean rates, obtained in 1994/1995 from dried sediments smaller than 1 mm, varied between 0.53 and 1.55 mg cm^{-2} d^{-1}. The highest values were obtained in January and February of each year when trade winds were strong. Solano (1987) reported much higher sedimentation rates at the same site during August-October 1985: 5.09-33.3 (mean 14.4) mg cm^{-2} d^{-1}. These large differences could be due to different sampling methodologies, as Solano (1987) used small vials (9.2 cm long, 2.2 cm in diameter) as traps fixed on sandy substrates for 7-14 days.

The local tide is mixed, mainly diurnal with a form number of 1.7 and a mean range of 17 cm (Kjerfve, 1981). The entire variation between high and low tidal levels during an entire year was only 25 cm (Brattstrom, 1980).

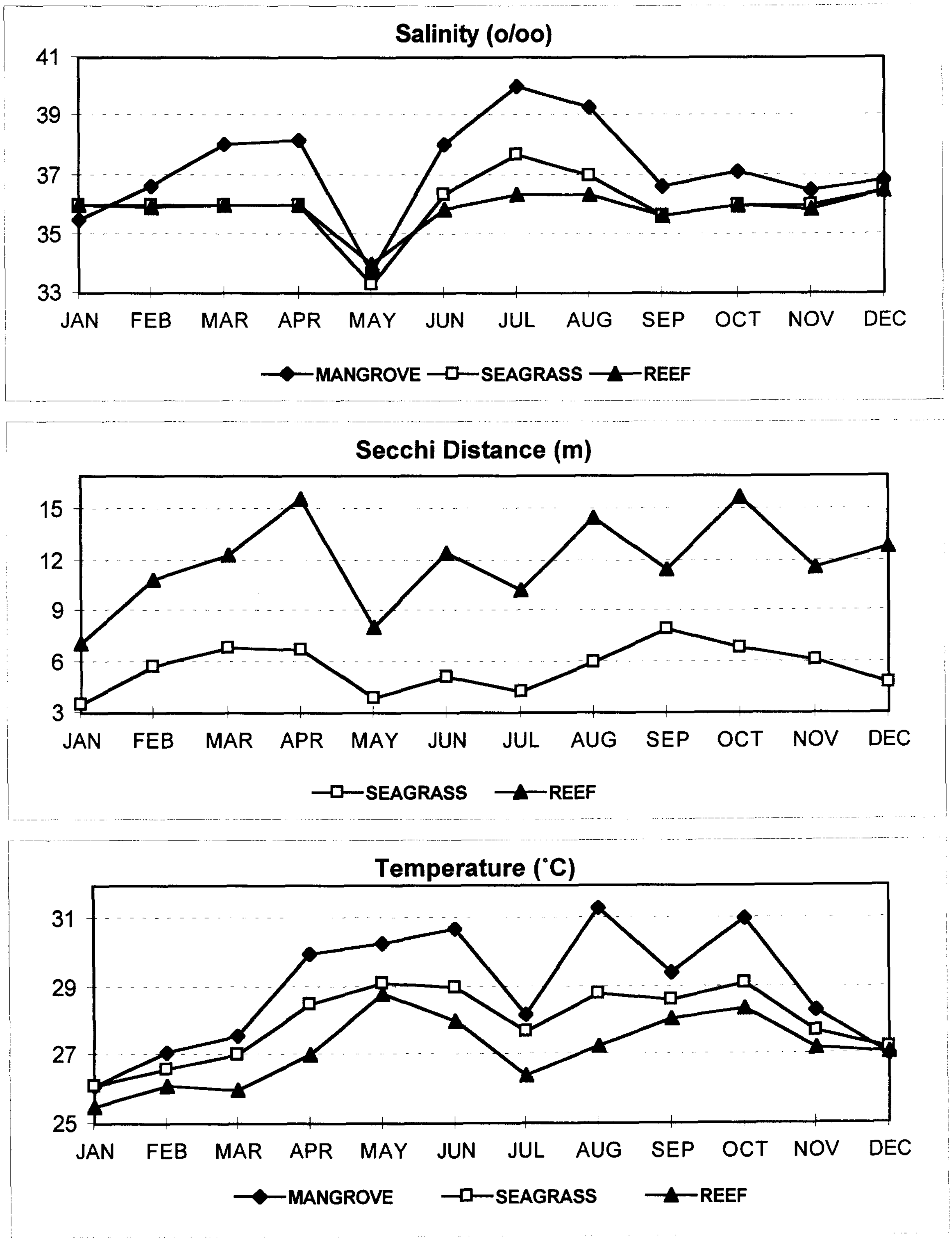

Fig. 3. Mean monthly surface salinity and temperature, and Secchi disk visibility at CARICOMP habitat sites (mangrove wetland, seagrass bed, and coral reef) in Bahía de Chengue during 1993.

Mangroves

Garzón-Ferreira and Cano (1991) mapped the shoreline red mangrove (*Rhizophora mangle*) fringes of Bahía de Chengue (Fig. 1). They found three additional mangrove species in nearby less swampy terrain: *Avicennia germinans, Conocarpus erectus,* and *Laguncularia racemosa.* Of these, *A. germinans* is the only tree that forms monospecific stands of considerable size landward of the *Rhizophora* fringes. The red mangroves are twisted and form a dense, intricate but narrow forest. CARICOMP plots for monitoring mangrove structure and function were established along the southeastern shore of the southern lagoon, where *Rhizophora* stands appear to be most luxuriant. Data obtained from these plots in 1995, according to CARICOMP protocols, show *Rhizophora* trees reaching heights of 13 m (mean 7.2), with trunk diameters of 30 cm (mean 11.5), basal areas of 47.4 m^2 ha^{-1} (mean 42.8), and densities of 3,800 trees ha^{-1} (mean 3,467). Interstitial water salinity at the plots fluctuated between 36.4 and 49.2‰ (mean 42.8). Reyes (1991) described the root epifaunal community of the red mangrove (*Rhizophora mangle*) in Chengue, reporting 119 species from the southern lagoon and 140 species from the seaside fringe of the southern shore of the bay.

Seagrass Beds

Five species of seagrasses occur in Bahía de Chengue (Garzón-Ferreira and Cano, 1991). *Thalassia testudinum* beds are most extensive but are restricted to the shallow (less than 3 m deep) and quiet waters of the southern portion of the bay (Fig. 1). Within these beds there exist monospecific patches of *Syringodium filiforme* and, less frequently, *Halodule wrightii* and *Halophila baillonis,* although the latter species may also appear mixed with *Thalassia.* Plants of all four species grow sparsely to a depth of 5 m in sediment patches of the adjacent coral fringes. In deeper waters of the eastern bay, there are also wide stands of *Halophila decipiens,* which grow more densely below a depth of 15 m.

Thalassia beds grow over calcareous sediments, mainly coarse sands. Coral rubble and small colonies of live sponges and corals of the genera *Manicina, Siderastrea, Millepora, Diploria, Porites,* and *Cladocora* are common in these beds, as are the sea urchins *Tripneustes ventricosus* and *Lytechinus variegatus.* The calcareous algae *Halimeda opuntia* is abundant and, in many places, is the dominant live component covering the bottom of *Thalassia* beds (Garzón-Ferreira and Cano, 1991). The shrimp community associated with the seagrass beds was studied by Puentes (1990), who found 26 species and registered maximum values of leaf *Thalassia* density and biomass in March and minimum values in November (1140-3140 leaves/m^{-2}, 48.8-221.2 g dry weight/m^{-2}). CARICOMP biomass and productivity measurements of *Thalassia* were done in March 1994. Estimates of total biomass (including below ground material) fluctuated between 631 and 1831 (mean 1101) g dry weight/m^{-2}, green leaves representing less than 10% in average. Areal productivity was estimated at 1.71-5.36 (mean 3.64) g m^{-2} d^{-1} dry weight, with a turnover rate of 2.69-7.95% (mean 4.01) per day.

Coral Reefs

Werding and Sánchez (1989) reviewed the information on corals in the Santa Marta area, indicating that reef development is impaired by continental run-off, lack of adequate substrate for reef settlement, and low water temperatures due to the local upwelling, although coral communities are diversely structured and rich in species. These investigators described eight types of coral communities in the bays of Parque Natural Tayrona, and discussed specific species composition and form of colonies. The most outstanding factor in determinating variation in community structure is degree of exposure to the predominant wave impact along the shore of the bay. Coral communities from Chengue have been described by Werding and Erhardt (1976), Solano (1987), and Garzón-Ferreira and Cano (1991).

Thirty-one species of hermatypic corals plus three hydrocorals of the genus *Millepora* are known in Bahía de Chengue. Although corals are present along the coastal rocky belt of the bay, only in areas protected from direct northeasterly ocean wave action have they grown sufficiently to modify the bottom morphology as true coral reefs (Fig. 1). Two main types of coral reefs are identified in Chengue: narrow, short coastal fringes growing over the belt of metamorphic rocks in the northern deep half of the bay, and extensive fringes growing away from shore on sedimentary flats of the bay. Although some *Acropora palmata* can be found in shallow water, the coastal fringes are dominated by massive and encrusting corals (mainly *Diploria, Montastraea,* and *Colpophyllia*), which form a reef slope extending to a depth of 15-25 m, <70 m from shore. In contrast, the inner fringes of the bay have extensive shallow reef flats, dominated by foliaceous and branching corals, which become reef slopes covered with massive corals at depths of 6-8 m. The southeastern inner fringe at depths between 3 and 6 m is dominated by large and dense *Agaricia tenuifolia* stands, with wide patches of *Madracis mirabilis* on the upper reef slope (6-10 m). The western inner fringe is more exposed to wave action and has a shallow zone dominated by *Acropora palmata* (1-4 m), with abundant *Millepora squarrosa* and *Palythoa caribbea* on the upper reef crest. As in many other areas of the Caribbean, shallow water coral formations in Chengue Bay have suffered considerable mortality among branching (*A. palmata, A. cervicornis, Porites porites*) and foliose corals (*A. tenuifolia*) over the last decade (Garzón-Ferreira and Cano, 1991).

CARICOMP coral reef stations in Chengue are located at depths between 9 and 12 m at two coastal sites separated by 400 m (Fig. 1). Due to the short horizontal extent of the coral communities, the CARICOMP random method for location of transects could not be applied in Chengue. Transects were placed arbitrarily following depth contours, trying to maintain the same community type. The coral community at the northern site (C2) is exposed to swells, which can reach considerable heights on days of strong trade winds; as a result, branching or foliaceous corals are almost absent. The dominant forms are small to medium-sized coral heads, and live coral cover is high (mean 42% at five CARICOMP transects in 1993). Site C1 is rarely disturbed by waves and *Acropora palmata* is abundant in shallow water. The coral community at depths of 9-12 m is dominated by medium-sized coral heads, but it also includes some delicate species — *e.g., Leptoseris cucullata* and *Agaricia tenuifolia;* live coral cover is lower (mean 26% at five CARICOMP transects in 1993). At present, algae are the most important component covering the reef surface at both sites.

Acknowledgements

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References

Acero, A., J. Garzón. 1987. Peces arrecifales de la región de Santa Marta (Caribe colombiano). I. Lista de especies y comentarios generales. *Acta Biológica Colombiana,* **1**(3):83-105.

Alvarez-León, R., G. Ramírez-Triana, E. Wedler. 1995. Registro de las condiciones ambientales de la Laguna Sur (Bahía de Chengue, Caribe colombiano) entre 1981-1984. *Revista de la Academia Colombiana de Ciencias Exactas, Físicas y Naturales,* **19**(74): 509-525.

Brattstrom, H. 1980. Rocky-shore zonation in the Santa Marta area, Colombia. *Sarsia,* **65**(3-4):163-226.

Bula-Meyer, G. 1977. Algas marinas bénticas indicadoras de un área afectada por aguas de surgencia frente a la costa Caribe de Colombia. *Anales del Instituto de Investigaciones Marinas de Punta de Betín,* **9**:45-71.

Doolan, B. L., W. D. MacDonald. 1976. Structure and metamorphism of schists of the Santa Marta area, Colombia. **In:** *Memorias Primer Congreso Colombiano de Geología (Aug. 4-8, 1969),* pp 187-205. Universidad Nacional, Bogotá, Colombia.

Garzón-Ferreira, J., M. Cano. 1991. Tipos, Distribución, Extensión y Estado de Conservación de los Ecosistemas Marinos Costeros del Parque Nacional Natural Tayrona. Final Report, INVEMAR, Santa Marta, Colombia, 82 pp.

Kjerfve, B. 1981. Tides of the Caribbean Sea. *Journal of Geophysical Research,* **86**(C5):4243-4247.

Puentes, L. G. 1990. *Estructura y Composición de las poblaciones de Camarones (Crustacea: Decapoda: Natantia) Asociadas a Praderas de Thalassia testudinum en la Región de Santa Marta, Caribe Colombiano.* M.Sc. Biología Marina Thesis, Universidad Nacional, Bogotá, Colombia, 146 pp.

Ramírez, G. 1983. Características físico-químicas de la Bahía de Santa Marta (agosto 1980-julio 1981). *Anales del Instituto de Investigaciones Marinas de Punta de Betín,* **13**:111-121.

Ramírez, G. 1990. Distribución de nutrientes inorgánicos en las aguas costeras de la región de Santa Marta, Caribe colombiano. **In:** *Memorias VII Seminario Nacional de Ciencias y Tecnologías del Mar,* pp 244-254. CCO, Bogotá, Colombia.

Reyes, R. 1991. *Macroinvertebrados Asociados a las Raíces de Rhizophora mangle Linnaeus, 1753 (Mangle Rojo), en la Ciénaga Grande de Santa Marta y en las Bahías de Chengue y Nenguange, Caribe Colombiano.* M.Sc. Thesis Biología Marina, Universidad Nacional, Bogotá, 95 pp.

Salzwedel, H., K. Muller. 1983. A summary of meteorological and hydrological data from the Bay of Santa Marta, Colombian Caribbean. *Anales del Instituto de Investigaciones Marinas de Punta de Betín,* **13**:67-83.

Solano, O. D. 1987. *Estructura y Diversidad de la Comunidad de Corales Hermatípicos en la Bahía de Chengue.* M.Sc. Biología Marina Thesis, Universidad Nacional, Bogotá, 111 pp.

Velásquez, L. E. 1987. *Inventario, Distribución y Abundancia de los Moluscos (Bivalvia y Gastropoda) de la Bahía de Chengue (Parque Nacional Natural Tayrona, Colombia).* M.Sc. Thesis Biología Marina, Universidad Nacional, Bogotá, Colombia, 259 pp.

Werding, B., H. Erhardt. 1976. Los corales (Anthozoa y Hydrozoa) de la Bahía de Chengue en el Parque Nacional Tayrona (Colombia). *Mitteilungen aus dem Instituto Colombo-Alemán de Investigaciones Científicas Punta de Betín,* **8**:45-57.

Werding, B., H. Sánchez. 1989. The coral formations and their distributional pattern along a wave exposure gradient in the area of Santa Marta, Colombia. *Medio Ambiente,* **10**(2):61-68.

Curaçao, Netherlands Antilles[1]

Leendert P. J. J. Pors and Ivan A. Nagelkerken
Carmabi Foundation
Piscaderabaai z/n
PO Box 2090
Curaçao, Netherlands Antilles

Curaçao, an island of the Lesser Antilles has a surface area of 443 km^2 and a population of approximately 150,000. The island is completely surrounded by fringing reefs. Seagrass and mangrove communities are found in several drowned coastal valleys; the CARICOMP seagrass and mangrove monitoring sites are situated in two of these inner bays: Spaanse Water and St. Jorisbaai, respectively. Spaanse Water still contains well developed seagrass, algal, and mangrove areas, despite the threat posed by a high level of coastal development. Mean *Thalassia* biomass ranges from 193 g m^{-2} to 504 g m^{-2}. The mean areal productivity of *Thalassia* ranges from 0.14 g m^{-2} d^{-1} to 1.2 g m^{-2} d^{-1}. The mangrove plots are located along the western shore of St. Jorisbaai. This bay is in pristine condition. The maximum tree density per 100 m^2 plot is 51, with dbh > 2.5 cm. The maximum biomass is 12.7 kg m^{-1}. The CARICOMP reef site is located just west of the entrance to Spaanse Water. The total number of hermatypic corals found at this site is 28, and maximum hard coral cover is 36%.

Introduction

Curaçao, an island of the Lesser Antilles, lies between latitudes 12°2'80" to 12°23'30"N and longitudes 69°10'00" to 68°44'30"W. The island is 61 km long and 14 km wide at its widest point. The surface area measures 443 km^2 (Fig. 1). The island is of volcanic origin and was formed 88 million years ago during the formational phase of the evolution of the Caribbean Plate (Sinton *et al.*, 1993). During later phases, sedimentary rocks were deposited in certain areas (Beets, 1972). During the Quartenary, ice-age controlled coral reef development dominated. Limestone terraces resulted; they are especially well developed along the north coast (De Buisonjé, 1974). Reef development, in the form of fringing reefs around the island, continues. Several inner bays were formed as a result of a sea level rise after the last glacial period 16,000 years ago. It is in these drowned erosional valleys that seagrass beds and most of the mangrove stands are found nowadays.

[1] *CARICOMP — Caribbean Coral Reef, Seagrass and Mangrove Sites* (edited by B. Kjerfve), pp 127-139. UNESCO, Paris, 1998, 347 pp.

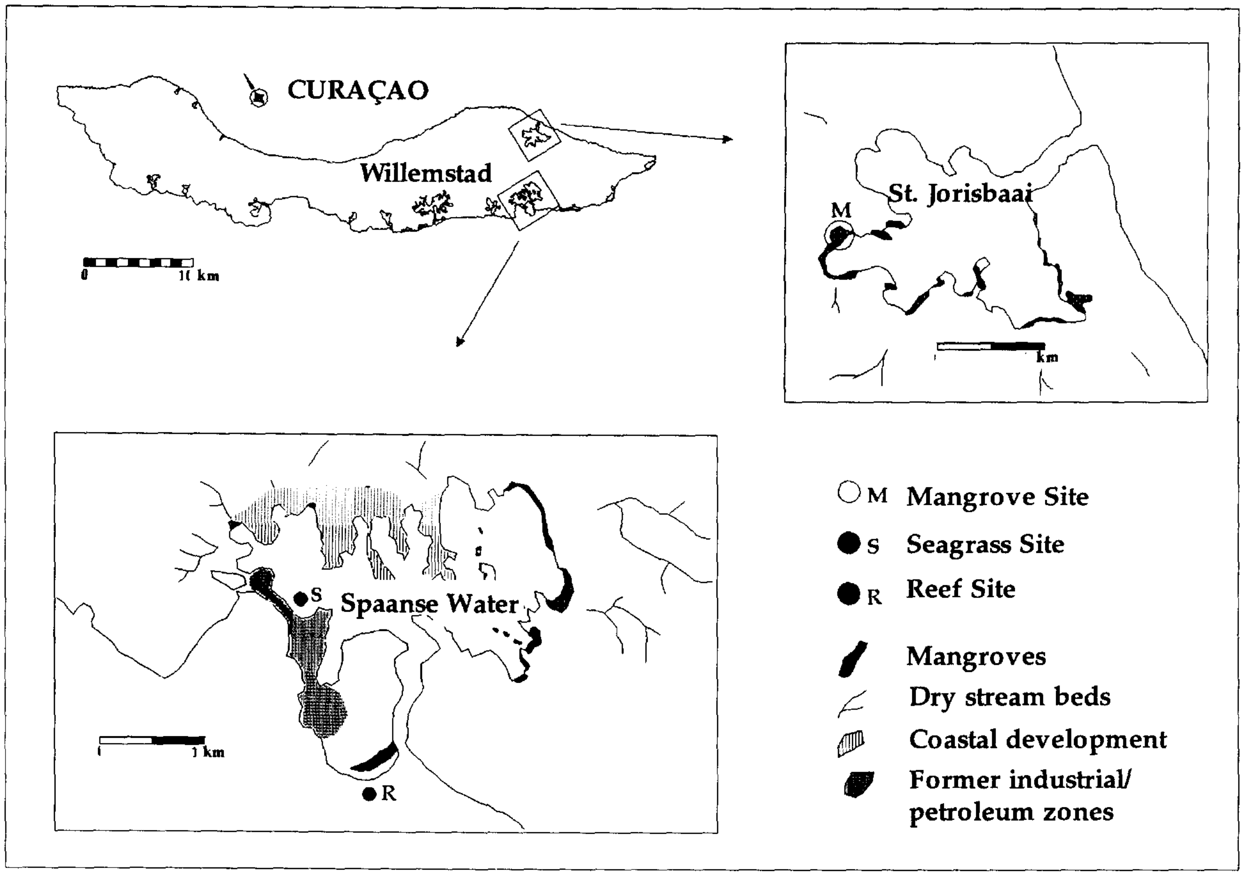

Fig. 1. Location map of Curaçao, Netherlands Antilles, showing CARICOMP sites.

Due to relatively low rainfall (average 570 mm/year) and high evaporation, the climate of the island is classified as semi-arid. Vegetation consists of drought-resistant cacti and thorn scrub.

The population of Curaçao is ~150,000 and is centered around the capital city, Willemstad, which surrounds a natural harbor, the Schottegat inner bay. Although the population has decreased somewhat over the last few years due to increased emigration, pressure on the natural environment has increased dramatically. Massive coastal development, which is linked to tourism, is an increasing threat to marine ecosystems; increased sewage discharge and sedimentation due to deforestation are considered the biggest problems.

The Curaçao Underwater Park was established in 1983, covering 20 km of south-coast reefs, starting at the eastern tip and extending to the west. Some of the best developed reefs are located within the park, which is managed by the Carmabi Foundation (Carmabi: Caribbean Research and Management of Biodiversity). The park includes Spaanse Water, one of the CARICOMP locations.

Two separate areas were selected for CARICOMP monitoring (Fig. 1). Mangrove monitoring takes place in St. Jorisbaai, an inner bay located on the northeastern coast, which has a maximum depth of 5 m and is more or less unspoiled because of the lack of nearby population centers and the absence of coastal development. Heavy grazing by goats of surrounding areas over the past 200 years, however, has resulted in increased erosion and consequently increased sedimentation. The water in the bay is now always somewhat turbid. Chemical data indicate higher levels of heavy metals within the bottom sediments, as compared to pristine areas (Table 1). The source of the heavy metals is unknown. Fringing mangroves are found along the shore, consisting mainly of *Rhizophora mangle*. Some *Thalassia testudinum* meadows occur in shallow water areas.

The CARICOMP seagrass site is located in the southwestern part of Spaanse Water, and the reef site is situated just west of the entrance to this inner bay. Spaanse Water is the second largest inner bay, with an area of 3.19 km^2 and a mean depth of 5 m. The bay contains the largest seagrass, algal, and mangrove areas of the Curaçao Underwater Park, and it has been identified as a priority area for conservation (Debrot and de Freitas, 1991). However, all ecosystems within Spaanse Water are threatened by increasing urbanization and tourism development. The entire northern coastline of the bay has been developed, and untreated waste is discharged into the bay. The southern section, known as the Caracas Baai Peninsula, used to be a Shell petroleum storage and transshipment facility, and soils are heavily contaminated with petroleum (Fig. 1). A relatively high level of watersports activity takes place in the bay, as well as yacht anchoring. A survey carried out on 11 May 1992 resulted in the following minimum usage numbers for an area within approximately 75 m of the waterline: 188 houses, 57 other buildings larger than 25 m^2, 522 small boats without a cabin, 199 small boats with a cabin, 115 motor yachts, and 159 sailing yachts, for a total of 995 boats. Well developed fringing mangroves occur along the eastern and northeastern coastline, but these are threatened by major tourism development planned for the area.

Table 1. Average chemical concentrations January-June 1988 (Djohani and Klok, 1988).

	East Spaanse Water	Northwest Spaanse Water	Middle St. Jorisbaai	South St. Jorisbaai	Seawater
Silicate ($\mu mol\ l^{-1}$)	3.24	2.59	3.67	2.32	1.16
Nitrite ($\mu /mol\ l^{-1}$)	0.02	0.02	0.03	0.03	0.02
Nitrate ($\mu mol\ l^{-1}$)	0.91	0.56	4.65	1.64	0.37
Phosphate ($\mu mol\ l^{-1}$)	0.93	0.87	0.85	1.14	0.76
Copper ($\mu g\ g^{-1}$)*	4.0	21.0	37.0	28.0	
Lead ($\mu g\ g^{-1}$)*	1.8	6.7	4.9	13.8	
Zinc ($\mu g\ g^{-1}$)*	14.3	30.0	39.2	57.0	
Cadmium ($\mu g\ g^{-1}$)*	0.04	0.07	0.08		

* Copper, lead, zinc, and cadmium levels measured in the upper 2 cm of bottom sediments.

Climate and Oceanography

Curaçao is located within an area of low rainfall that extends along the north coast of South America between the Orinoco and Magdalena Rivers. According to the Meterological Service (1990), the average annual rainfall for 1905-1980 was 570 mm. The dry season is March-May, the rainy season is November-December. The mean annual rainfall generally shows some variability between years.

Based on hourly measurements from 1947 through 1980, the mean annual air temperature is 27.5°C, with mean daily variations ranging from a nocturnal minimum of about 26°C to a midday peak of about 30°C. Temperature varies seasonally: January is generally the coolest month, September the hottest. The mean daily relative humidity is 77% (yearly 24-hour mean for the period 1962-1977) and varies slightly in connection with the seasonal rain pattern. Relative humidity is somewhat higher at night than during the day. The mean amount of evaporation is 8.4 mm per day (yearly mean, based on measurements gathered on Bonaire since 1968), which is high compared to the amount of rain the island receives.

Steady trade winds influence sea conditions around the island. The wind direction is primarily (95%) from the east and east-northeast. Mean wind speed is 7.1 m s^{-1} (yearly mean for the period 1964-1980). The maximum wind speed is 8 m s^{-1} and occurs in June, decreasing to a minimum of 6 m s^{-1} in November.

Curaçao is located south of the Atlantic hurricane belt, but tropical storms pass within 200 km of the island every 4-5 years. Thirty tropical cyclones have been reported for 1876-1996, the most recent include Edith (1971, intensity 31 m s^{-1}), Irene (1971, 16 m s^{-1}), Cora (1978, 16 m s^{-1}), Greta (1978, 20 m s^{-1}), Joan (1988, 22 m s^{-1}), Brett (1993, 34 m s^{-1}), and Cesar (1996, 27 m s^{-1}).

Wave action is high along the northeastern coast due to the easterly trade winds; the southern coast is more sheltered. Waves are highest along the southeastern tip of the island and decrease westward. At the CARICOMP reef site, wave heights of 1.5 m are common (Van Duyl, 1985). The ocean current generally flows towards the northwest, with a speed below 0.5 m s^{-1}. However, strong currents and occasionally strong countercurrents and eddies may develop near promontories along the coastline. The mean tidal range is 30 cm, with a maximum of 53 cm and a minimum of 7 cm. The mean range for January-April is consistently lower than the average annual range, whereas the mean range for May-August is higher. As measured in Annabaai Harbor (Schottegat), the tides exhibit a periodic change from diurnal to semidiurnal tides over a 13.7 day period and can be characterized as mixed mainly diurnal (De Haan and Zaneveld, 1959).

Spaanse Water is connected to the sea by a 70 m wide, up to 19 m deep, channel. Water movement in the deeper parts of the bay (up to 12 m in the central portion of the bay) is impeded by a coralline sill at a depth of 6 m at the entrance to the bay. Deeper areas of the bay form a sediment sink, typically with warmer water temperatures and increased turbidity. Annual ranges in physical parameters as given by De Kock and de Wilde (1964) and Djohani and Klok (1988) are: temperatures 26-29°C; salinity 34-39‰; and Secchi-disk depth in the central area of the bay 2.1-2.8 m. The bay straddles two principal geological formations. The first is a fossil coralline limestone rock formation in the southwestern quadrant of the bay (location of the monitoring site), the second is altered basaltic rock which dominates in the remainder of the bay (Beets, 1972). Because of its varied geology and contrasts between wind-exposed and wind-sheltered areas, a significant range of turbidities and bottom characteristics are found within Spaanse Water.

Kuenen and Debrot (1995) distinguished four principal sediment types for Spaanse Water, based on grain size dominance. Sediments with dominant coarse grain fractions are most common at shallow depths and on exposed shores (such as at the monitoring site). Fine grained sediment are found predominantly in the deeper parts of the channel and central portions of the bay and in sheltered mangrove areas. However, most of the latter sites lie in the eastern basin. Kuenen and Debrot (1995) also measured sedimentation rates and turbidity in Spaanse water and found that the southwestern quadrant has lower sedimentation rates and turbidities. Sedimentation rates averaged 25.5 ± 14.9 g m^{-2} d^{-1} for the bay as a whole; the lowest rates were in the western part of the bay (average: 15.1 ± 9.7 g m^{-2} d^{-1}), the highest rates (average: 31.3 ± 22.0 g m^{-2} d^{-1}) were in the eastern part. Water column turbidities also differ significantly. Lowest turbidities (light extinction coefficients from 0.332 to 0.421) are from the channel, central basin, and western basin, while highest turbidities are from the eastern basin. By comparison, the average turbidity for Curaçao reef waters as measured by Bosscher (1992) are 0.115 m^{-1}. Kuenen and Debrot (1995) ascribe the reduced turbidity of the western basin to the domination of fossil coralline limestones, which limit terrigenous sediment input, and to a combination of wind exposure and tidal flushing. Detailed information on turbidity, salinity, and temperature for St. Jorisbaai is lacking. As estimated by Frank and Bouma (1990), the turbidity is 2 to 3 on a 1 (clear) to 5 (very turbid) scale.

Mangroves

The mangroves of Curaçao are restricted to a few isolated areas of well-developed intertidal fringe forests in drowned coastal valleys, and in small areas along the coast where a barrier protects the trees from wave action and erosion. Ongoing destruction of mangrove habitat has led to a dramatic decrease in coverage. Curaçao has 55 ha of mangroves remaining (0.12% of the surface area), of which a significant portion is threatened by coastal development (Debrot and de Freitas, 1991). This is less than half of the mangrove coverage of a century ago. Measurements of leaf size of *Rhizophora mangle*, from stands in the vicinity of Willemstad, indicated that these mangroves, in spite of the high level of eutrophication and pollution in that area, are in good health (Snedaker, 1988).

The St. Jorisbaai mangroves also appear to be in good shape. The forest selected for CARICOMP monitoring reaches a maximum width of 100 m and consists mainly of *Rhizophora mangle*. Some *Laguncularia racemosa* trees occur along the landward boundary. *Avicennia germinans*, as well as *Conocarpus erecta*, occur in neighboring areas. Within the selected area, five successive 100 m^2 quadrants have been set out perpendicular to the coast.

The tallest *R. mangle* tree in the plots reached a maximum length of 10.2 m and was found in the most landward plot (reference is made to total length, not total height, as a number of the trees in this area grow in a subhorizontal position). Figure 2 summarizes the amount of trees (dbh > 2.5 cm) per plot as well as biomass (kg m^{-2}), according to Golley *et al.* (1962). Dry weight of litter (leaves, fruits, flowers, wood) has been determined for July 1994-July 1995 (Fig. 3). The production of leaves tends to be somewhat higher during July-August. Fruit production is high in April-September and low in September-April, which mirrors the usual seasonal rain pattern for the island, although the 1994-1995 rain pattern was erratic (Fig. 4). During June 1994-August 1995, the salinity of interstitial water within the plots was measured monthly (Fig. 4), but although mean monthly rainfall for the island is known (Meteorological Service, 1996), there is no obvious relationship. Table 2 lists animal species found in mangrove habitats during the study period.

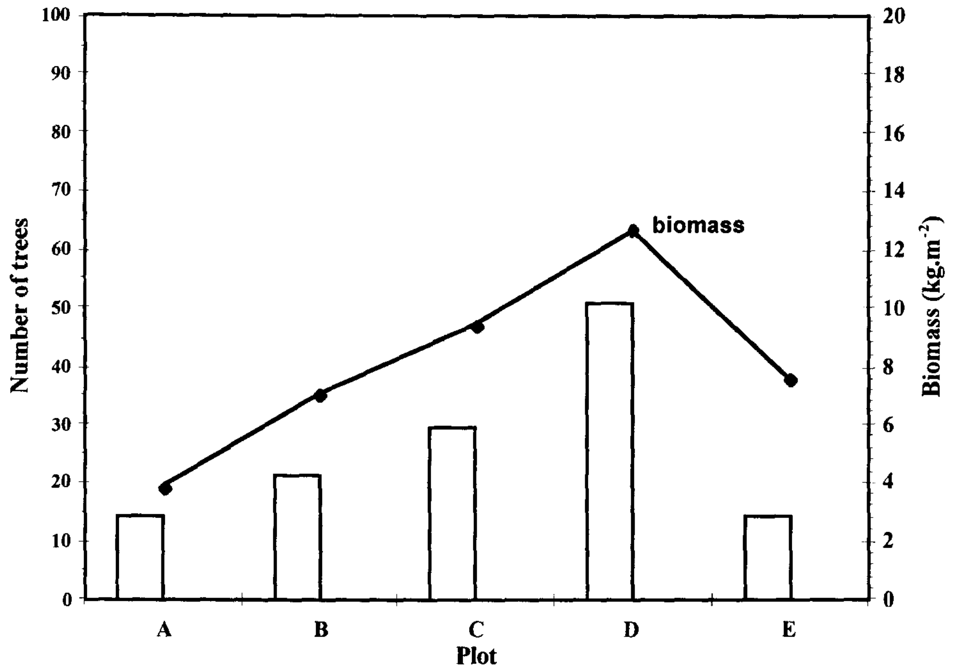

Fig. 2. Number of mangrove trees and biomass in five 100 m^2 quadrants, St. Jorisbaai.

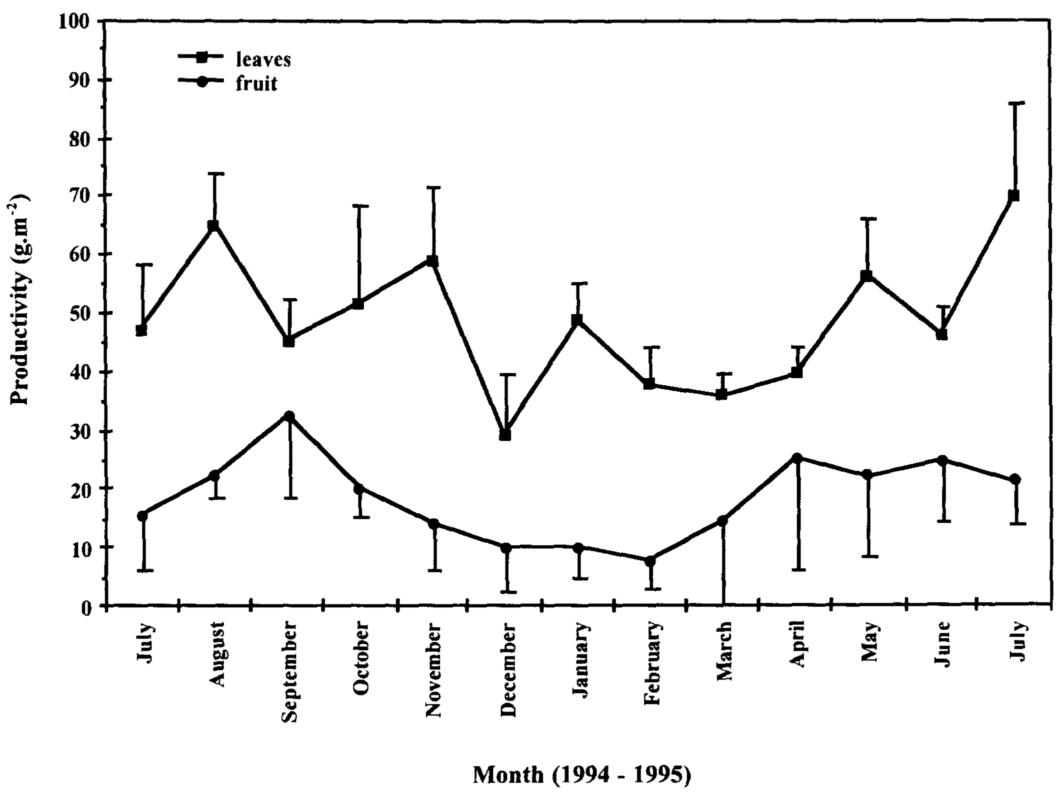

Fig. 3. Mean weight of leaves and fruit produced July 1994 through July 1995.

Table 2. Mangrove habitat species composition: 1994-1995.

Crustacea	Mollusca	Aves
Aratus pisonii	*Batillaria minima*	*Coereba flaveola*
Cardisoma guanhumi	*Brachidones* cf. *recurvus*	*Columba corensis*
Chthamalus stellatus	*Columbella mercatoria*	*Dendroica petechia*
Ucides cordatus	*Crassostrea rhizophorae*	*Tyrannus dominicensis*
Goniopsis cruentata	*Isognomon alatus*	
Sesarma curacaoense	*Littorina angulifera*	
Uca pugnax rapax	*Melampus coffeus*	

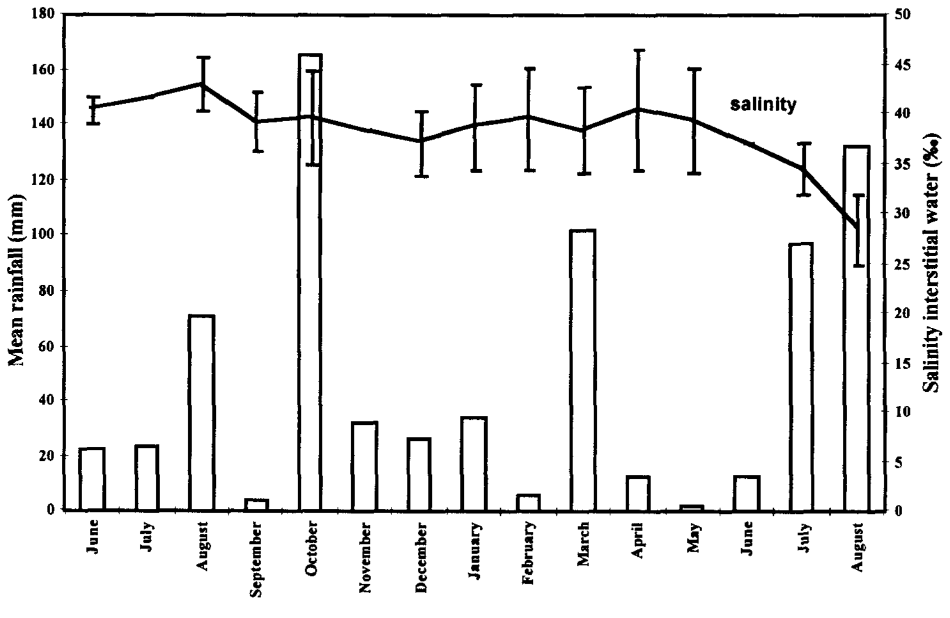

Fig. 4. Mean monthly rainfall and salinity of interstitial water in mangrove soils June 1994 through August 1995.

Seagrass and Algal Beds

Several studies have been done on the macrobenthos of Spaanse Water (Van der Horst, 1927; Roos, 1964, 1971; van den Hoek *et al.*, 1972; Bak, 1975; Fransen, 1986). Also, an assessment of the nursery function of the bay by Briones (1994) and a study of the seagrass and algal beds by Kuenen (1991) and Kuenen and Debrot (1995) have been carried out.

Of the thirteen different seagrass and algal assemblages described by Kuenen and Debrot (1995) for Spaanse Water, two were found in the vicinity of the CARICOMP seagrass monitoring site. The first was a shallow *Thalassia-Halimeda opuntia* assemblage from average depths of 0.8 m, average light penetration of 75.2%, and negligible amounts of hard substrate. Average sediment grain size was the highest observed in their study. The dominant species of this assemblage were *Thalassia testudinum* and *Halimeda opuntia*. Other species included the algae *Acetabularia crenulata, Amphiroa fragilis-*

sima, Halimeda incrassata, Hypnea cervicornis, Penicillus capitatus, Spyridia filamentosa, and *Valonia ventricosa,* the hydrozoan *Eudendrium* sp., and a polychaete *Sabella* sp. This cluster showed one of the highest levels of total biotic cover (48.2%). Sessile species richness per (6 m^2) station was intermediate (15.6); both diversity (1.0) and evenness (0.4) were low, as compared to other assemblages from the bay.

The second assemblage (Kuenen and Debrot, 1995) was labelled a shallow *Halimeda incrassata* assemblage, from an average depth of 3.3 m. Light penetration (33.8%) and average sediment grain size (0.43 mm) were intermediate. The dominant alga was *Halimeda incrassata.* Other species were *Acetabularia crenulata, Cladophora* sp., *Caulerpa sertularioides, Penicillus capitatus,* and *Spyridia filamentosa,* the bryozoan *Bugula* sp., and the sponges *Mycale microsigmatosa* and *Tedania ignis* as well as *Halophila decipiens, Thalassia testudinum,* the alga *Hypnea cervicornis,* and the sponge *Desmapsamma anchorata.* Sessile biotic cover was reported as intermediate (16.2%) and dominated by green algae. Average number of species per station was intermediate (18.1), as were diversity (1.5) and evenness (0.5).

Some community biomass and *Thalassia* growth data, as measured on three separate occasions at the monitoring site, are shown in Table 3. Total biomass levels (for seagrass and attached macroalgae) ranged from 560 to 670 g m^{-2}. Mean areal productivity for *Thalassia* varied from 1.20 g m^{-2} d^{-1} in March 1994 to 0.14 g m^{-2} d^{-1} in September 1995 (Table 4). Mean biomass turnover was less variable, with a high of 3.14% day^{-1} in March 1995 and a low of 2.44% day^{-1} in September 1995 (Table 4).

Table 3. Seagrass biomass data (mean of 4 replicates).

	Thalassia (g m^{-2})	Fleshy Algae (g m^{-2})	Calcareous Algae (g m^{-2})
March 1994	504.1	20.2	144.6
March 1995	452.6		109.8
September 1995	192.7	0.2	382.6

Table 4. Seagrass growth data (mean of 6 replicates).

	Mean Areal Productivity (g m^{-2} day^{-1})	Mean Turnover per Biomass of Plants (% day^{-1})
March 1994	1.2	2.29
March 1995	0.6	3.14
September 1995	0.14	2.44

Scleractinian corals (particularly *Siderastrea siderea*) which formerly were a conspicuous component of the seagrass and algal beds of the bay have suffered serious mortalities in recent decades (Kuenen, 1991). This can be ascribed largely to pollution associated with the rapid urbanization of the bay and burgeoning uncontrolled recreational use. The seagrass beds of the bay are important nursery areas for various reef fish species, such as snappers and grunts (Briones Sierra, 1994), and also the spiny lobster *Panulirus argus* (Jalink and Donkersloot, 1985).

Coral Reefs

Curaçao is completely surrounded by fringing reefs, situated at a distance from the coast ranging from 20 m to 250 m (Van Duyl, 1985). Although the reef profile is variable along the coast, a general pattern can be distinguished. From the shore, mostly consisting of steep cliffs and rubble beaches, a submarine terrace gradually slopes to a "drop-off" at 7-12 m depth (Bak, 1975). Here, the reef slopes steeply at 45°-90°, sometimes interrupted by an inclined terrace at 50-60 m, to a second drop-off at 70-80 m, ending in a sandy plain at 80-90 m (Bak, 1975). Two additional common reef profiles are distinguished by Van Duyl (1985): one profile with a broad terrace, a relatively deep drop-off (15-18 m) and a less steep slope (<30°); the second profile with a narrow terrace, bordering on a subsea cliff wall. At the CARICOMP site, the reef corresponds to the first mentioned profile and is bordered by a rubble beach that consists mostly of *Acropora* fragments. The rubble beach has a high abundance and diversity of intertidal mollusks, indicative of pristine conditions (Nagelkerken and Debrot, 1995). The submarine terrace, where the CARICOMP line transects are situated at a depth of 6-8 m, stretches 75 m seaward from the shore to the drop-off, which is located at a depth of 8 m (see Van Duyl, 1985).

The distribution of reef corals in the Netherlands Antilles has been described by Roos (1964, 1971) and Bak (1975, 1977), while Bak (1977) also provided quantitative data on the composition of the coral community in Curaçao. The total number of coral species found in various marine environments in Curaçao is 57, of which 50 species are hermatypic, belonging to 24 genera (Bak, 1975). These numbers indicate that Curaçao belongs to the Caribbean diversity center (Bak, 1977). At the CARICOMP reef site, the total number of hermatypic coral species was found to be 28, at a depth of 6-8 m, in an area of 90 m^2.

Bak (1975) recognized various zones along the vertical reef profile of Curaçao. The shore zone is a high energy environment that is occasionally subject to partial aerial exposure during low tides. In general, typical organisms of this zone are algae, echinoderms, the coral *Diploria clivosa*, and other encrusting corals (Bak, 1975). At a depth of 1-4 m, the *Acropora palmata* zone is characterized by the dominance of the coral *A. palmata*. Encrusting calcareous red algae, such as *Porolithon pachydermum*, are important stabilizers of the coral rubble in this zone (Bak, 1975). The barren zone, at 3-4.5 m, is largely devoid of coral growth. The substrate consists largely of sand and coral rubble, or coral rock in more exposed areas. The scouring action of the sand and, before the mass mortality, the grazing of the sea urchin *Diadema antillarum*, largely inhibit larval settlement of benthic organisms (Bak, 1975). Below 4-5 m, coral cover and diversity increase towards the first drop-off, shifting from a sandy bottom with fields of *Acropora cervicornis*, towards a substrate of coral rock and living coral dominated by *Montastraea annularis*, *Agaricia agaricites*, and *Madracis mirabilis* (Bak, 1975). Coral cover and diversity remain high over the drop-off, but they decrease rapidly below 35-40 m where the influence of sedimentation is high. Here, calcareous red algae become abundant, although the corals *Montastraea annularis* and *Agaricia undata* can still be found down to a depth of 80 m (Bak, 1975).

The algal zonation on the coral reef at the southwestern coast of the island has been described by Van den Hoek *et al.* (1975) at Klein Piscadera (near the Carmabi lab) along a depth gradient of 0-20 m. Seven different zones were distinguished, and a profusion of fleshy and filamentous algae were found, averaging 54 species per 25 m^2. The highest combined coverage and diversity of fleshy and filamentous algae and of crustose corallines were found in shallow (1-4 m) *A. palmata-Porolithon-Millepora* reefs, while lowest values were found in the deeper (5-13 m) and rich *M. annularis* and *M. cavernosa* coral community (Van den Hoek *et al.*, 1975). It is not known, however, to what extent the algal community at the CARICOMP reef site corresponds to these findings.

Few quantitative data are available for the coral reef fish communities of Curaçao. Research on the distribution, abundance, and species diversity of coral reef fishes has been done by Nagelkerken (1974, 1977) and Leloup and Van der Mark (1984), while Briones Sierra (1994) provided quantitative work for the coral reef, mangrove, seagrass, and algal biotopes of Spaanse Water in the vicinity of the CARICOMP seagrass and coral reef sites. The fish community near the latter, at a depth of 8-25 m, is dominated by the four fish species *Haemulon chrysargyreum*, *Acanthurus bahianus*, *Mulloidichtys martinicus*, and *Ocyurus chrysurus*, accounting for 50% of the total recorded fish abundance (Briones Sierra, 1994). Herbivorous fish of the families Acanthuridae (17%, density 3.9 per 100 m^2) and Scaridae (15%, density 3.4 per 100 m^2) accounted for about one-third of the total recorded fish abundance, while carnivorous fish accounted for 54%. The coral predator *Chaetodon capistratus* accounted for 6% (density 1.3 per 100 m^2) of total fish abundance.

The shallow-water ecosystems of Spaanse Water appear to play an important role as nursery areas and habitats for coral reef fishes (Briones Sierra, 1994). The reefs of Curaçao are heavily overfished as a result of high fishing pressure and the uncontrolled use of spear guns, fish traps, and gill-nets (Van't Hof *et al.*, 1995). In 1984, Leloup and Van der Mark found groupers (Serranidae) to be smaller and less abundant on the reefs of Curaçao compared to those in Bonaire, and suggested the higher degree of spearfishing in Curaçao as a likely cause. One species, the balloonfish *Diodon holocanthus* increased in abundance on the reefs of Curaçao as a result of a mass recruitment of juvenile fish in 1994 (Debrot and Nagelkerken, 1997).

The coral reefs of Curaçao, including the CARICOMP reef site, have recently been impacted by a number of natural and anthropogenic disturbances. Bak and Nieuwland (1995) found that during the last two decades coral cover and number of coral colonies decreased significantly on the shallow fore-reef (depths 10 and 20 m) in Curaçao. Species richness also decreased at a depth of 30-40 m, and rare species disappeared. Coastal development activities, such as sewage discharge and artificial beach construction, are likely to have caused the decline of the shallow reef (Bak and Nieuwland, 1995).

Curaçao is located outside the hurricane belt. The most recent hurricane passing within 100 nautical miles of the island was Hurricane Joan in 1988 (Meteorological Service, 1990), but its effect on the coral reef was not documented. Tropical storm Brett passed 145 km from Curaçao in 1993 and caused considerable damage to shallow water *Acropora palmata* and *Millepora complanata* colonies to a depth of at least 8 m, especially on the exposed eastern side of the southwestern coast of the island (Van Veghel and Hoetjes, 1995). As the CARICOMP reef site is situated in this area, and is located at an exposed promontory, the storm-related damage to the shallow part of this reef was severe as well.

Massive coral bleaching has been documented for Curaçao reefs: in 1987 (Williams and Bunkley-Williams, 1990), in 1990 (Meesters and Bak, 1993), and in 1995 (CARICOMP, 1997). The coral *Montastraea annularis* is normally most heavily affected. The bleaching-related mortality in *M. annularis* at the CARICOMP reef site during the 1995 bleaching event was found to be much higher in comparison to other more pristine reef areas (Nagelkerken *et al.*, 1997b). As *M. annularis* is a main reef builder on

Curaçao reefs (Bak, 1975), this event may thus have caused a higher than average disturbance of the coral community at the CARICOMP reef compared to other reef areas.

Several diseases have had detrimental effects on coral reef organisms of Curaçao reefs in the 1980s and 1990s. In 1980, the corals *Acropora palmata* and *A. cervicornis* were affected by white-band disease (Bak and Criens, 1981), and in 1983 the population of the sea urchin *Diadema antillarum* was reduced by 98-100% by an unknown cause (Bak *et al.*, 1984). The latter resulted in a significant increase in cover of fleshy and filamentous algae in combination with a general decrease in coral, crustose coralline, and/or loose sediment cover (De Ruyter van Steveninck and Bak, 1986). In 1995, widespread mortality was observed in Caribbean sea fans (*Gorgonia* spp.), and in Curaçao the sea fan *Gorgonia ventalina* was affected (Nagelkerken *et al.*, 1997a). The effects of the disease appeared to be positively related to water depth; the sea fan community at the CARICOMP reef (depth 5 m) showed 62% of the sea fans to be infected, and the mean percentage of tissue surface injured was 7% (Nagelkerken *et al.*, 1997a). The disease was probably caused by a water-borne pathogen likely to have been distributed by sediment particles (Smith *et al.*, 1996). Finally, according to Bak and Nieuwland (1995) black-band disease in corals is rare in Curaçao.

The compound ascidian *Trididemnum solidum* is a common competitor for space on Curaçao reefs and can easily overgrow corals. Its abundance was first quantified in 1978 by Bak *et al.* (1981); during a re-survey in 1993, Bak *et al.* (1996) found that its abundance had increased significantly over 15 years. Eutrophication has been suggested as a possible cause for this increase (Bak and Nieuwland, 1995). So far, *T. solidum* has not been observed at the CARICOMP reef site, but it is located only 3 km upstream of the nearest reef where the presence of *T. solidum* has been confirmed (Bak *et al.*, 1996).

References

Bak, R. P. M. 1975. Ecological aspects of the distribution of reef corals in the Netherlands Antilles. *Bijdragen tot de Dierkunde*, **45**(2):181-190.

Bak, R. P. M. 1977. Coral reefs and their zonation in the Netherlands Antilles. *AAPG Studies in Geology*, **4**:3-16.

Bak, R. P. M., S. R. Criens. 1981. Survival after fragmentation of colonies of *Madracis mirabilis*, *Acropora palmata* and *A. cervicornis* (Scleractinia) and the subsequent impact of a coral disease. *Proceedings of the 4th International Coral Reef Symposium*, **2**:221-227.

Bak, R. P. M., F. Van Duyl, J. Sybesma. 1981. The ecology of the tropical compound ascidian *Trididemnum solidum*. II. Abundance, growth and survival. *Marine Ecology Progress Series*, **6**:43-52.

Bak, R. P. M., M. J. E. Carpay, E. D. de Ruyter van Steveninck. 1984. Densities of the sea urchin *Diadema antillarum* before and after mass mortalities on the coral reefs of Curaçao. *Marine Ecology Progress Series*, **17**:105-108.

Bak, R. P. M., G. Nieuwland. 1995. Twenty years of change in coral communities over deep reef slopes along leeward coasts in the Netherlands Antilles. *Bulletin of Marine Science*, **56**(2):609-619.

Bak, R. P. M., D. Y. M. Lambrechts, M. Joenje, G. Nieuwland, M. I. J. van Veghel. 1996. Long term changes on coral reefs in booming populations of a competitive colonial ascidian. *Marine Ecology Progress Series*, **133**:303-306.

Beets, D. J. 1972. *Lithology and Stratigraphy of the Cretaceous and Danian Succession of Curaçao.* Uitgaven Natuurwetenschappelijke Studiekring voor Suriname en de Nederlandse Antillen 70, Utrecht, The Netherlands, 153 pp.

Bosscher, H. 1992. *Growth Potential of Coral Reefs and Carbonate Platforms*. Doctoral dissertation, Vrije Universiteit Amsterdam, The Netherlands, 157 pp.

Briones Sierra, E. E. 1994. *Size Distribution Patterns of Some Selected Fish Species in Mangrove, Seagrass, Algal Bed and Coral Reef Habitats at Spaanse Water Bay — Curaçao*. Unpublished report, Catholic University Nijmegen/Carmabi Foundation, 46 pp.

CARICOMP. 1997. Studies on Caribbean coral bleaching, 1995-1996. **In:** *Proceedings of the 8th International Coral Reef Symposium (Panama, June 1996)* (edited by H. A. Lessios and I. G. Macintyre), Vol. I, pp 673-678. Smithsonian Tropical Research Institute, Balboa, Republic of Panama.

Debrot, A. O., J. A. de Freitas. 1991. Wilderness areas of exceptional conservation value in Curaçao, Netherlands Antilles. *Netherlands Commission of International Nature Protection, Mededelingen*, **26**:1-25.

Debrot, A. O., I. Nagelkerken. 1997. A rare mass recruitment of the balloonfish (*Diodon holocanthus* L.) in the Leeward Dutch Antilles, 1994. *Caribbean Journal of Science*, **33**:284-286.

De Buisonjé, P. H. 1974. *Neogene and Quaternary Geology of Aruba, Curaçao and Bonaire*. Uitgaven Natuurwetenschappelijke Studiekring voor Suriname en de Nederlandse Antillen 78, Utrecht, The Netherlands, 252 pp.

De Haan, D., J. S. Zaneveld. 1959. Some notes on tides in Annabaai Harbor, Curaçao, Netherlands Antilles. *Bulletin of Marine Science of the Gulf and Caribbean*, **9**(2):224-236.

De Kock, W. C., W. J. J. O. de Wilde. 1964. *Verslag over het onderzoek naar de fertiliteit van enige Curaçaose binnenbaaien*. Unpublished report of the Carmabi Foundation, Curaçao, Netherlands Antilles, 14 pp.

De Ruyter van Steveninck, E. D., R. P. M. Bak. 1986. Changes in abundance of coral-reef bottom components related to mass mortality of the sea urchin *Diadema antillarum*. *Marine Ecology Progress Series*, **34**:87-94.

Djohani, R. H., C. Klok. 1988. *Een onderzoek naar de waterkwaliteit van enkele baaien van Curaçao op basis van biologische en abiotische parameters*. Unpublished student report, Carmabi Foundation/University of Amsterdam, 53 pp.

Frank, U., P. Bouma. 1990. *Cryptic Communities of Sublittoral Hard Substrate in Relation to Abiotic Parameters at Some Inner Bays of Curaçao*. Unpublished student report, Carmabi Foundation/University of Amsterdam, The Netherlands, 32 pp.

Fransen, C. H. J. M. 1986. Caribbean Bryozoa: Anasca and Ascophora imperfecta of the inner bays of Curaçao and Bonaire. *Studies of Fauna of Curaçao and Other Caribbean Islands*, **68**:1-119.

Golley, F., H. T. Odum, R. F. Wilson. 1962. The structure and metabolism of a Puerto Rican red mangrove forest in May. *Ecology*, **43**:9-19.

Jalink, C., C. Donkersloot. 1985. *Onderzoek naar de verspreiding van Panuliris argus aan de zuidkust van Curaçao*. Unpublished student report, Carmabi Foundation/Rijksuniversiteit Utrecht, The Netherlands, 70 pp.

Kuenen, M. 1991. *De benthische gemeenschappen van het Spaanse Water, Curaçao*. Unpublished student report, Carmabi Foundation/University of Amsterdam, The Netherlands, 50 pp.

Kuenen, M. M. C. E., A. O. Debrot. 1995. A quantitative study of the seagrass and algal meadows of the Spaanse Water, Curaçao. *Aquatic Botany*, **51**:291-310.

LeLoup, M. J., C. Van der Mark. 1984. *De dichtheden en grootte samenstelling van de roofvis populaties op de koraalriffen van Curaçao en Bonaire, bepaald volgens verschillende censusmethodes*. Unpublished report, Carmabi Foundation-University of Amsterdam, The Netherlands, 68 pp.

Meesters, E. H., R. P. M. Bak. 1993. Effects of coral bleaching on tissue regeneration potential and colony survival. *Marine Ecology Progress Series*, **96**:189-198.

Meteorological Service. 1990. *Hurricanes and Tropical Storms of the Netherlands Antilles and Aruba*. Unpublished report, Meteorological Service of the Netherlands Antilles and Aruba, 40 pp.

Meteorological Service. 1996. *Overzicht weergesteldheid 1995.* Unpublished report, Meteorological Service of the Netherlands Antilles and Aruba, 19 pp.

Nagelkerken, W. P. 1974. On the occurrence of fishes in relation to corals in Curaçao. *Studies on the Fauna of Curaçao and Other Caribbean Islands,* **45**:118-141.

Nagelkerken, W. P. 1977. The distribution of the Graysby *Petrometopon cruentatum* (Lacepede) on the coral reef at the southwest coast of Curaçao. *Proceedings of the Third International Coral Reef Symposium,* 311-315.

Nagelkerken, I. A., A. O. Debrot. 1995. Mollusc communities of tropical rubble shores of Curaçao: Long-term (7^+ years) impacts of oil pollution. *Marine Pollution Bulletin,* **30**:592-598.

Nagelkerken, I., K. Buchan, G. W. Smith, K. Bonair, P. Bush, J. Garzón-Ferreira, L. Botero, P. Gayle, C. Herberer, C. Petrovic, L. Pors, P. Yoshioka. 1997a. Widespread disease in Caribbean fans: I. Spreading and general characteristics. **In:** *Proceedings of the 8th International Coral Reef Symposium (Panama, June 1996)* (edited by H. A. Lessios and I. G. Macintyre), Vol. I, pp 659-682. Smithsonian Tropical Research Institute, Balboa, Republic of Panama.

Nagelkerken, I., K. Buchan, G. W. Smith, K. Bonair, P. Bush, J. Garzón-Ferreira, L. Botero, P. Gayle, C. D. Harvell, C. Heberer, K. Kim, C. Petrovic, L. P. J. J. Pors, P. Yoshioka. 1997b. Widespread disease in Caribbean sea fans, II: Patterns of infection and tissue loss. *Marine Ecology Progress Series,* **160**:255-263.

Roos, P. J. 1964. The distribution of reef corals in Curaçao. *Studies on the Fauna of Curaçao and Other Caribbean Islands,* **20**:1-51.

Roos, P. J. 1971. The shallow-water stony corals of the Netherlands Antilles. *Studies on the Fauna of Curaçao and Other Caribbean Islands,* **37**:1-108.

Smith, G. W., I. D. Ives, I. A. Nagelkerken, K. B. Ritchie. 1996. Caribbean sea fan mortalities. *Nature,* **383**:487.

Snedaker, S. C. 1988. *The Mangroves of Curaçao: Ecological Status and Management Options.* Unpublished report of the Carmabi Foundation, Curaçao, Netherlands Antilles, 15 pp.

Sinton, C. W., R. A. Duncan, M. Storey. 1993. ^{40}Ar-^{39}Ar ages from Gorgona Island, Colombia, and the Nicoya Peninsula, Costa Rica [abstract]. *EOS,* **74**:553.

Van den Hoek, C., F. Colijn, A. M. Cortel-Breeman, J. B. Wanders. 1972. Algal vegetation-types along the shores of the inner bays and lagoons of Curaçao and of the lagoon Lac Bay (Bonaire), Netherlands Antilles. *Verhandelingen Koningklijke Nederlandse Akademie van Wetenschap, Afdeling Natuurkunde (2),* **61**(2):1-72.

Van den Hoek, C., A. M. Cortel-Breeman, J. B. W. Wanders. 1975. Algal zonation in the fringing coral reef of Curaçao, Netherlands Antilles, in relation to zonation of corals and gorgonians. *Aquatic Botany,* **1**:269-308.

Van der Horst, C. J. 1927. Resultaten eener reis van Dr. J. C. Van der Horst in 1920, in bijdragen tot de kennis der fauna van Curaçao. *Bijdragen Dierkunde,* **25**:1-164.

Van Duyl, F. C. 1985. *Atlas of the Living Reefs of Curaçao and Bonaire.* Ph.D. dissertation, Free University Amsterdam/Foundation for Scientific Research in Surinam and the Netherlands Antilles, Utrecht, 37 pp.

Van Veghel, M. L. J., P. C. Hoetjes. 1995. Effects of tropical storm Brett on Curaçao reefs. *Bulletin of Marine Science,* **56**(2):692-694.

Van't Hof, T., A. O. Debrot, I. A. Nagelkerken. 1995. *Curaçao Marine Management Zone: A Plan for Sustainable Use of Curaçao's Reef Resources.* Unpublished report, Curaçao Tourism Development Bureau/Carmabi/STINAPA, 89 pp.

Williams, E. H., L. Bunkley-Williams. 1990. The world-wide coral reef bleaching cycle and related sources of coral mortality. *Atoll Research Bulletin,* **335**:1-71.

Bonaire, Netherlands Antilles[1]

Kalli De Meyer
Bonaire Marine Park
PO Box 368
Bonaire, Netherlands Antilles

The island of Bonaire, one of the five islands that form the Netherlands Antilles, is one of the most southerly sites within the CARICOMP Program and is characterized by a hot, dry climate, hypersaline conditions, low population density, and lack of industrialization. Bonaire's economy is firmly based on dive tourism, and the health of the island's marine resources is therefore of paramount importance to its economic wellbeing. An open lagoonal area on the windward shore, Lac Bay, was selected as a study site because it is the only area where seagrass and mangrove ecosystems are significantly present on Bonaire. Because reef development is relatively poor in waters shallower than 12 m along the windward shore, a coral reef monitoring site was selected on the leeward shore, in an area where disturbance was low and where reefs are characteristically dominated by massive colonies of *Montastraea annularis*.

Introduction

Bonaire is situated in the southern Caribbean (12°10'N, 68°15'W) approximately 100 km north of Venezuela (Fig. 1). It is one of the five islands that form the Netherlands Antilles: Bonaire, Curaçao, and the Windward Islands of St. Maarten, Saba, and St. Eustatius (Statia). Bonaire is a crescent shaped island, oriented NW-SE, approximately 40 km long by 11 km at its widest point, with a land area of 288 km^2. The small uninhabited satellite island of Klein Bonaire ("small" Bonaire), which is located some 750 m off the western shore of Bonaire, is a RAMSAR site; it is privately owned and, to date, is entirely undeveloped.

In 1990, the resident population was 10,791 (CBS, 1991). With a population density of only 37 persons/km^2, Bonaire is the least densely populated island of the Netherlands Antilles. The main center of population, Kralendijk (locally called "Playa") is located in the center of the island; a second and older center, Rincon, is located in the north. There are only five other "villages," and the rest of the island is uninhabited and undeveloped. The coastal zone adjacent to Kralendijk has been extensively developed to provide tourist accommodation and, more recently, for private residential housing to

[1] *CARICOMP — Caribbean Coral Reef, Seagrass and Mangrove Sites* (edited by B. Kjerfve), pp 141-149. UNESCO, Paris, 1998, 347 pp.

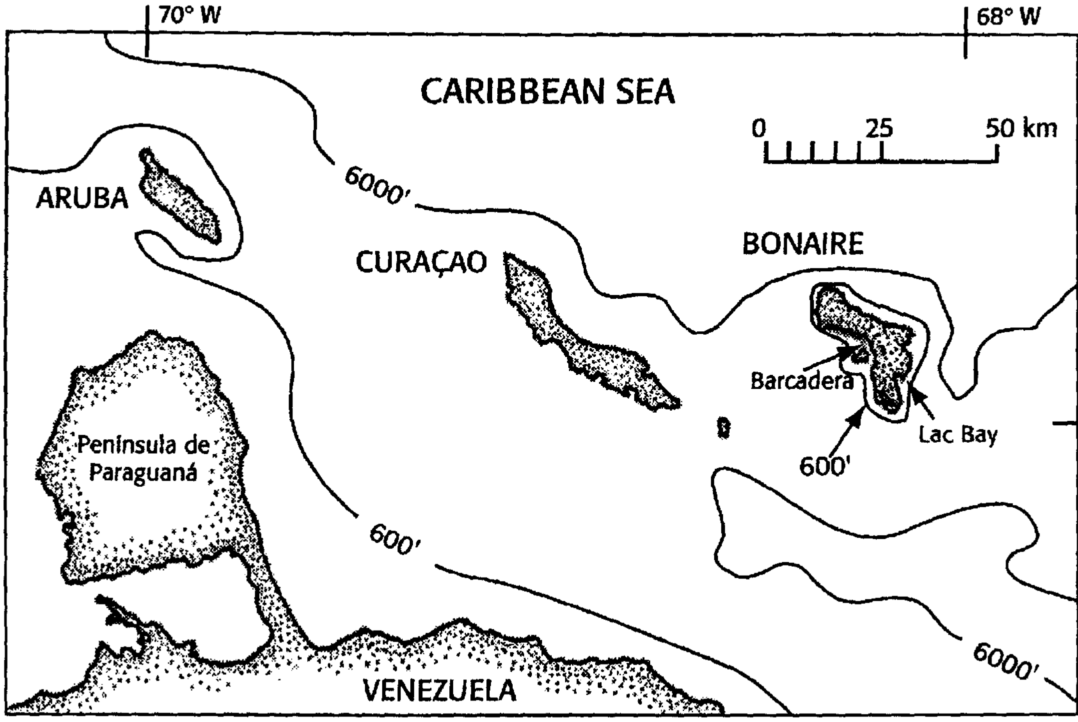

Fig. 1. Map of Bonaire showing relevant locations.

accommodate an influx of wealthy retirees taking advantage of tax concessions. The economy of Bonaire is remarkably undiversified (Scura and van't Hof, 1993) consisting of an oil transshipment facility located on the northwestern shore, a solar salt extraction plant whose "condensers" (evaporation ponds) take up most of the southern end of the island, and tourism which is firmly based on the dive travel segment. Tourism is considered the mainstay of the island economy, with gross revenues from dive tourism in 1994 estimated at US$34 million (Scura and van't Hof, 1993).

Geography and Geology

Both Bonaire and Klein Bonaire are very flat. Little of the southern land area of Bonaire is more than 2 m above sea level, with higher elevations found only in the north and reaching a maximum of 238 m. The geology of Bonaire is complex, with the core of the island consisting of strongly folded and faulted rocks of volcanic origin, silica rich sediments and turbidites formed during the Cretaceous era some 120 million years BP (Beets, 1972a,b). Overlying this are later fossil reef and reef-generated calcareous deposits. It is these limestone formations which make up the coastline in the form of coral-rubble beaches (coral shingle and calcareous sand) or iron shore, except in the north where low limestone cliffs are found (Zonneveld *et al.*, 1972). Klein Bonaire consists entirely of limestone formations (Buisonje, 1974). Substantial changes in sea level have left up to four stranded terraces above the present mean sea level, and one below, most of which can be distinguished by "solution notches" (undercutting caused by bioerosion and/or wave action) in the elevated seaward facing limestone cliffs.

Water retention of the soil is poor so that most rainfall quickly runs off into permanently or temporarily flooded "salinas" (hypersaline lakes separated from the sea by a coral rubble barrier), or directly into the sea (Roos, 1971). Together with low rainfall, this means that less than 10% of the land area of Bonaire is suitable for rain-fed agriculture. Natural vegetation is xerotrophic, comprising some 340 species of flora; Cactaceae, *Acacia, Prosopis, Capparis, Haematoxylon, Lantana* and *Croton* are characteristic species.

The climate is semi-arid tropical, with little seasonal variation and almost constant easterly trade winds. Average monthly air temperatures range from 26.6°C (February) to 28.4°C (October), and average rainfall is just 490.5 mm/year. Rainfall is unequally distributed geographically, with approximately four times as much rain falling in the northern portion of the island as in the south. The rainy season begins at the end of October and lasts until around the beginning of January; a second, shorter rainy season occurs in July. Commonly, no rainfall is recorded during the dry months. For 97.2% of the time, Bonaire experiences constant easterly trade winds (from 70°-110°) with an average velocity of 6.7 m s^{-1}. Wind speeds are generally highest in June and July and lowest in November at the start of the rainy season. Bonaire lies outside the hurricane belt (the last recorded hurricane occurred in 1877), although tropical storms and hurricanes passing north of Bonaire can cause the wind to swing around (locally known as a "wind reversal"), which may cause extensive damage to the reefs and coastal zone of the leeward shore. Damaging wind reversals were recorded in 1976, 1981, 1985, 1990, and 1996.

The exposed eastern (windward) and protected western (leeward) shorelines are strikingly different. The windward shore is a very high wave energy environment characterized by rough water conditions and constant waves breaking against low limestone cliffs or onto the iron-shore coast. Water conditions on the leeward shore rarely exceed Beaufort Force 4, with only moderate swells affecting the northern and southern extremes of the island.

The maximum annual tidal range is approximately 1 m, with an average range of 0.30 m during a lunar cycle (Bak, 1977). Currents are unpredictable but slight, rarely exceeding 0.5 m s^{-1}. The predominant current movement is toward the north along the leeward shore, but this pattern is complicated by local eddies and upwelling. Water conditions are stable, with a constant 34-36 ppt salinity and mean water temperatures varying from 26°C to 28°C.

Conservation and Human Impact

Bonaire has always taken the conservation of its resources, both terrestrial and marine, very seriously. Since 1969, nearly 20% of the total land area of Bonaire has been protected as a national park. Since 1979, the waters around Bonaire, from the high water mark to the 200 foot depth contour, have been designated a marine park and are protected by law (Verordening Marien Milieu, 1991). Activities within the marine park are restricted in order to ensure the continued sustainability of the coral reef, sea grass, and mangrove systems. Destructive practices such as anchoring, coral collection, and spearfishing are banned within the marine park.

Bonaire's industrial base is confined to the transshipment of oil, the production and transportation of salt, and the refining of rice. Since both fishing and agriculture are essentially small-scale artisanal activities, major impacts on the marine ecosystem are direct and indirect results of tourism.

Most of the tourist activity associated with Bonaire's reefs is confined to scuba diving, although snorkelling is increasing. Lac Bay is visited by tourists mainly for windsurfing, with some kayaking and snorkelling. Dive tourism began in 1963 and, by 1994, visitation had risen to approximately 57,000, of whom 25,000 were divers; tourist activity continues to rise by 7-10% annually. The direct impact of tourism includes occasional illegal anchoring, groundings, and dragging of mooring barrels through misuse, as well as direct contact damage by divers and snorkellers. Preliminary work carried out by van't Hof in 1991 suggests that the estimated carrying capacity of 250,000 dives per annum has already been exceeded at some of the more popular sites. This is evident through the loss of coral cover and changed species diversity when comparing dived and undived "reserve" sites (Scura and van't Hof, 1993). However, levels of physical damage to the reef are low, with only 2.7% of corals showing signs of damage, even at the most heavily utilized sites (Roberts and Hawkins, 1994), probably as a result of intensive educational efforts aimed at making divers aware of reef fragility. The more insidious and indirect results of increased tourism and coastal zone development are more difficult to quantify; they include increased nutrient loading through leaching of septic waste into the sea, particularly from hotels in the coastal zone, and also poor landscaping practices and increased sedimentation through land clearance and poor construction practices. The effects of these have resulted in increased algal cover (Roberts and Hawkins, 1994) and reduced visibility, especially after rain.

Coral Reefs

Both Bonaire and Klein Bonaire are surrounded by continuous, fringing coral reefs from the shoreline seaward to depths in excess of 70 m, covering an area of some 2,600 ha. Reef formation begins at the shoreline with a gradually shelving submarine terrace extending seaward by up to 250 m. Beyond this, at depths of 10-12 m, the terrace drops off and the reef slope commences. The dropoff zone exhibits maximum diversity of benthos and maximum coral cover (Bak, 1977). The reef slope drops down steeply at a 20-50° angle to depths of 25-55 m where it flattens out into a shelf. A second dropoff occurs beyond this (van Duyl, 1985).

Van't Hof (1982) recognized six distinct coral zones from the shoreline to 50 m. These are: a shore zone (0-1 m), characterized by *Diploria clivosa*; an elkhorn zone (1-4 m), dominated by *Acropora palmata*, *Millepora* sp., and crustose coralline algae; a staghorn zone (4-7 m), characterized by *Acropora cervicornis* interspersed with *Madracis mirabilis*, *Colpophyllia natans*, and *Montastraea annularis* and bounded by gorgonians; a dropoff zone (7-12 m), characterized by gorgonians, *Montastrea annularis*, *Madracis mirabilis*, and *Eusmilia fastigiata*; an upper reef slope (12-25 m), characterized by massive *Montastrea annularis* and *Agaricia* sp.; and finally a lower reef slope (25 m+), dominated by *Agaricia* sp. and some flattened forms of *Montastraea annularis*, *Montastraea cavernosa*, and *Stephanocoenia michelinii* but with few other abundant corals.

A conspicuous feature of the reef slope, especially along the northwestern shore, are coral tongues (spurs) separated by sediment channels (grooves) which may form as a result of the inherent instability of corals at the top of the reef slope causing the reef to collapse locally. True spur-and-groove coral formations occur in shallow water at only two sites on Bonaire on the northwestern shore (Boca Bartol and Playa Benge). Along the windward shore, coral development is virtually absent in water shallower than 12 m, where there is an abundance of crustose coralline algae and dense stands of *Sargassum platycarpum* that may extend to 40 m water depth. Bonaire's reefs were mapped in 1983, and detailed maps were produced of the shallow coral communities to a depth of 10-12 m along the leeward shore and Klein Bonaire (van Duyl, 1985).

In addition to storm damage, significant natural impacts on Bonaire's reefs during the 1970s and 1980s include an outbreak of white band disease (1980-1982), which caused the death of 90% of the standing stock of *Acropora cervicornis*, and the mass mortality of *Diadema antillarum* (1985) thought to be caused by a water-borne pathogen. Both events affected the entire Caribbean Basin to a greater or lesser extent. Bonaire supports some of the best remaining coral reefs in the Caribbean, with exceptionally high coral cover and exceptionally large populations of predatory fish (Roberts and Hawkins, 1994). The importance of maintaining healthy reefs both for their own intrinsic value and to ensure a sustainable economy for the island of Bonaire cannot be overstressed.

The CARICOMP coral reef monitoring site, known locally as Barcadera, is situated at 12°11'45"N, 68°18'00"W. This site is on the leeward shore of Bonaire, north of the town of Kralendijk, and consists of typical *Montastraea annularis* dominated fringing reefs at the 10-12m depth range (Fig. 2). The stony coral cover ranges from 20 to 40%. The site is located approximately 400 m from the nearest dive mooring and gives only limited shore access via an open rung ladder from a low limestone cliff. Land use at this area has changed dramatically over the past five years, particularly with the building of up-scale residential housing in a previously undisturbed natural area. Increased sedimentation through land clearance and landscaping is affecting the reefs, as is increased nutrient loading from sewage. As the coastal zone has now been developed, perhaps land use has stabilized for the foreseeable future.

Because the prescribed 10-12 m depth range corresponds to the dropoff zone, transects were laid out oblique to the coast so as to fall within the prescribed depth range in two adjacent groups of five transects. Within the groups, transects are approximately 2 m apart. Data collected at this site show a reef benthos dominated by massive stony corals (29.4 % mean cover) and algae (33.0% mean cover), with few soft corals (2.4% mean cover) or sponges present.

Mangroves and Seagrass Beds

A sheltered shallow inland bay, Lac Bay, occurs on the windward shore in southeastern Bonaire. It is the largest inland bay in the Netherlands Antilles, with a flooded area of approximately 7.5 km^2, and is internationally protected as a RAMSAR site. The maximum water depth within the bay is 4.5 m; tidal range is limited to approximately 0.3 m (van Moorsel and Meijer, 1993). The bay is bounded seaward by exposed fringing coral reefs that protect the bay from wave action. Waves break over the reef, flood the bay, and flow out though a deep water channel at the northernmost tip of the bay, creating a rip current. Lac Bay supports Bonaire's only significant mangrove and seagrass ecosystems. The open water area of the bay is covered by seagrass beds dominated by *Thalassia testudinum* (varying in cover from 5 to 100%) together with *Syringodium filiforme*, and banks of the calcareous

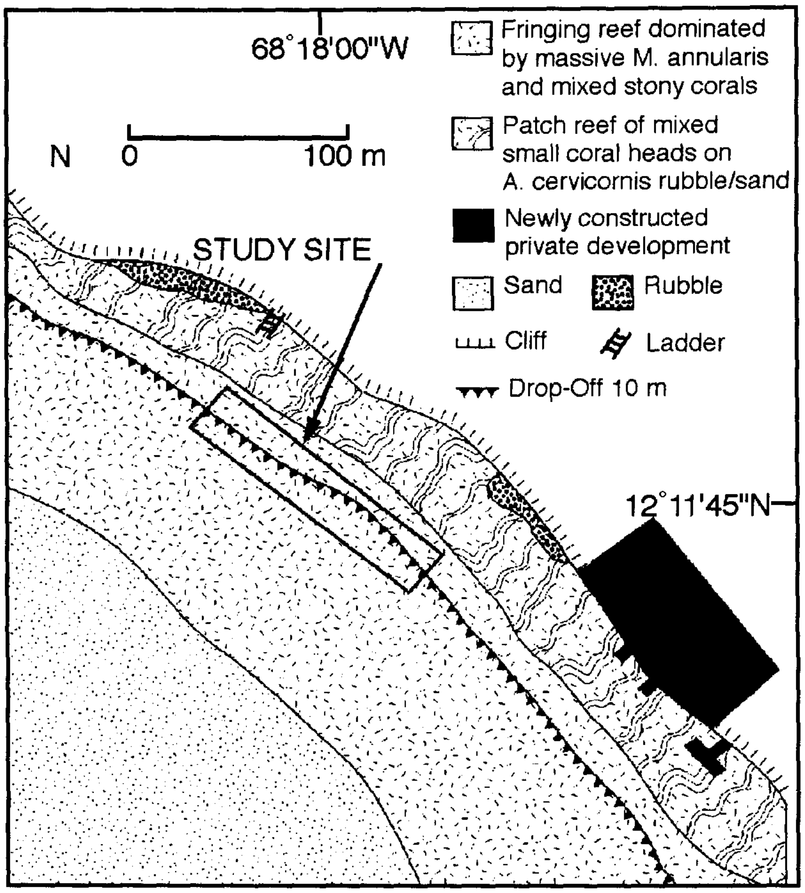

Fig. 2. Map showing the position of Bonaire's CARICOMP coral reef monitoring site.

alga *Halimeda* sp. Along the landward edge of the bay is an actively growing fringe of *Rhizophora mangle* (with an average height of 8 m and an average dbh of 17 cm) that is systematically encroaching on the bay. The geomorphological nature of the mangrove stands is relatively rare, as classified by Thom (1984); there is no riverine input into the system, making them particularly vulnerable. Within the mangrove system are a number of permanently dry, ribbon-like cays as well as several important feeder channels that supply water to the back of the mangrove fringe. The mangroves are dominated by *Rhizophora mangle* along the landward and seaward edges and *Avicennia germinans* within the mangroves and around the drier ground associated with the islands. Within the *Avicennia* zone, average tree height is 5 m and average dbh is 8.1 cm. *Conocarpus erectus* is also not uncommon. One of the dominant features of the mangrove system is a significant die-back of *Rhizophora mangle* at its northwestern extreme, thought to be due to hypersaline conditions created by the landward damming of freshwater and choking of feeder channels on the seaward side resulting in water temperatures of 40°C and salinities of up to 100 ppt (van Moorsel and Meijer, 1993). The mangrove stands are particularly important as nesting and roosting areas for birds, and the seagrass beds form nursery grounds for some important reef fish as well as an important foraging area for *Chelonia mydas*. The bay is possibly also a breeding ground for *Caretta caretta* and *Eretmochelys imbricata* (van Moorsel and Meijer, 1993).

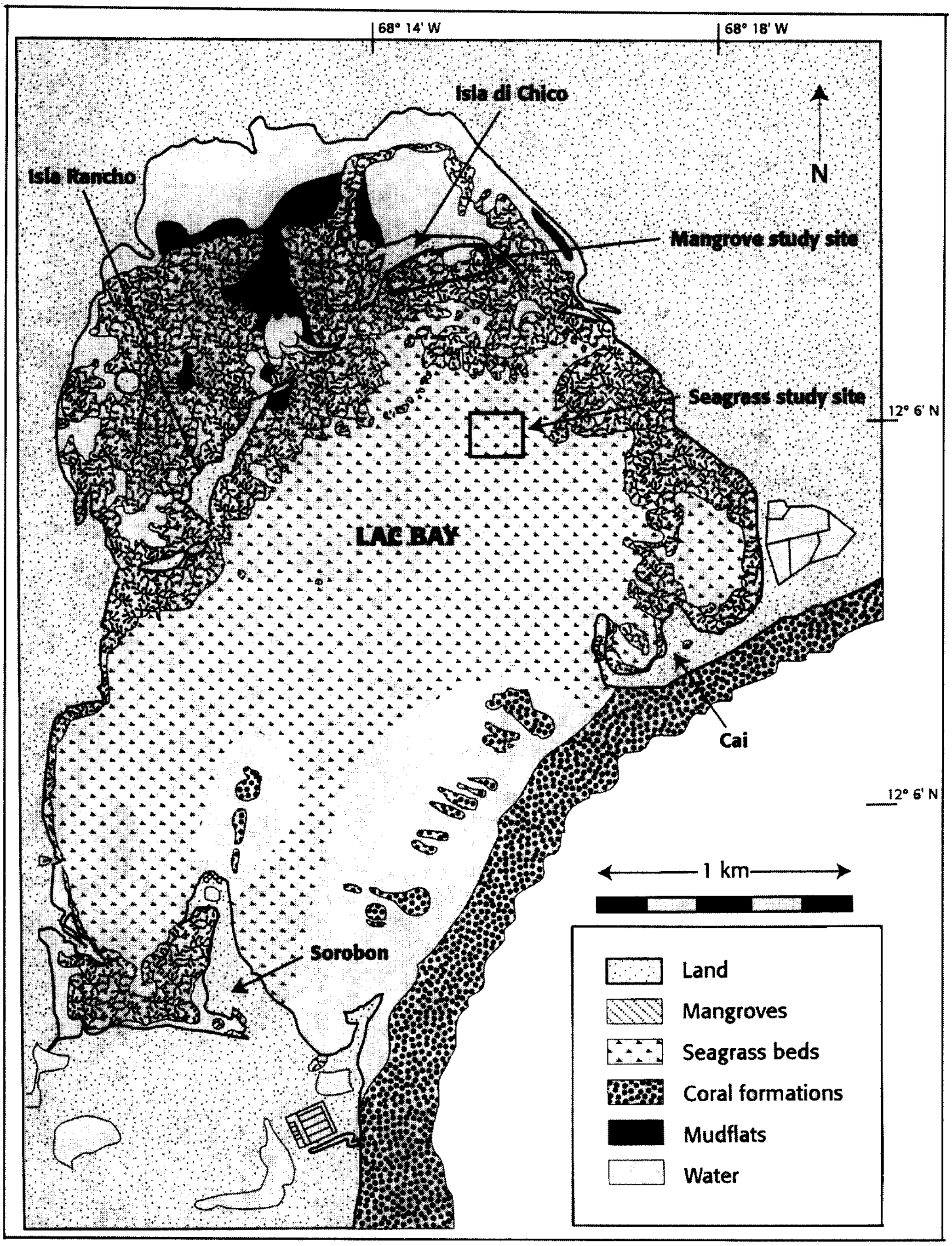

Fig. 3. Map showing the position of Bonaire's CARICOMP seagrass and mangrove monitoring sites.

The mangrove monitoring site is situated on the windward coast in Lac Bay at 12°7'40"N, 68°13' 70"W (Fig. 3). This site was chosen as it is one of the very few places where the mangroves can be accessed relatively easily; the landward and shoreward stands of *Rhizophora mangle* are effectively impenetrable due to high tree density. The site is completely undisturbed, as is the adjacent mangrove area. The five mangrove plots are set up on the seaward side of Isla di Chico. From the westernmost tip of Isla di Chico, the first three plots (A, B, and C) are laid out at intervals of approximately 100 m and are adjacent to the cay at a distance of approximately 35 m. The final two plots (D and E) are located along a transect line approximately 500 m from the eastern end of the cay. Plots A, B, and C consist entirely of *Rhizophora mangle* (mean tree density 0.22 m^{-2}; mean height 7.7 m). Plots D and E, in contrast, consist entirely of *Avicennia germinans* (mean tree density 0.50 m^{-2}; mean height 4.6 m).

The seagrass monitoring site is situated on the windward coast in Lac Bay at 12°7'00"N, 68°13' 70"W. It is located in an area of dense seagrass cover, made up predominately of *Thalassia testudinum* (Fig. 3). *Halimeda* sp. is also present within the benthic community, and occasional *Meoma ventricosa, Oreaster reticulatus, Strombus gigas,* and *Petochirus diogenes* can be found. The area is also an important foraging area for *Chelonia mydas* as witnessed by the fact that the seagrass within the study site was twice leveled by their activity during productivity experiments.

Acknowledgements

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References

Bak, R. P. M. 1975. Ecological aspects of the distribution of reef corals in the Netherlands Antilles. *Bijd. Dierk.*, **45**:181-190.

Bak, R. P. M. 1977. Coral reefs and their zonation in the Netherlands Antilles. *Studies in Geology*, 4:3-16.

Bak, R. P. M., J. J. W. M. Brouns, F. M. L. Heys. 1977. Regeneration and aspects of spatial competition in the scleractinian corals *Agaricia agaricites* and *Montastraea annularis*. **In:** *Proceedings of the 3rd International Coral Reef Symposium (Miami).*

Beets, D. J. 1972a. *Lithology and Stratigraphy of the Cretaceous and Danian Succession of Curaçao* Natuurwetenschappelijke Studiekring voor Suriname en de Nederlandse Antillen 7, Utrecht, The Netherlands, 153 pp.

Beets, D. J. 1972b. Outline of the Cretaceous and Early Tertiary history of Curaçao, Bonaire and Aruba. **In:** *Guide to the Field Excursions on Curaçao, Bonaire and Aruba, Netherlands Antilles*, pp 1-6. Natuurwetenschappelijke Studiekring voor Suriname en de Nederlandse Antillen, Utrecht, The Netherlands.

Buisonje, P. H de. 1974. *Neogene and Quaternary Geology of Aruba, Curaçao and Bonaire.* Natuurwetenschappelijke Studiekring voor Suriname en de Nederlandse Antillen 78, Utrecht, The Netherlands, 291 pp.

CBS (Central Buro voor Statistiek). 1991. Census Office, Bonaire, Netherlands Antilles.

Roberts, C. M., J. P. Hawkins. 1994. *Report on the Status of Bonaire's Coral Reefs*. Eastern Caribbean Center, University of the Virgin Islands, St. Thomas, USVI, 31 pp.

Roos, P. J. 1971. The shallow water stony corals of the Netherlands Antilles. **In:** *Studies of Fauna: Curaçao and Other Caribbean Islands 37*, pp 1-108. Natuurwetenschappelijke Studiekring voor Suriname en de Nederlandse Antillen, Utrecht, The Netherlands.

Scura, L. F., T. van't Hof. 1993. *The Ecology and Economics of Bonaire Marine Park*. The World Bank Environment Department Divisional Paper No. 1993-44, 48 pp.

Sybesma, J. 1992. *Sea Turtle Recovery Action Plan for the Netherlands Antilles*. CEP Technical Report No. 11, UNEP Caribbean Environmental Programme, 63 pp.

Thom, B. G. 1984. *Coastal Landforms and Geomorphic Processes*. **In:** *The Mangrove Ecosystem: Research Methods* (edited by S. C. Snedaker, J. G. Snedaker). UNESCO, Paris, 17 pp.

van Duyl, F. C. 1985. *Atlas of the Living Reefs of Curaçao and Bonaire (Netherlands Antilles)*. Natuurwetenschappelijke Studiekring voor Suriname en de Nederlandse Antillen 117, Utrecht, The Netherlands, 37 pp.

van Moorsel, G. W. N. M., A. J. M. Meijer. 1993. *Base-Line Ecological Study van het Lac op Bonaire*. Bureau waardenburg BV, Holland, 120 pp.

van't Hof, T. (1982) *Guide to the Bonaire Marine Park*. Orphan Publishing Company, Curaçao, Netherlands Antilles, 152 pp.

Verordening Marien Milieu (Marine Environment Ordinance), A. B. 1991, Nr. 8, Island Territory of Bonaire.

Zonneveld, J. I. S., P. H de Buisonje, J. P. Herweijer. 1972. Geomorphology and denudation processes. **In:** *Guide to the Field Excursions on Curaçao, Bonaire and Aruba, Netherlands Antilles*, pp 59-69. Natuurwetenschappelijke Studiekring voor Suriname en de Nederlandse Antillen, Utrecht, The Netherlands.

Parque Nacional Morrocoy, Venezuela[1]

David Bone[1,3], Daisy Perez[1,3], Alicia Villamizar[2], Pablo E. Penchaszadeh[3,4], and Eduardo Klein[3,4]

[1]*Departamento de Biología de Organismos*
[2]*Instituto de Recursos Naturales Renovables*
[3]*Instituto de Tecnología y Ciencias Marinas (INTECMAR)*
[4]*Departamento de Estudios Ambientales*
Universidad Simón Bolívar
PO Box 89000, Caracas, Venezuela

The CARICOMP site in Parque Nacional Morrocoy is located on the northwestern coast of Golfo Triste, a large inlet on the west-central coast of Venezuela (10°52'N, 69°16'W). The 32,090 ha park includes continental, insular, and marine ecosystems, and two marine zones are distinguished within the park. The seaward zone is connected to the open ocean and is characterized by coraline communities, moderate swells, low turbidity, and 20 m water depths. The inshore zone is characterized by low wave activity, higher turbidity, and shallow waters with mangrove (mainly *Rhizophora mangle*) and sea grass (*Thalassia testudinum*) communities developed primarily along the lee sides of keys and on sandy bottoms of the internal lagoons. Since 1974, the park has been subject to intense tourism, which extensively stresses the coral reefs. At present, the park is still being used for recreational purposes, but efforts are underway to preserve it and to carry out scientific research with international cooperation. Our aim is to monitor Morrocoy ecosystems to allow comparison with other coastal sites in the Caribbean.

Introduction

Golfo Triste (Fig. 1) is a large inlet on the west-central coast of Venezuela, in easternmost Falcón state between the villages of Tucacas and Chichiriviche. The gulf lies south of the Bonaire trench, the central region of the Venezuelan Basin, and is the submerged part of an extensive sedimentary deltaic-alluvial plain resulting from sediment dispersal by the Yaracuy and Aroa Rivers. The 32,090 ha Parque Nacional Morrocoy is located on the northwestern coast of the Golfo Triste and encompasses continental, insular, and marine areas.

[1] *CARICOMP — Caribbean Coral Reef, Seagrass and Mangrove Sites* (edited by B. Kjerfve), pp 151-159. UNESCO, Paris, 1998, 347 pp.

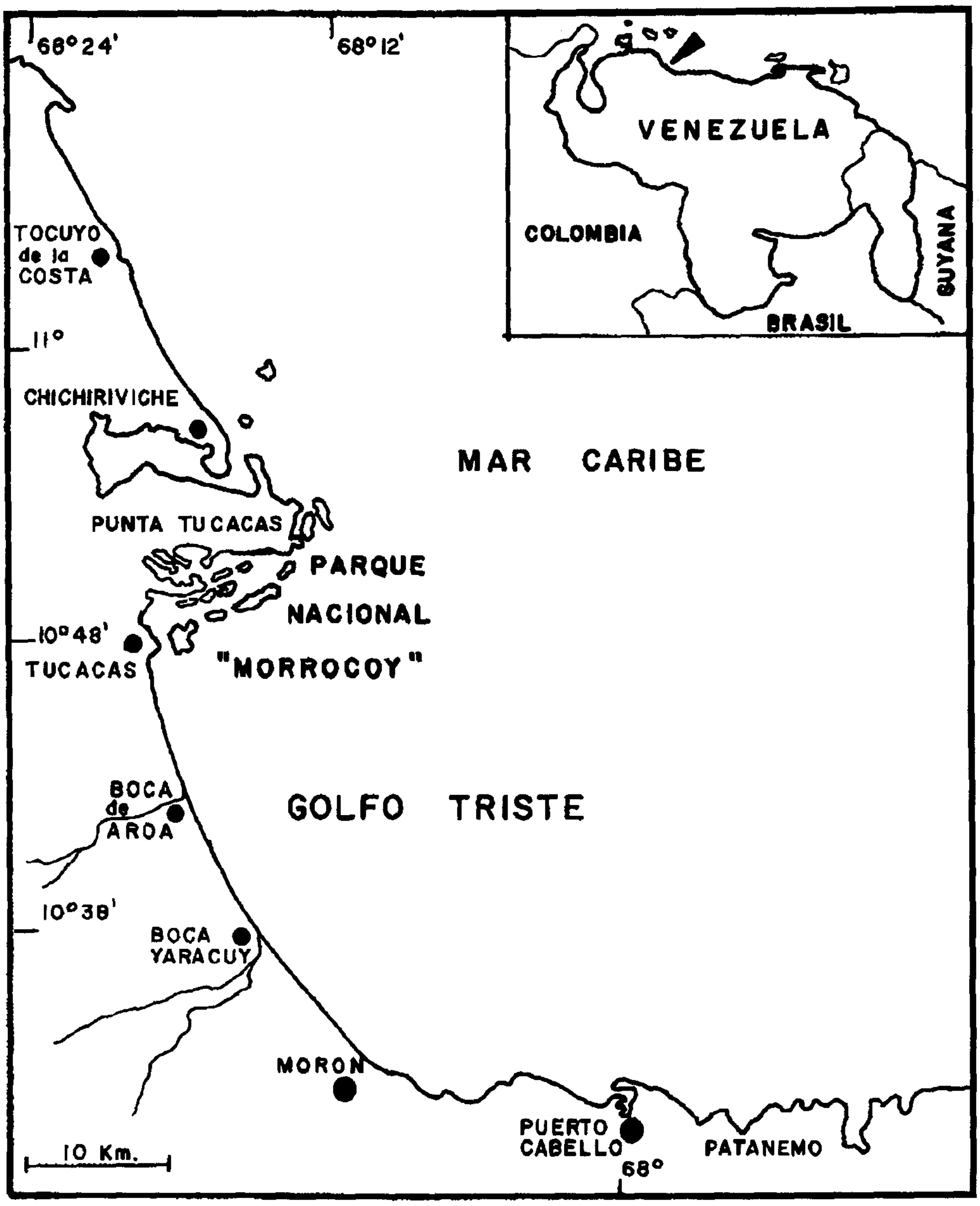

Fig. 1. Map of Golfo Triste showing the locations of the Parque Nacional Morrocoy, major towns (dots), and drainages of the Aroa and Yaracuy Rivers.

Physico-Chemical Parameters

The continental platform that extends from the southeast to the northwest to Golfo de la Vela is characterized by a gentle slope, except near Puerto Cabello and the keys off Tucacas and Chichiriviche, where bathymetric dropoffs occur. Such irregularities correspond to depressions, shallows, and coral islands — keys partially covered by mangroves. The bottom consists of terrigenous and biogenic sediments: fine sand (80-100%), muddy sand (50-80%), sandy mud (20-50%) and mud (0-20%).

Golfo Triste is characterized by a relatively constant climate throughout the year (Fig. 2). The air temperature varies from 24.9 to 29.7°C during the dry season (December-April); maximum temperatures occur during the rainy season (May-October). The relative humidity is high, 83-90%, with the highest

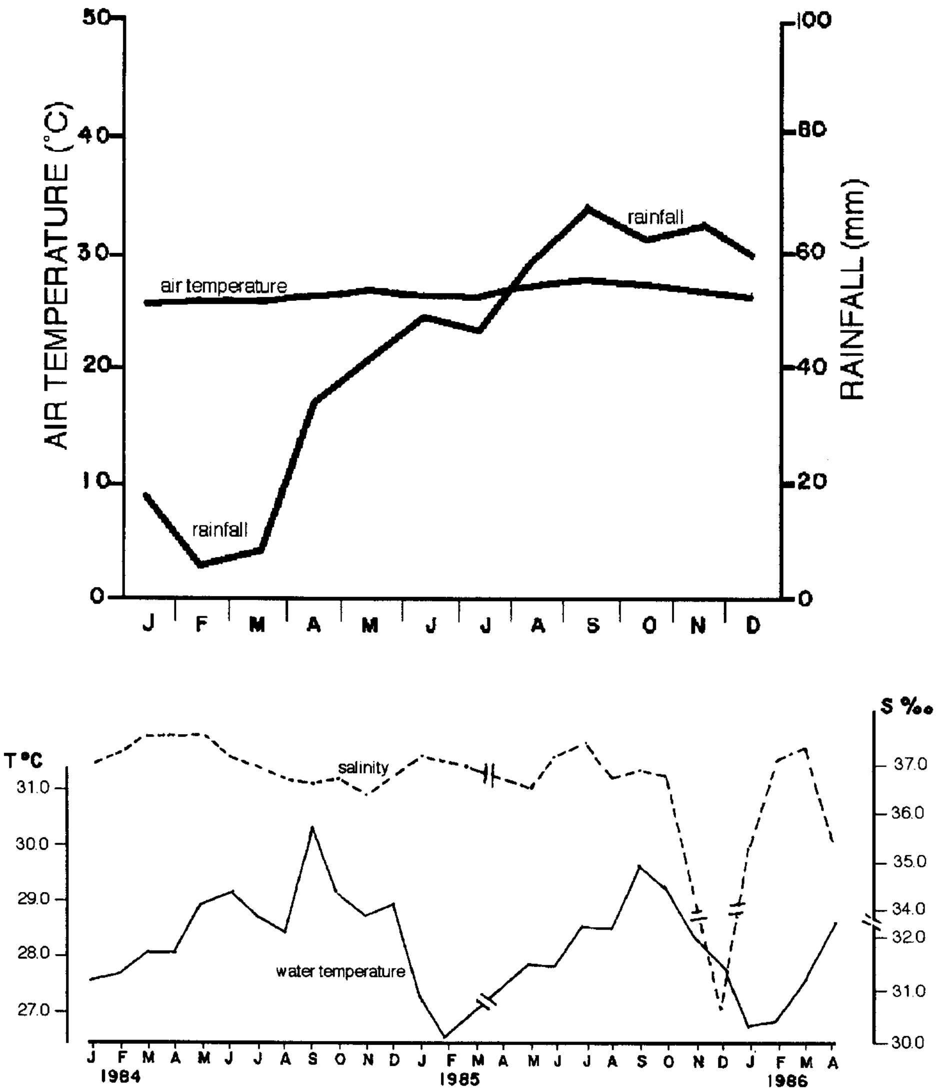

Fig. 2. Annual air temperature and rainfall pattern (top) and annual water temperature and salinity fluctuations (bottom) at Punta Morón, Morón, Golfo Triste.

values recorded between May and August. Mean wind velocity ranges from 1.5 to 2.5 m s^{-1} (Pagán, 1992), the predominant wind direction is NE-SW during most of the year. Seasonal changes in physico-chemical parameters are closely related to variations in wind intensity, which is at maximum during the dry season (Pérez-Nieto, 1980). Water temperature ranges are 26-29°C at the surface and 18-20°C at 150 m depth. Salinities are consistently greater than 36‰ and, because of low runoff and high evaporation rates, often exceed 36.5‰ in the Venezuelan coastal fringe.

The Parque Nacional Morrocoy has a total surface area of 32,090 ha (Fig. 3). The climate of the Morrocoy region is a savannah climate with seasonal influence. The diurnal temperature variation of surface waters fluctuates between 27°C and 32°C, where oceanic influence prevails; the salinity varies between 30 and 38‰ (Bitter, 1988), being more constant near the ocean. Mean annual precipitation is 1,213 mm and varies seasonally (Fig. 2). Two marine zones are distinguished within the park. The seaward zone is connected to the open ocean and is characterized by coraline communities, moderate swells, low turbidity and depths to 20 m. The inshore zone is characterized by low wave activity, higher turbidity, and shallow waters with mangrove (mainly *Rhizophora mangle*) and seagrass (*Thalassia testudinum*) communities (Losada and La Schiazza, 1989). Such communities develop mainly along the lee shores of the keys and in sandy sediments near the mouths of ocean inlets to the internal lagoons.

Human Impact

Weiss and Goddard (1977) reviewed damage to the northern reefs of the park up through 1973 and reported on a series of changes at Chichiriviche, a former fishing village that is now a tourist-centered town within the park. From 1957 to 1964, a cement plant, a water tank and pipeline, and an asphalt road connecting the town to the coastal highway were constructed. These brought about a population explosion in the area, as well as an increase in tourism and related activities that affected not only the mainland but also the keys off Chichiriviche. Towards the end of the 1960s, the reefs began to show signs of man-made disturbances, due to the construction of houses and docks and the disposal of garbage, sewage, and other materials. Weiss and Goddard (1977) considered that sewage caused the most damage.

The 1970s began with the construction of buildings on all existing keys and on many shoals, sand banks, and reef flats. In May 1974, the government of Venezuela declared the area a national park,

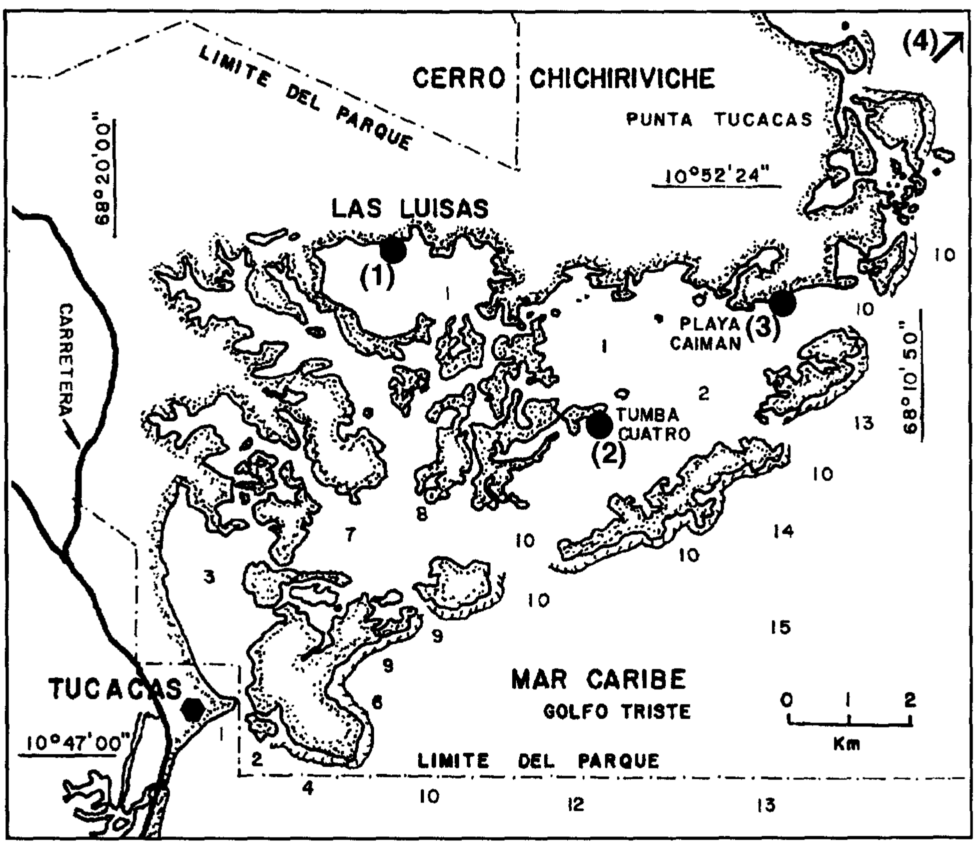

Fig. 3. Map of Parque Nacional Morrocoy (southern portion) showing locations of the CARICOMP sampling sites: (1) seagrass beds, (2) mangroves, and (3 and 4) coral reefs. Small numbers represent depth in fathoms.

ordered demolition of all construction on the keys and beaches, and prohibited further development of coastal towns within the park. Despite these and other protective measures, the damage suffered by the reefs has continued to increase. The reefs, reported healthy by Weiss and Goddard (1977) in 1973, were found to be greatly damaged when first studied in 1979 by Bone (1980) and Weil (1980). Other reefs, in the northern part of the park, had obvious symptoms of deterioration such as high dead coral coverage (>70%) and the stressing and burial of reef colonies by sediments (Bone, 1980). Man-made disturbances in this area include those resulting from bad management of mainland agriculture, with erosion products being carried into the gulf by river drainages and the action of marine coastal currents. Bone *et al.* (1993) suggested that the extent and degree of the damage was due mainly to high sedimentation rates, which began to increase around 1972 with land clearing and construction and have increased further since then.

Other disturbances, both natural and man-made, have impacted the southern portion of the park for several years. Before the park was officially established, elevated houses ("palafitos") were constructed over *Thalassia testudinum* beds. The loss of vegetation and their stabilizing rhizomes produced drastic changes in substrate granulometry such that, more than ten years since demolition, there has been no recolonization of denuded areas. The cutting of mangrove for wood is still a common activity by inhabitants of the area, as is cutting of mangrove roots to collect the oysters that grow on them.

Seagrass Beds

The seagrass ecosystem is well represented in submerged areas of the park, where extensive monospecific prairies of *Thalassia testudinum* and associated algae are found. The sampling site is located in the northern portion of the bay known as Las Luisas (Figs. 3 and 4). The *Thalassia* prairie develops from shore for 80-100 linear meters seaward, where it reaches a depth of 3 m (Losada and La Schiazza, 1989). This prairie is characterized by long leaf plants (30 cm or more), an elevated number of rhizomes, and a leaf cover of more than 60%. Maximum productivity (3.30 ± 0.41 g m^{-2} d^{-1}) and total biomass (862.41 ± 190.89 g m^{-2}) are found in July and August, respectively. The contribution of each fraction of the plant to the total biomass is: green leaves 18.4%, non-green leaves and short stalks 30.1%, live rhizomes 30.2%, dead rhizomes 2.0%, live roots 13.9%, and dead roots 3.5%. Minimum productivity (1.69 ± 0.22 g m^{-2} d^{-1}) and total biomass (385.18 ± 78.74 g m^{-2}) are found in October and July, respectively (Guevara, 1993). The contribution of each fraction to the total biomass is: green leaves 12.5%, non-green leaves and short stalks 25.4%, live rhizomes 40.9%, dead rhizomes 3.4%, live roots 11.1%, and dead roots 5.8% (Guevara, 1993). The seagrass bed ends in a muddy-sand substrate (Losada and La Schiazza, 1989), where the depth is 3 m.

Mangrove Wetlands

Mangroves are well represented in Morrocoy, where they dominate most of the inner emerged areas of the park. The mangrove station is located at Tumba Cuatro (Figs. 3 and 5), where the mangroves are a fringe type that are common throughout the park. The dominant tree species is *Rhizophora mangle*,

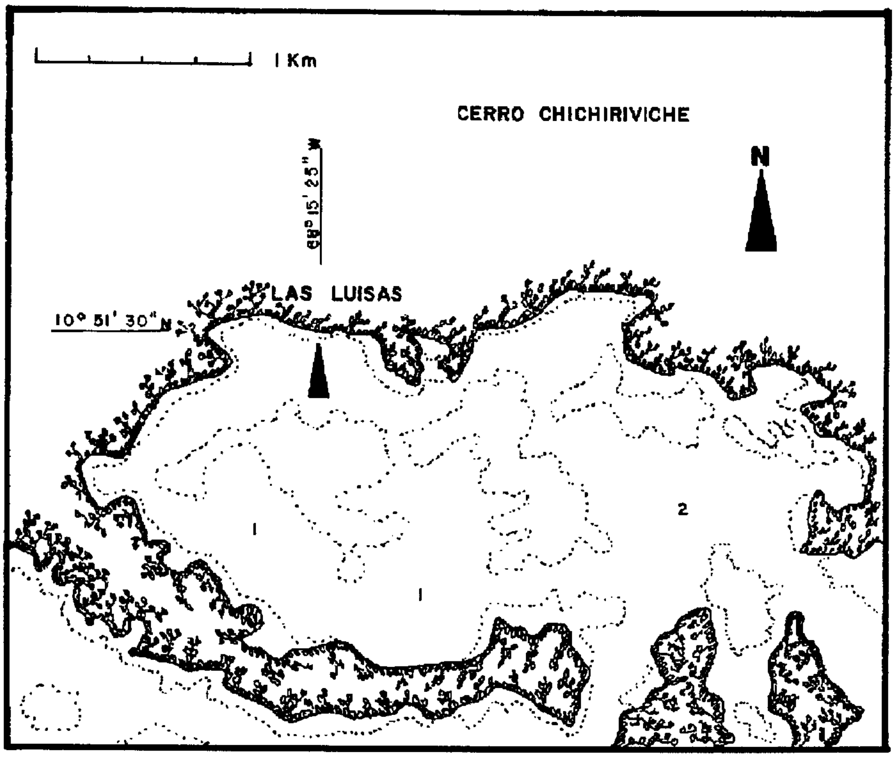

Fig. 4. Detailed map showing the CARICOMP seagrass study site at Las Luisas.
Small numbers represent depth in fathoms.

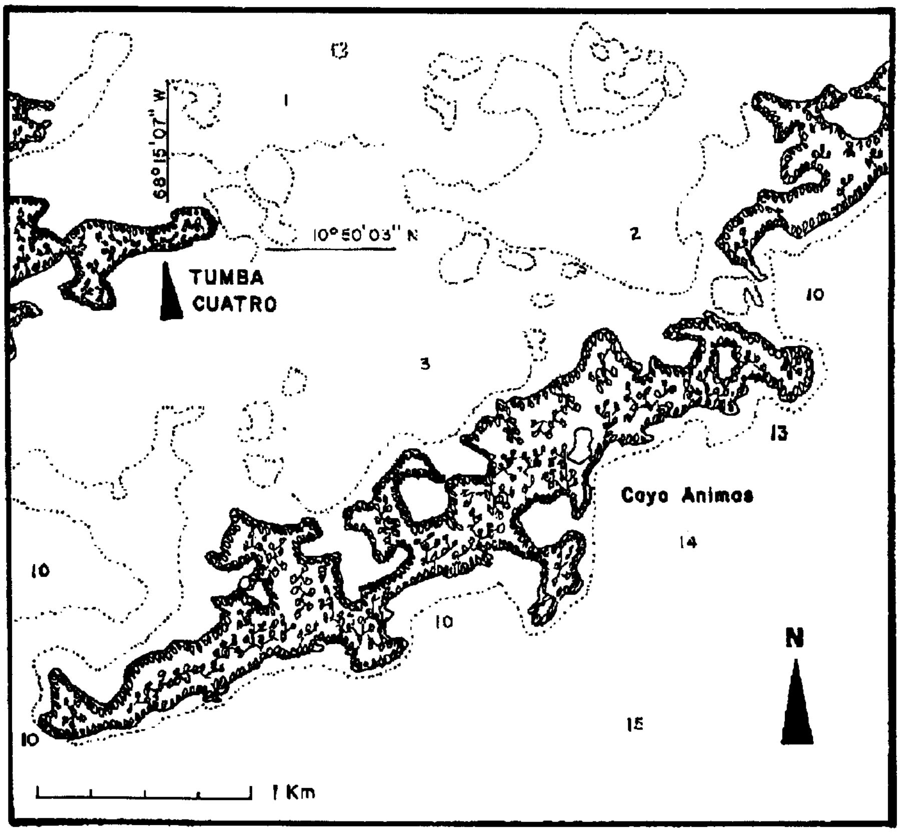

Fig. 5. Detailed map showing the CARICOMP mangrove study site at Tumba Cuatro.
Small numbers represent depth in fathoms.

which is found exclusively at the fringe and occurs mixed with *Laguncularia racemosa* farther inland. The trees are represented by 68% *Rhizophora mangle*, 29% *Laguncularia racemosa*, 8% *Avicennia germinans* (*A. nitida*, Jacq.), and less than 1% unidentified species. The density of the forest is approximately 348 trees/0.1 ha, a value within the range reported for other fringe forests in the Caribbean (densities varying between 100 and 500 trees/0.1 ha; Schaeffer-Novelli and Cintrón, 1986; Lugo and Snedaker, 1974; Snedaker, 1982; Lugo, 1980). According to the "value of importance index" (VI), *R. mangle* is the most valuable species of the area from a structural point of view, with a VI of 259.65; *L. racemosa* has a VI of 140.28; *A. germinans* has a VI of 54.35. The mean height of the trees is 8.0 m, with a maximum height of 15 m for trees with diameter breast height, dbh > 10 cm, and a minimum height of 5 m for trees with dbh < 2.5 cm. The mean dbh for the group of trees with dbh > 10 cm = 37.5 m, representing 45% of the total trees sampled; trees with dbh < 2.5 cm comprise the other 55%. In this area, the mangrove community has reached a high level of structural development — *i.e.*, a high density both of mature and juvenile trees.

Coral Reefs

Coral reef formations dominate the entire coast along the east-northeast shores of the Morrocoy keys, including some shallows in inlets to the park. The reef sites are located at Playa Caimán, in front of Boca Grande, and at Cayo Sombrero, an exposed key in the eastern portion of the park (Figs. 3 and 6).

Playa Caimán is a fringing reef with a channel that breaks with the continuity of the reef and separates the area in two zones: northern and southern. The northern zone has been more affected by man-made disturbances (until 1974, there were three elevated houses located on a small inlet on the leeward side of the reef). The southern zone is more secluded and less disturbed; the reef platform is only 50 m wide and the reef slope reaches to a maximum depth of 12 m. The anterior zone of the platform borders the mangrove forest and a poorly developed *Thalassia testudinum* prairie. The mean depth of the platform is 0.3 m. The algal species reported for the platform are *Halimeda* spp., *Dyctiota cervicornis*, *Caulerpa* spp., *Panicilum capitatus*, *Jama capillosa*, among others (Weil, 1980). The coral species reported are *Diploria* spp., *Millepora alcicornis*, *Siderastrea radians*, and *Porites astrecides*. Extensive formations of the zoanthids *Palithoa mamillosa* and *Zoanthus sociatus* are found toward the reef front. Several species of sponges as well as soft corals of the *Plexaura* sp. are found in crevices in the reef. The reef front (0.20-3.0 m depth) is dominated by formations of *Acropora palmata*, which give rise to high morphological heterogeneity. Other colonies found here are *Millepora alcicornis*, *Millepora complanata*, and *Montastraea annularis*, which grow in columns. This zone continues with an extensive fringe dominated by *Montastraea annularis* (2.5-7 m in depth). There are also colonies of *Colpophyllia natans*, *Diploria* spp., *Agaricia* spp., and some colonies of *Solenastrea bornuoni* in this zone, the most homogeneous coral zone. The deepest zone of the reef (7.0-11 m depth) or slope is mainly dominated by large colonies of *Colpophyllia natans* and also by *Montastraea cavernosa*. There are also several well developed colonies of soft coral such as *Pseudopterogorgia* sp., *Plexaura homomalla*, *P. dichotoma*, and *Eunicea* sp. among the most abundant. This zone ends in a

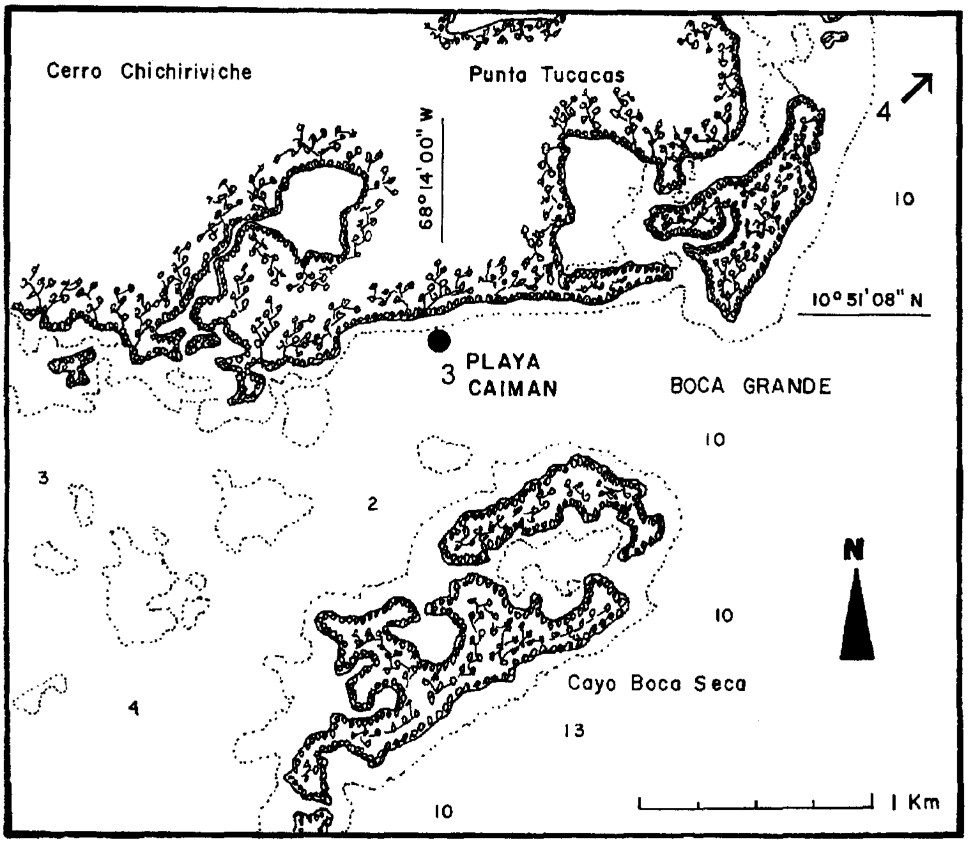

Fig. 6. Detailed map showing the CARICOMP coral reef study sites at Playa Caimán and Cayo Sombrero. Small numbers represent depth in fathoms.

sandy bottom with a soft slope that continues down to 15 m depth, with dispersed patches of coral colonies of variable sizes (Bone, 1980).

Cayo Sombrero is a sandy key surrounded by coral reefs. The CARICOMP station, established in June 1996, is located on the lee side of the key; however, the reef is influenced by strong lateral currents due to the bottleneck configuration of the key system. The main reef is separated from shore by a shallow sandy channel 80 m wide. There is not a genuine reef front. The shallow reef (3 m depth) is covered mainly by soft corals such as *Pseudoplexaura* sp., *Plexaura homomalla*, *P. flexuosa*, and *Pseudopterogorgia americana*. The predominant hard coral at this depth is *Madracis mirabilis*. The slope begins at a depth of 4 m; it reaches 15 m on the southern side and 6 m on the northern side. The CARICOMP station is located in the southern zone characterized by the deeper slope. Between 3 and 5 m deep, the community is represented by *Millepora alcicornis* and *Madracis mirabilis*. Down to 12 m, large colonies of *M. annularis* dominate the reef, with some conspicuous colonies of *C. natans*. There are also some colonies of *M. cavernosa*, *D. strigosa*, *P. porites*, and *A. agaricites*. The reef ends at a depth of 15 m with a gently sloped sandy bottom. In general, this station is structurally more complex than Playa Caimán, although *M. annularis* does not have large vertical formations.

In January 1996, a mass mortality event affected many reefs in the park and left less than 1% of live massive coral cover at Playa Caimán. At this site, only *P. porites*, *S. sidera*, and *Millepora alcicornis* survived. An uncommon upwelling event combined with large river outputs enriched waters with nutrients, leading to an anomalous planktonic bloom. Huge amounts of macroaggregates were produced by dinoflagellates and diatoms, forming a mucous layer that covered the reefs. Very calm seas and low wind speeds kept the bloom within the park. This condition persisted for a week, inducing mortality among fishes, crustaceans, mollusks, equinoderms, annelids, sipunculids, sponges, and cnidarians by either mechanical asphyxiation (obstruction of respiratory mechanisms by a thick layer of mucus) or anoxia (reduction of dissolved oxygen by decomposition of organic matter). The station at Cayo Sombrero was slightly affected, as it was one of the few sites in the park still presenting an important live coral cover.

Acknowledgements

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References

Bitter, R. 1988. *Análisis Multivariado de la Comunidad Asociada a* Thalassia testudinum *en el Parque Nacional Morrocoy.* Tesis de Doctorado, Universidad Central de Venezuela, 240 pp.

Bone, D. 1980. *El Impacto de las Actividades del Hombre Sobre los Arrecifes Coralinos del Parque Nacional Morrocoy, Estado Falcón.* Tesis de Grado, Universidad Central de Venezuela, 89 pp.

Bone, D., F. Losada, E. Weil. 1993. Origin of sedimentation and its effects on the coral communities of a Venezuelan national park. *Ecotrópicos,* **6**(1):10-21.

Guevara, M. 1993. Variación *Temporal y Espacial de la Productividad de* Thalassia testudinum *en el Parque Nacional Morrocoy.* Tesis de Licenciatura, Universidad Simón Bolívar, 80 pp.

Losada, F., J. A. La Schiazza. 1989. Caracterización biológica de algunas comunidades marinas en el Parque Nacional Morrocoy. **In:** *Línea Base de Referencia Biológica en el Ambiente Marino Costero del Área de Golfo Triste* (edited by D. Pérez de Acosta), pp 305-344. Informe Final del Proyecto por Contrato PEQUIVEN-USB. V. II., Caracas, 385 pp.

Lugo, A. E. 1980. Mangrove ecosystems: Successional or steady state? *Tropical Succession,* **6**:72.

Lugo, A. E., S. C. Snedaker. 1974. The ecology of mangroves. *Annual Review of Ecology and Systematics,* **5**:39-64.

Pagán, F. E. 1992. *Estructura Espacio-Temporal de la Comunidad Demersal de Golfo Triste, Estado Carabobo, Venezuela.* Trabajo Especial de Grado, Universidad Simón Bolívar, 159 pp.

Pérez-Nieto, H. (editor) 1980. *Estudio Ambiental Marino Costero de Golfo Triste y Marco de Referencia para Evaluar Efectos de Operaciones Petroleras.* Proyecto MARAVEN-USB, Tomo II, 557 pp.

Schaeffer-Novelli, G., G. Cintrón. 1986. *Guía Para el Estudio de Áreas de Manguezal: Estructura, Funçao e Flora.* Caribbean Ecological Research, Instituto Oceanográfico, São Paulo, Brazil, 150 pp.

Snedaker, S. C. 1982. Mangrove species zonation: Why? **In** *Tasks for Vegetation Science, Vol. II* (edited by D. N. Sean and K. S. Rajpurohit), pp 111-125. W. Junk, The Hague.

Weil, E. 1980. *Papel del Erizo* Diadema antillarum *Philliphi en la Regulación de la Estructura de las Comunidades Coralinas.* Tesis de Licenciatura. Universidad Central de Venezuela, 195 pp.

Weiss, M. P., D. A. Goddard. 1977. Man's impact on coastal reefs: An example from Venezuela. **In:** *Reefs and Related Carbonates: Ecology and Sedimentation* (edited by H. S. Forst, M. P. Weiss, J. B. Sanders). American Association of Petroleum Geologists, 421 pp.

Punta de Mangle, Isla de Margarita, Venezuela[1]

Ramon Varela, Martin Llano, Juan Carlos Capelo, and Yully Velasquez
Estación de Investigaciones Marinas de Margarita (EDIMAR)
Fundación La Salle de Ciencias Naturales, Apartado 144
Porlamar 6301-A, Isla de Margarita, Venezuela

The CARICOMP site at Isla de Margarita is a sandy spit covered by 16 ha of mangroves and 36 ha of seagrass beds. Coral reefs are not present at Punta de Mangle and are scarce around the island. Human activity at the site has been insignificant, historically, although there are harbor facilities nearby. The climate is semi-arid and strongly influenced by trade winds throughout the year (11-25 km h^{-1}); the strongest winds occur February through June. The daily range of air temperature is equal to or greater than the seasonal variation (monthly average of 24.7-30.6°C). Total monthly precipitation is in the range 0-250 mm. Precipitation is most frequent in the months July-September and November-December. The driest months are March-May. Fringe-type mangroves are found along the coast: *Rhizophora mangle, Avicennia germinans*, and *Laguncularia racemosa*. Studies on mangroves began in May 1992 with one plot; two more plots were established during 1995. Tree heights range from 7 to 12 m; trunk diameters range from 26 cm to 119 cm. The total litterfall analyzed over 3.5 years exhibit seasonality: maximum during May-July, 6.0 to 9.8 g m^{-2} d^{-1}; minimum during November-February, 3.0 to 4.0 g m^{-2} d^{-1}. *Thalassia* grows vigorously in most parts of the area. The biomass of the green parts ranges from 190 to 840 g m^{-2}, with an increase in biomass during May. Production shows a large variation, from 2.88 to 11.03 g m^{-2} d^{-1}; the greatest production coincides with the greatest part biomass recorded and with the times of flowering (May) and fruiting (July).

Introduction

Punta de Mangle, which is located on the southern coast of Isla de Margarita (10°51'49"N, 64°03' 28"W; Fig. 1), is a sandy spit extending WSW from the island and oblique to the dominant direction of ocean currents, waves, and trade winds. The strait separating Isla de Margarita from Coche and Cubuagua Islands to the southeast and southwest, respectively, funnels and accelerates the predominantly E-W current, but this has little effect on the mangrove-fringed coastal zone. The major part of the energy is dissipated as the channel deepens into the Las Marites Depression and continues through the Mar-

[1] *CARICOMP — Caribbean Coral Reef, Seagrass and Mangrove Sites* (edited by B. Kjerfve), pp 161-170.
UNESCO, Paris, 1998, 347 pp.

garita Depression to the Fosa de Cariaco (Gines, 1972). Punta de Mangle is the eastern limit of El Guamache Bay, on which are located several towns and a large dock for merchant ships.

The stations for study of the mangroves and seagrass meadows are located at the southern end of Punta de Mangle (Fig. 2). The entire area consists of 163 ha, in which is included 7 ha occupied by the harbor facilities at El Guamache, 26 ha of dry saline soils without vegetation, 36 ha covered by *Thalassia* beds, 21 ha of shallow muddy bottom covered with small algae, and 16 ha of mangroves. The mangroves are located exclusively at the southern half of the sandy point and are predominantly *Rhizophora mangle* and *Avicenia germinans.*

Close to this site are two docks, one for merchant ships along the western face of Punta de Mangle, and the other an oil terminal situated 5 km to the east in Los Algodones. The coast is unpopulated between these docks; the closest human development is quite small and far from the coast. There is no evidence of detrimental effects upon the environment resulting from the presence of the docks. Conversely, the location is commonly visited by native fishermen who sweep the seagrass area with small seine nets. The area is also frequently visited by marine birds, which utilize this coastal area and the mangroves as a resting site.

Historical, Geological, and Human Inventory of the Study Site

Isla de Margarita is the most easterly part of the coastal mountain chain (Cordillera de la Costa) that covers the northern coastal region of Venezuela. This region is separated from the mountainous country of the interior by the Cariaco-Casanay tectonic depression (De Miró, 1974). Isla de Margarita is formed by two mountainous sectors oriented along an east-west axis and united by an isthmus. The eastern part is the more extensive and is Margarita proper, the western part is a peninsula called Macanao. The isthmus between the two sectors consists of extensive flat sedimentary areas where the principal coastal lagoons of the island are found. The southern coasts are characterized by the presence of shallow waters with abundant aquatic vegetation (mangroves and seagrasses) of considerable beauty (Hoyos, 1985).

The paleogeography of the study area is related to sea level fluctuations in the Caribbean and the tectonic morphology of the northern limit of the South American Plate (De Miró, 1974). Nevertheless, the geological history of Punta de Mangle is very recent; this sandy point probably developed during the late Holocene.

Human activity historically had little impact on the coastal ecology of Punta de Mangle, with the exception of the exploitation by local fishermen. The construction of the harbor facilities and access causeway at El Guamache in 1974 destroyed some mangrove areas in the small lagoons north of the study site, but this has seemingly not had a negative affect on the Punta de Mangle.

The mangroves on Isla de Margarita are now protected by environmental laws that forbid cutting mangrove areas for timber or development. However, the impact of public works (*i.e.*, roads and piers) near the mangroves has not been taken into account, in particular runoff and the movement of the subsoil waters and superficial sediments. This is the primary cause of the loss of mangrove areas on the island.

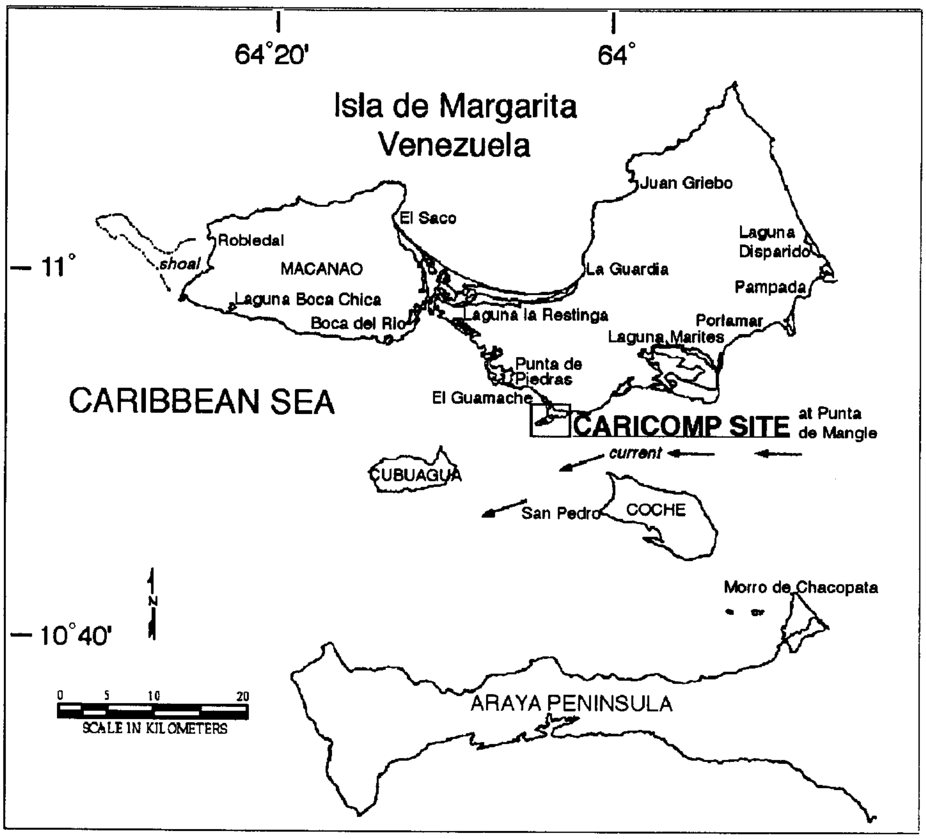

Fig. 1. Isla de Margarita, Venezuela, showing the location of the CARICOMP study site at Punta de Mangle.

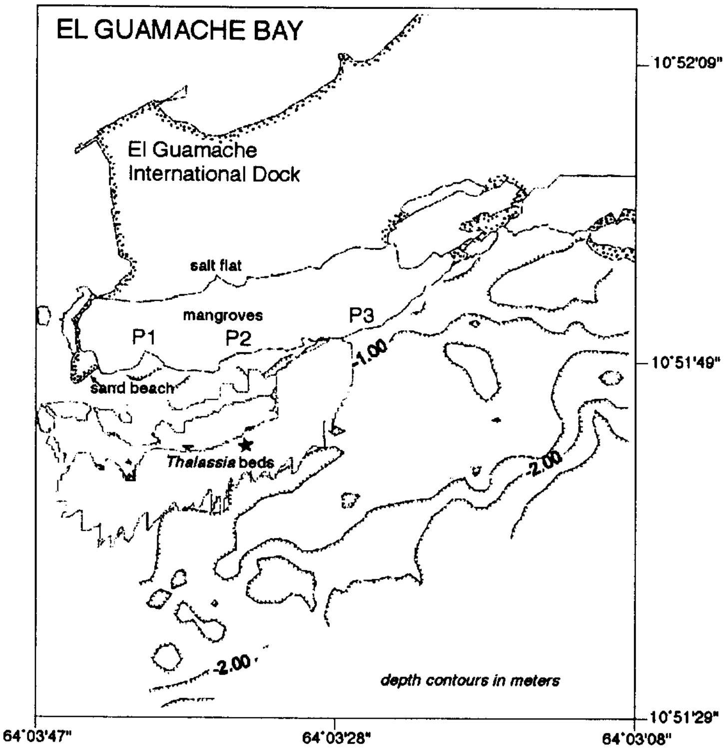

Fig. 2. Punta de Mangle, showing its bathymetry and the distribution of mangroves and seagrass meadows.

Climate

According to the classification of Köppen (Hoyos, 1985), the island is located in a zone of tropical humid climate under the subdivision "humid climate with short rainy seasons." Still, the climate is generally arid or semi-arid. Owing to the stationary high in the coastal zone during much of the year, rainfall is minimal, generating semi-arid conditions and characterized by a water deficit throughout the year. We present here a summary of 24 years of meteorological information collected in Punta de Piedras at the Fundación La Salle marine station, which is 6 km from the CARICOMP site study (Campo and Velásquez, 1991).

Between 1966 and 1989, temperatures fluctuated between 24.7 and 30.6°C (monthly average), during which there was a low frequency oscillation, with a period of 12 years overlying the annual variation. The highest monthly temperatures occurred between April and November, with September and October being the hottest. During that time, no temperature increase could be attributed to global warming. During the study period of January 1993 to October 1995, temperatures taken at Punta de Piedras showed a similar pattern (Fig. 3). What is significant is that the daily range is equal to or greater than the seasonal variation (mode of daily difference 6°C, maximum 12°C, minimum 1.5°C) . Again, no long-term trends are noticeable.

Historically, the average relative humidity has increased with time, with the most humid conditions recorded in January 1985 (91%) and the least humid in May 1967 (63%). For the study period 1993-1995, the average is 78%. The average monthly relative humidity is lowest between February and May and highest between June and November, with a plateau in October.

Total monthly precipitation ranges from zero to 250 mm, indicating the scarcity of rainfall in this area; the average monthly rainfall never exceeds 30 mm. The historical data indicate two groups of months in which precipitation is greatest: July-September and November-December (Campo and Velásquez, 1991). During these times, the precipitation averages 30-50 mm. The driest months are

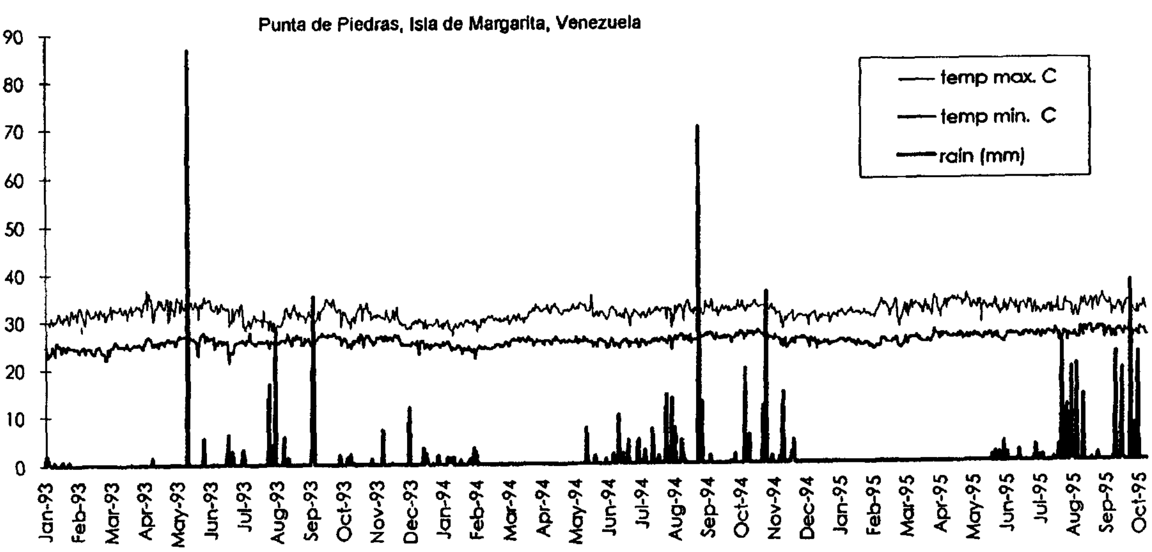

Fig. 3. Daily air temperature and precipitation recorded at Punta de Piedras meteorological station, 1993-1995.

March through May, with an average rainfall of less than 12 mm. There is no permanent streamflow along the entire southern coast of Isla de Margarita, and rainwater runoff into Punta de Mangle region is insignificant because of the small drainage basin.

Daily observations from January 1993 to October 1995 demonstrate rainfall variability (Fig 3). There was significant rainfall in May through July in 1993 and 1994, but not in 1995; in 1994 and 1995, the second rainy season began earlier than in 1993.

Average daily evaporation is 9 mm; average monthly evaporation is approximately 266 mm. Comparing these values with precipitation values (<30 mm), it is clear that evaporative loss greatly exceeds precipitation gains. Average daily insolation is 8.5 hours, varying from zero to 12 hours. The months of greatest insolation are January to March, with about 9 hours; months with minimum insolation are June, July, and December, averaging 8 hours at the most. Average daily radiation varies between 250 and 600 cal cm^{-2} d^{-1} with an average 500 cal cm^{-2} d^{-1}. During the 24-year period of data from Punta de Piedras, these values are similar to the average monthly temperature in that they show an oscillation associated with solar flares.

The average monthly wind velocity analyzed by Campo and Velásquez (1991) ranged from 11 to 25 km h^{-1}, with the strongest winds occurring February through June. The wind pattern on Isla de Margarita is dominated by the trade winds, most commonly from the ENE, as indicated by data collected during 1975-1989.

For the past 200 years, hurricanes and tropical storms have had little effect on Isla de Margarita. Most such storms pass north of the island, producing torrential rains of short duration. The risk of hurricanes and severe meteorological impact is quite small (Carvajal and Buitrago, 1991).

Oceanography

Along the southern coast of Isla de Margarita, the zone of wave generation is reduced to a fringing stretch from east to west, owing to the easterly winds; waves from the north or northeast add little or nothing to the intensity of the local waves. Wave characteristics have not been determined locally; farther east, they vary from 0.6 to 1.0 m, with a periodicity of 4 to 7 sec. The waves at Punta de Mangle are smaller and with still shorter periodicity. Only during infrequent and anomalous atmospheric conditions would waves be generated from the south or southwest. Tides are typically semi-diurnal, with an average range of 0.22 m. The maximum water levels observed over nine years were a high tide of 0.6 m and a low tide of -0.42 m. In general, the marine current passing south of the island is a branch of the Caribbean Current that flows in a westerly direction close to the continental border of South America. This current is derived from the Guyana Current, which enters the Caribbean through the Grenada Strait located between the islands of Grenada and Trinidad and Tobago. Studies completed by the Estación de Investigaciones Marina de Margarita (EDIMAR) indicate that, at Punta de Mangle, the current flows east to west. However, a tide-associated countercurrent has been detected 10 m above the bottom (Campo, 1992). When the tide is rising, the direction of this current is to the west; when the tide is falling, the direction is to the east.

Vector analysis of average grain size was utilized to determine marine dynamics (Llano, 1989; Llano *et al.*, 1991). Sediment type is a function of many variables, including energy forces. Based on preliminary studies of surface sediments from the *Thalassia* zone, we have determined that the site is affected by moderate kinetic energy, which dissipates toward the mangroves — *i.e.*, from south to north.

Three years of weekly temperature and salinity readings were taken at mangrove and seagrass sites (Fig. 4; *CARICOMP Manual*, 1991). The results indicate that the temperature of the water oscillates between 24.5°C and 32.0°C. Sea temperature is always somewhat higher than air temperature; it seems to follow fluctuations in minimum air temperature, as one can observe by comparing both temperatures. The water temperature minimum occurs in March-April, the maximum in August-September. The minimum coincides with the latter part of the upwelling season along the eastern coast of Venezuela (Muller-Karger *et al.*, 1989). The salinity of the sea is relatively high, ranging from 35‰ to 40‰, values common for the southern coast of the island. Secchi depths show no clear tendency but may be dependent on local winds (Fig. 4).

Ecosystems

Of the three communities studied in the CARICOMP program, only mangroves and seagrasses are found together and are well represented on Isla de Margarita. Coral reefs are scarce around the island and are not associated with seagrasses or mangroves. The paucity of coral reefs on the island may be related to the relatively cold water, the turbidity resulting from the occasionally high productivity of plankton, the proximity of discharge from the Orinoco River, and wind-induced turbulence, as well as normal currents. The definitive causes of the poor representation of hermatypic coral in the region have

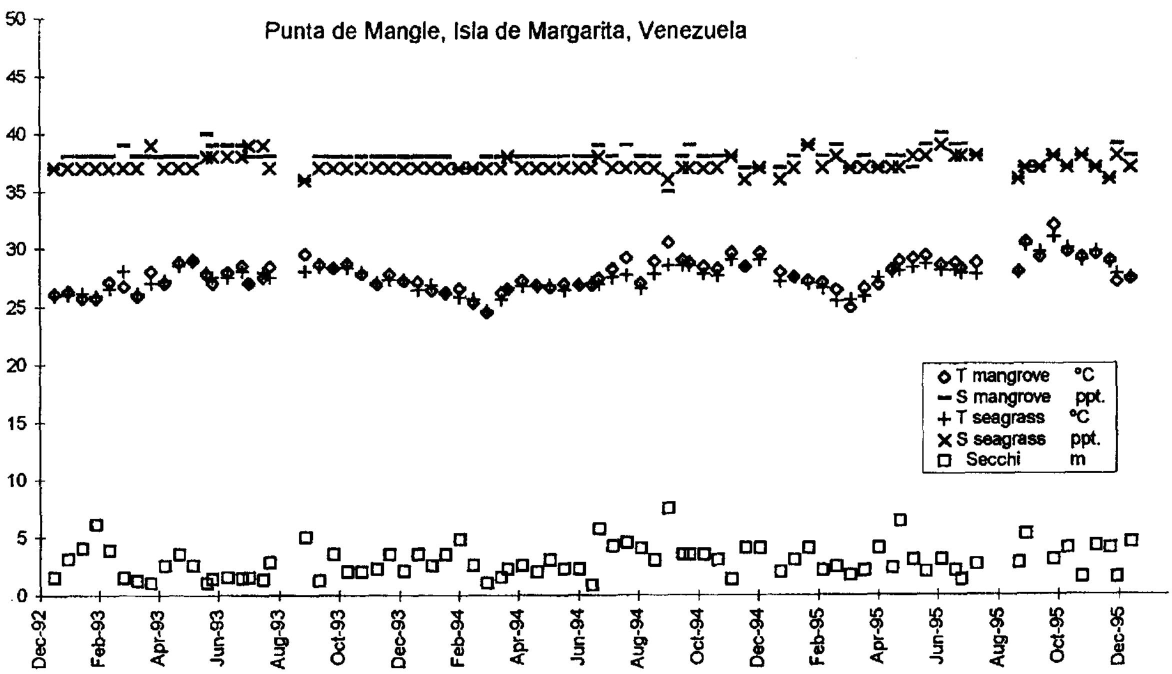

Fig. 4. Seawater temperature and salinity at mangrove and seagrass stations, Punta de Mangle, Isla de Margarita, along with Secchi disk measurements of water transparency at the seagrass station.

not been adequately studied. We are unaware of any biological or geological studies in the area of Punta de Mangle, or of any analysis of the marine ecosystems. Wagenaar Hummelinck (1977, 1981) mentioned Punta de Mangle as a site of both marine and land studies but provided no information about the flora and fauna. Goodbody (1984) utilized samples from Punta de Mangle for studies of ascidians.

Mangroves

The mangroves on Isla de Margarita are associated with hypersaline lagoons with no freshwater input. Typically, the trees are short, with the majority lacking a well-defined trunk. La Restinga and Las Marites are two coastal lagoons with extensive mangroves of this type. Other mangroves of limited range are found along the leeward coast, associated with small lagoons or growing in shallow and protected zones but always associated with seagrasses. Punta de Mangle represents this last type, which may be considered a mangrove fringe (Pannier and Fraiño, 1989).

The mangrove study area covers 16 ha. There is a small lagoon in the area, draining toward the southern coast. Among the three species of mangrove found in the study area, *Rhizophora mangle* (red mangrove) and *Avicennia germinans* (black mangrove) are well represented. The third species, *Laguncularia racemosa*, is not common but is represented by several small trees growing in dry sandy ground in the extreme west. *Rhizophora* forms a band 1,200 m long that is directly exposed to the sea. The community is well developed in comparison with nearby lagoon mangroves. *Avicennia* occupies a landward fringe without the continuity of *Rhizophora*, growing on saline ground affected by high tides.

Studies beginning in May 1992 recorded litterfall in a 100 m^2 study plot populated exclusively by *Rhizophora*; these studies utilized the methodology proposed by CARICOMP (1991). There were five trees in this first study plot; tree heights ranged from 7 to 12 m; trunk diameters ranged from 26 to 119.3 cm, and basal area was 31.4 $m^{-2}\ ha^{-1}$. Two additional plots were studied in 1995 but data are not reported here. The total litterfall in the study plot demonstrated a clear seasonal tendency (Fig. 5). Maximum litterfall occurred May-July: 9 $g\ m^{-2}\ d^{-1}$ in June 1992; 9.8 $g\ m^{-2}\ d^{-1}$ in July 1994; 7 $g\ m^{-2}\ d^{-1}$ in May 1993; 6 $g\ m^{-2}\ day^{-1}$ in May 1995. The minimum occurred in November through February, measuring 3-4 $g\ m^{-2}\ d^{-1}$. Component analysis of the litter showed that flower biomass is constant during the year, indicating that a flowering season is not well defined. Although some seasonal effects occur, the production of leaves is well correlated with total litter. The seasonal fruit-seed falling from the trees is the element which most contributes to variations in the production of foliage.

Seagrasses

Thalassia beds cover an area of 36 ha at Punta de Mangle. The distribution of these grasses seems to be related to type of bottom sediment. *Thalassia* is sparse in the area closest to the mangroves, which has a muddy soft bottom. The seagrass has poorly developed buds and is covered with many epiphytes and coated with fine sediments. The most abundant meadows are some distance from the mangroves (160 m; Fig. 2), where *Thalassia* has colonized the firmer sandy substrate and extends in a wide fringe along the coast. The depths at which *Thalassia* was found ranged from 0.2 m to more than 1.8 m, but the

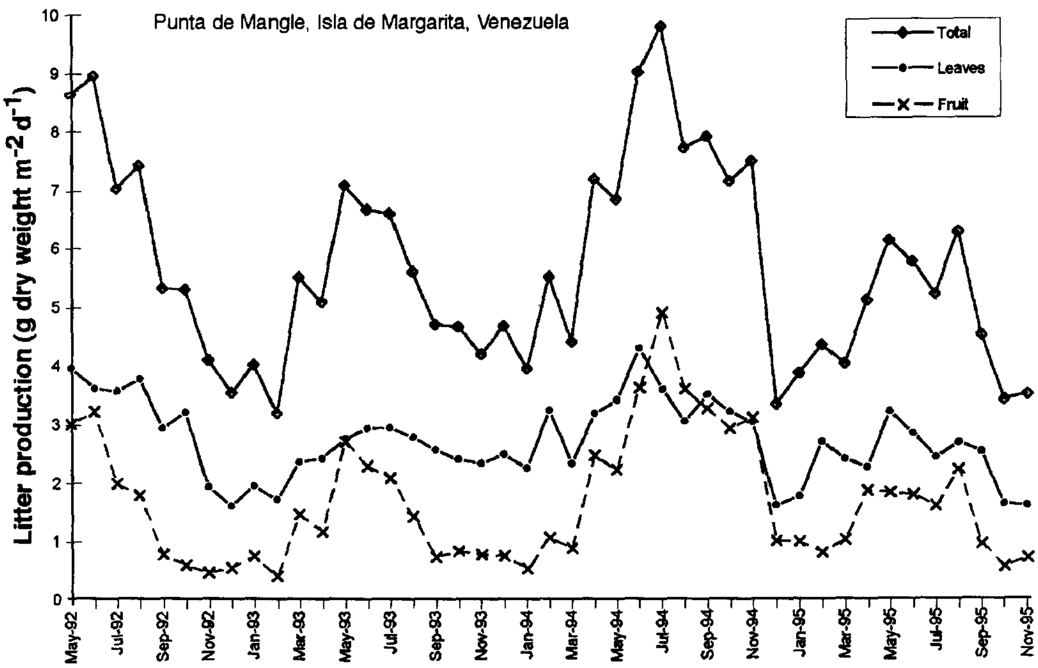

Fig. 5. Litterfall in a plot of *Rhizophora mangle* located in Punta de Mangle, Isla de Margarita.

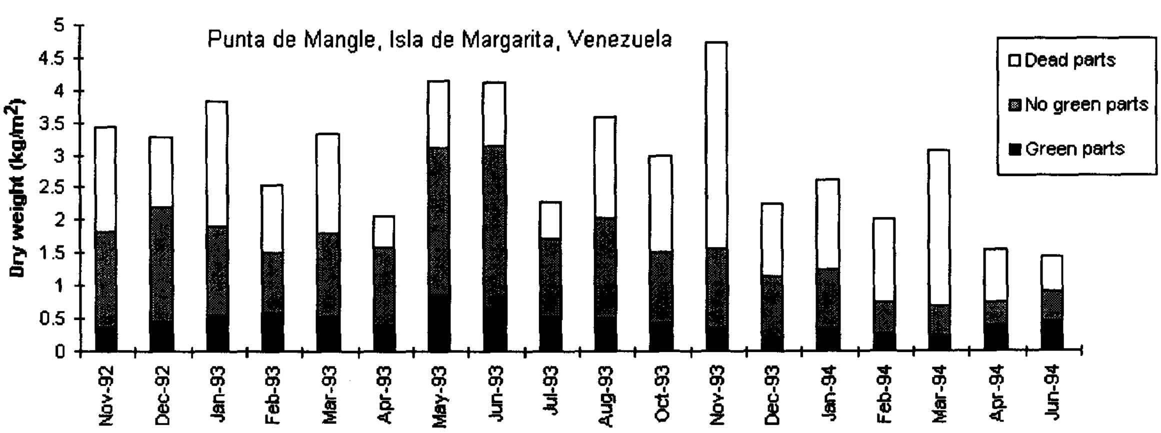

Fig. 6. Monthly variations of *Thalassia* biomass (standing crop) at Punta de Mangle, Isla de Margarita.

greatest depth could not be determined due to high turbidity levels. *Thalassia* grows vigorously at a depth of 0.4-1 m at the CARICOMP station. At a depth of 1.5 m, the leaves are very small and the shoots are less dense along the muddy bottom. From January 1993 through October 1995, the horizontal transparency of the water above the *Thalassia* beds ranged from 0.8 to 7.5 m, with an average visibility of 3 m (Fig. 4).

Preliminary biomass and productivity estimates have been made for the 18-month period between November 1992 and June 1994; it should be noted that, in some instances, insufficient replicates were taken during each sampling. The biomass of green parts ranged from 190 to 840 g m^{-2} (Fig. 6). Even considering the limitations of obtaining only one nucleus per collection, we recorded an increase in green biomass beginning in May. Non-photosynthetic tissues demonstrated a higher biomass: 1,420 g m^{-2} on average, with one large variation among the samples. There was no evidence of seasonality. The biomass of dead tissues also varies and showed no pattern; they averaged 1,380 g m^{-2}.

Thalassia production and daily turnover in 1993 and 1994 are shown in Table 1. Production oscillated between 2.88 and 11.03 g m^{2} d^{-1}. The greatest production coincides with the highest green biomass values as well as with the time of flowering in May and fruiting in July.

Table 1. *Thalassia* production in Punta de Mangle, Isla de Margarita, Venezuela.

Date of Measurement	Production ($g\ m^{-2}\ d^{-1}$)	Turnover (% per day)
01/21/93	5.70	0.03
02/01/93	7.34	0.05
02/21/93	3.95	0.03
03/08/93	11.03	0.03
03/27/93	7.21	0.03
08/31/93	10.04	0.06
09/15/93	9.97	0.05
12/15/93	2.88	0.04
01/19/94	7.31	0.04
02/02/94	5.27	0.04
03/09/94	4.09	0.04
04/0-5/94	8.29	0.03
06/01/94	5.51	0.03
06/16/94	4.27	0.03

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References

Campo, M. 1992. *La Dinámica Marina entre la Isla de Margarita y La Península de Araya. Informe Final al Proyecto Conicit, Subvención: S1-1570.* Fundación LaSalle, Estación de Investigaciones Marinas de Margarita, EDIMAR, 440 pp.

Campo, M., F. Velásquez. 1991. *Resumen Climatológico de la Estación Meteorológica de Punta de Piedras, Estado Nueva Esparta, Venezuela. Período: 1966-1989.* Pole de Recherche Oceanologique et Halieuthique Caraibe, Document Scientifique No. 29, Mai 1991; Ifremer, UAG, ORSTOM, 39 pp., 39 fig.

CARICOMP. 1991. *Manual of Methods for Mapping and Monitoring of Physical and Biological Parameters in the Coastal Zone of the Caribbean.* UNESCO, Paris, 35 pp.

Carvajal, F., J. Buitrago. 1991. *La Ostra Perla Pinctata Radiata Leach, en el Nororiente de Venezuela y su Posibilidad de Cultivo.* Informe técnico EDIMAR, 42 pp.

De Miró, M. 1974. *Morfológia Submarina y Sedimentos Marinos Recientes del Margen Continental del Nororiente de Venezuela.* Cuadernos Azules No. 14, Caracas, 230 pp.

Gines, H. 1972. *Carta Pesquera de Venezuela: 1, Area del Nororiente y Guayana.* Fundación La Salle de Ciencias Naturales, Monografía No. 16, Caracas, 328 pp.

Goodbody, I. 1984. Ascidians from Caribbean shallow water localities. *Studies on the Fauna of Curaçao and Other Caribbean Islands,* **67**: 62-76.

Hoyos, J. 1985. *Flora de la Isla de Margarita, Venezuela.* Sociedad y Fundación La Salle de Ciencias Naturales, Monografía No. 34, Caracas. 927 pp.

Muller-Karger, F. E., C. R. McClain, T. R. Fisher, W. E. Esaias, R. Varela. 1989. Pigment distribution in the Caribbean Sea: Observations from space. *Progress in Oceanography,* **23**:23-64.

Llano, M. 1989. Dinámica sedimentaria en la Bahía del Guamache, deducida del análisis vectorial del tamaño medio de los granos. *Boletín Instituto Oceanográfico de Venezuela, Universidad Oriente,* **28** (1-2):269-275, 1 table, 6 fig.

Llano, M., P. I. Guevara, A. Acevedo. 1991. El análisis vectorial en la determinación de zonas de erosión, transporte y sedimentación en lagunas costeras. *Memoria Sociedad Ciencias Naturales La Salle,* **51** (135-136):43-56.

Pannier, F., R. Fraiño de Pannier. 1989. *Manglares de Venezuela.* Cuadernos Lagoven, Caracas, 67 pp.

Wagenaar Hummelinck, P. 1977. Marine localities. *Studies on the Fauna of Curaçao and Other Caribbean Islands,* **51**:15-68.

Wagenaar Hummelinck, P. 1981. Land and freshwater localities. *Studies on the Fauna of Curaçao and Other Caribbean Islands,* **63**:1-133.

Buccoo Reef and Bon Accord Lagoon, Tobago, Republic of Trinidad and Tobago[1]

Richard S. Laydoo, Kurt Bonair, and Gerard Alleng
Institute of Marine Affairs
PO Box 3160, Carenage Post Office
Republic of Trinidad and Tobago

Buccoo Reef and Bon Accord Lagoon are located on the leeward coast of southwestern Tobago. This is one of two localities in Trinidad and Tobago characterized by contiguous reef, seagrass, and mangrove ecosystems. The reef system is approximately 7 km^2 in area and is characterized by an arc of five reef flats that enclose a shallow reef lagoon and the Bon Accord Lagoon. There is patchy distribution of coral communities within the reef lagoon, mainly staghorn coral and star coral. The Bon Accord Lagoon is characterized by macroalgae and seagrass communities. The mangrove wetland fringing the lagoon is primarily red mangrove. Seaward of the reef flats, the forereef slopes to depths of 15-30 m. Brain coral, star coral, and elkhorn coral are the dominant coral species on the forereef.

Introduction

The Buccoo Reef and Bon Accord Lagoon system is located at the southwestern end of the island of Tobago between 11°08'N to 11°12'N latitude and 60°40'W to 60°51'W longitude (Fig. 1). The reef covers an area of 7 km^2. It is a fringing reef, characterized by five insular emergent platforms to the north, a shallow sandy lagoon with a patchy distribution of coral communities, and the mangrove-fringed Bon Accord Lagoon in which a seagrass community is present. This system is the best example of contiguous reef, seagrass, and mangrove wetland in Trinidad and Tobago (Fig. 2).

The extant reef is of Holocene origin (*ca.* 10,000-12,000 years BP) lying on a Pleistocene carbonate platform. The platform, which is emergent to the south of the reef system, characterizes the terrestrial geology of the low-lying southwestern region of Tobago (Maxwell, 1948). The Buccoo Reef-Bon Accord Lagoon area is unique to the southern Caribbean due to its size, attractiveness, and easy accessibility (Goreau, 1967). It is located on the low-energy, leeward southwestern coast of Tobago. Such attributes have led to its development as a major tourist attraction.

Guided tours to the reef were initiated in the 1930s. Today, the primary activities associated with visitor use at Buccoo Reef include glass-bottom boat tours to the Outer Reef flat, the Coral Gardens, and

[1] *CARICOMP — Caribbean Coral Reef, Seagrass and Mangrove Sites* (edited by B. Kjerfve), pp 171-176.
UNESCO, Paris, 1998, 347 pp.

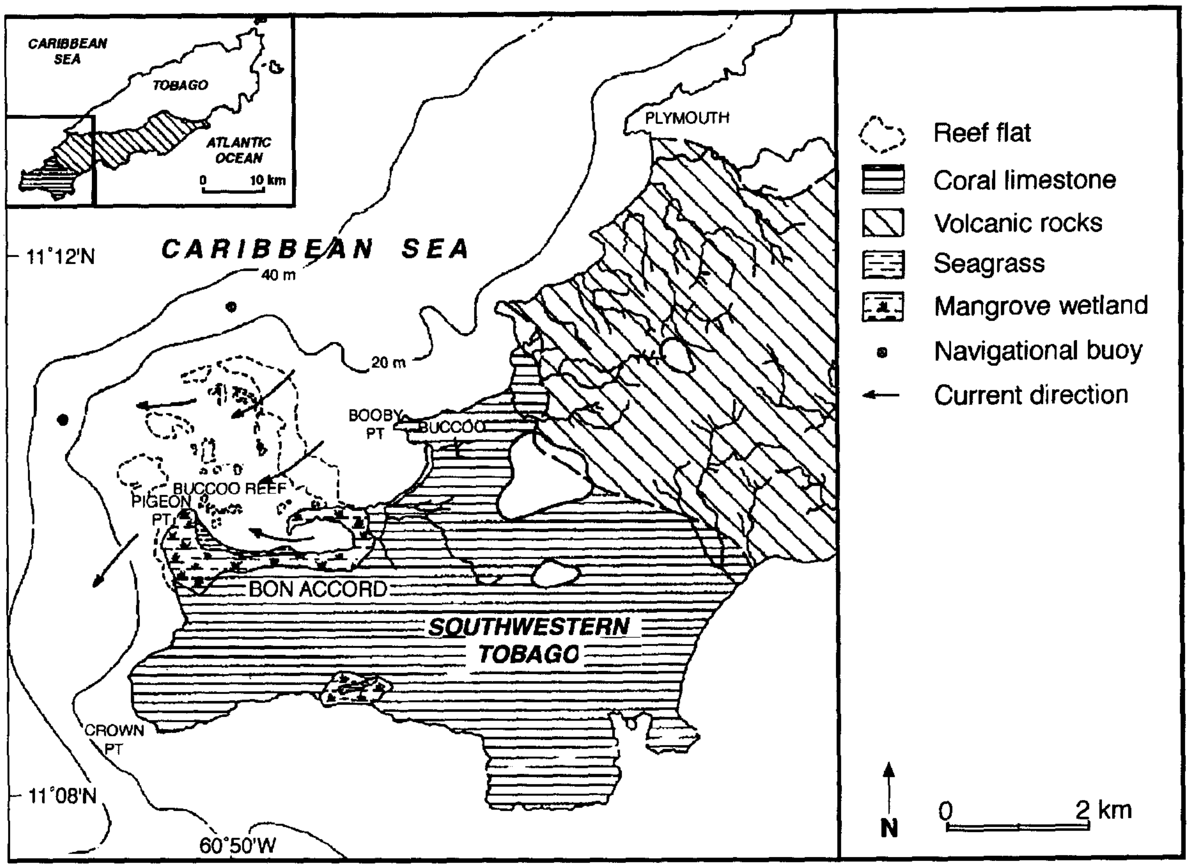

Fig. 1. Map of southwestern Tobago and location of Buccoo Reef.

the Nylon Pool, along with reef-walking and snorkelling on the shallow backreef areas of the Outer Reef flat. Sport-diving occurs at forereef sites, but this activity is not common at Buccoo Reef due to the presence of higher quality dive sites at other reef localities in Tobago.

The promotion of the Buccoo Reef area as a major tourist attraction, combined with hotel and residential development in adjacent coastal areas, has resulted in direct and indirect negative impacts on the ecosystems. Direct impacts are evident as physical damage over an extensive area of the Outer Reef flat; corals have been broken or crushed by trampling feet, falling anchors, and intermittent boat groundings (Goreau, 1967; Kenny, 1976). Indirect impacts are more insidious and are linked to the discharge of untreated sewage and to increased surface run-off (Laydoo and Heileman, 1987). Major population centers adjacent to the Buccoo Reef system are the villages of Buccoo and Bon Accord, as well as numerous hotels and guest houses along the coast from Plymouth to Crown Point (Fig. 1). Pollution threatens the viability of the reef through nutrient enrichment of the seawater and increased algal growth. This, combined with the effects of reef-walking, potentially reduces the possibility of coral regeneration in damaged areas. Sewage pollution at some localities presents a serious hazard to sea-bathers.

Recognition of the resource value of the Buccoo Reef system has resulted in its designation in 1973 as the country's only marine protected area under the Marine Areas (Preservation and Enhancement) Act of 1970. However, no effective management has been implemented since its designation as a protected area, even though management proposals and draft plans have been developed. Only recently, the Institute of Marine Affairs, with assistance from the Tobago House of Assembly (the local government authority), developed a management plan for the proposed Buccoo Reef Marine Park.

Climate and Oceanography

Trinidad and Tobago have a humid, tropical climate. The mean annual temperature is 25.7°C, and precipitation is highest May to December. Southwestern Tobago generally gets little precipitation, with a maximum of 40 mm during the wet season and a maximum of 15 mm during the dry season (Berridge, 1981). Trinidad and Tobago, located at the southern extremity of the Antilles Archipelago, lie south of the hurricane belt. However, the islands occasionally experience tropical storms and hurricanes. The most recent hurricane in Tobago occurred in September 1963. The prevailing winds during the wet season are the northeast trades. In the dry season, winds are generally stronger and the prevailing wind direction is westerly. The Buccoo Reef system is exposed to the northeast trades throughout the year. Consequently, the Outer and Eastern Reef flats are subject to moderate to high wind and wave energy, particularly during the dry season when winds are stronger. Wave energy on the northeastern reef fringe is also high during the winter months, November-December, when strong oceanic swells are common. This generally results in increased turbidity in the reef area (Kenny, 1976).

Water movement in the Buccoo Reef area is predominantly wind driven; it is generally westerly, with some reversal in the Bon Accord Lagoon and the southwest channel near Pigeon Point during flood tide (Kenny, 1976; Fig. 1). Surface circulation to the west of Buccoo Reef, however, is apparently more influenced by northwesterly water movement between Trinidad and Tobago. The salinity and turbidity of this water is strongly influenced by Orinoco River discharge during the wet season. This has marked effects on the water quality at Buccoo Reef, where lower mean salinity (34 ‰) and higher turbidity (15 m visibility) are common during the wet season. In the dry season, a higher mean salinity (36 ‰) and clearer water is generally observed (Berridge, 1981). Seawater temperature is generally constant within depths less than 20 m, ranging from 24°C in winter to 27°C in summer (Berridge, 1981).

Mangrove Wetlands

The Bon Accord Lagoon is bordered to the south and east by a mangrove wetland (Fig. 2) of lagoon fringe type, which forms a belt several meters wide and has an area of 77 ha. Indications are that this is a mature community, with conditions for growth close to optimum (Goreau, 1967). Red mangrove (*Rhizophora mangle*) predominates, but white mangrove (*Laguncularia racemosa*) is also common. Black mangrove (*Avicennia germinans*) and button mangrove (*Conocarpus erectus*) are also present.

In the northeastern sector, the mangrove fringe is connected by a small channel to another mangrove area located in the southern sector of Buccoo Bay. This is a basin mangrove community type located behind a sandy beach barrier. There are several perennial inlets into the system in this sector, but there are no outlets except the small channel connecting to the lagoon fringe community. It has been suggested that this basin area is a continuation of the Bon Accord Lagoon wetland system (Alleng, 1994). Although the land adjacent to the entire Bon Accord-Buccoo Bay wetland is privately owned, the wetland

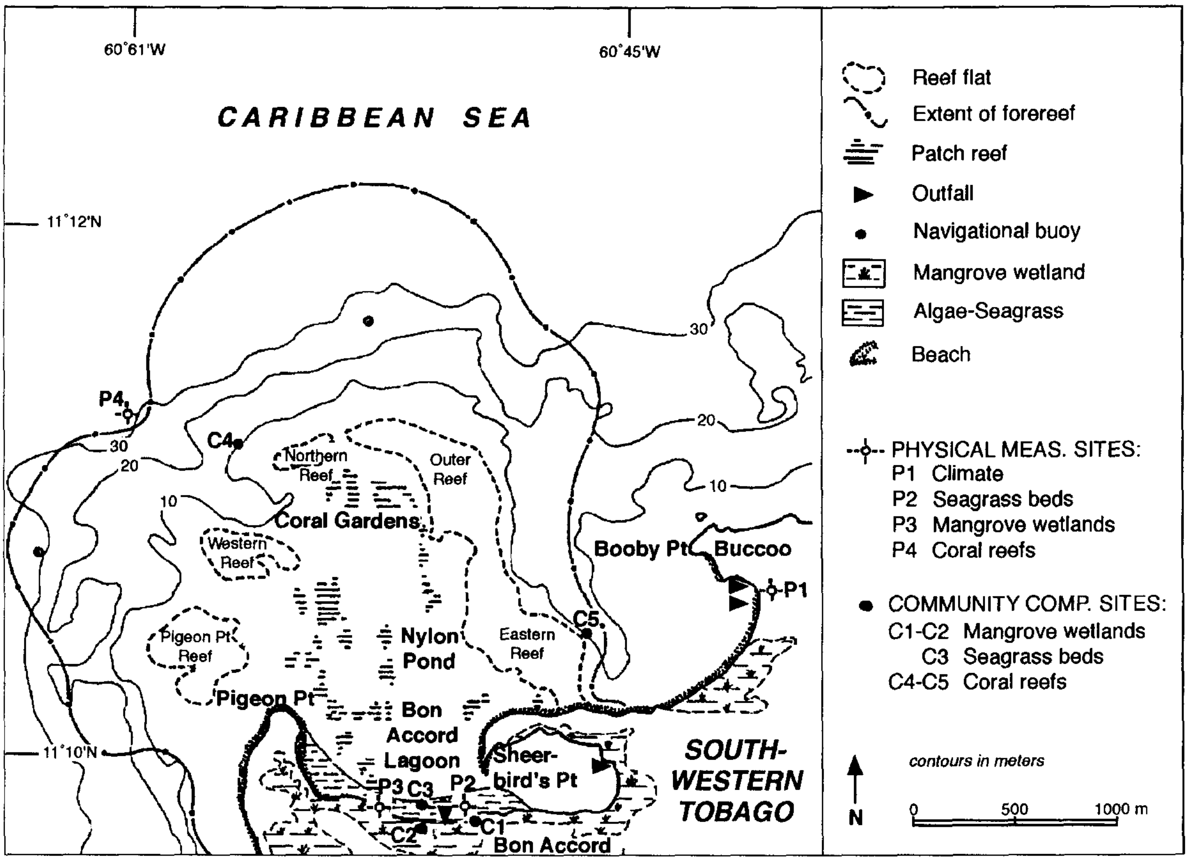

Fig. 2. Buccoo Reef and adjacent seagrass and mangrove ecosystems, with location of CARICOMP sampling localities.

itself has been included in the Buccoo Reef Restricted Area and the proposed Buccoo Reef National Park. Adjacent land use is mainly agriculture, residential development, or scrub vegetation.

The system has been impacted by both natural and human factors. Most of the western part of the mangrove wetland was destroyed by Hurricane Flora in September 1963 but it has recovered since then. Some mangroves were also cleared at Sheerbird's Point for beach improvement in the 1960s, and gaps have been cut for jetties and drainage canals. In the past two years, a housing estate has been developed along the southwestern boundary of the wetland, with concomitant construction of sewage treatment ponds. It has been proposed that some enclosed lagoons in this area of the wetlands be utilized for the discharge of treated domestic waste.

Seagrass Beds

An extensive seagrass bed is located in the western area of the Bon Accord Lagoon (Fig. 2). Turtle grass (*Thalassia testudinum*) is the dominant seagrass. The benthic community also contains macroalgae (*Bryopsis* spp., *Dictyota* spp., *Chaetomorpha* spp.), sea urchins (*Lytechinus variegatus*), mollusks (*Strombus* spp.), oysters (*Pinctada radiata*) and holothurians (unidentified) (Kenny, 1976).

Coral Reefs

North of the Bon Accord Lagoon is the extensive, shallow reef lagoon of Buccoo Reef (Fig. 2). Small coral formations, characterized by one or a few species, occur throughout the reef lagoon. Four types of these patch reefs have been identified (Hudson, 1984). Patch reefs of finger coral (*Porites porites*) occur in the Bon Accord Lagoon and south of it. The patch reefs in the western area of the reef lagoon are composed of thickets of staghorn coral (*Acropora cervicornis*), while those in the eastern area are composed of both staghorn and fire coral (*Millepora* spp.). The patch reefs in the northern area of the reef lagoon consist primarily of large formations of star coral (*Montastraea annularis*) and brain coral (*Diploria strigosa*). Due to the presence of sea fans (*Gorgonia ventalina*) and other octocorals, as well as numerous colorful reef fishes, this northern patch reef locality is popularly known as "Coral Gardens."

Five emergent reef flats arc seaward of the reef lagoon, from Pigeon Point in the west to Sheerbird's Point on the east, known as Pigeon Point Reef, Western Reef, Northern Reef, Outer Reef, and Eastern Reef (Fig. 2). The reef flats are separated by sandy-bottom channels, the widest and deepest of which is the Deep Channel between the Western and Northern Reefs. The reef flats are generally characterized by a narrow seaward reef crest and a more extensive backreef toward the reef lagoon. The reef crests coincide with a conspicuous breaker zone. Due to the turbulent nature of this zone, the faunal composition of the reef crests is limited to wave-resistant corals such as *M. annularis*, and elkhorn coral, *A. palmata*. Generally, the backreef areas are characterized by coral rubble (Kenny, 1976).

West of the reef flats, the forereef slopes gently to a depth of 20 m. To the east, the forereef slopes to a depth of 15 m, while to the north the forereef slopes gently to depths over 30 m (Laydoo, 1985). The benthic fauna of the forereef is dominated by large colonies of stony corals. In the shallow forereef zone (2-6 m depth) *A. palmata* is common. In deeper areas of the forereef, large colonies of *Diploria* spp., *Montastraea* spp., and starlet coral (*Siderastrea* spp.) are common. The substrate of the shallow forereef is mainly composed of rubble and dead standing remains of *A. palmata* (Laydoo, 1985).

Acknowledgements

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References

Alleng, G. P. 1994. *Advanced Application of Remote Sensing with Specific Reference to Caribbean Coastal Environments.* Final Report to the Caribbean Development Bank, Barbados, 51 pp.

Berridge, C. E. 1981. Climate. **In:** *The Natural Resources of Trinidad and Tobago* (edited by St. G. Cooper and P. R. Bacon), pp 3-6 and 113-117. Edward Arnold, London, UK, 223 pp.

Goreau, T. F. 1967. *Buccoo Reef and Bon Accord Lagoon, Tobago: Observations and Recommendations Concerning the Preservation of the Reef and its Lagoon in Relation to Urbanisation of the Neighbouring Coastal Islands.* Memorandum to Permanent Secretary (Agriculture), Economic Planning Unit, Prime Minister's Office, Government of Trinidad and Tobago, 8 pp.

Hudson, D. I. G. 1984. *Patch Reef Zonation on Buccoo Reef, Tobago.* Proceedings of the Association of Island Marine Laboratories of the Caribbean, Number 18, 7 pp.

Kenny, J. S. 1976. *A Preliminary Study of the Buccoo Reef/Bon Accord Complex, with Special Reference to Development and Management.* Department of Biological Sciences, University of the West Indies, Trinidad, 123 pp.

Laydoo, R. S. 1985. *The Forereef Slopes of the Buccoo Reef Complex, Tobago.* Technical Report, Institute of Marine Affairs, Trinidad, 22 pp.

Laydoo, R. S., L. Heileman. 1987. *Environmental Impacts of the Buccoo and Bon Accord Sewage Treatment Plants, Southwestern Tobago. A Preliminary Report.* Institute of Marine Affairs and Crusoe Reef Society, 27 pp.

Maxwell, J. S. 1948. Geology of Tobago. *Bulletin of the Geological Society of America,* **59**:801-854.

Barbados[1]

Christoph Parker and Hazel A. Oxenford
Bellairs Research Institute, McGill University, Holetown, St. James, Barbados
Marine Resource and Environmental Management Programme, University of the West Indies, Cave Hill, Barbados

The CARICOMP sites on Barbados include a reef site near Holetown on the west coast and, 25 km away on the south coast, a seagrass site (St. Lawrence Lagoon) and a mangrove site (Graeme Hall Swamp). The 32 ha Graeme Hall Swamp is fringed by red and white mangroves and is greatly impacted by a large population and several channel-dredging projects. The seagrass site is located in a shallow lagoon that is protected from high energy waves by a reef rubble bank; turtle and manatee grasses dominate. Shallow fringing reefs are fairly extensive along the west coast of Barbados. The reef site, the Bellairs fringing reef, extends 300 m seaward from the shoreline and is very shallow, with the base of the reef at a depth of 6 m. *Agaricia agaricites* is the dominant coral species, but *Porites porites* was dominant before Hurricane Allen in 1980.

Introduction

Barbados is a small island (430 km^2), with a large population (258,000), located 190 km east and windward of the Lesser Antilles island chain in the southeastern Caribbean (Fig. 1). The island has a relatively low relief (maximum elevation 340 m) and is largely covered (88%) by a Pleistocene coral cap. Average annual rainfall in the coastal regions of the island varies from 1100 mm to 1250 mm (James *et al.*, 1977). There are no locations on the island where a mangrove wetland, a seagrass bed, and a shallow nearshore hard coral reef can be found in close proximity. Therefore, two CARICOMP monitoring sites have been established in Barbados; one on the west coast just north of Holetown at Folkestone Park (13°11'18"N, 59°38'31"W), to monitor a nearshore hard coral reef (Bellairs fringing reef), and one on the southwest coast at Graeme Hall, St. Lawrence (13°04'06"N, 59°34'39"W), to monitor a mangrove wetland (Graeme Hall Swamp) and a seagrass bed (St. Lawrence Lagoon).

A surface water current with a predominately westward component passes through the Lesser Antilles from the Atlantic Ocean into the Caribbean Sea (Brucks, 1971; Emery, 1972; Kinder, 1983). Barbados receives both South and North Equatorial waters, depending on the time of year. Barbados receives South Equatorial water via the Guiana Current (Ryther *et al.*, 1967; Borstad, 1979; 1982) beginning in January. After August, a change in the tradewind pattern gives the current a stronger westerly

[1] *CARICOMP — Caribbean Coral Reef, Seagrass and Mangrove Sites* (edited by B. Kjerfve), pp 177-185. UNESCO, Paris, 1998, 347 pp.

component, and the main oceanic water mass arrives via the North Equatorial Current (Borstad, 1982). Analyses of coastal zone color scanner images collected between November 1978 and December 1982 illustrate the existence of ephemeral countercurrent eddies (100 to 250 km diameter) east of Trinidad (Muller-Karger *et al.*, 1989). The generalized surface water flow around Barbados is shown in Fig. 1.

Mangrove Wetlands

Graeme Hall Swamp covers an area of 32 ha in one of the most densely populated areas of the island (Riven-Ramsey, 1988) (Fig. 2). Residential development surrounds the swamp along the southern, eastern, western and northwestern boundaries, a main coastal road (Hwy 7) runs between the swamp and the sea on the south side, and agricultural lands border the swamp along the northeastern side. The swamp is essentially divided into an eastern and a western quadrant by a wide, man-made footpath/ roadway oriented from north to south through the area.

In the western quadrant of the swamp, a shallow, roughly rectangular (150 × 120 m) brackish lake is surrounded by a dense fringe of red (*Rhizophora mangle*) and white (*Avicennia racemosa*) mangroves. A detailed survey done in 1987 by Cattaneo *et al.* (1987) shows that the shores of the lake drop rapidly to a depth of 1 m or more, except along the northeastern shore which remains very shallow (<0.5 m) due to the presence of a deep layer of soft mud. The average depth of the lake is 1.32 m and the maximum depth is 2.71 m. Red mangroves dominate much of the lake shoreline, although white mangroves dominate the northeastern shore and are also found in isolated clusters along the southern boundary of

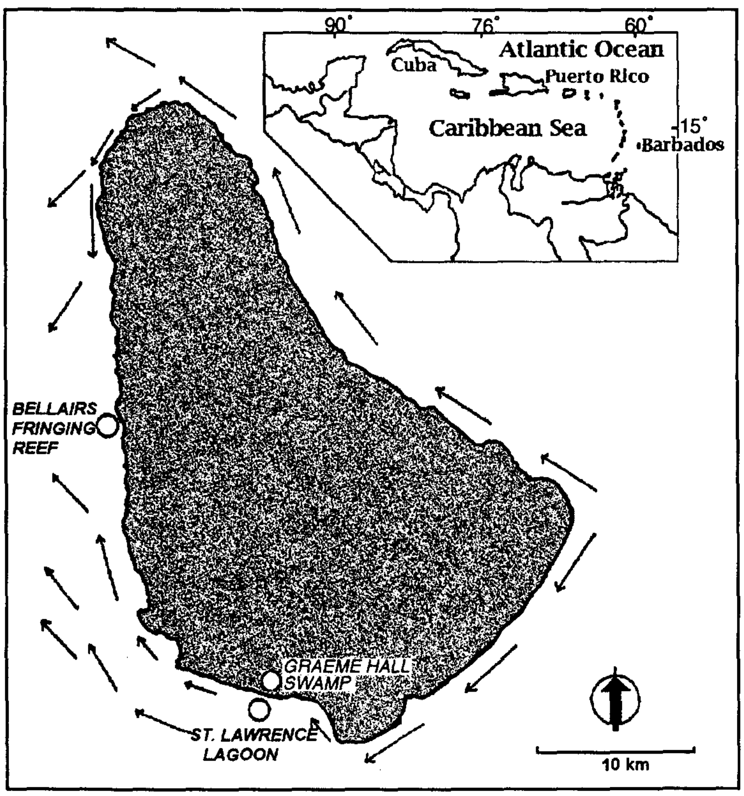


Fig. 1. Map of Barbados with postulated current patterns and locations of CARICOMP sites. (Redrawn from Younglao, 1988; based on studies by Murray *et al.*, 1977; Peck, 1978).

the swamp. A freshwater marsh is located in the eastern quadrant of the swamp, which contains a large stand of mature white mangroves and a network of man-made drainage canals with lotus and water lilies, water lettuce, and filamentous green algae. The banks of the canals support a dense growth of sedges and strips of grassland. The CARICOMP mangrove monitoring site is located in the largest contiguous stand of accessible red mangrove trees, along the eastern shore of the lake.

Graeme Hall Swamp is an important ecosystem to Barbados and has several unique features. It is the largest body of inland water on the island and contains the largest remaining areas of red and white mangrove forest. The swamp is also home to the widest diversity of resident and migratory birds in the island, including locally rare and endangered species such as the red seal coot (*Gallinula chloropus barbadensis*) and the yellow warbler (*Dendroica petechia*) (Cattaneo *et al.*, 1987). The oldest nesting site for the cattle egret (*Bulbulcus ibis*) on the island is also found in the swamp (Riven-Ramsey, 1988) and is presently located in a white mangrove stand in the northeast corner of the lake. Furthermore, over 20 species of fresh and brackish water fish reside in the swamp, including the unique killifish (*Rivulus marmoratus*), which is the only vertebrate in the world to fertilize its own eggs (Oxenford *et al.*, 1993).

Graeme Hall Swamp has been highly impacted by anthropogenic activities during the last 150 years. The history has been reported in detail by Hutt (1982) and Riven-Ramsey (1993) and is summarized here. A coastal roadway was first built on the sand bar separating the mangrove swamp from the sea in the early 1700s, and the stone bridge over the main exit channel, which remains today, was built in 1871. The swamp itself, which was part of the Graeme Hall Estate, probably remained largely untouched until the mid 1800s when a hunting club was established to shoot water birds in the eastern

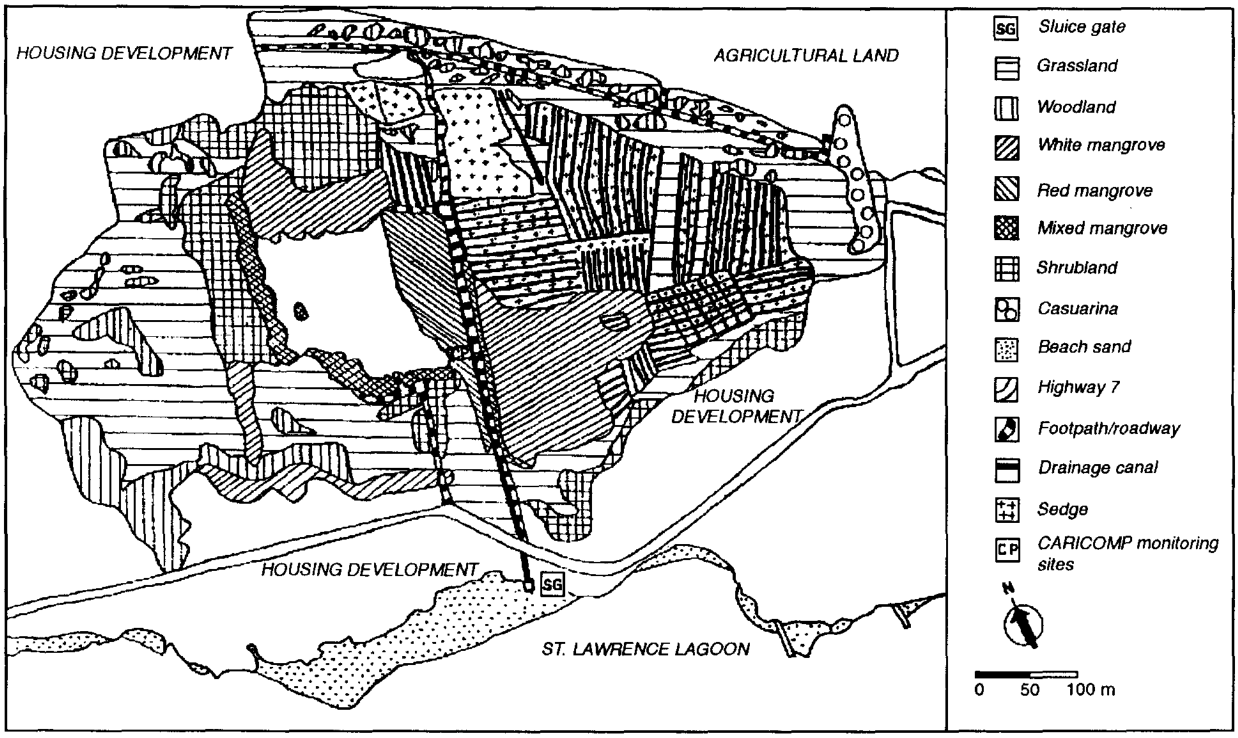


Fig. 2. Habitat map of Graeme Hall Swamp showing main vegetation types and location of CARICOMP monitoring plots.

quadrant. At that time, the freshwater marsh was extensively altered by canalizing the water flow into a series of freshwater trays (dykes) to attract water birds for shooting, and high grass banks from which mule fodder was cut and sold. Peat and mangrove poles were also known to have been cut and sold. Sometime later, a second hunting club was established in the western quadrant, and a number of shallow ponds were cleared and maintained to attract water birds, plus there was an annual cutting of the surrounding mangrove trees. A sluice gate was also installed in the narrow exit channel between the swamp and the sea in the 1930s and was opened only at low tide to control the water level in the shooting pools. *Tilapia* was introduced to the main lake around this time, and commercial seine harvesting took place. In 1972, the main lake was dredged and the sludge was used to fill in the western ponds and convert the land to pasture. The extensive annual mangrove cutting in the swamp ceased in the 1970s, and shooting in the swamp has been banned since 1981.

The swamp, particularly the eastern quadrant, is now managed by the Ministry of Health for mosquito control (Spielman and Nathan, 1990). The regime consists of periodic clearing of vegetation from the freshwater dykes; cutting down of mangroves that overhang the embankment path/roadway and clog the exit canal to the sea; intensive thermal fogging with Malathion (Spielman and Nathan, 1990), periodic opening of the sluice gate and maintenance of the channel over the beach with heavy digging equipment. The swamp is now mainly used for recreational line fishing and for model yacht racing. Several serious proposals have recently been submitted to the Government and the Inter-American Development Bank (IADB) to establish the swamp as a nature/bird reserve and a protected ecotourism site (Riven-Ramsey, 1993), and to incorporate it into a national marine park (Oxenford *et al.*, 1993). There are also plans to establish a sewage treatment plant for the south coast east of the swamp.

Seagrass Beds

Graeme Hall Swamp drains directly into St. Lawrence Lagoon (Fig. 3). The lagoon covers an area of approximately 18 ha, is protected from high energy waves to seaward by an old reef flat and rubble bank (50-150 m wide), and becomes exposed at spring low tides. Extensive areas of sediment accumulation occur on the southwestern shelf of Barbados (Murray *et al.*, 1977), and the lagoon is bounded on the landward side by an actively accreting, fine, coral sand beach (now 60 m wide). The lagoon is shallow (1-3 m deep at low tide); it has a sand substrate and seagrass beds that are occasionally exposed at spring low tides. The seagrasses are primarily turtle grass (*Thalassia testudinum*) and manatee grass (*Syringodium filiforme*), although some sparse, monospecific beds of shoal grass (*Halodule beaudettei*) occur nearshore in the vicinity of the mangrove swamp drainage canal (Oxenford *et al.*, 1993). Macroalgae, *Bryothamnion* spp., *Caulerpa* spp. and *Padina* spp., are also present in the area directly adjacent to the swamp outfall. The seagrass beds act as adult foraging and/or nursery habitat for sand dollars (*Mellita sexiesperforata*), a commercially important sea urchin (*Tripneustes ventricosus*), the endangered green turtle (*Chelonia mydas*), and several estuarine and reef-associated fishes such as mullet (*Mugil* spp.), wrasse (*Halichoeres* spp.), razorfish(*Xyrichtys* spp.), and grunts (*Haemulon* spp.)

(Oxenford *et al.* 1993). The CARICOMP monitoring sites are located in the main area of mixed seagrass towards the eastern end of the lagoon.

The coral rubble bank is a high energy zone of breaking waves and supports little if any living coral; it is primarily covered by coralline, filamentous, and macroalgae. Beyond the rubble bank is a sandy substratum with a series of soft coral patch reefs found in water depths of 8-15 m. The patch reefs are dominated by gorgonians, but a healthy and diverse coral community is also found, with the hard corals *Diploria clivosa, Diploria labyrinthiformis, Diploria strigosa, Meandrina meandrites, Millepora alcicornis, Millepora complanata, Porites astreoides,* and *Siderastrea siderea* dominating (Bellairs Research Institute, 1984). Beyond the patch reefs, the slope is sandy to a depth of 53 m, beyond which a deep hard coral bank reef begins, approximately 1 km from shore.

The St. Lawrence Lagoon is an important ecosystem to Barbados. It is the only area with significant seagrass cover on the west, southwest, and southeast coasts of the island. It also provides an important habitat for the commercially important sea urchin *T. ventricosus,* the critically endangered green turtle *C. mydas,* which feeds in the lagoon, and the hawksbill turtle *Eretmochelys imbricata,* which occasionally nests on the beach. It is also the only location in Barbados where mangrove swamps, seagrass beds, and deep hard coral reefs can be found in close association. A comparison of aerial photographs of the St. Lawrence Lagoon in 1964 and 1991 indicates that the area of seagrass cover has decreased and beach width has increased over the 27 years. In fact, in just the last few years the beach has accreted so rapidly that seagrass in the western end of the lagoon has been smothered by sand and replaced by a beach exposed at low tide. The lagoon is currently used as a mooring basin for small fishing boats and for recreational swimming and windsurfing. A proposal has been submitted to the Government to

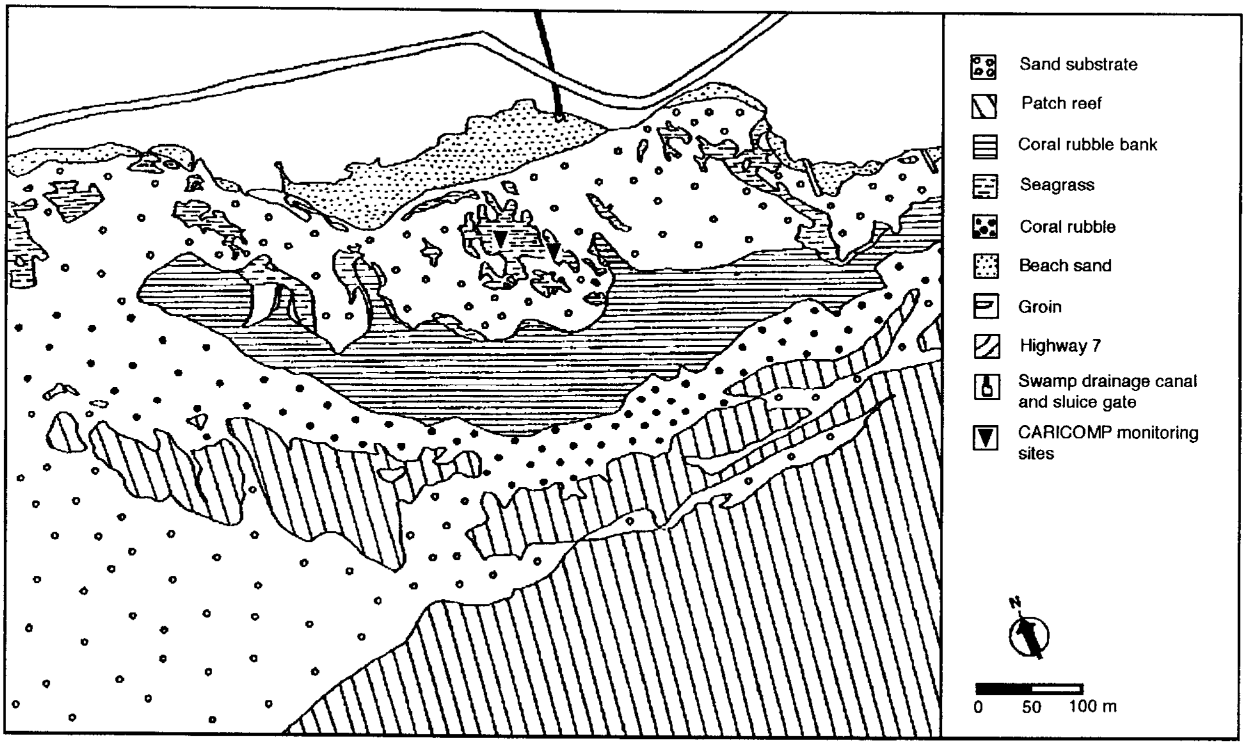


Fig. 3. Habitat map of St. Lawrence Lagoon showing seagrass beds, other substrate types, and locations of the CARICOMP monitoring plots.

incorporate the area into a national marine park (Oxenford *et al.*, 1993).

Coral Reefs

Actively growing, shallow, fringing coral reefs are found along most of the west (leeward) coast of Barbados, extending about 300 m from the shoreline (Lewis, 1960; Oxenford *et al.*, 1993). Monthly mean seawater temperatures off the west coast range from 29.6°C in autumn to 26.0°C in February (Sander and Steven, 1973; Johnson, 1994). Monthly mean salinity varies from 32 to 36‰ (Johnson, 1994); the lower salinity results from water masses drifting northwards from the Amazon River (Ryther *et al.*, 1967). Tides are mixed semidiurnal, with two low and two high tides every 24.8 hours and with significant diurnal inequality. The maximum tidal range is 1.1 m.

The Bellairs fringing reef is located directly in front of the Folkestone Park beach and the Bellairs Research Institute within the Barbados Marine Reserve (Fig. 4). Net current speed recorded at Porters, just south of Bellairs in 1983, was 0.12 m s^{-1}, with little significant seasonal variation (Cambers, 1984). However, the net current direction observed in the vicinity of the Bellairs fringing reef appears to be highly variable. Murray *et al.* (1977) observed a flow towards the north in this area, Vezina (1974) recorded a flow towards the southwest, and Ott (1975) postulated the existence of eddies in the area of the bank reef. Cambers (1984) reported that a dominant current flowing towards the northwest was recorded 22 out of 46 times, a southwest current 20 out of 46 times, and an onshore wind-driven current during the remaining four observation periods. These data suggest that the Bellairs fringing reef may be located in an area where major current streams from the south and north of the island meet (Fig. 1; Cambers, 1984).

A triangular sand channel divides the reef into two unequal sections, with the southern lobe extending 200 m seaward and the northern lobe extending 100 m seaward (Fig. 5). During most of the year, the sand separating the two lobes terminates in a narrow beach. However, the beach is seasonally unstable and is often completely eroded during periodic high swell events, which occur between November and March. The bathymetry of the area and ecological zones of the Bellairs fringing reefs are shown in Figs. 4 and 5, and the ensuing description follows that of Stearn *et al.* (1977). The CARICOMP monitoring plots are located in the spur-and-groove zones of the north and south Bellairs fringing reefs, in the areas of highest live coral cover.

The swash zone or backreef area of the fringing reef is narrow (20-30 m) and lies in depths ranging from 0 to 1 m. This area is composed largely of dead coral rubble covered by filamentous algae and mobile sand. The crest zone extends 40 m from the seaward edge of the swash zone, usually in water depths of 1 m, is occasionally exposed during very low tides, and comprises mainly coralline algae coating dead coral. The crest zone is responsible for reducing the wave energy reaching the backreef area by about 75%, calculated from reduction in wave height (Roberts *et al.*, 1975). The coalesced spurs zone supports several mixed species of hard coral in depths ranging from 1 to 2 m. The outermost zone of the reef is the spur-and-groove zone. The spurs range in width from 3 to 10 m, and the tops of the spurs lie in water depths of 1 to 3 m. The largest proportion of living coral is found on the reef spurs. The coral

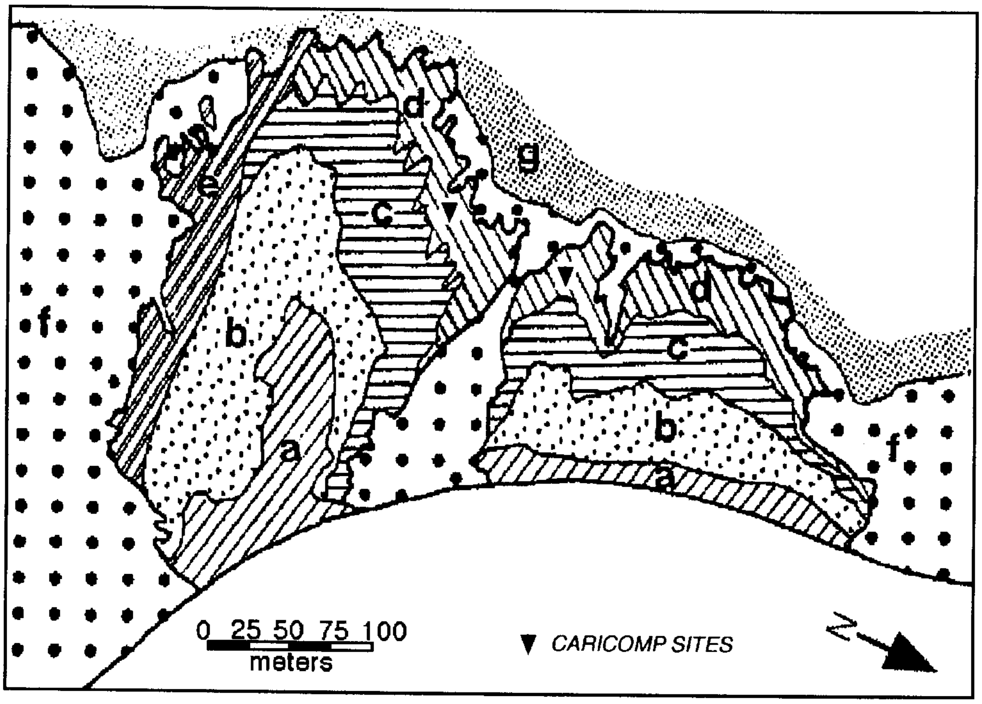


Fig. 4. Diagram of the north and south lobes of the Bellairs fringing reef showing the ecological zones, dominant substrate types and the positions of the two CARICOMP monitoring sites (redrawn from Stearn *et al.*, 1977). Zones are: (a) swash; (b) crest; (c) coalesced spurs; (d) spur-and-groove; (e) *Porites porites*; (f) sand; (g) rubble.

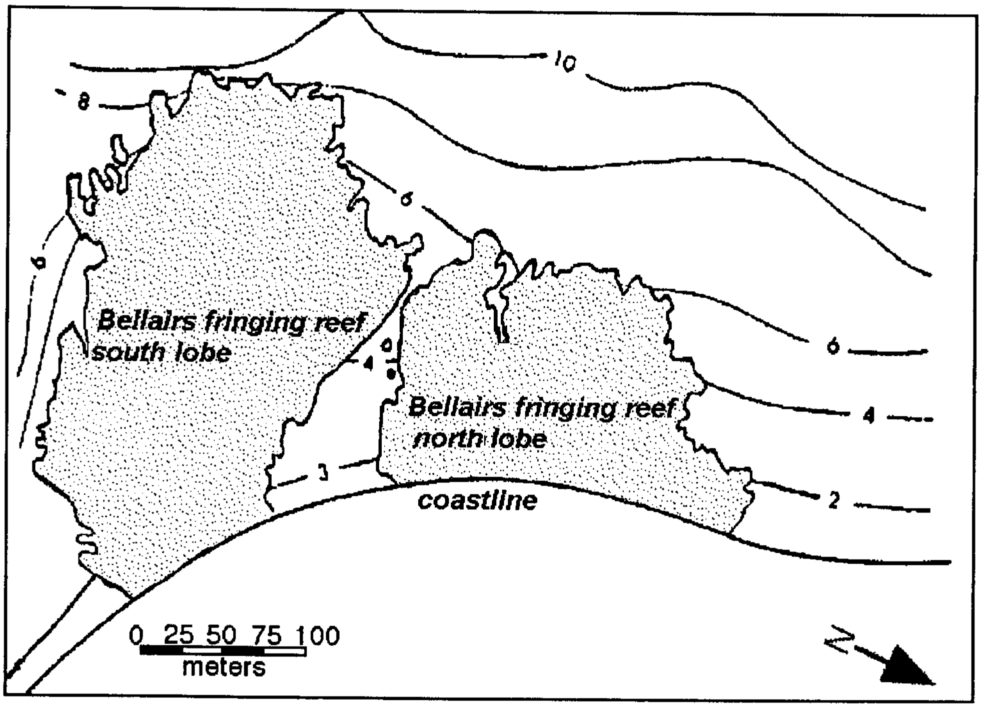


Fig. 5. Bathymetric chart of the seafloor in the area of the Bellairs fringing reef (depth in meters).

species composition has changed periodically over the years. From examination and radiocarbon dating of the reef framework, Lewis (1984) suggested that *Acropora palmata* was a major component of the coral community up to the early 1900s, but that it has declined considerably in abundance since then. Adramatic change in the coral community resulted from the passage of Hurricane Allen in 1980. *Porites porites* was the dominant coral species on the reef prior to Hurricane Allen, according to Stearn *et al.* (1977). A re-survey of the reef after the hurricane (1981-1982) indicated that *Porites porites* coverage had been reduced by 96% and that *Agaricia agaricites* had become the dominant coral species.

The north and south lobes of the reef lie within the northern limit of the Barbados Marine Reserve, which was established in 1981. Thus, fishing is prohibited in this area and boat use is limited to authorized vessels. However, the area is very popular for recreational swimming, snorkeling, and diving. The area is also periodically exposed to heavy sediment loads originating from surface water runoff out of the nearby Holetown Hole, a narrow brackish water lagoon to the south, and it is also impacted by a general deterioration in nearshore water quality over the last 20 years (Johnson, 1994). Contaminated surface water runoff, ground water seepage, and waste water effluent pipes along the coastline have resulted in elevated nutrient levels (particularly NO_3-NO_2-N and PO_4-P), and signs of eutrophication are obvious in the reef community (Tomascik and Sander, 1985). However the size, shape, and zonation patterns of the reef have not noticeably changed.

References

Bellairs Research Institute. 1984. *Marine Studies Component of the South and West Coast Sewage Project.* Technical Report 13, Barbados, West Indies, 140 pp.

Brucks, J. T. 1971. Currents of the Caribbean and adjacent regions as deduced from drift-bottle studies. *Bulletin of Marine Science*, **21**:455-465.

Borstad, G. A. 1979. ASTP at Barbados: Mesoscale pools of Amazon river water in the western tropical Atlantic. In *ASTP Summary Science Report, Vol. 2: Earth Observations and Photography* (edited by E. E. Baz and D. M. Warner), pp 481-498. NASA Special Publication 412, Washington DC, USA.

Borstad, G. A. 1982. The influence of the meandering Guiana current and Amazon river discharge on surface salinity near Barbados. *Journal of Marine Research*, **40**:421-434.

Cambers, G. 1984. *South and West Coasts and Greater Bridgetown Sewerage Studies.* Technical Memorandum 12: Report to the Ministry of Health, Government of Barbados.

Cattaneo, A., D. L. Kramer, V. Kramer, R. H. Peters. 1987. *A Limnological and Ichthyological Reconnaissance of Graeme Hall Swamp, Barbados.* Report to the Ministry of Housing, Government of Barbados, 47 pp.

Emery, A. R. 1972. Eddy formation from an oceanic island: Ecological effects. *Caribbean Journal of Science*, **12**:121-128.

Hutt, M. 1982. Untitled report for CCA, Barbados, 65 pp.

James, N. P., C. W. Stearn, R. S. Harrison. 1977. *Field Guide Book to Modern and Pleistocene Reef Carbonates, Barbados, W.I.* Third International Symposium on Coral Reefs, The Atlantic Reef Committee, University of Miami, Miami FL, USA, 30 pp.

Johnson, A. 1994. *Compilation, Critical Review and Summary of Water Quality Studies on the West and Southwest Coasts of Barbados from 1968 to 1993.* Report for Delcan International/CCPU, Governement of Barbados, 123 pp.

Kinder, T. H. 1983. Shallow currents in the Caribbean Sea and Gulf of Mexico as observed with satellite-tracked drifters. *Bulletin of Marine Science*, **33**:239-246.

Lewis, J. B. 1960. The coral reef community of Barbados. *Canadian Journal of Zoology*, **38**:1133-1145.

Lewis, J. B. 1984. The *Acropora* inheritance: A reinterpretation of the development of fringing reefs in Barbados, West Indies. *Coral Reefs*, **3**:117-122.

Muller-Karger, F. E., C. R. McClain, T. R. Fisher, W. E. Esaias, R. Varela. 1989. Pigment distribution in the Caribbean Sea: Observations from space. *Progress in Oceanography*, **23**: 23-64.

Murray, S. P., H. H. Roberts, O. M. Conlon, G. M. Rudder. 1977. Nearshore current fields around coral islands: Control on sediment accumulation and reef growth. *Proceedings of the 3rd International Coral Reef Symposium*, 54-59.

Ott, B. 1975. *Quantitative Analysis of Community Pattern and Structure on a Coral Reef Bank in Barbados, W.I.* Ph.D. Thesis, McGill University, Montreal, Quebec, Canada, 185 pp.

Oxenford , H. A., M. Wittenberg, L. Vermeer. 1993. *Nearshore Benthic Marine Communities of the West and Southwest Coasts of Barbados: Importance, Impacts, Present Status and Management Recommendations.* Report to Delcan International/CCPU, Government of Barbados, 171 pp.

Peck, G. S. 1978. *A Physical Oceanographic Study Off the South-Western Coast of Barbados.* MSc. Thesis, McGill University, Montreal, Quebec, Canada, 96 pp.

Riven-Ramsey, D. 1988. *Foraging and Breeding Behaviour of the Cattle Egret (Bulbulcus ibis) in Barbados.* M. Phil. thesis. University of the West Indies, Barbados, 131 pp.

Riven-Ramsey, D. 1993. *Terms of Reference and Supporting Material for the Feasibility Study of the Development of Graeme Hall Swamp as a Nature Reserve.* Report to the Government of Barbados and the Inter-American Development Bank, 22 pp.

Roberts, H. H., S. P. Murray, J. N. Suhayda. 1975. Physical processes in a fringing reef system. *Journal of Marine Research*, **33**:233-260.

Ryther, J. H., D. W. Menzel, N. Corwin. 1967. Influence of the Amazon river outflow on the ecology of the western tropical Atlantic: 1. Hydrography and nutrient chemistry. *Journal of Marine Research*, **25**:69-83.

Sander, F., D. M. Steven. 1973. Organic productivity of inshore and offshore waters of Barbados: A study of the island mass effect. *Bulletin of Marine Science*, **23**:771-792.

Stanley International (Toronto). 1983. *South and West Coast Sewage Project.* Report to the Ministry of Health, Government of Barbados, and the Inter-American Development Bank.

Spielman, A., M. Nathan. 1990. *Managing the Graeme Hall Swamp of Barbados to Prevent Malaria Transmission.* Report to the Ministry of Health, Government of Barbados, 25 pp.

Stearn, C.W., T.P. Scoffin, W. Martindale. 1977. Calcium carbonate budget of a fringing reef on the west coast of Barbados: Part 1. Zonation and productivity. *Bulletin of Marine Science*, **27**:479-510.

Tomascik, T., F. Sander. 1985. Effects of eutrophication on reef-building corals. 1. Growth rate of the reef building coral *Montastraea annularis*. *Marine Biology*, **87**:143-155.

Vezina, R. R. 1974. *Seawater Quality and Phytoplankton of Inshore Waters of Barbados: A Study of the Effects of Organic Pollution in a Tropical Environment.* M.Sc. thesis, Marine Sciences Centre, McGill University, Quebec, Canada, 95 pp.

Younglao, D. 1987. *Spawning, Aggregation and Recruitment in the Black Sea Urchin Diadema antillarum.* M.Sc. Thesis, Department of Oceanography, McGill University, Montreal, Quebec, Canada, 174 pp.

Saba, Netherlands Antilles[1]

Kenny Buchan
Saba Marine Park
Fort Bay, PO Box 18
The Bottom, Saba, Netherlands Antilles

In comparison to other CARICOMP sites, the tiny island of Saba, in the Windward Islands arc of the Lesser Antilles, can be described as atypical in terms of its topography, geology, and marine environment. Saba has a small human population and anthropogenic impacts on the nearshore marine environment are limited. Sedimentation, dive tourism, and fishing are the three main impacts in coastal waters. Saba is devoid of mangrove stands; *Thalassia* seagrass beds and coral communities are restricted to a narrow shelf and offshore seamounts. CARICOMP sampling occurs only at one reef area on the leeward west coast. Physical oceanographic data are available for this site, and meteorological data are available for the island. Benthic composition is described based on CARICOMP surveys carried out to date and on a baseline monitoring program that was executed in 1993 as part of a study for the Saba Marine Park.

Introduction

Saba is located in the northeastern Caribbean (17°36'59'N, 63°15'09"W), part of the Windwards Islands and the Netherlands Antilles. The island has an area of 13 km^2 and a maximum elevation of 866 m above sea level, resulting in an extremely mountainous topography. Saba has a small population, approximately 1200 inhabitants, and for the most part, access to the ocean from the population centers is impossible because of the steep slopes of the mountain. Typically, supplies to the island and access to the ocean is only via Cove Bay, Fort Bay, Ladder Bay, and Wells Bay (Fig. 1). The nearshore marine environment (from the high tide mark to the 60 m depth contour) is a protected area maintained under the auspices of the Saba Marine Park.

With population centers on the island lying at least 240 m above sea level, direct human impacts on the marine resources are limited. There is little industry on the island and no significant agriculture. Thus, effluents such as pesticide and industrial chemicals are nonexistent. The three main impacts on the marine environment are sedimentation, dive tourism, and fishing.

Sedimentation comes from a rock-crushing plant in the Fort Bay area and from natural runoff during heavy rains. At the end of 1995, a large-scale operation to export rocks and sand was initiated at the

[1] *CARICOMP — Caribbean Coral Reef, Seagrass and Mangrove Sites* (edited by B. Kjerfve), pp 187-193. UNESCO, Paris, 1998, 347 pp.

rock-crushing site. This has added significantly to the amount of sedimentation on Tent Reef and other sites in the southwest portion of the island. Natural runoff is significant and for the most part discharges directly into the ocean because of the steep slopes of the island, which are made up of loose agglomerates. In most places, the slopes are separated from the ocean by a thin fringing boulder beach.

The economy of Saba is dependent on tourism; 66% is dive related. The Saba Marine Park, which surrounds the entire island, hosts about 5,000 divers per year who carry out approximately 25,000 dives. Undoubtedly some damage results from diving activities, although this is limited and has been decreasing since 1993. Roberts *et al.* (1993) reported damage to 3.2% of coral colonies close to marine park mooring lines at the study sites (high use areas 0-20 m from mooring) and to 2.4% of colonies in low use areas (40-60 m from mooring). The number of divers visiting Saba is slowly increasing. The results of a 1996 study of the carrying capacity of the park are not yet available but will be used to reduce or alleviate development and diving pressure on the marine ecosystem.

Various studies have assessed the impact of fishing on the surrounding reefs (Polunin and Roberts, 1993; Roberts *et al.*, 1993; Roberts, 1995; Roberts and Hawkins, 1995). Within the no-fishing zone of the marine park (the coral reef site is also located in this area), fish biomass was greater for five commercially fished families than in the fishing zones. Between 1991 and 1995, overall biomass of commer-

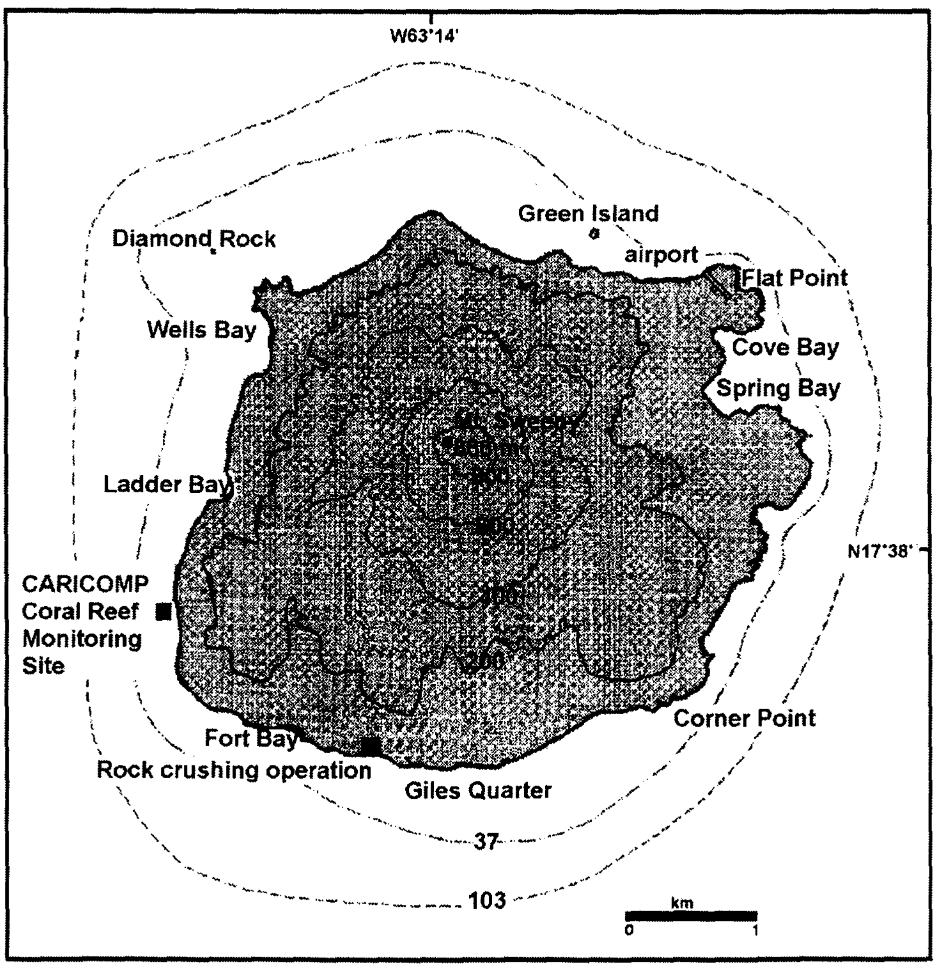


Fig. 1. Map of Saba, Netherlands Antilles, showing CARICOMP and other relevant sites (contours in meters).

cially important families increased by over 60%. Fish populations within the study site are healthy.

To date the island government, on the advice of the Saba Marine Park, has declined proposals for coastal development. However, with future political changes there may be pressure to develop a marina and hotel/dive resort in the southern part of the island at Giles Quarter. According to island law, all coastal developments must be preceded by an independent environmental impact assessment.

Island and Marine Geology

Saba is a single, composite, dormant volcano (Westermann and Kiel, 1961) rising from depths of 600 m (Roos, 1971). The island consists of a main peak surrounded by several individual peaks and domes. The slopes of the main mountain are characterized by numerous relatively straight V- and U-shaped valleys, locally known as guts. The petrological composition of the island has been described by Baker *et al.* (1977) as mostly andesites (volcanic boulders) formed through processes such as fractionation and magmatic mixing from both mantle and crustal sources. The relatively narrow shelf of the island is principally remnants of the abraded volcano, consisting of boulders that have slid from the eroded walls over time (Zonneveld, 1977; Van't Hof *et al.*, 1991). There is no permanent running water on the island, but during heavy rains the guts act as channels carrying water and sediments directly to the ocean.

The bathymetry of Saba is characterized by nearshore dropoffs at Flat Point, Spring Bay, and Corner Point (Deslarzes, 1994). Within 60 m depth limits, the shelf surrounding Saba is typically 300-500 m wide; at its widest point north of the island, the shelf measures approximately 1,000 m.

Reef development in the Windward Islands (St. Maarten, St. Eustatius, and Saba) of the Antilles is poor in comparison to those of the Leeward Islands (Curaçao and Bonaire). According to Bak (1977), coral communities are common in the Dutch Windward Islands but no structural reefs were observed. Contrary to this observation, Van't Hof *et al.* (1991) suggested that, overall, coral communities around Saba are made up of encrusted andesites and rock, but noted that true biogenic reef does exist in one location — at the Giles Quarter reef complex (Fig. 1). Approximately 1.8 km off the western coast of Saba lies the third category of coral communities common to Saba, described by Van't Hof *et al.* as sea-mounts and pinnacles. Bak (1977) and Deslarzes (1994) described 33 and 30 hermatypic coral species, respectively, in comparison to the 50 found in the leeward Netherlands Antilles. According to Deslarzes (1994), mean hard coral cover in Saba on average ranges from 7.8% to 21.9% and reaches 29% in some reef areas; 11 coral species were common throughout his sample sites: *Agaricia* spp., *Colpophyllia* spp., *Diploria labyrinthiformis*, *Diploria strigosa*, *Madracis decactis*, *Millepora* spp., *Montastraea annularis*, *Montastraea cavernosa*, *Porites astreoides*, *Porites porites*, and *Stephanocoenia michelinii*. Of these, *Montastraea annularis* was most dominant overall, followed by *Agaricia* spp., *Millepora* spp. and *Diploria strigosa*.

Saba lacks mangrove stands and *Thalassia* seagrass beds because of its exposed coast. There is a small patch of *Syringodium* east of Fort Bay, a remnant of a large bed which once existed but was affected by sedimentation from the rock-crushing plant adjacent to this area. There are other small patches of *Syringodium* on the leeward western coast of the island.

Climate and Oceanography

The mean annual rainfall on Saba is approximately 1,000 mm (Westermann and Kiel, 1961). The dry season is normally between December and July, and precipitation varies depending on altitude and exposure to the eastern tradewinds. Annual rainfall has been known to exceed 1,920 mm on the higher windward slopes and the summit of the island. Data collected from January 1992 through December 1995 show an average rainfall of 776.8 mm annually (Table 1). This is far below the figures quoted by Westermann and Kiel (1961) and is an indication of the serious drought that occurred in Saba in 1994. Variation in rainfall intensity over the small area and different elevations of the island may partly account for the low readings.

Table 1. Rainfall data (mm) for Saba, Netherlands Antilles, 1992-1995.

	1992	1993	1994	1995
January	71.4	66.6	22.8	22.7
February	19.6	30.8	44.8	30.6
March	93.0	46.4	6.0	30.7
April	117.7	78.3	16.0	64.1
May	140.9	213.3	12.3	71.3
June	28.4	38.8	70.2	39.6
July	48.5	72.8	15.0	35.8
August	54.5	49.10	60.8	79.1
September	30.2	68.5	57.3	300.5
October	30.2	63.2	58.2	34.4
November	191.3	68.3	56.2	127.3
December	53.0	62.6	32.3	73.7
Total Annual Rainfall	878.7	858.7	451.9	909.8

Saba is located within the hurricane belt and has been exposed to numerous tropical storms and hurricanes, the most significant being Hugo in 1989 and Luis in 1995. The prevailing wind is from the southeast and, since 1988 (only records available), has averaged 5.6 m s^{-1}. Because of Saba's exposure, sea conditions in the south and east are usually rough. Air temperatures vary from monthly maxima exceeding 33°C in June-August, to monthly minima less than 25°C in January-March (Table 2).

With Saba's exposed nature, narrow shelf and surrounding deep water, strong currents and rough seas (1-2 m average wave height) are prevalent around most of the island. Information on ocean currents is limited; there have been no field investigations to date, and available data are inconclusive. The intensity of the prevailing southeasterly winds makes for rough seas on the southern and eastern coasts of the island for much of the year. From November to March, powerful swells that originate in the North Atlantic impact the leeward western side of the island.

Although no tidal data have been recorded for Saba, it may be possible to estimate tidal variations from data recorded on adjacent islands. From 45 tide gauge locations in the Caribbean, Kjerfve (1981) concluded that, for the most part, the Caribbean has a microtidal range of 10-20 cm. Saba is located in an area with a predominantly mixed diurnal tide, with a mean tidal range of 15 cm.

Table 2. Maximum and minimum air temperatures (°C) on Saba, October 1992 through December 1995.

	1992		1993		1994		1995	
	max	min	max	min	max	min	max	min
January			26.2	24.3	27.1	28.8	27.8	23.9
February			27.0	24.2	26.2	23.5	28.9	24.2
March			28.0	24.1	28.2	24.0	28.0	23.9
April			31.8	24.9	30.4	25.5	31.3	25.7
May			32.8	25.0	33.9	27.2	32.5	27.8
June			34.4	26.2	34.3	27.0	34.0	29.8
July			34.7	26.3	33.8	27.8	32.1	28.9
August			35.0	27.1	33.4	28.3	33.0	27.8
September			34.1	26.2	32.0	27.2	31.9	28.0
October	31.6	25.9	33.7	25.9	30.5	27.1	30.0	26.0
November	28.3	25.0	28.3	26.1	29.7	26.4	28.9	25.2
December	27.0	25.0	27.7	25.0	27.8	24.9	28.1	24.3

Coral Reef Site

The CARICOMP coral reef monitoring site is located at 17° 37'34.0"N, 63° 15' 35.5"W (Figs. 1 and 2) on the leeward western coast of the island about 100 m north of a dive mooring in an area known as the Ladder Labyrinth. The transects are 100 m from the shore on a reef characterized by parallel coral ridges separated by sand channels. Van't Hof *et al.* (1991) hypothesized that coral colonies in this area, which originally encrusted a volcanic boulder substrata, have fused to form a reef structure.

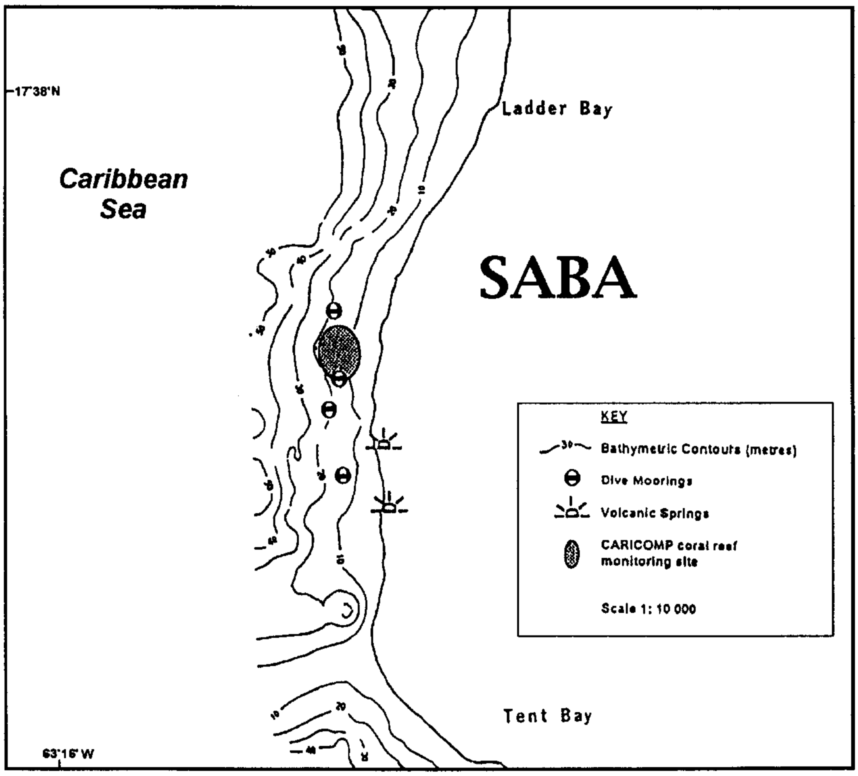


Fig. 2. Map showing the CARICOMP coral reef monitoring site on the west coast of Saba, Netherlands Antilles.

This site has been characterized as a spur-and-groove reef. According to Deslarzes (1994), there is an average hard coral coverage of 24.3% ± 3.8 (SD). Impacts on this area are limited to sedimentation and recreational diving. Some volcanic hot springs occur near the shore but, according to seawater temperatures collected at this site, there are no unusually high temperatures. CARICOMP surveys to date have shown that the reef benthos is dominated by fleshy algae, turf algae, and sand. The dominant hard coral species are massive in structure, with *Montastraea annularis* covering approximately 42% of the total hard coral area. The results from the CARICOMP benthic surveys are presented in Table 3.

Physical data, including surface water temperature, light attenuation, and salinity, have been recorded weekly at the reef site since September 1992. Generally, salinity does not deviate much from 35‰. Light attenuation ranges from 12.5 to 30 m, averaging 22 m at this site. The average surface water temperature ranges from 26.5°C to 29.1°C.

Table 3. Results of benthic surveys at the CARICOMP coral reef site, Saba, Netherlands Antilles.

Classification	% Occ	Classification	% Occ	Species	% Occ
Turf algae	30.7	Anemones	—	*Agaricia* spp.	15.9
Fleshy algae	18.2	Zooanthids	0.01	Ascidians	3.4
Calcareous algae	2.7	Erect sponges	1.8	*Diploria strigosa*	6.0
Crustose algae	—	Encrusting sponges	1.1	*Meandrina* spp.	2.4
Branching corals	0.2	Other organisms	0.5	*Millepora* spp.	0.1
Massive corals	10.4	Bare rock	1.5	*Montastraea annularis*	42.7
Encrusting corals	5.8	Bare rubble	0.08	*Montastraea cavernosa*	22.0
Foliaceous corals	0.07	Holes, gaps, overhangs	5.4	*Porites porites*	4.9
Milleporines	0.04	Recent dead coral	—	*Siderastrea* spp.	2.4
		Sand	21.5		

% Occ = occurrence, and refers to the percentage of a particular classification or species relative to others present.

Conclusions

Saba is unique in the CARICOMP program, with the existence of only one of the three ecosystems specified for determining coastal marine productivity. Anthropogenic impacts on the coast are limited, but the threat of development, increased dive tourism, and erosion require continuous monitoring. Saba is one protected area in the CARICOMP program and, as such, can be useful for comparison with other, more impacted sites.

References

Bak, R. P. M. 1977. Coral reefs and their zonation in the Netherlands Antilles. *Studies in Geology*, **4**:3-16.

Baker, P. E., F. Buckley, T. Padfield. 1977. Petrology of the volcanic rocks of Saba, West Indies. *Abstracts of the 8th Caribbean Geological Conference (Curaçao, 9-24 July 1977).*

Deslarzes, K. P. 1994. *Coral Reef Monitoring in Support of Management, Saba Marine Park, Netherlands Antilles.* Unpublished report on preliminary data.

Kjerfve B. 1981. Tides of the Caribbean Sea. *Journal of Geophysical Research*, **86**(C5):4243-4247.

Polunin, N. V. C., C. M. Roberts. 1993. Greater biomass and value of target coral-reef fishes in two small Caribbean marine reserves. *Marine Ecology Progress Series*, **100**:167-176.

Roberts, C. M., J. P. Hawkins, S. White. 1993. *Status of Fish and Coral Communities on the Reefs of the Saba Marine Park during April/May 1993.* Eastern Caribbean Center, University of the Virgin Islands, St. Thomas, USVI, 57 pp.

Roberts, C. M. 1995. Rapid build-up of fish biomass in a Caribbean marine reserve. *Conservation Biology,* **9**:815-826.

Roberts, C. M., J. P. Hawkins. 1995. *Status of Reef Fish and Coral Communities of the Saba Marine Park — 1995.* Eastern Caribbean Center, University of the Virgin Islands, St. Thomas, USVI, 59 pp.

Roos, P. J. 1971. The Shallow-Water Stony Corals of the Netherlands Antilles. *Studies of the Fauna of Curaçao,* **37**:1-108.

Van't Hof, T., S. L.Walker, J. Boosma, J. M. Buchanan. 1991. *Guide to the Saba Marine Park.* Saba Conservation Foundation.

Westermann, J. H., H. Kiel. 1961. *The Geology of Saba and St. Eustatius, with Notes on the Geology of St. Kitts, Nevis and Montserrat (Lesser Antilles).* Uitgaven Natuur Wetenschappelijke Studiekring Voor Suriname en de Nederlandse Antillen 24, Utrecht, The Netherlands.

Zonneveld, J. 1977. Saba and the Saba Bank. *Abstracts of the 8th Caribbean Geological Conference (Curaçao 9-24 July 1977).*

La Parguera, Puerto Rico, USA[1]

Jorge R. García, Christoph Schmitt, Craig Heberer, and Amos Winter
Department of Marine Sciences, University of Puerto Rico
Isla Magüeyes Laboratories, La Parguera
PO Box 908, Lajas PR 00667 USA

The insular shelf of La Parguera, on the southwest coast of Puerto Rico, is characterized by an extensive development of coral reefs, seagrass beds, and mangrove forests. The dry, warm, and relatively stable climate, low wave energy, high water transparency, relatively wide shelf, oligotrophic offshore waters, and low urban coastal development are some of the factors that contribute to the conditions of the marine ecosystem of La Parguera. Interactions among coral reef, seagrass, and mangrove communities provide for a highly productive, structurally complex, and biologically diverse ecosystem. Coastal development and associated anthropogenic impact, technologically advanced exploitation of fisheries, global climatic change, and natural events all have potentially detrimental effects on marine ecosystems and need to be analyzed from a regional perspective. We review and summarize information leading to a baseline characterization of the ecosystem of La Parguera.

Introduction

La Parguera is a coastal village within the township of Lajas on the southwestern coast of Puerto Rico. Its insular shelf boundaries extend from Punta Montalva in the east (66°59'W) to Punta Tocón in the west (67°06'W) and from the coastline (18°01'N) to the shelf edge (18°07'N) (Fig. 1). The southwestern coast is a generally dry and warm region, classified as a subtropical dry forest life zone (Ewel and Whitmore, 1973). A chain of low hills, known as Sierra Bermeja, separates the coastal plain from the Lajas Valley. Sierra Bermeja acts as an important hydrographic boundary that confines the watershed of La Parguera to the southern slopes of the Sierra and to the relatively narrow coastal plain. The shelf is composed mainly of carbonates deposited during the Cretaceous (Almy, 1965) and flooded some 5,000 to 9,000 years ago due to eustatic sea level rise (Goenaga, 1988), thereby forming the neritic zone of La Parguera.

La Parguera is recognized for the exceptional value of its marine resources, which include two bioluminiscent bays (Bahía Fosforescente and Monsio José), a coastal mangrove fringe with several small

[1] *CARICOMP — Caribbean Coral Reef, Seagrass and Mangrove Sites* (edited by B. Kjerfve), pp 195-212. UNESCO, Paris, 1998, 347 pp.

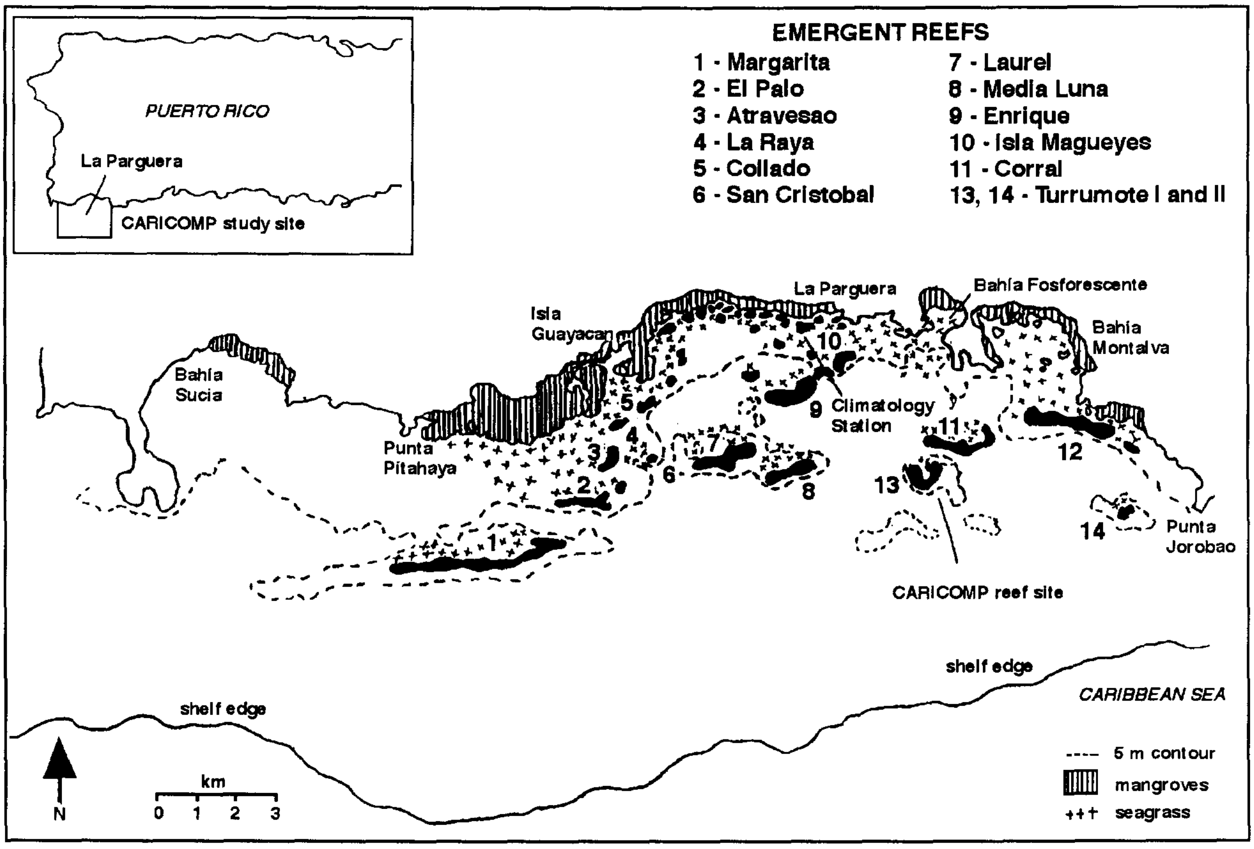


Fig. 1. Location map of La Parguera, Puerto Rico, and its marine ecosystems.

lagoons, mangrove islands associated with coral reefs, seagrass beds, and perhaps the best developed, most extensive coral reef ecosystem of the island. Such attributes, and the significant improvement in transportation and infrastructure across the island, have transformed La Parguera from a mostly undeveloped and quiet fishing village to a center of tourism. Resorts, guest houses, and private vacation homes have proliferated over the past ten years, and the transient population has increased at least three-fold — from approximately 35,000 visitors per year (NOAA/DNR, 1984) to more than 100,000. In order to halt chaotic deforestation of the natural semi-arid forest and mangrove coastline, the Puerto Rico Planning Board classified La Parguera as a Zone of Special Planning. In further recognition of the ecological value of its marine resources, La Parguera has also been designed as a Natural Reserve by the Department of Natural Resources. At present, there is a proposal for the establishment of a Marine Fishery Reserve at Turrumote Reef (Plan Development Team, 1990; García, 1990); a previous effort to establish a Marine Sanctuary Program (NOAA/DNR, 1984) was not accepted by the local community (Fiske, 1992). Field and laboratory research facilities of the Department of Marine Sciences, University of Puerto Rico Mayaguez Campus, are based on Magüeyes Island off La Parguera.

The coexistence and interdependence of coral reef, seagrass, and mangrove communities within the insular shelf of La Parguera result in a highly productive and structurally complex ecosystem with very high biodiversity. Coral reefs act as barriers to wave action and permit the establishment of seagrasses and fringing mangroves (Goenaga and Cintrón, 1979). In turn, seagrasses and mangroves contribute organic matter for coral nutrition and serve as important foraging and nursery habitats for coral reef fishes and other organisms. Each of these communities can be regarded as highly productive and taxonomically diverse. For example, mangrove lagoons function as nurseries for many juvenile coral reef fishes (Austin, 1971; Yáñez-Arancibia and Nugent, 1977; Gonzalez-Sansón, 1983), many of which are commercially important as adults (*e.g.*, snappers, jacks, barracudas, and others). The lagoons are also the natural habitat of resident populations of, for example, snook, tarpon, ladyfish, mojarra, and sole that add to the structural complexity and diversity of the ichthyofauna in La Parguera. Likewise, seagrasses are particularly important foraging (transient) areas for coral reef fishes and endangered species such as manatees and green sea turtles (Gonzalez-Liboy, 1979) and, as well, provide a permanent niche for a highly diverse and abundant flora (Glynn, 1964; Matthews, 1967) and fauna (Gonzalez-Liboy, 1979; Vicente, 1992).

The diversity of benthic and pelagic populations associated with the different habitats found in La Parguera is also reflected in plankton community structure and trophodynamics. This occurs by introduction of meroplanktonic (larval) stages, which include almost the entire taxa of marine invertebrates and fishes. Onshore-offshore gradients of phytoplankton production associated with the high plankton production of mangrove lagoons (Burkholder and Burkholder, 1958; Margalef, 1957; Gonzalez-Lagoa, 1967; García and López, 1989; García, 1990) and offshore oceanic oligotrophic waters (Margalef, 1957; Gonzalez-Lagoa, 1967) add substantial richness to the taxonomic structure of neritic zooplankton. A pattern of lower diversity and higher abundance of holoplankton prevails inshore, whereas both the diversity and the abundance of meroplankton decline offshore and within mangrove channels and lagoons.

Coral reefs extend throughout a wide range of depths and distances from the coast in La Parguera and consequently are exposed to gradients of physical, chemical, and biologically interacting forces (*e.g.*, wave energy, light penetration, temperature, salinity, nutrient availability, suspended sediments). These gradients affect the structure of the biological community within reefs (*e.g.*, vertical coral zonation patterns) and between reefs (Morelock *et al.*, 1977; Acevedo and Morelock, 1988). This variability in community structure within and between reefs promotes the biological diversity of coral reef-associated organisms. These changes in coral reef community structure introduce variable patterns of sedimentation adjacent to the reefs (Morelock *et al.*, 1977), potentially influencing variability in benthic communities associated with different sediment types. The submerged shelf-edge reef of La Parguera is an important spawning site for coral reef fishes (Colin and Clavijo, 1988) and serves as a foraging area for pelagic (oceanic) predators. Such neritic-pelagic interaction contributes to ichthyofaunal biodiversity and local fisheries production.

The prevailing low wave energy, extensive insular shelf, and low rainfall and freshwater runoff along the southwestern coast of Puerto Rico are all important factors that contribute to the excellent growth potential of coral reefs, seagrass beds, and mangroves at La Parguera. The Lesser Antilles chain generally shields the area from both NNE (North Atlantic) and ESE swells; thus, wave action on the southern coast is normally produced by systems of relatively short fetch. Nevertheless, the northern Caribbean region, which includes the southern coast of Puerto Rico, is within the trajectory of tropical depressions, tropical storms, and hurricanes. These systems generate the highest waves in the region and affect coral reef formations and other coastal ecosystems. Where insular platforms are narrow, wave action from tropical storms is high and causes massive destruction.

The insular shelf of La Parguera extends 8-10 km offshore; a well developed coral reef formation exists at the border of the shelf (Morelock *et al.*, 1977) and serves as a first barrier against wave action. Two other lines of barrier reefs provide further protection for the mangrove coastline and submerged seagrass beds of La Parguera. Nevertheless, storm-generated waves may play an important role in the distribution, structural complexity, and biodiversity of local coral reefs and associated communities (Yoshioka and Yoshioka, 1989).

The paucity of rainfall and the absence of large rivers along the SSW coast of Puerto Rico, combined with the oligotrophic ocean waters in the northern Caribbean contribute to the high level of water transparency on the insular shelf. This condition optimizes growth rates and maximizes the depth range and distribution of corals and seagrasses. Sediment runoff from rivers discharging upcurrent along the south coast of Puerto Rico and from intermittent streams in the watershed of La Parguera can be significant during and for a few days after heavy rainfall and affect water transparency. Locally induced inorganic turbidity is quickly diluted by flushing. Mesoscale processes such as the northwestern plume of the Orinoco River (Muller-Karger *et al.*, 1989) may affect water transparency locally at times, due to seasonal increments in organic (planktonic) productivity associated with fronts (Yoshioka *et al.*, 1985).

A series of "coral bleaching" events has taken place recently at La Parguera (Goenaga *et al.*, 1989; Williams and Bunkley-Williams, 1989; Bunkley-Williams *et al.*, 1991). In total, more than 60 species of corals have been affected (Williams and Bunkley-Williams, 1989). Extremes in climatological conditions, particularily water temperature, have been suggested as possible precusors to these bleaching events.

Climate and Oceanography

Caribbean surface waters are part of the North Atlantic anticyclonic surface gyre that controls currents of the subtropical North Atlantic. Under the influence of trade winds, north and south equatorial water masses flow into the Caribbean and farther, through the Yucatan Channel into the Gulf of Mexico (Pickard and Emery, 1982). The current system of the Caribbean Sea undergoes seasonal fluctuations influenced by changes in the position of the inter-tropical convergence zone (ITCZ). During the winter, when the thermal equator is farthest south, the ITCZ is located between 0° and 5°S, and waters of the tropical Atlantic flow with increased strength westward into the Caribbean. In summer, the thermal equator shifts north, the ITCZ is located between 6°and 10°N, and surface waters in the Caribbean are influenced by increasing precipitation. This is also the time of year when the north equatorial counter-current (NECC) is established and surface waters of the equatorial Atlantic are displaced to the east (Busalacci and Picaut, 1983; Richardson and McKee, 1984).

The zonal shift of the ITCZ is responsible for the change from wet to dry seasons in the Caribbean. In the dry season (February to May), the ITCZ is near the equator; in the rainy season (August to October), the ITCZ is at its most northerly position in the Caribbean (Etter *et al.*, 1987). The seasonal change is mirrored in the change of surface water salinity; however, precipitation affects salinity only indirectly. The main contribution to buoyancy in the Caribbean is the discharge from three rivers: the Amazon (average outflow 17.3 × 10^4 m^3 s^{-1}), the Orinoco (3.9 × 10^4 m^3 s^{-1}; Meade *et al.*, 1983), and the Magdalena (0.8 × 10^4 m^3 s^{-1}; Milliman and Meade, 1983). These discharges increase silica concentrations (3-5 μm), decrease salinity (Froelich *et al.*, 1978; Morrison and Nowlin, 1982) as well as chlorophyll pigments (Muller-Karger *et al.*, 1989), and increase loading of terrestrial materials onto the Caribbean floor (Milliman and Meade, 1983). Seasonal changes in Caribbean surface salinity directly influence the water mass transport of the Gulf Stream. Periodic fluctuations in water transport are aso linked to wind speed changes in the tropical-subtropical trade wind zone.

La Parguera is located on the southwestern coast of Puerto Rico in the subtropical climate belt influenced by easterly trade winds during 90% of the year. However, by the time the moisture-laden trade winds have crossed the island and reached La Parguera, most of the moisture has been lost. Therefore, La Parguera is one of the driest and hottest areas along the coast of Puerto Rico; the average annual rainfall 1961-1990 was 74.52 cm (Table 1), compared to 132.74 cm at San Juan. The "rainy season" occurs during the fall (average 35.61 cm), the "dry season" occurs in winter (average 9.12 cm). The highest one-day rainfall 1961-1990 was 35.31 cm on September 17, 1975 (Table 1). Most of the high rainfall amounts are caused by tropical storms that stall in the northeastern Caribbean. Occasional cold fronts in winter, which may sometimes be associated with large amounts of rain in Puerto Rico,

Table 1. Historical monthly mean rainfall record from the Isla Magüeyes climatological station in La Parguera (NOAA 665693).

	Total Rainfall						
	Mean	High		Low		1-Day Max	
	cm	cm	year	cm	year	cm	dd/yyyy
January	2.77	7.87	1984	0.00	1967	5.46	27/1973
February	2.41	11.07	1984	0.10	1975	6.60	04/1984
March	2.69	9.88	1983	0.30	1964	7.16	13/1983
April	3.28	10.52	1983	0.13	1974	5.46	21/1983
May	6.73	29.29	1986	0.00	1974	14.63	28/1980
June	3.76	20.80	1987	0.51	1977	11.94	15/1990
July	4.45	19.96	1984	0.05	1976	18.24	05/1984
August	8.64	32.82	1978	1.50	1972	29.85	17/1978
September	11.79	39.34	1975	2.84	1971	35.31	17/1975
October	12.93	54.69	1985	2.08	1965	26.04	07/1985
November	10.87	41.40	1987	0.00	1962	18.54	04/1984
December	3.94	16.21	1981	0.00	1979	9.53	11/1981
						cm	dd/mm/yyyy
Annual	74.52	110.90	1978	40.94	1977	35.31	17/09/1975
Winter	9.12	29.16	1961	2.44	1990	9.53	11/12/1981
Spring	12.70	34.24	1986	3.23	1974	14.63	28/05/1980
Summer	16.84	35.79	1988	5.11	1967	29.85	17/08/1978
Autumn	35.61	79.12	1985	9.83	1980	35.31	17/09/1975

seem not to affect the southwestern corner of the island. Total precipitation amounts vary from year to year (Fig. 2). The lowest annual rainfall 1960-1991 was 40.94 cm in 1977, the highest was 123.57 cm in 1960.

The average mean air temperature at La Parguera 1960-1991 was 27.0°C (Table 2). This value is similar to all coastal locations in Puerto Rico. However, the average annual maximum of 31.8°C is nearly 1.4°C higher than at San Juan, while the average annual minimum of 22.5°C is 1.3°C lower than at San Juan. The average annual maximum, minimum, and mean temperatures do not change appreciably throughout the year — winter months are only 2.2°C cooler than summer months. The highest temperature recorded 1960-1991 was 41.1°C in October 25, 1991, and the lowest, occurring on a number of occasions, was 15.7°C. The high of 41.1°C is unusual, as the maximum average for October is 32.3°C.

There exists no long-term salinity record for La Parguera. During the two-year period 1971-1972, Froelich *et al.*, (1978) recorded a 1.0‰ change in annual salinity at a station located 34 km south of Puerto Rico. Salinities were depressed in late October through early November, coinciding with advected Amazon River water (Muller-Karger *et al.*, 1989) rather than local rainfall and runoff. Glynn (1973) measured near-daily surface salinities between 1960 and 1966 at a nearshore site and found that the inter-annual range of monthly means varied from 1.5 to 2.0‰, with a depression in salinity occurring from October to January. Yoshioka *et al.* (1985) measured monthly salinity values at a number of stations over the southern shelf of Puerto Rico from January through November of 1980. Salinity fluctuations at the water surface were no greater than 0.5‰ and were also depressed in October and November. Since corals live in an exposed area on the shelf, the salinity measurements taken by Yoshioka *et al.* (1985) are the most representative. In contrast, surface salinities at the CARICOMP reef monitoring site in La Parguera (Turrumote Reef) averaged 35.2‰ (Table 3).

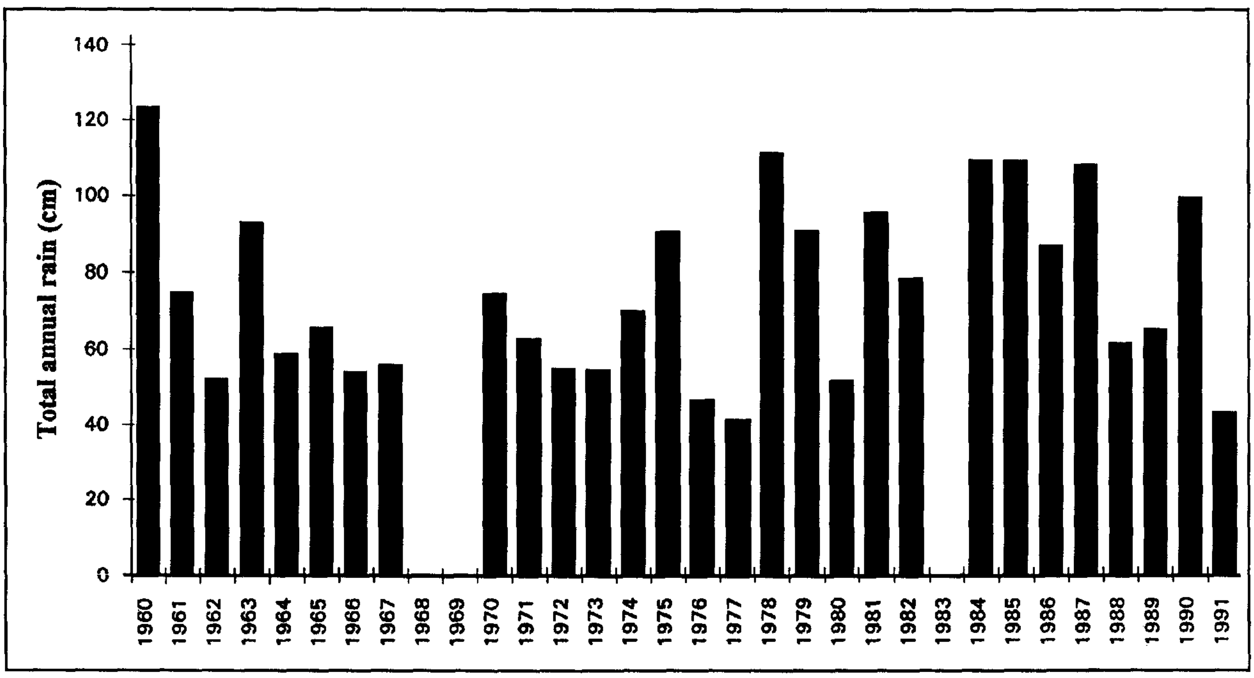


Fig. 2. Historical trends in total annual rainfall measured at the climatological station, Magüeyes Island, La Parguera.

Table 2. Historical trends in monthly maximum, minimum, and mean air temperature measurements at the Isla Magüeyes climatological station, La Parguera.

	Averages (°C)			Daily Extremes (°C)			
	Max	Min	Mean	High	dd/yyyy	Low	dd/yyyy
January	30.3	20.3	25.4	33.0	13/1977	15.7	11/1975
February	30.2	20.4	25.5	34.2	26/1978	15.7	23/1971
March	30.7	20.8	25.9	34.7	19/1977	16.8	22/1967
April	31.8	21.9	26.9	35.8	24/1978	15.7	07/1986
May	32.0	23.2	27.7	36.4	03/1978	18.5	20/1981
June	32.5	24.1	28.4	36.4	18/1978	19.6	03/1985
July	32.9	24.0	28.6	36.4	11/1977	19.0	06/1967
August	33.1	23.9	28.6	37.0	20/1979	17.9	10/1968
September	33.0	23.8	28.6	37.0	01/1979	16.8	27/1963
October	32.3	23.6	28.1	41.4	25/1979	19.0	21/1985
November	31.5	22.3	27.0	34.7	08/1977	18.5	30/1970
December	30.7	20.8	25.9	33.6	13/1977	16.8	09/1976
	Max	Min	Mean	High	mm/dd/yyyy	Low	mm/dd/yyyy
Annual	31.8	22.5	27.2	41.4	10/25/1979	15.7	01/11/1975
Winter	30.4	20.5	25.6	34.2	02/26/1978	15.7	01/11/1975
Spring	31.5	22.0	26.9	36.4	05/03/1978	15.7	04/07/1986
Summer	32.9	24.0	28.6	37.0	08/20/1979	17.9	08/10/1968
Autumn	32.3	23.2	27.9	41.4	10/25/1979	16.8	09/27/1963

Table 3. Biweekly hydrological measurements at Turrumote Reef, La Parguera, January-December 1993.

	Surface Temp (°C)	Surface Salinity (‰)	Secchi (m)
01/15/1993	26.0	35.0	12.0
01/29/1993	26.0	35.0	13.5
02/17/1993	27.2	36.0	13.5
03/03/1993	27.1	35.0	12.5
03/17/1993	27.0	36.5	7.0
03/31/1993	29.0	35.0	18.0
04/21/1993	29.0	37.0	16.0
04/28/1993	27.0	36.0	10.0
05/10/1993	28.0	35.0	5.0
05/21/1993	29.0	36.0	8.0
06/04/1993	29.8	33.0	10.0
06/18/1993	29.0	35.0	11.0
07/09/1993	29.5	35.0	13.0
07/23/1993	29.0	35.0	12.0
08/06/1993	29.0	34.8	8.0
08/20/1993	29.0	34.8	11.0
09/03/1993	29.5	35.2	8.0
09/17/1993	28.8	34.0	12.0
10/08/1993	29.0	34.2	10.5
10/22/1993	29.0	34.0	20.0
11/05/1993	29.0	36.0	10.0
11/24/1993	28.8	36.0	8.0
12/03/1993	28.0	36.0	12.0
Mean	28.4	35.2	11.3
Std Dev	1.11	0.91	3.48

Sea surface temperature (SST) and rainfall measurements have been collected since 1957 by the Department of Marine Sciences of the University of Puerto Rico at Mayaguez; NOAA facilitated the operation in 1976. The data set is reliable only after 1964 when time of measurement was standardized to within several hours. However, to reduce the effect of daily variations, only readings collected between 0700 and 0900 hours are used, representing 85% of all readings after 1964. Figure 3 shows the timing of the high temperature peaks and the duration of warm events throughout the year. Monthly means of measured temperatures between 1957 and 1992 illustrate intra-annual and inter-annual variations. The data show no warming trend for the duration of the record, in agreement with other data from the Caribbean (Atwood *et al.*, 1992). During the 35 years illustrated, August 1958, September 1987, and September 1990 had mean monthly temperatures above 30°C. Since 1987, every year has had at least three months with mean temperatures above 29°C. Surface water temperatures at Turrumote Reef (fore-reef) averaged 28.4°C and ranged from 26.0°C to 29.5°C (Table 3).

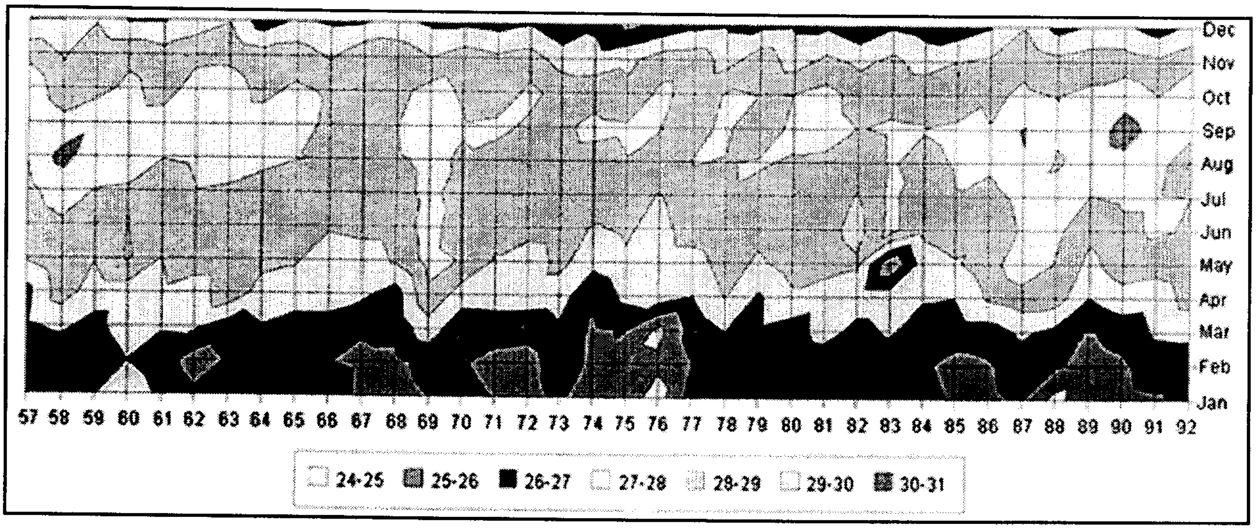


Fig. 3. Historical trends in monthly mean sea surface temperatures (°C) measured at the climatological station, Magüeyes Island, La Parguera.

Coral Reefs

According to Almy (1969), coral reefs in La Parguera originated from erosion and deformation of Upper Cretaceous limestones (with interbedded mudstones and volcanic rocks) into a WNW-ESE trending syncline. The northern limb of the syncline is the Sierra Bermeja, and the southern limb is a platform of lower relief represented by the coral reefs on the shelf. The rise in sea level associated with the last Pleistocene glaciation (Wisconsin) flooded the lower limestone ridges on the shelf, providing appropriate sites for coral growth and subsequent reef development (Glynn, 1973; Goenaga and Cintrón, 1979). Cross-shelf seismic profiles (Morelock *et al.*, 1977) support the theory of Kaye (1959), which states that the reefs developed on drowned calcarenite cuestas formed as eolianite structures parallel to the coastline during the Wisconsin glaciation. Substrate, depth, and water transparency conditions in La Parguera allowed for extensive development of coral reefs during the mid-Holocene (Vicente, 1993).

Two distinct lines of emergent reefs align east-west, parallel to the coastline, and divide the insular shelf of La Parguera into inner, middle, and outer shelf zones (Morelock *et al.*, 1977). There are many other smaller submerged patch reefs dispersed throughout the shelf, as well as a large submerged reef at the shelf edge. Altogether, it has been estimated that coral reefs occupy about 20% of the La Parguera insular shelf (Morelock *et al.*, 1977). Margarita Reef, the westernmost in the second line of emergent reefs, is the largest of the "island reefs," with a maximum underwater extension of 4.2 km. The shelf-edge reef is located at 20 m and has a "buttressed" appearance, with channels cut into the slope down to 30 m (Morelock *et al.*, 1977).

Almy and Carrion-Torres (1963) reported 35 species of scleractinian corals, and at least 30 other species of shallow-water octocorals have been reported from La Parguera (Yoshioka and Yoshioka, 1989). A generalized pattern of coral zonation at the fore-reef of emergent coral reefs in La Parguera was described by Acevedo and Morelock (1988). Zonation is similar to other Caribbean coral reefs, except that the *Lithothamnium* ridge found elsewhere is replaced by *Millepora* in La Parguera.

Turrumote Reef is located 3.5 km south off Punta Papayo, Lajas (17° 56.2'N; 67°1.2'W; Fig. 1). Adjacent emergent reefs are Corral (~0.8 km to the north) and Media Luna (~2.0 km to the west). Turrumote Reef runs east-west with a longitudinal extension of 1.8 km; its emergent extension is 0.5 km along the E-W axis, and its total surface area is ~1.3 km^2. This reef is situated on an isolated platform with its base at 20 m. The base substrate is covered with sandy silt sediments. Several other submerged reef platforms, rising to ~5 m from the surface, are located close to Turrumote to the southeast, including "Pinnacles." A small patch reef lies to the northeast, and a hard ground, low relief platform known as "Turrumote Ridge" is found to the southwest. The emergent section of Turrumote Reef is shaped like a horseshoe, forming a shallow reef lagoon at its center; this section is partially vegetated with red mangroves. Turrumote is farther offshore than any other reef in La Parguera.

The fore-reef is characterized by a long reef crest, an abrupt slope that includes several terraces, and a deep reef zone of irregular topography featuring massive coral formations at the base. At its easternmost section, the fore-reef extends 0.8 km to the south as a low-relief platform dominated by soft coral. Elsewhere, the fore-reef has horizontal extensions of less than 100 m from the surf zone to the reef base. The back-reef of Turrumote lacks the typical sandy-silt substrate leading to turtlegrass beds (*Thalassia testudinum*) that is found on many other reefs in La Parguera. Instead, the back-reef presents substantial hermatypic, soft coral, and hydrocoral (*Millepora*) development on a mostly sandy substrate.

The reef crest (depth 0-5 m) of Turrumote is a zone of energetic wave action dominated by encrusting biota: firecoral, *Millepora* spp., and branching coral, *Acropora palmata*. A dense algal turf composed of an assemblage of red and filamentous green algae covers most of the non-living hard substrate. The encrusting sponge *Anthosigmella varians* is found in multiple, small to intermediate patches (max 1.5 m diameter). Zoanthids, mostly *Palythoa caribbea*, and encrusting soft coral (*Erythropodium* sp.) are also common at the reef crest. Topographic relief ranges from 2 to 3 m and is influenced by the presence of large colonies of *A. palmata* .

The reef slope (5-13 m) is an area of intermediate wave and surge action and good light penetration. Using CARICOMP methodology, five chain transects, 10 m long, were surveyed at the fore-reef slope of

Turrumote Reef. The data on percent linear cover by sessile-benthic taxa for 1994 are summarized in Table 4. Massive corals, mainly *Montastraea annularis* dominate linear cover with a mean of 41.2%. Branching coral (mostly *Porites porites*) represents an additional 6.6%, for a total of 47.8% of live coral cover at a depth of 10 m. Bell-shaped colonies of *M. annularis* are generally of large size, ending with extensive overhangs on the sides. Some of these colonies measure more than 4 m in diameter and are contiguous with other colonies, creating sections of live coral that exceed 10 m in length. In addition *to M. annularis,* other massive coral species that are present in excellent condition at the reef slope of Turrumote include *Montastraea cavernosa, Dendrogyra cylindricus, Siderastrea spp.*, and *Diploria spp.* Algal turf follow live corals in linear cover, averaging 27.2% along the surveyed transects (range 13.9-38.3%). A highly diverse and abundant population of gorgonians represents another important component of the benthos at the reef slope.

Table 4. Percent linear cover by sessile-benthic biota at the fore-reef slope of Turrumote Reef at a depth of 10 m, La Parguera, 1994.

Category	Sp. Code	Tr-1	Tr-2	Tr-3	Tr-4	Tr-5	Mean
Algae							
turf		25.1	24.2	38.3	13.9	34.6	27.2
calcareous				1.6	2.2	1.1	1.0
Sponges							
erect				0.4		0.7	0.2
encrusting	Clio			0.6		0.3	0.2
Milleporids	Malc				1.5		0.3
Gorgonians							
erect		0.5					0.1
encrusting	Ecar	10.7	3.8	13.7	8.9	7.6	8.9
Anemones				0.3			0.1
Zoanthids	Zoan			2.1			0.4
	Paly						
Corals							
massive	Mann	48.1	29.4	13.4	56.4	24.6	34.4
	Mcav		3.4	5.6			1.8
	Past	3.5	3.0				1.3
	Dipl	4.0		7.2		4.0	3.0
	Side	2.8		0.3		0.1	0.6
branching	Pori	8.5	2.9	9.3		4.2	5.0
	others	1.6					0.3
	Agar		0.5	0.5	3.0	1.7	1.1
	others			0.9	0.3		0.2
total live							47.8
Bare sediments		5.2	17.1				4.5
Bare rock						0.6	0.1
Gaps		1.0	0.6	1.1		0.1	0.6
Overhangs		14.0	15.2	4.7	13.8	20.2	13.6
Boulders							
Rugosity		1.6	1.6	1.5	1.7	1.8	1.6

Species codes: Clio = *Cliona sp.*; Malc = *Millepora alcicornis*; Ecar = *Erythropodium caribaeorum*; Zoan = *Zoanthus sp.*; Paly = *Palythoa sp.*; Mann = *Montastraea annularis*; Mcav = *Montastraea cavernosa*; Past = *Porides astreoides*; Dipl = *Diploria sp.*; Side = *Siderastrea sp.*; Agar = *Agaricia sp.*

The deep fore-reef (13-20 m) is a zone of low wave and surge energy. Reef rugosity is irregular, influenced by the growth of massive scleractinian corals, particularly *Montastraea annularis*. As on the fore-reef slope, *Montastraea* colonies grow with extensive lateral projections, creating ledges and overhangs. Many massive coral colonies are overgrown by an algal turf, an encrusting soft coral (*Erythropodium* sp.), or a combination of both. The most common massive coral species at the deep fore-reef are *M. annularis* , *M. cavernosa*, *Diploria* spp., *Siderastrea* spp., and *Dendrogyra cylindricus*. A profuse development of soft coral colonies is also found at the deep fore-reef of Turrumote.

Mangroves

The southwestern coast of Puerto Rico contains 996 ha of mangroves, representing 15.3% of the total mangrove area in Puerto Rico (Martinez *et al.*, 1979). The original area of mangroves in Puerto Rico was estimated at 30,000 ha; by 1975, only half of that area remained. Unfortunately, the destruction of mangrove areas continues despite political resolutions and laws (Lugo, 1988). Some of the emergent portions of the shelf reefs at La Parguera are colonized by mangroves. The degree of exposure to the incoming waves limits mangrove development on these offshore islands (Yoshioka, 1975). Red mangrove, *Rhizophora mangle*, is the dominant species on island reefs; a few white mangroves (*Laguncularia racemosa*) are also present. Mangrove development is greatest in zones of intermediate wave energy. On the exposed outer cays, the strong surf does not allow deposition of the fine sediments needed for the growth of red mangroves. On the middle shelf zone, waves and currents are strong enough to maintain a constant flow of water, yet allow for accumulation of fine sediments. Consequently, red mangroves prevail at these middle shelf reefs. The inner shelf reefs are not subject to enough wave energy to maintain adequate flushing; consequently, these reefs normally have strong transverse salinity gradients. Salt builds up in the center of these islands and enables the succession of red mangroves by the more salt-tolerant black mangrove (*Avicenna*). Prolonged accumulation of salt eventually leads to the death of the black mangroves.

The Pitahaya mangrove forest, the largest and best developed mangrove stand in the southwestern corner of Puerto Rico, reaches 1.2 km inland and stretches 6.5 km along the coast between Punta Guayacan and Punta Pitahaya (Fig. 1). The area is characterized by a well-developed fringe forest of red mangrove and a less developed basinal forest that includes red, white, and black mangrove species. The structural characteristics of the mangrove forests at La Parguera are summarized in Table 5. Differences in mean plot stand height and trunk diameter are observed within and between mangrove sites. The tallest stands and greatest mean trunk diameter correspond to red mangroves of fringe forest type. The basinal mangrove stand at Pitahaya has lesser stand heights and trunk diameters. Farther inland, vegetation gives way to barren salt flats (Martinez *et al.*, 1979). Inshore islands and fringing (coastal) mangroves are separated by channels and embayments. Large areas between the mangroves are covered by turtle grass (*Thalassia testudinum*) and associated algae (*e.g.*, *Dictyota divarica, Laurencia obtusa, Caulerpa verticillata,* and *Acanthophora spicifera*). The upside-down jellyfish (*Cassiopeia frondosa*), the starfish (*Oreaster reticulatus*), and the sea cucumber (*Ludwigothuria mexicana*) are some of the dominant faunal components in the embayments and channels (Cerame, 1973), along with a diverse ichthyofauna of juvenile marine fishes and resident estuarine populations (Austin, 1971; García, 1981). The red mangroves bordering the channels, bays, and islands protrude with drop and prop roots into the sediments. This root system provides a unique habitat for a variety of sessile organisms. Typical epifaunal species are sponges (*Tedania ignis, Callyspongia, Ircinia, Chondrilla, Haliclona*), hydroids, sea anemones (*Aiptasia* and *Bartholomea*), oysters (*Crassostrea rhizophorae*), tunicates (*Clavelina spp., Ascidia nigra, Ecteinascidia turbinata*), and polychaetes (*Sabellastarte magnifica* and *Sabella melanostigma*) (Matthews, 1967). The structure and composition of this epifaunal community seem to vary due to different hydrodynamic regimes (Yoshioka, 1975).

Table 5. Structural characteristics of mangrove forests in La Parguera; all values are from live stems (after Cintrón *et al.*, 1978).

	Stand Type*	Mean DBH (cm)	No. of Spp.	No. of Trees With Trunk Diameter >2.5 cm	>10 cm	Basal Area (m) >2.5 cm	>10 cm	Stand Height (m)
Caballo Blanco Reef								
Plot 1	I	16.2	1	63	33	1	0.8	14.8
Plot 2	I	14.1	1	140	104	1.9	1.75	14.3
Enrique Reef								
Plot 1	I	8.1	1	659	64	2.7	0.6	9.2
Laurel Reef	I	14.1	2	281	236	3.7	3.4	7.3
Pitahaya-1								
Plot 1	F	13	1	277	170	2.7	2.3	12.2
Plot 2	F	6	2	798	10	1.85	0.1	6
Plot 3	B	7.2	3	318	17	0.55	0.2	4.5
Pitahaya-2								
Plot 1	F	14.6	1	294	214	3.8	3.5	13.8
Plot 2	F	11.2	1	283	50	1.5	0.8	8.8

*Stand Type: I = island; F = fringe; B = basin.

Seagrass Beds

Seagrass meadows and associated macroalgae are highly productive habitats that provide living space, foraging grounds, and refuge from predators for populations of invertebrates and fishes, many of which are commercially valuable species. The extensive seagrass beds that occur in southwestern Puerto Rico, in close proximity to some of the island's most pristine coral reef and mangrove habitats, provide nursery and feeding grounds. In addition to providing basic nutrients, primary productivity, and stable habitats, these beds provide essential foraging grounds for such endangered marine species as the West Indian manatee, *Trichechus manatus*, and the green sea turtle, *Chelonia mydas*.

Of the twelve recognized genera of seagrasses distributed throughout the temperate and tropical coastal zones of the world, four are found in the Caribbean and Puerto Rico. These four genera are represented by seven local species: turtle grass, *Thalassia testudinum* (Banks ex Konig); the sea vines *Halophila decipiens* (Ostenfeld), *H. baillonis* (Ascherson), and *H. engelmannii* (Ascherson); manatee grass, *Syringodium filiforme* (Kutzing); the shoal grass *Halodule wrightii* (Ascherson); and the widgeon grass *Ruppia maritima* (Linnaeus). Of these species, *Thalassia testudinum, Syringodium filiforme, Halophila decipiens,* and *Halodule wrightii* inhabit the insular shelf zones on both the Atlantic and Caribbean coasts of Puerto Rico as well as the nearby islands of Vieques and Culebra. The sea vines *Halophila baillonis* and *H. engelmannii* have been found only in restricted localities on the northern and southeastern coasts of Puerto Rico. *Halophila decipiens*, although patchy in distribution, can be quite abundant when encountered and appears to tolerate low salinities (<20‰) and turbidity (Secci <1 m), enabling this vine to invade polluted environments (Vicente *et al.*, 1980). Widgeon grass (*R. maritima*) has been found only in enclosed lagoons with little or no oceanic influence (Detres, 1988).

Large areas of *Thalassia* on the reef flat are periodically exposed to air, resulting in increased temperature and desiccation. Glynn (1968) observed that *Thalassia* leaves do not survive when temperatures reach their upper tolerance levels of 35-40°C but that rhizomes of the plants are apparently unaffected, due primarily to the thermal buffering effect of fine-grained sediments covering the underground portion of the plants. Tidal fluctuations accompanying strong spring tides can cause extreme temperature shifts that, coupled with desiccation, kill vast quantities of leaves, which then are shed by the plants. The process occurs sporadically throughout the year and seems to be an integral part of the ecology of the seagrasses, with no apparent negative long-term effect on the population as a whole.

Large seagrass beds are established in the La Parguera area, with *Thalassia* and *Syringodium* being the most abundant and widely distributed seagrasses over the insular shelf and also in the back-reef zones of middle shelf reefs. The most extensive seagrass beds are found within the 2-m depth contour, fringing the red mangrove coastline. Mangrove forests border almost the entire southwestern coastline, and mangrove islets are common inside the inner shelf (Cintrón *et al.*, 1978). The distribution of *Thalassia* near the offshore reefs and mangrove islets is generally restricted to the lee (north) side of these formations and commonly occurs in association with coral species such as fire coral (*Millepora complanata*), staghorn coral (*Acropora cervicornis* and *A. prolifera*), and finger coral (*Porites spp*). Seagrasses are absent from the exposed reef fronts. On the inundated central portion of the reef flats and in the shallow lagoon side of the reefs, *Thalassia* develops among the coral rubble and sand, providing a rich feeding ground for diurnal reef residents. Prominent grazers in the seagrass beds include the long-spined sea urchin (*Diadema antillarum*); the variegated sea urchin (*Lytechinus variegatus*); the West Indian sea egg (*Tripneustes ventricosus*), the Queen conch (*Strombus gigas*), the green sea turtle (*Chelonia mydas*), and a sizable assemblage of herbivorous fishes.

Reproduction in seagrasses occurs vegetatively (rhizome propagation) and sexually (incomplete dioecious flowers). Male and female *Thalassia* flowers begin to appear in March, reaching peak abundance in April and May, after which time flower production begins to wane. The season normally ends in June. The percentage of shoots with reproductive structures (buds, flowers, or fruits) varies from 4% to 54% during May. Inter-annual variation is dependent on factors such as wave energy, sediment load, turbidity, and water temperature, all of which affect the success of the reproductive season (Vicente *et al.*, 1980).

There are considerable temporal and spatial fluctuations in total biomass of the seagrasses. *Thalassia* has low biomass (100 g m^{-2} dry weight) in areas where mangrove growth is prolific, thereby reducing the amount of available light, whereas biomass under high light intensity may reach 5,800 g m^{-2} dry weight (Vicente, 1992). For our purposes, "standing crop" refers to the above-sediment living component (including calcareous epiphytic algae), whereas "biomass" refers to the above- and below-sediment (roots, rhizomes, and short shoots) components.

For *Thalassia* growing in an industrial estuary that receives thermal effluent from a power plant, primary production values have been reported as 0.43 to 2.61 g m^{-2} dry weight per day (Vicente 1992). Biomass values for the same bay were reported as 330 g m^{-2} dry weight. Primary production is likely to be higher in less polluted environments of Puerto Rico. Higher productivity values (up to 18.9 g m^{-2} dry weight) have been measured for *Thalassia* in other parts of the Caribbean (Buesa, 1972): an average of 70 t yr^{-1} ha^{-1} of *Thalassia*. Gonzalez-Liboy (1979) summarized *Thalassia* biomass and standing crop values (g m^{-2} dry weight) for various sites scattered throughout Puerto Rico, with means for south-western Puerto Rico in the range 229-586 g for standing crop estimates and 532-1,986 g for biomass estimates. Burkholder *et al.* (1959) reported 80-450 g m^{-2} dry weight as a range of means for biomass estimates taken at several sites in Puerto Rico. Delgado-Hyland (1978) reported standing crops for *Thalassia* in the La Parguera area as in the range 96-480 g m^{-2} dry weight.

In summary, the seagrass beds of southwestern Puerto Rico appear to be in good condition and serve as a key component, intimately and functionally associated with the coral reef and mangrove ecosystems, in providing important nursery and foraging grounds for many commercially important fish and invertebrate populations. In order to ensure the long-term health and sustainability of these nearshore marine ecosystems, future development plans will have to take into consideration the physical and biological requirements of the seagrass beds and offer protection whenever possible, as well as restoring the original mangrove fringe where it has been cut or destroyed.

Human Utilization and Impact on Marine Resources

Approximately 100 fishermen concentrate their efforts within the insular shelf of La Parguera, evenly split between commercial and recreational fishing. Fish traps (arrow type) and monofilament gill nets are the main methods used by the commercial fishermen. A recent survey determined that 1,050 traps are utilized in the commercial fishing effort. Recreational fishing involves hook and line, flycasting, jigging, trolling, and spearfishing. Both commercial and recreational fishing here have suffered a sharp decline in CPUE (catch per unit effort), consistent with the decline seen for all of Puerto Rico (Appeldoorn *et al.*, 1992). The direct and indirect implications of changes in ichthyofaunal community structure upon sessile-benthic communities are not well established.

The mangrove areas of La Parguera have been, and continue to be affected by several anthropogenic factors. For example, mangrove trees were cut down during the construction of 200 summer houses along the shoreline. Strips of salt marsh were filled to provide access to these houses, altering normal tidal flow throughout the mangroves. Boat traffic in the channels and embayments perturbs the sediments covering mangrove root systems.

Another important factor influencing coastal ecosystems is the sewage treatment plant (STP) that is located between La Parguera and Isla Guayacan. This plant discharges an average of 228,000 liters of secondary sewage effluent per day into percolation ponds at the landward margin of the coastal mangrove fringe. The mangrove area subject to the intrusion of effluent waters covers at least 0.123 km^2

(Corredor and Morell, 1994). Investigations of surface nitrate concentrations indicated that some nitrates do not percolate completely into the sediments and thus reach the seaward fringe in effluent streams. However, experiments revealed that microbial communities in mangrove sediments are capable of depurating 10 to 15 times the nitrate added by the STP effluent (Corredor and Morell, 1994). The mangroves themselves seem to respond favorably to nutrient additions, as can be seen around the STP where the heights of the trees are much greater than in undisturbed areas. Nervertheless, the mangrove root community appears to be less diverse near the STP.

Deforestation is a common practice in construction of homes, camping areas, and other projects within the watershed. Such development has increased drastically during the last ten years, leading to alterations in the natural pattern of rainfall drainage and runoff and to an increase in sediments reaching coastal waters.

La Parguera is probably the single most popular tourist destination on the southwestern coast of Puerto Rico. Boat traffic can be quite heavy, especially on weekends and during the summer. Many tourists utilize the nearshore mangrove islets and associated seagrass beds as a psuedo-beach area, anchoring their boats in the lee of the islets. Thus, these habitats at times are subject to heavy boat and foot-traffic, with ensuing trampling effects in addition to propellor and anchor scars. According to Zieman (1976), although *Thalassia* is highly productive and capable of vigorous regeneration, it does not recover rapidly when injuries extend down to the root-rhizome system. Tracks from propeller damage have been observed to persist in *Thalassia* beds for more than five years.

References

Acevedo, R., J. Morelock. 1988. Effects of terrigenous sediment influx on coral reef zonation in southwestern Puerto Rico. *Proceedings of the 6th International Coral Reef Symposium, Australia,* **2**:189-194.

Almy, C., D. Carrion-Torres. 1963. Shallow-water stony corals of Puerto Rico. *Caribbean Journal of Science,* **3**:133-162.

Almy, C. 1965. *Parguera Limestone, Upper Cretaceous Mayaguez Group, Southwestern Puerto Rico.* Ph.D. Thesis, Rice University, Houston TX, USA.

Almy, C. 1969. Sedimentation and tectonism in the Upper Cretaceous Puerto Rican portion of the Caribbean island arc. *Gulf Coast Association Geological Society Transactions,* **19**:269-279.

Appeldoorn, R., J. Beets, J. Bohnsack, S. Bolden, D. Matos, S. Mayers, A. Rosario, Y. Sadovy, W. Tobias. 1992. *Shallow Water Reef Fish Stock Assessment for the U. S. Caribbean.* NOAA Technical Memorandum NMFS-SEFSC-304, 70 pp.

Atwood, D. K., J. C. Hendee, A. Méndez. 1992. An assessment of global warming stress on Caribbean coral reef ecosystems. *Bulletin of Marine Science,* **51**:118-130.

Austin, H. M. 1971. A survey of the ichthyofauna of the mangroves of western Puerto Rico during December 1967-August 1968. *Caribbean Journal of Science,* **11** (3-4):171-178.

Buesa, R. J. 1972. Producción primaria de las praderas de *Thalassia testudinum* de la plataforma noroccidental de Cuba. *Contribuciones Investigaciones Pesqueras,* **3**:101-143.

Bunkley-Williams, L., J. Morelock, E. H. Williams. 1991. Lingering effects of the 1987 mass bleaching of Puerto Rican coral reefs in mid to late 1988. *Journal of Animal Health,* **3** (4):242-247.

Burkholder, P. R., L. M. Burkholder. 1958. Studies on B vitamins in relation to productivity of Bahía Fosforescente, Puerto Rico. *Bulletin of Marine Science of the Gulf and Caribbean*, **8**:202-223.

Burkholder, P. R., L. M. Burkholder, J. A. Rivero. 1959. Some chemical constituents of turtle grass, *Thalassia testudinum. Bulletin of the Torrey Botanical Club*, **86**(2):88-93.

Busalacchi, A. J., L. Picaut. 1983. Seasonal variability from a model off the tropical Atlantic Ocean, *Journal of Physical Oceanography*, **13**:1564-1588.

Cerame, M. J. 1973. *Mangroves of Puerto Rico*. P. F. Z. Properties Inc., and M. C. Cerame-Vivas Inc., San Juan PR, USA, 64 pp.

Cintrón, G., A. Jugo, D. Pool, G. Morris. 1978. Mangroves of arid environments in Puerto Rico and adjacent islands. *Biotropica*, **10**(2):23-35.

Colin, P. L., I. E. Clavijo. 1988. Spawning activity of fishes producing pelagic eggs on a shelf edge coral reef, southwestern Puerto Rico. *Bulletin of Marine Science*, **43**:249- 279.

Corredor, J., J. Morell. 1994. Nitrate depuration of secondary sewage effluents in mangrove sediments. *Estuaries*, **17**(1b):295-300.

Detres, Y. 1988. *Estudio de la Fanerogama Marina Ruppia maritima L. en la Región Suroeste de Puerto Rico*. M.Sc. Thesis, Department of Marine Science, University of Puerto Rico, Mayaguez PR, USA, 60 pp.

Delgado-Hyland, A. 1978. *La Ecología de las Comunidades de Thalassia testudinum en La Parguera, Lajas, Puerto Rico*. M.S. Thesis, Marine Science Department, University of Puerto Rico, Mayaguez PR, USA, 97 pp.

Etter, P. C., P. J. Lamb, D. H. Potis. 1987. Heat and freshwater budgets of the Caribbean with revised estimates of the Central American seas. *Journal of Physical Oceanography*, **17**:1232-1248.

Ewel, J. J., L. Whitmore. 1973. *The Ecological Life Zones of Puerto Rico and the U.S. Virgin Islands*. Forest Service Research Paper ITF 18, U.S. Department of Agriculture, 18 pp.

Fiske, S. J. 1992. Sociocultural aspects of establishing marine protected areas. *Ocean and Coastal Management*, **18**:25-46.

Froelich Jr., P. N., D. K. Atwood, G. S. Giese. 1978. Influence of Amazon River discharge on surface salinity and dissolved silicate concentration in the Caribbean Sea. *Deep-Sea Research*, **25**:735-744.

García, J. R. 1981. *Ecological Aspects of a Community of Fishes in Laguna Joyuda*. **In:** *Proceedings of the 8th Symposium*. Department of Natural Resources, San Juan PR,USA.

García, J. R., J. M. López. 1989. Seasonal patterns of phytoplankton productivity, zooplankton abundance and hydrological conditions in Laguna Joyuda, Puerto Rico. *Scientia Marina*, **53**(2-3):625-631.

García, J. R. 1990. Population dynamics and production of *Phyllorhiza punctata* (Cnidaria:Scyphozoa) in Laguna Joyuda, Puerto Rico. *Marine Ecology Progress Series*, **64**:243-251.

Glynn, P. W. 1964. *Common Marine Invertebrate Animals of the Shallow Waters of Puerto Rico*. Instituto de Cultura Puertorriqueño, Historia Natural de Puerto Rico, San Juan PR, USA, 48 pp.

Glynn, P. W. 1968. Mass mortalities of echinoids and other reef flat organisms coincident with midday low water exposures in Puerto Rico. *Marine Biology*, **1**:226-243.

Glynn, P. W. 1973. Aspects of the ecology of coral reefs in the Western Atlantic region. **In:** *Biology and Geology of Coral Reefs* (edited by O. A. Jones and R. Endea), Vol. 2, pp 271-324. Academic Press, New York NY, USA.

Goenaga, C., G. Cintrón. 1979. *Inventory of the Puerto Rican Coral Reefs*. Department of Natural Resources, Coastal Zone Management Program, San Juan PR, USA, 190 pp.

Goenaga, C., V. P. Vicente, R. Armstrong. 1989. Bleaching induced mortalities in reef corals from La Parguera, Puerto Rico: A precursor of change in the community structure of coral reefs? *Caribbean Journal of Science*, **25**:59-65.

Goenaga, C. 1988. *The Distribution and Growth of Montastraea annularis (Ellis and Solander) in Puerto Rican Inshore Platform Reefs*. Ph.D. Thesis, University of Puerto Rico, Mayaguez PR, USA, 186 pp.

Gonzalez-Lagoa, J. 1967. *Primary Productivity of the Neritic and Offshore Waters of Western Puerto Rico*. Final Report NONR-4318, U.S. Office of Naval Research, 13 pp.

Gonzalez-Liboy, J. 1979. *An Examination of the Present Condition of Seagrass Meadows in La Parguera, Puerto Rico*. Final Report, State of Puerto Rico Project No. 4, June, 1979.

Gonzalez-Sansón, G. 1983. Estructura de las comunidades de peces en las lagunas costeras de Tunas de Zaza, Cuba. *Revista de Investigaciones Marinas*, **4**:135-158.

Kaye, C. 1959. Shoreline features and quaternary shoreline changes, Puerto Rico. In *USGS Professional Paper 317-B*, pp 49-140. U.S. Geological Survey, Reston VA, USA.

Lugo, A. R. 1988. The mangroves of Puerto Rico are in trouble. *Acta Cientifica*, **2**(2-3):124.

Margalef, R. 1957. Fitoplankton de las costas de Puerto Rico. *Investigaciones Pesqueras*, **6**:39-52.

Martinez, R., G. Cintrón, L. A. Encarnacion. 1979. *Mangroves in Puerto Rico: A Structural Inventory*. Department of Natural Resources, San Juan PR, USA, 149 p.

Matthews, B. 1967. *An Ecological Guide to the Littoral Fauna and Flora of Puerto Rico*. Department of Education, San Juan PR, USA, 37 pp.

Meade, R. H., C. F. Nordin Jr., D. Perez Hernandez, A. Mejia, J. M. Perez-Godoy. 1983. Sediment and water discharge in Rio Orinoco, Venezuela and Columbia. **In:** *Proceedings of the 2nd International Symposium on River Sedimentation (Nanjing, China)*, pp 1134-1144. Water Resources and Electric Power Press, Beijing, China.

Milliman, J. D., R. H. Meade. 1983. World-delivery of river sediment to the oceans. *Journal of Geology*, **91**:1-21.

Morelock, J., N. Schneiderman, W. Bryant. 1977. Shelf reefs, southwestern Puerto Rico. *Studies in Geology*, **4**:17-25.

Morrison, J. M., W. D. Nowlin. 1982. General distribution of water masses with the eastern Caribbean Sea during the winter of 1972 and fall of 1973. *Journal of Geophysical Research*, **87**:4207-4229.

Muller-Karger, F. E., C. R. McClain, T. R. Fisher, W. E. Esaias, R. Varela. 1989. Pigment distribution in the Caribbean Sea: Observations from space. *Progress in Oceanography*, **23**:23- 64.

Nazario-Sepúlveda, E. 1984. *Algunos Aspectos de la Biología de Halophila decipiens, Ostenfeld (Angiospermae:Hydrocharitaceae)*. M.S. Thesis, Marine Science Department, University of Puerto Rico, Mayaguez PR, USA, 61 pp.

NOAA/DNR. 1984. *Declaración de Impacto Ambiental Final y Plan de Manejo Para el Sanctuario Marino Nacional de La Parguera*. National Oceanic and Atmospheric Administration/Puerto Rico Department of Natural Resources, 277 pp.

Picard, G. L., W. J. Emery. 1982. *Descriptive Physical Oceanography, 4th Edition*. Pergamon Press, Oxford, UK, 249 pp.

Plan Development Team. 1990. *The Potential of Marine Fishery Reserves for Reef Fish Management in the U. S. Southern Atlantic*. NOAA Technical Memorandum NMFS- SEFC-261, 40 pp.

Richardson, P. L., T. K. McKee. 1984. Average seasonal variation of the Atlantic equatorial currents from historical ship drifts. *Journal of Physical Oceanography,* **14**:1226-1238.

Vicente, V. P., L. R. Almodovar, J. A. Rivera, D. Corales. 1980. An ecological evaluation of seagrasses in Guayanilla Bay. *Science-Ciencia,* **7**:91-103.

Vicente, V. P., J. A. Rivera. 1982. Depth limits of the seagrass *Thalassia testudinum* (Konig) in Jobos and Guayanilla Bays. *Caribbean Journal of Science,* **17**:79-89.

Vicente, V. P. 1992. A summary of ecological information on the seagrass beds of Puerto Rico. **In:** *Coastal Plant Communities of Latin America,* pp 123-133. Academic Press, New York, NY, USA.

Vicente, V. P. 1993. *Decline of Coral Populations in a Coral Reef: Cayo Enrique, La Parguera, Puerto Rico.* Paper presented at the 78th Caribbean Fisheries Council Meeting, 1-3 June 1993, St. Thomas, USVI.

Williams Jr., E. H., L. Bunkley-Williams. 1989. Bleaching of Caribbean coral reef symbiots in 1987-1988. *Proceedings of the Sixth International Coral Reefs Symposium (Australia),* **3**:313-318.

Trueblood, D. D. 1991. Spatial and temporal effects of terebellid polychaete tubes on soft-bottom community structure in Phosphorescent Bay, Puerto Rico. *Journal of Experimental Biology and Ecology,* **149**:139-159.

Yáñez-Arancibia, A., R. S. Nugent. 1977. El papel ecológico de los peces en estuarios y lagunas costeras. *UNAM Anales Centro Ciencias del Mar y Limnología,* **4**:107-114.

Yoshioka, P. 1975. Mangrove root communities in Jobos Bay. **In:** *Puerto Rico Nuclear Center: Aguirre Environmental Studies, Jobos Bay, Puerto Rico, Final Report, 1975,* **1**:50-65.

Yoshioka, P. M., G. P. Owen, D. Pesante. 1985. Spatial and temporal variations in Caribbean zooplankton near Puerto Rico. *Journal of Plankton Research,* **7**(6):733-751.

Yoshioka, P. M., B. B. Yoshioka. 1989. Effects of wave energy, topographic relief and sediment transport on the distribution of shallow-water gorgonians of Puerto Rico. *Coral Reefs,* **8**:145-152.

Zieman, J. C. 1976. The ecological effects of physical damage from motor boats on turtle grass beds in southern Florida. *Aquatic Botany,* **2**(2):127-139.

Parque Nacional del Este, Dominican Republic[1]

Francisco X. Geraldes
Centro de Investigaciones de Biología Marina
Universidad Autónoma de Santo Domingo
Aptdo. 1355, Santo Domingo, República Dominicana

The CARICOMP site in the Dominican Republic is located in the Parque Nacional del Este on the southeastern coast of the island of Hispaniola. The site is typical of leeward marine and coastal environments, with frequent calm seas and noticeable currents. The sunny days, average air temperature of 26.5°C, and rainfall of 1,000 mm yr^{-1} contribute to a tropical semi-arid forest growing on coral/limestone bedrock. There are few anthropogenic impacts; boating, diving, and fishing are the primary sources of disturbance. The ecosystems selected are located along a NW-SE transect near Palmillas. The mangrove site (Catuano), is a fringing forest type, with a dense growth of trees no taller than 5 m. The seagrass station (Hierbas los Cocos) is 1.5 km to the northwest in a sandy and rubble shallow (2-4 m) just inshore of a hard platform where soft corals dominate. The coral reef station (El Peñón) is farther north and lies at a depth of 10 m on a rocky platform where diverse species of corals form a low relief spur-and-groove reef system. The park represents one of the largest pristine marine and coastal environments in the Caribbean. It is a protected area under Dominican law, and continuous efforts are being made to maintain it. Mooring buoys are being installed and fishing and navigational regulations are being implemented to minimize the impact of users and visitors.

Introduction

The Parque Nacional del Este is located on the southeastern coast of the Dominican Republic; it is bordered by San Rafael de Yuma on the north, the Bahía de Yuma on the east, and the Caribbean Sea on the south (Fig. 1). The park, 42,000 ha, was declared a protected area in September of 1975.

Only a few marine research studies have been conducted in the park. In 1973, a physical oceanographic study was conducted by Metcalf *et al.* (1977) using drift bottles. A similar study, but encompassing the entire Caribbean, was performed by Brucks (1971). Metcalf *et al.* (1977) indicated the existence of "an extremely complex current condition in Mona Passage, with some bottles drifting from the Caribbean into the Atlantic Ocean and others in the opposite direction." Geraldes (1983) surveyed

[1] *CARICOMP — Caribbean Coral Reef, Seagrass and Mangrove Sites* (edited by B. Kjerfve), pp 213-220. UNESCO, Paris, 1998, 347 pp.

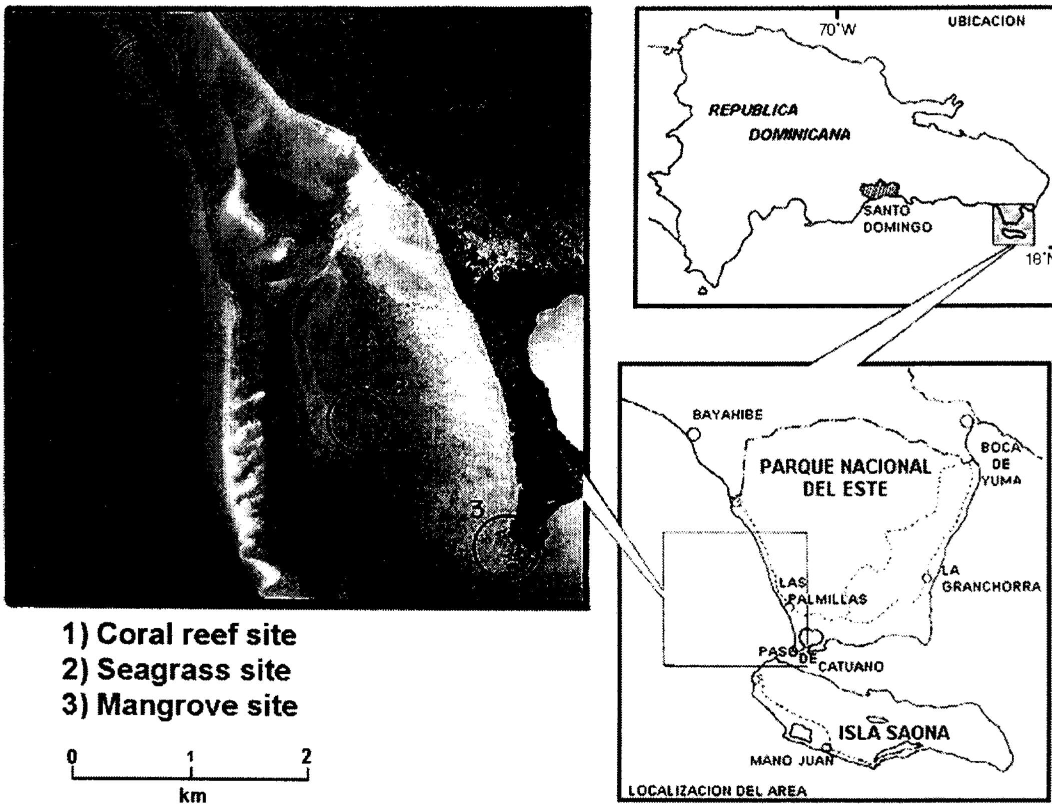


Fig. 1. CARICOMP sites in the Parque Nacional del Este, Dominican Republic.

marine habitats on the western shore of the Parque Nacional del Este, especially mangrove forests and the Bahía las Calderas. Olivares (1984) studied the composition, distribution, and abundance of zooplankton community in Bahía de las Calderas on the southern coast of the park. Data were collected on temperature, salinity, and depth of the area; the salinity gradient in nearby Bahía de las Calderas suggests freshwater intrusion in the area. The zooplankton analysis indicates that the composition of the community remains fairly constant as the tide changes.

Using ground-truthed aerial photograph interpretations and helicopter reconnaissance surveys, Island Resources Foundation, Inc. (Towle, 1975) offered well-documented descriptions of marine habitats and biota in the park before the marine Rapid Ecological Assessment in 1994-1995 (Vega, 1994). In 1975, a brief underwater survey was conducted by Caboza and Pierce in marine areas within and adjacent to the present park. Although it is largely a descriptive study, it does point out that there is a lack of large fish and suggests that spearfishermen may be responsible.

After the declaration of the area as a national park, the Dirección Nacional de Parques elaborated the Plan de Manejo del Parque Nacional del Este (Fahrenkrog, 1979). This management plan was the first of this nature in all the parks in the Dominican Republic. The plan not only describes the park and its resources, but it includes preliminary species lists of the marine fishes, marine reptiles and mammals, corals, marine molluscs, and marine seagrasses and algae.

In a series of studies in the Catalinita and Saona Islands (Vega, 1987), Dominican archaeologists discovered and photographed great conch piles, called "conchales" or "concheros," demonstrating the economic importance of *Strombus gigas* for the Taino Indians as well as for modern fishermen. Vega (1987) noted: "It is interesting to see how the places where the most numerous Precolombian conch piles exist are the same places where, today, the fishermen still dedicate themselves to the same work and create 'modern' parallel conch piles. The place in the country with the greatest modern conch piles is Catalinita Island, between Saona and Boca de Yuma."

Climate and Oceanography

The inland features of the park consist largely of terraces of Pleistocene coralline rock that emerged from the ocean and whose present elevations are 0, 5, 18, and 60 m above sea level. The coastal limestone is porous and filled with cavities and casts of coralline fossil organisms (Benchmarks, 1973). There are two shore-normal geologic faults: one is in the northeast near Boca de Yuma and extends for almost 20 km from east to northeast, the other is located in the southeast near La Granchorra and extends for approximately 12 km east to southeast (Cano Corcuera, 1993).

The climate of the park is tropical. The mean annual air temperature is 26.5°C with only ±2° variation. The humidity is stable, averaging 79%. Rainfall averages 1,000 mm per year, with 70% of the precipitation occurring May-July and September-October. The northeast tradewinds blow almost continuously (Benchmarks, 1973). A salient feature of the park is the absence of running freshwater; there are no rivers, lakes, ponds, streams, or freshwater swamps (Towle, 1975). However, there are sinkholes that accumulate rainwater. In general, oceanic currents flow east to west, although there is evidence of much variability in the Mona Passage between Puerto Rico and the Dominican Republic (Metcalf *et al.*, 1977).

The geology, geomorphology, and hydrogeology of the park combined with the semi-humid tropical climate indicate that, due to the high porosity of the coralline ground, there is a relatively large flow of groundwater (Cano Corcuera, 1993).

The terrestrial flora and fauna of the park have been previously described (Benchmarks, 1973; Cano Corcuera, 1993); more recently, an extensive Rapid Ecological Assessment was performed concurrently on the terrestrial systems of the park. To summarize, many different types of terrestrial and marine environments occur in the Parque Nacional del Este, including mangrove swamps, coconut plantations, moist subtropical deciduous forests, salt-resistant plant communities, and dry subtropical forests.

The coastline of the park is varied. There are white sandy beaches and relatively shallow waters in the western and southern portions of the park mainland and around most of the southern portion of Saona Island. There are rocky intertidal coasts and cliffs on the eastern side of the mainland and on the northeastern coast of Saona Island. And there are well-developed, varied mangrove forests in some places on the southern coast of the mainland.

Ecosystems in the Parque Nacional del Este

The marine nearshore tropical ecosystems (mangroves, seagrass beds, and coral reefs) in the park are found mainly on the western leeward shore. These ecosystems have not been disturbed and are protected. Human interventions and anthropogenic impacts are few; plastics and other debris are found occasionally. Neither freshwater influences nor pollutants are common in this region or in adjacent ecosystems.

A Rapid Ecological Assessment that was performed in 1994 aboard the Shed Aquarium's R/V *Coral Reef II* by a team of US and Dominican scientists produced the first comprehensive document regarding the coastal and marine ecosystems in the park. Table 1 summarizes the marine biodiversity found after a three-week cruise.

Table 1. Number of species in benthic communities in the Parque Nacional del Este, Dominican Republic.

	Algae	Sponges	Octocorals	Corals
Low-Relief Spur-and-Groove				
Parque Nacional	15	29	10	22
El Peñón	15	36	16	26
El Toro	–	28	22	23
Arrecife de Rubén	14	34	16	18
Reef Flat				
Pasa Grande	36	7	5	12
Arrecife del Tronco	27	16	7	14
Arrecife Fuerte Olas	28	5	3	10
Transitional Reef				
El Faro #2	24	–	22	23
Patch Reef				
Arrecife del Angel #1	21	20	7	11
Arrecife del Angel #2	15	18	3	15
El Faro #1	19	–	18	23
Low-Relief Hard Bottom				
Arrecife los Cocos	29	28	23	14
Rocky Coast Platform Reef				
Acantilado de Catuano	29	28	13	20
Puerto Catuano	17	14	9	12
Soft Bottom				
Hierba de Tronco	25	0	0	2
Pila de Lambí	9	1	0	1
Los Manglecitos	11	0	0	2
Ciudad de Penicillus	17	2	0	0
Hierba los Cocos	10	2	0	3

The CARICOMP sites are located at Palmillas on the western shore of the park near the Catuano Passage that divides the mainland from Saona Island. The names of the CARICOMP sites are: Punta Mangle at Catuano (mangroves), Hierbas los Cocos (seagrasses), and El Peñón (coral reefs). In general, these sites represent seagrasses and coral reefs; however, some variations were found related to the oceanography, geomorphology, and substrate that affect productivity and biodiversity.

Coral Reef Communities. Four of the benthic sites are characterized as belonging to the low-relief spur-and-groove community: Parque Nacional and El Peñón (where the CARICOMP site is located), both of which are on the west side of the park, are the most representative of this category; Arrecife de Rubén is located on the western coast of Saona Island; El Toro is also located on the western coast of Saona but farther south. These sites are relatively protected from direct wave action by land barriers. They lie in water depths of 15-25 m and have well-defined but low relief (<1m) spur-and-groove features. They do not appear to be actively accreting. The substrate in low-relief spur-and-groove communities is mostly hard reef, but crevices, depressions, and space grooves are filled with sediment. The life form data show that these communities are characteristically dominated by algae, sponges, and octocorals, while hard coral cover is very low. Diversity of all lifeforms is high, and it is in this reef category that we find the sites with some of the greatest octocoral species richness (El Toro with 22 species), sponge species (El Peñón with 36 species), and hard coral species (El Peñón with 26 species). Most algae are calcareous (*Halimeda*) or turf algae, although *Dictyota* is also present. Octocoral and sponge individuals are characterized by large size. Corals, when found, are mostly *Diploria labyrinthiformis, Siderastrea siderea*, or *Montastraea cavernosa*.

Three reef flat communities, consisting of low-relief consolidated carbonate platforms, are identified in the park: Pasa Grande, Arrecife del Tronco, and Arrecife de Fuertes Olas. All are in relatively shallow water (0.5-3.0 m) on the eastern portion of the channel between the mainland and Saona Island. They are thus subjected to heavy wave action and strong currents from the Mona Passage. Life form characteristics in reef flats vary substantially. Pasa Grande is dominated by algae cover (in more than three quarters of the quadrats, the coverage is 72%), although sparse hard coral colonies (*Acropora palmata, Diploria clivosa, Porites astreoides, Porites porites*) are also present. The greatest algal species richness, especially of phaeophytes, occurs at this station. The most important algae here are the genera *Dictyota, Turbinaria, Stypopodium*, and *Halimeda*. Arrecife del Tronco is also dominated by algae, although not as strongly as Pasa Grande. There is sparse to moderate sponge and hard coral (mostly *Porites porites forma furcata*) cover at this site. Arrecife de Fuertes Olas is also strongly dominated by algae, with some sparse hard corals and seagrasses present.

Three patch reef communities were identified in the park. Arrecifes del Angel #1 and #2 are both relatively circular in shape and are surrounded by a sand halo and then a seagrass bed (*Thalassia testudinum*). It has been shown that these sand halos can be caused by nocturnal grazing activities of long-spined *Diadema antillarum* sea urchins, which move out of their hiding places on the reef at night to feed on the adjacent seagrass beds (Vega, 1990). The substrate at Arrecife del Angel #1 consists of nonconsolidated rubble or cemented dead *Porites porites* corals, with sediment increasing towards the periphery of the reef. The substrate at Arrecife del Angel #2 is a mixture of hard reef, sediment, and rubble. El Faro #1 is a heterogeneous series of patches separated by sediments and rubble from *Acropora cervicornis*. The substrate itself consists of a consolidated reef platform with some coral heads. The dominant biota in all three patch reefs is algae. At Arrecifes del Angel #1 and #2, algae covers >50% of the quadrats in 72% of the area. *Dictyota* are very common at El Faro #1. Although sponges, octocorals, and hard corals occur in all three patch reefs, El Faro #1 and Arrecife del Angel #2 are also characterized by having a diverse octocoral and hard coral fauna. For example, El Faro #1 is the only place where *Agaricia tenuifolia* is found and where colonies of *Millepora squarrosa* are also common. This latter coral species is found only at the El Faro #1 and #2 stations. Hard coral and octocoral species are also very common at Arrecife del Angel #2, where large colonies are abundant.

Seagrass and Algae Communities. *Thalassia testudinum* and *Syringodium filiforme* characterize the mixed seagrass and mixed seagrass/algae communities along the western nearshore coastline in the park, with six different hard bottom and three different soft bottom community types. In the shallow areas, there are moderate to dense seagrass and algal communities. In the leeward, western portions of the park, low-relief spur-and-groove and hard bottom communities are the types of bottom typically found. The substrate of all soft bottom benthic communities surveyed in the park is composed mostly of sediment with small amounts of rubble and patches of hard reef.

Hierba del Tronco is the only soft-bottom station whose biota is dominated by the seagrass *Syringodium*. Hierba del Tronco is located in the eastern portion of the passage between Saona and Catalinita Islands and is subject to heavy wave energy. As expected, its biota is predominantly seagrasses, although some patches of algae were encountered. A comparison of the relative cover and frequency of occurrence of the different seagrass species shows that although *Syringodium* is dominant, *Thalassia* is also present in moderate amounts. The algal species richness here is surprisingly high, with 25 species found. Most dominant of these algal species is *Halimeda incrassata*, followed by *Penicillus dumetosus* and *Udotea flabellum*.

The Pila de Lambí site is located NNW of Catalinita Island, 8 km from the mainland, where large white piles of dead *Strombus gigas* are clearly visible — hence the name of the site. Its biota consists of moderate to dense cover by different seagrasses (*Thalassia*, *Syringodium*, and *Halodule*), with some algae dispersed throughout. Algal species richness is low, and no single species of algae is dominant in terms of cover, although *Penicillus dumetosus* individuals are quite numerous (occurring in 84% of the quadrats).

Three of the communities surveyed in the park are mixed algae/seagrass communities: Los Manglecitos, La Ciudad de Penicillus, and Hierba de los Cocos. These communities are characterized by their location in relatively shallow water (<3 m) and the co-dominance of seagrasses and algal species. Los Manglecitos is less than 100 m from the southeastern coast of the mainland. It has a highly variable cover of both algae (*Halimeda*, *Laurencia intricata*, and *Dictyota*) and *Thalassia testudinum*. The most common algal species in terms of numbers are *Penicillus capitatus*, *P. dumetosus*, and *Laurencia intricata*. In terms of cover, however, the dominant species are *Halimeda opuntia*, *Laurencia intricata*, and *Dictyota cervicornis*. Ciudad de Penicillus has the same characteristics in terms of dominant biota as Los Manglecitos, but there are more anemones and sponges present in this soft bottom community. The dominant seagrass is *Thalassia testudinum*. The most important algal species in terms of cover are *Penicillus dumetosus*, *Halimeda monile*, and *Halimeda incrassata*. In terms of number, the most important are various species of *Caulerpa*, *Halimeda*, *Penicillus*, and *Udotea*. It is interesting to note that the density of seagrass shoots and blades in Ciudad de Penicillus is low compared to Hierba del Tronco, which is dominated by *Syringodium*, although blade length is greater there. Finally, Hierba los Cocos is dominated by the alga *Lobophora variegata*, although *Udotea* and *Avrainvillea* species are also common. Both *Thalassia* and *Syringodium* are found at this station.

Mangrove Communities. The mangroves in the park are typically fringing mangroves with an average height of 4 m. No large trees have been found, but they may have been cut down; this part of Hispaniola was impacted by indigenous inhabitants, pirates, and smugglers and, more recently (until about 1930), by timbermen and cattle ranchers. About 1,500 ha of the park consists of fringing mangrove forest of the species *Rhizophora mangle*, *Laguncularia racemosa*, *Avicennia germinans*, and *Conocarpus erecta*, which are found mostly around low-lying shorelines where wave action is minimal. The mangroves also are part of a series of coastal lagoon habitats, where juveniles of the spiny lobster *Panulirus argus* and other fish species use them as refuges and nursing grounds. There are some dwarf mangroves at Bahía las Calderas.

Mangrove-associated fauna include frigate birds (*Fregata magnificens*), pelicans (*Pelicanus occidentalis*), and white crown pigeons (*Columba leucocephala*); about 26 species of fishes; molluscs, including *Crassostrea* sp. *Isognomon* sp., and *Littorina* sp.; and crustaceans, including *Cardisoma guahsnumi, Gerarcinus* sp. and others of the family Ocipodidae. The sponges *Tedagnia ignis* and hydorids are relatively abundant. The up-side-down jellyfish *Cassiopea frondosa* is occasionally found in backwaters and lagoons. *Halimeda* is the most common algae found.

Coral Reef Site

The El Peñón station (18°15.24'N; 68°46.79'W) is located on the leeward side of the mainland, facing west, 8 km north of Punta Catuano and 1.5 km northwest of Punta Palmillas at mooring buoy #2 of the El Peñón dive site (Fig. 1). The depth of this station is 9 to 12 m (averaging 10 m). The base of the reef lies on a hard coralline bedrock, which is the substrate for corals, octocorals, sponges, and other benthic organisms in a low-relief spur-and-groove system perpendicular to shore. This system ends in a sand channel that parallels the shore. This station represents one of the healthiest coral reef communities in the Parque Nacional del Este; continuous visitation is possible due to the oceanic conditions in the area: wave heights average 0.2 m, winds are usually from the southeast at an average speed of 2-3 m s^{-1}, currents usually flow to the northwest at a rate of 0.1 m s^{-1}, and temperature is normally 28-29°C.

Seagrass Site

The Hierba los Cocos station (18°13.527'N; 68°46.107'W) is located on the leeward side of the mainland, half-way between Punta Mangle at the Catuano Passage and El Peñón (Fig. 1). The site is characterized by a dense seagrass bed, located towards the shallow side of Arrecife Los Cocos. This seagrass bed lies on top of a soft substrate mixed with gravel. The principal species occurring here are *Thalassia testudinum* and *Syringodium filiforme*, together comprising more than 75% of the cover; the remainder of the cover includes eight species of algae (most commonly *Avrainvillea* and *Udotea*, but *Lobophora* is also quite abundant).

Mangrove Site

The Canal Punta Mangle al Catuano station (18°12.217'N; 68°45.215'W) lies in the northern section of the Catuano Passage (Fig. 1). When the winds and tides are active in this sector, strong currents flow through the mangrove system forming channels, some of which are navigable. Large deposits of organic sands, originating mainly from *Halimeda* and other sand-producing organisms, are created by current eddies. The CARICOMP site is located at the edge of one of these channels in the middle of the forest. It was chosen as representative of a young and stable mangrove community that is always inundated. Trees are mainly *Rhizophora mangle*, 5-6 m high with trunk diameters generally 0.4 m.

References

Benchmarks, Inc. 1973. *Un Parque Nacional en la República Dominicana*, 50 pp.

Brucks, J. T. 1971. Currents of the Caribbean and adjacent regions as deduced from drift-bottle studies. *Bulletin of Marine Science*, **212**:455-465.

Caboza, F. T., W. W. Pierce. 1975. *An Underwater Survey of the Waters in the Vicinity of La Romana, Dominican Republic.* Private Report for Gulf and Western Corporation.

Cano Corcuera, C. 1993. *Proyecto Uso Público, Protección y Recuperación de Vida Silvestre del Parque Nacional del Este.* Documento Técnico del Proyecto, Dirección Nacional de Parques, Agencia Española de Cooperación Internacional, República Dominicana, 512 pp.

CIBIMA. 1992. Estudio *Preliminar sobre la Biodiversidad Costera y Marina en la Republica Dominicana.* Editora Alfa y Omega, 459 pp.

Dayton, P. 1971. Competition, disturbance and community organization: The provision and subsequent utilization in a rocky intertidal community. *Ecological Monograph*, **41**:351-359.

Fahrenkrog, E. 1979. *Plan de Manejo Nacional: Parque Nacional del Este.* Dirección Nacional de Parques, República Dominicana, 55 pp.

Geraldes, F. X. 1983. *Reporte Preliminar de la Expedición a los Manglares del Parque Nacional del Este. Bayahibe, Bahía de las Calderas, Isla Saona, 20-21 de Marzo 1982.* Contribuciones de CIBIMA/ UASD No. 38, 7pp.

Littler, M. M., D. S. Littler, B. E. Lapointe. 1986. *Baseline Studies of Herbivory and Eutrophication on Dominant Reef Communities of the Looe Key National Marine Sanctuary.* NOAA Technical Memorandum NOS MEMD 1, 41 pp.

Metcalf, W. G., M. C. Stalcup, D. K. Atwood. 1977. Mona Passage drift bottle study. *Bulletin of Marine Sciences*, **273**:586-591.

Olivares, A. 1984. Estudio preliminar sobre la composición y la distribución cuantitativa de la Bahía de Las Calderas, Provincia La Altagracia, República Dominicana. **In:** *Memorias de la Segunda Jornada Científica: Medio Ambiente y Recursos Naturales, en Homenaje al Prof. Ricardo Ramírez Nuñez*, pp 78-105. Academia de Ciencias de la República Dominicana.

Sullivan, K. M., R. Roca, E. C. Peters, M. Chiappone. 1993. Global status of Scleractinia, Alcyonaria, Antipatharia, Stylasterina, and Milleporina in the tropical western Atlantic: Guidelines and assessment. In: *Global Aspects of Coral Reefs: Health, Hazards, and History*, pp M50-M56. University of Miami, Miami, USA.

Sullivan, K. M., M. Chiappone. 1993. Hierarchical methods and sampling design for conservation monitoring of tropical marine hard bottom communities. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **3**:169-187.

Towle, E. 1975. National parks in the Caribbean area. *Publicaciones Biologicas* (Instituto de Investigaciones Cientifícas. Universidad Autónoma de Nuevo Leon), **1**(7):195-208.

Vega, B. 1987. Santos *Shamanes y Zemíes.* Fundación Cultural Dominicana, Santo Domingo, República Dominicana, 185 pp.

Vega, M. B. 1990. *Effects of Diadema antillarum Philippi on Community Structure in the Caribbean: A Review of the Literature.* Thesis, Division of Marine Biology and Fisheries, Rosenstiel School of Marine and Atmospheric Sciences, University of Miami, Miami FL, USA, 114 pp.

Vega, M. B. 1994. *Rapid Ecological Evaluation of the Marine Area of Parque Nacional del Este, Dominican Republic.* Monograph, Acuario Nacional, 91 pp.

Cayo Coco, Sabana-Camagüey Archipelago, Cuba[1]

Pedro M. Alcolado[1], Grisel Menéndez[1], Pedro García-Parrado[1], Daily Zúñiga[2], Beatriz Martínez-Darana[1], Magalys Sosa[1], and Raúl Gómez[2]
[1]*Instituto de Oceanología, Ministerio de Ciencia, Tecnología y Medio Ambiente*
Ave. 1ra. No. 18406, Rpto. Flores, Playa, CP 12100
Ciudad de La Habana, Cuba
[2]*Centro de Investigaciones de Ecosistemas Costeros,*
Ministerio de Ciencia, Tecnología y Medio Ambiente,
Morón, Cayo Coco, CP 69400
Ciego de Avila, Cuba

Cayo Coco is part of the Sabana-Camagüey Archipelago off the north coast of Cuba. The sampling site on the northern shore of the cay includes reefs, seagrass beds, and a permanently flooded red mangrove forest. Human influence on marine, coastal, and terrestrial environments is limited. Wave action and sedimentation are the most important large-scale physical stressors governing the marine ecology of the site. Freshwater runoff is limited and influences salinity only very close to the coast. The virtual absence of the black urchin *Diadema antillarum* probably accounts for the great proliferation of fleshy algae on rocky reef substrates. The marine and coastal ecosystems of this area remain almost pristine and are included in plans for biodiversity conservation and sustainable tourism development.

Introduction

The Cuban CARICOMP Site is located on the northern shore of Cayo Coco, which lies north of Cuba in the Sabana-Camagüey Archipelago, at 22°33'N, 78°26'W (Fig. 1). The northern coast of Cayo Coco is open to the Old Channel of Bahamas; the southern coast is open to the very shallow and hypersaline Perros Bay. Cayo Coco occupies an area of 370 km^2, making it the second largest cay within the archipelago (after Cayo Romano).

Three institutions of the Cuban Ministry of Sciences, Technology and Environment (formerly the Academy of Sciences) participate in CARICOMP: the Institute of Oceanology (IO), the Institute of Ecology and Systematics (IES), and the Coastal Ecosystems Research Center (CERC). The excellent new research facility of CERC at Cayo Coco contains a well equipped Class A meteorological station.

[1] *CARICOMP — Caribbean Coral Reef, Seagrass and Mangrove Sites* (edited by B. Kjerfve), pp 221-228.
UNESCO, Paris, 1998, 347 pp.

Site mapping was done using black/white aerial photographs (scale 1:10,000). The three sampling sites are located in Ensenada Puerto Coco cove and comprise three habitats: reef, seagrass beds and a permanently flooded red mangrove forest. The marine and coastal ecosystems of this area remain almost pristine and are included in plans for biodiversity conservation and sustainable tourism development.

Human influence on marine, coastal, and terrestrial environments is limited. Wave action and sedimentation are the most important physical stressors governing the ecology of this offshore marine shelf. Freshwater runoff is limited and apparently influences salinity only very close to the coast. The virtual absence of the black urchin *Diadema antillarum*, since a massive die-off in the early 1980s, probably accounts for the great proliferation of fleshy algae on reef rocky substrates.

Geological Setting

The relief of the Sabana-Camagüey Archipelago is due to the neotectonic transformation of ancient structures and formation of new tectonic disruptive features that fragmented the area into transverse and longitudinal blocks. Other factors include the trend of block movements during the Holocene (ascending and descending), its geographical location in the northern tropical belt, sea level oscillations during the Quaternary, and the predominance of carbonate lithological assemblages during the Quaternary (Magáz *et al.*, 1990).

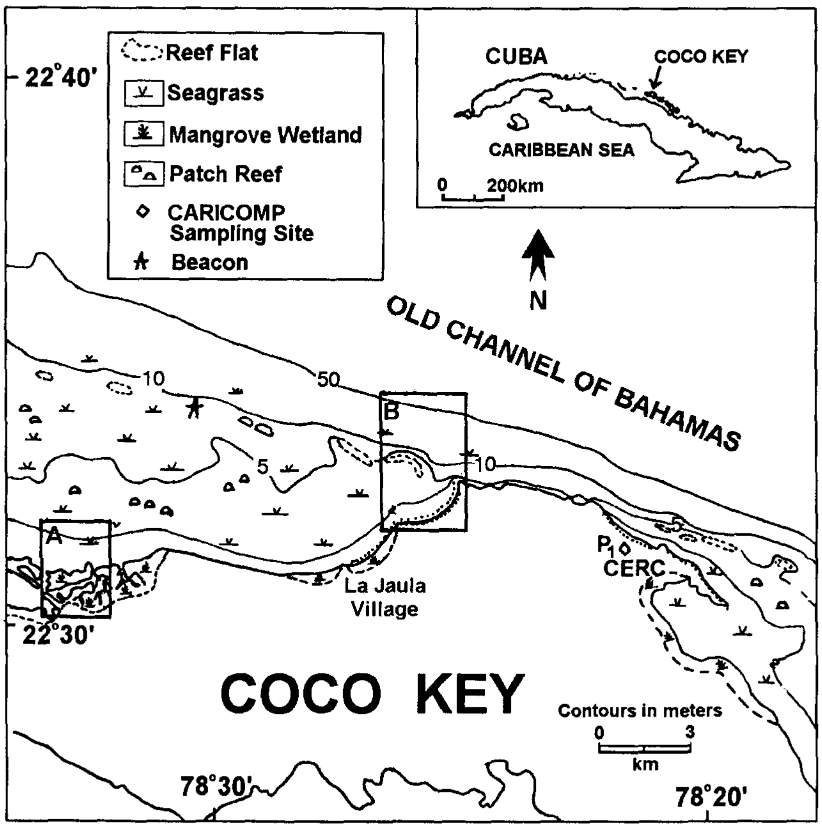


Fig. 1. Geographic setting of Cayo Coco, Cuba, and broad scale habitat distribution; CERC is the Coastal Ecosystem Research Center.

The archipelago was formed by elevation of the central northern margin of the shelf of Cuba, reaching down to the insular slope (northward). It is separated from the mainland by a longitudinal tectonic depression (southward), which is occupied by an ensemble of lagoons. A line of bordering cays on the north exists on the domes of the fragmented structural elevations (Magáz *et al.*, 1990).

The sectors of discontinuous emersion are manifested in the relief by the existence of several erosive and erosive-accumulative relict marine terraces, as well as in the formation of sand bar systems and consolidated dunes with crossbedding where the coast is elevated. The immersion sectors are represented by the predominance of cumulative and swampy marine biogenic flats with thick layers of sandy-argillaceous and peaty sediments. There also exists superposition of facies of coastal sand bars over peaty facies of sealed lagoons and swamps (Magáz *et al.*, 1990).

Hydrogeology and Oceanography

Pooling data from Cayo Coco (1985-1990) and Cayo Paredón Grande (1946-1963), the monthly average minimum air temperature at the site is 20.0°C and the average maximum is 32.5°C. The monthly average mean air temperature varies from 23.3°C to 28.7°C. (Fig. 2). Average precipitation at Cayo Coco is 1,076 mm annually (1985-1990), whereas nearby Cayo Paredón Grande has only 733 mm (1946-1963). The recorded average number of rainy days per year at these two cays is 92 and 76 days, respectively. The rainy season is from May to October (maxima in September and October); the dry season is November to April (Pazos-Alberdi *et al.*, 1990). Annual average evaporation is in the range 2,100-2,200 mm (IGEO/ICGC/IGN, 1989), resulting in a strongly negative hydrobalance. Eastward winds predominate at Cayo Coco. From May 1989 through April 1990, annual average wind speed was 4.4 m s^{-1}; calm periods made up only 1.2% (Pazos-Alberdi *et al.*, 1990). Horizontal Secchi disk measurements at the reef station on March 27 and 29, 1994, varied from 26.1 m (cloudy noon) to 32 m (sunny noon); at the

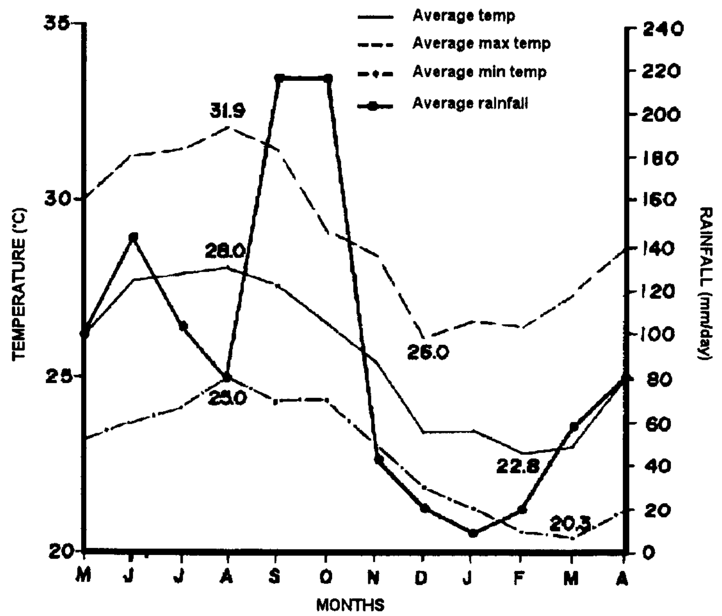


Fig. 2. Monthly variation of air temperature and rainfall at the Cayo Coco station, 1985-1990 (after Pazos-Alberdi *et al.*, 1990).

seagrass stations, measurements on March 28, 1994, were in the range 11.5-11.6 m (sunny noon). Coastal currents are predominantly westward. Rodríguez-Portal and Rodríguez-Ramírez (1983) classified the tides at the site as mixed (two cycles daily with different ranges) and recorded a maximum range of 1.2 m. Cold fronts affect the site with a frequency of 14.6 times per year (data from 1916-1917 and 1987-1988), occurring between October and April, resulting in decreased air temperature and humidity and increased rainfall, cloudiness, wind speed, and wave height (Pazos-Alberdi *et al.*, 1990). Synoptic cyclones and hurricanes rarely affect the site, with hurricanes occurring only once every 6.6 years, most commonly from August to October. Only one high-intensity hurricane has hit the site in the last 178 years, on the 9th of November, 1932 (Pazos-Alberdi *et al.*, 1990).

Human Impact

Historically, Cayo Coco has been virtually devoid of human population. The social and economic assimilation of Cayo Coco and adjacent cays of the archipelago took place at the beginning of the 20th century, characterized mainly by forest exploitation and charcoal production. Cattle ranching was also tried, and some feral cattle still inhabit Cayo Coco. Many forest areas were cleared by timber harvesting or were burnt to clear land for pasture (Alcolado *et. al.*, 1992). Most cleared areas are redeveloping as secondary forests.

A small airport was constructed and began to operate in Cayo Coco in 1995. Two villages provide accommodations for coastguard, construction, and tourism personnel. One hotel has 450 rooms, another with 500 rooms is under construction, and others are projected. There are plans for significant growth of the tourism industry, focused on the beach and nature. A GEF/UNDP Project (CUB/92/G31) is dealing with protection of biodiversity and establishment of sustainable development, mainly tourism, in the region. A system of marine and terrestrial protected areas, including Cayo Coco, is being proposed.

The greater part of the offshore marine environment north of Cayo Coco has been only slightly affected by human activities; it seems to be driven mainly by wave action, sea level fluctuations, and wind and precipitation regimes. Fishing in this area has been maintained at near maximun sustainable yield. It is still common to observe great quantities of snappers and groupers while diving on the reefs. However, tourism is modifying the ecology along some stretches of the northern coast. Inshore waters tend to be hypersaline, with large fluctuations in salinity, due in part to limited exchange with ocean waters and in part to human activities such as the construction of bermed roads and dams. Fisheries have been severely affected in some inshore areas, and saline-induced mangrove mortality has been noted in some places. Mitigation actions are being planned and undertaken for improving the ecological situation in the affected areas. These include increasing the number of culverts and bridges along the bermed roads, releasing dammed-up waters, and channeling runoff.

Broad-Scale Habitat

The Cuban CARICOMP site (Fig. 3) is dominated by sandy and rocky-sandy Holocene plains that extend from the shore to a depth of 30-40 m. The slope steepens at 50 m deep, where the dropoff begins.

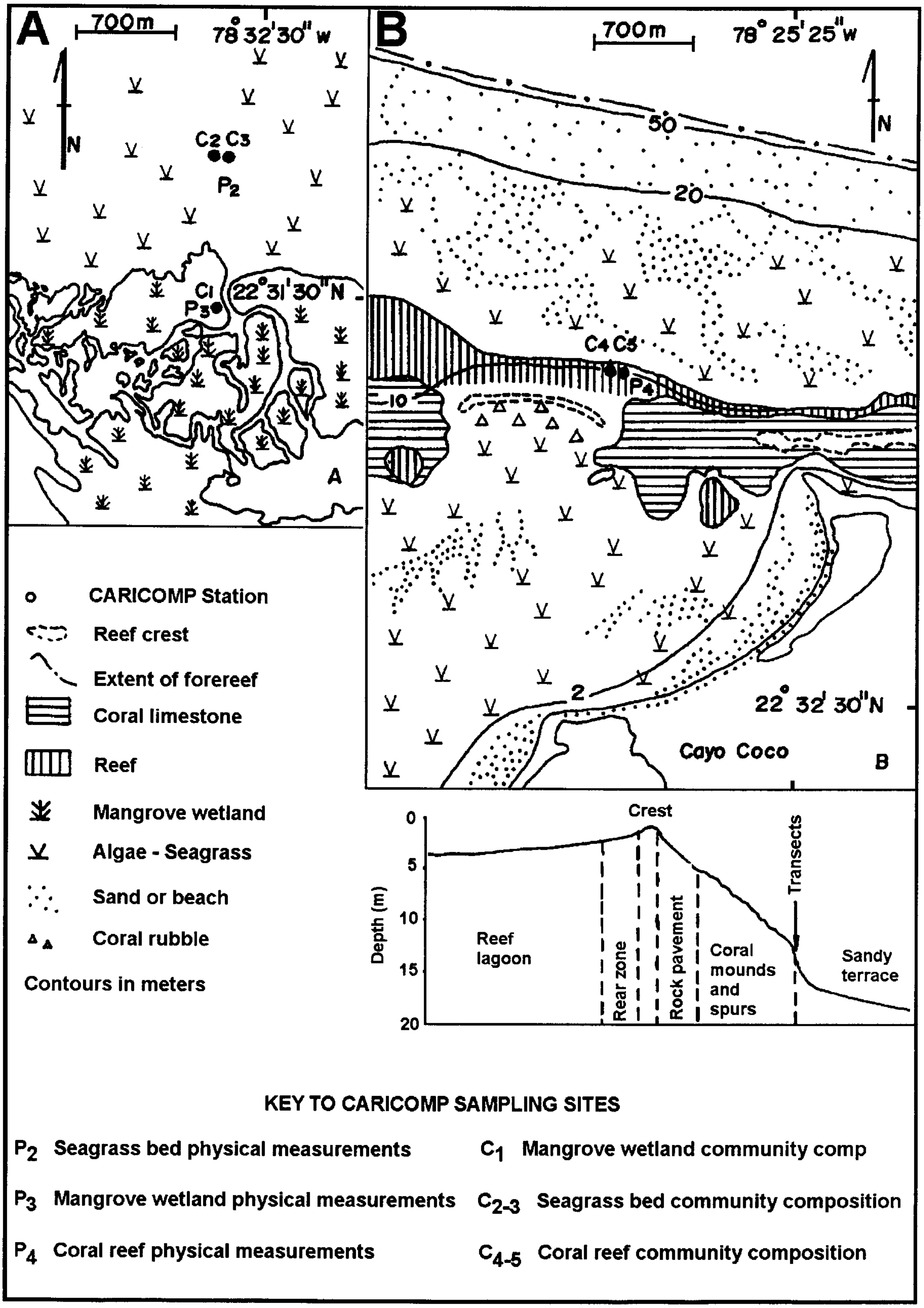


Fig. 3. Distribution of sampling stations and habitats.

Sandy surfaces are predominantly covered mainly by sparse seagrass beds of *Thalassia testudinum*. Unvegetated sandy bottoms are also common along stretches close to the coast, in bar-shaped patches within seagrass beds, in the reef channels and depressions, and in extensive patches along the forereef slope (lower terrace). Significant patches of *Syringodium filiforme* are found on this forereef slope, and abundant *Halimeda* has also been observed. Reefs are represented by zones of erosive-accumulative rock pavements, which are conspicuously inhabited by gorgonians and a few scleractinians. Several actual and relict reef crests and some spur-and-groove areas are also found. The spur-and-groove systems occur only close to the reef crests, perhaps as a consequence of the protection of these structures against the sediment-loaded waters outflowing from the shallow sandy plains during days with high wave energy. This protection allows better development of scleractinian corals. Some discontinuous reef escarpments, dropping 12-15 m, extend almost parallel to the coast north of Guillermo, Coco, and Romano Cays. The shores are characterized mainly by sandy beaches, with mangroves on the leeward sides. Some rocky shores are also present. Behind the shore, shallow lagoons are fringed by mangroves. In some places, complex channels and lagoon systems extend into extensive, marshy, mangrove plains that are dominated by *Rhizophora mangle*, especially northwest of Cayo Coco. As with many other cays in this area, terrestrial vegetation is represented by four forest assemblages: (1) tropical evergreen microphyllous woods, (2) subcoastal forests, (3) seasonally and temporally flooded forests with patches of herb communities and dominant *Conocarpus erecta* and *Bucida sp.*, and (4) mangrove systems in which *Rhizophora mangle* dominates. There are also areas of tropical thickets, halophyte vegetation, sandy and rocky vegetation assemblages, and herb communities. Vegetation is also represented by degraded and secondary forests (Menéndez *et al.*, 1990).

Coral Reef Stations

The coral reef transects are located at a depth of 10-12 m across a very poorly defined spur-and-groove bottom or a rather rocky-sandy bottom with coral mounds (Fig. 3: A, 22°33'49"N, 78°26'19"W; B, 22°33' 48"N, 78°26'42"W). This transect area is located in the forereef zone adjacent to an escarpment that drops from 12 to 15 m; the area is rich in corals, sponges, and gorgonians. The adjoining lower terrace on the forereef slope is a rocky plain that is covered by a sand layer of varying thickness and extensive patches of *Syringodium filiforme* (surveyed to a depth of 20 m). At both reef sites, bottoms exhibit irregular patterns of mounds, sand grooves, and patches. The relief is accentuated towards the 12 m contour, where the escarpment begins.

The reef data are averages from both transects from March 1994 to April 1995. At each transect, the mean coral cover, including sand patches, varies from 5.5 to 7%. The dominant scleractinians are *Montastraea annularis*, with 10-55% of cover among scleractinians, *M. cavernosa* (3-22%), *Porites porites* (3-26%), and *Siderastrea siderea* (3-17%). Gorgonians and sponges are fairly abundant and moderately developed; sponges cover 2-3% of the bottom. The most common sponges are *Aplysina cauliformis, Ircinia felix, Iotrochota birotulata*, and *Niphates digitalis*. Most common among the gorgonians are *Pseudopterogorgia americana, Briareum asbestinum*, and *Plexaura homomalla f. kuekenthali*. The rocky substrate is covered by a mat of fleshy algae, including *Dictyota, Lobophora*, and *Microdictyon*, that is covered by sand. Fleshy and turf algae cover 52-60% of the bottom. From a depth of 10 m to 2 m, the bottom grades from a poorly defined spur-and-groove system to plain rock pavement, dominated by gorgonians. A discontinuous reef crest consists of a line of rocky outcrops covered by abundant colonies of fire corals (*Millepora complanata*), sea fans (*Gorgonia flabellum*), and small, sparse colonies of elkhorn corals (*Acropora palmata*). At both ends of the reef crest, extensive low-relief sandy rock pavements with gorgonians penetrate deeply into the lagoonal area, showing the abrasive influence of open ocean waves and perhaps tidal currents. The bottom of the rear zone is homogeneously covered by abundant coral rubble, profusely colonized by brown algae (*Dictyota* and *Stypopodium*). In the reef lagoon, the rubble bottom is colonized by sparse short-leaved *Thalassia*. The bottom slopes from the shore to the sandy sparse *Thalassia* beds of the reef lagoon. Extensive sandy areas, without vegetation, occur among the grass beds. The nearshore bottom is void of macrophytes, although some, mainly *Thalassia*, occur in elongated patches.

Dominant fishes, at depths between 3 and 15 m, belong to the families Haemulidae (*Haemulon plumieri, H. flavolineatum* and *H. sciurus*), Labridae (*Thalassoma bifasciatum* and *Halichoeres bivittatus*), Pomacentridae (*Stegastes spp.*), and Scaridae (*Sparisoma spp.* and *Scarus spp.*). At depths of 15 to 25 m, specifically on the deep slopes, the predominant families are Labridae (*T. bifasciatum* and *Clepticus parrai*), Pomacentridae (*Chromis cyanea* and *S. partitus*), Inermiidae (*Inermia vittata*), and Scaridae (*Sparisoma spp.* and *Scarus spp.*).

The most important physical stressors on this reef are wave action and natural sedimentation. Freshwater sources are limited. Human impacts on these reefs are negligible so far, limited to lobster fisheries and some tourism. The virtual absence of the herbivorous black urchin, *Diadema antillarum*, may account for the great proliferation of algae on the rocky substrates of this reef.

Seagrass Bed Stations

At depths greater than 1.5 m, luxuriant seagress beds are rare at the sampling sites (22°31'N; 78°32'W; Fig. 3: A, C2 and C3). A seagrass bed with a moderate standing crop of green leaves of *Thalassia testudinum* (mean dry weight = 60-116 g m^{-2}, from samples at the two stations in March and October 1994) was monitored north of the mangrove station, north of Canalizo Genebra, at a depth of 1.40 m (Station A) and 1.75 m (Station B). Leaves are longer and less epiphytized than in the reef lagoon seagrass bed. Total *Thalassia* biomass, including roots and rhyzomes, varied from 931 to 2,396 g m^{-2} (data from March 1994 to September 1995). Some algae, e.g., *Halimeda, Penicillus, Rhipocephalus*, as well as many small sponges, anemones, gastropods, and holothurians, were observed. The bottom sediment is sandy. The water is transparent but greenish, suggesting nutrient enrichment from the neighboring mangrove swamp. Some influence of freshwater runoff during rainy days has been observed at this location.

Mangrove Forest Station

The mangrove sampling station is located in a permanently inundated forest of red mangrove, *Rhizophora mangle*. This is a basin forest occupying a depositional marshy plain with covered karst topography. A dendritic system of channels and lagoons of varying sizes irrigates the mangrove basin. A large, poorly irrigated marshy lagoon extends toward the southeast to Canalizo Ginebra, where flooding is continuous (Fig. 3, A: P3 and C1). *Rhizophora mangle* trees reach up to 7 m high at the sampling site. Tree height tends to decrease towards the highest high-water mark; thus, the distribution pattern of tree height is heterogeneous. Mangrove roots are poorly colonized by animals and algae. They are predominantly covered by some barnacles and biogenous silt. A few fire sponges (*Tedania ignis*) were observed. Fishes are apparently scarce and are represented primarily by Clupeidae (*Jenkinsia lamprotaenia*) and some Atherinidae (*Atherinomorus stipes*). Some black mangrove (*Avicennia germinans*) and buttonwood mangrove (*Conocarpus erectus*) trees are distributed near the eastern side of the entrance channel, also bordering the open coast, and in the band of contact between the mangrove swamp and the surrounding evergreen secondary microphyllous forest. An important influence of the freshwater runoff through this frontier during rainy days is expected. Until now, this mangrove ecosystem has not been impacted by human activity.

References

ACC/ICGC. 1990. *Estudio de los Grupos Insulares y Zonas Litorales del Archipiélago Cubano con Fines Turísticos: Cayos Guillermo, Coco y Paredón Grande 3* (edited by L. Fernández, E. García, M. Aguiar, G. Rodríguez, M. Páez). Editorial Científico Técnica, La Habana, Cuba, 174 pp.

Alcolado, P. M., L. Menéndez, A. Magáz. 1992. Interdisciplinary environmental assessment of the Archipelago Sabana-Camagüey (Cuba), prior to extensive tourism development projects. **In:** *Coastal Systems Studies and Sustainable Development. Proceedings of the COMAR Interregional Scientic Conference* (Paris, 21-25 May 1991). *UNESCO Technical Papers in Marine Science*, **64**:125-131.

IGEO/ICGC/IGN. 1989. *Nuevo Atlas Nacional de Cuba.* Instituto de Geografía de la Academia de Ciencias de Cuba, Instituto Cubano de Geodesia y Cartografía/Instituto Geográfico Nacional.

Magáz, A., A. Gómez, L. Ferrá, L. Rodríguez, P. Borroto, A. Priego, M. Sosa, F. Arteaga, T. Correa, L. Vega, E. Ramírez. 1990. Geomorfología. **In:** *Estudio de los Grupos Insulares y Zonas Litorales del Archipiélago Cubano con Fines Turísticos: Cayos Guillermo, Coco y Paredón Grande 3* (edited by L. Fernández, E. García, M. Aguiar, G. Rodríguez, M. Páez). Editorial Científico Técnica, La Habana, Cuba, 174 pp.

Menéndez, L., N. Ricardo, A. Priego, C. Chiappy, N. Aguila, P. Borroto, J. Hernández, C. Carrodeguas, M. Brito, A. M. Suárez, L. Ferrer, R. Oviedo, D. Rodríguez, A. Gonzáles, L. Gonzáles, L. Vidar, M. C. Sotolongo, E. Giménez. 1990. Vegetación, flora y fauna. **In:** *Estudio de los Grupos Insulares y Zonas Litorales del Archipiélago Cubano con Fines Turísticos: Cayos Guillermo, Coco y Paredón Grande 3* (edited by L. Fernández, E. García, M. Aguiar, G. Rodríguez, M. Páez). Editorial Científico Técnica, La Habana, Cuba, 174 pp.

Pazos-Alberdi, C., S. Echevarría, R. Rivero, V. Rey, T. Dontsova, M. E. Fuentes, N. Concepción, A. Osuma, M. Martínez, L. Espinosa, R. Abreu. 1990. Condiciones hidrometeorológicas. **In:** *Estudio de los Grupos Insulares y Zonas Litorales del Archipiélago Cubano con Fines Turísticos: Cayos Guillermo, Coco y Paredón Grande 3* (edited by L. Fernández, E. García, M. Aguiar, G. Rodríguez, M. Páez). Editorial Científico Técnica, La Habana, Cuba, 174 pp.

Rodríguez-Portal, J. P., J. E. Rodríguez-Ramírez. 1983. Las mareas en las costas cubanas. *Reporte de Investigación del Instituto de Oceanología. 6,* 37 pp.

San Salvador, Bahamas[1]

Donald T. Gerace[1], Gary K. Ostrander[2], and Garriet W. Smith[3]
[1]*Bahamian Field Station, San Salvador, Bahamas*
[2]*Department of Biology, The Johns Hopkins University, Baltimore MD 21120 USA*
[3]*Department of Biology & Geology, University of South Carolina, Aiken SC 29801 USA*

San Salvador is similar in many respects to other islands of the Bahamas Archipelago, but it is unique in its position away from the Bahama Banks. The isolation of San Salvador influences its climate and ecology as well as its cultural history. The CARICOMP mangrove sites are located along the southern coast of San Salvador, and represent the only such shoreline mangroves on the island. Data collected to date reflect the stressed nature of Bahamian mangrove systems. The seagrass sites are located in embayment areas at both the southern and northern parts of San Salvador. The data reveal the importance of *Thalassia* at both sites, but variations exist in its biomass between the two sites. The coral reef site is located off the west shore of the island and, while not representative of the majority of Bahamian reef systems, it does meet the criteria set up by CARICOMP. Data collected to date from the coral reef site shows little change from one monitoring to the next. Daily and weekly physical measurements at all of the sites reveal the importance of seasonal fluctuations.

Introduction

San Salvador is one of the 700 islands which make up the Bahama Archipelago located along the subsiding continental margin off the coast of Florida. This archipelago extends from the Navidad Bank, 20°N, off the coast of Hispaniola, north to the Little Bahama Bank at 27.5°N. While the entire archipelago extends 1,400 km north to south, the Commonwealth of the Bahamas is 1,126.5 km, from Grand Bahama to Inagua, the southernmost island.

Geological History

The Bahamas are low, carbonate islands that rest on two large bank systems, with water depths of less than 10 m. The Little Bahama Bank is in the northern Bahamas; the Great Bahama Bank extends from central to southwestern Bahamas. The remaining islands are isolated small platforms beginning at 24°N latitude in the eastern Bahamas and extending to Navidad Bank just north of Haiti. These

[1] *CARICOMP — Caribbean Coral Reef, Seagrass and Mangrove Sites* (edited by B. Kjerfve), pp 220-245. UNESCO, Paris, 1998, 347 pp.

Fig. 1. Location of San Salvador, Bahamas.

shallow seas give the Bahamas its name, from the Spanish "Baja Mar." The bank systems are separated from each other by a deep water basin, with depths up to 4,000 m.

The origin of the Bahamas is still controversial. The archipelago may be the result of plate tectonics activity 200 million years ago, forming as a horst graben (Mullins and Lynts, 1977), or it may be the remnant of a much larger platform (Meyerhoff and Hatten, 1974). It is generally accepted that these banks originated at a latitude with warm, shallow waters that encouraged the growth of a variety of marine organisms whose skeletal remains were deposited as sediments. The weight of these sediments caused subsidence as deposition continued, developing carbonate deposits which, at present, reach a thickness of more than 5.4 km (Meyerhoff and Hatten, 1974). The islands are all less than 61 m above sea level; the highest elevation on San Salvador is 37.5 m, atop one of the ridges on the east side of Flamingo Pond (Shaklee, 1994).

The Bahama Platform became exposed during sea-level lowstands as a result of four major glacial advances during the Pleistocene. Winnowed eolianite dunes formed during these periods and became lithified after flooding, thus forming the islands. During the interglacial stages, weather altered the landscape into karst formations of caves, sink holes, and solution pits. These conduits honeycomb the islands. Because of the great porosity of the limestone, water from rainfall and runoff is rapidly delivered underground through these conduits, resulting in a scarcity of freshwater rivers and streams in the Bahamas.

During the last ice advance, sea level was 91.5 m lower than today, exposing the banks. This allowed plants and animals to arrive from the Greater Antilles, across the short gap from Cuba or

Hispaniola. Some plants also arrived via birds and as flotsam, as is the case with mangroves. Thus, the majority of life forms are Caribbean in origin rather than North American.

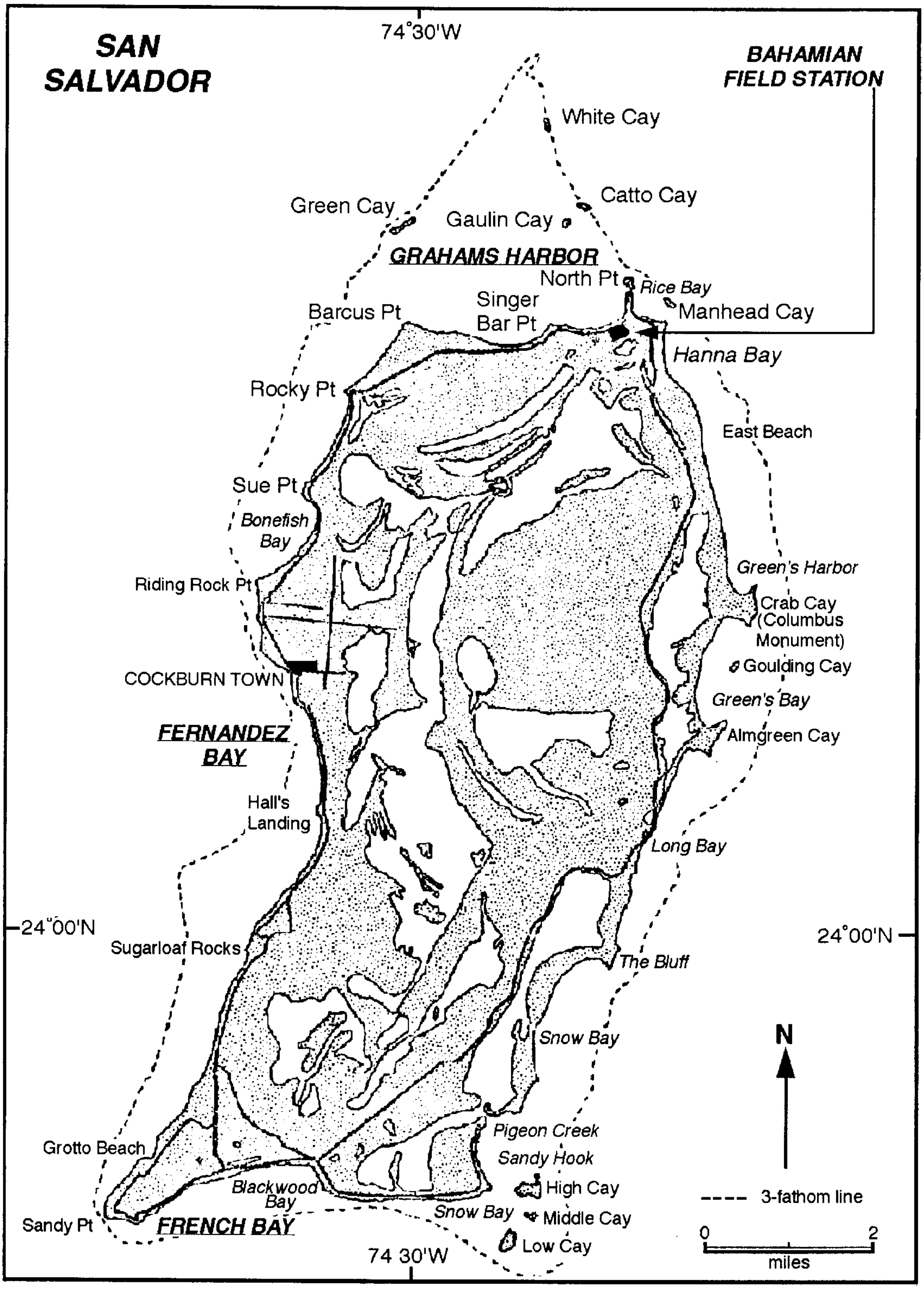


Fig. 2. Map of San Salvador, Bahamas (modified from Adams, 1980).

Physical Geography

San Salvador is located at 24°3'N latitude and 74°30'W longitude, 640 km ESE of Miami, Florida. It is surrounded by 4,000-m-deep waters and is exposed to waves from the Atlantic Ocean (Figs. 1, 2). The island is pod shaped, with a north-south orientation. It measures 11.2 km east-west and 19.25 km north-south, not including the offshore cays to the north. The island has 94.9 km^2 of surface area, most of which consists of dune ridges, with adjacent troughs forming brackish (hypersaline) lakes that constitute nearly a third of the total area (Fig. 2). A series of fringing reefs surrounds the island, with a break in the vicinity of Cockburn Town on the west coast. This breach in the reef provides access to the island for shipping, dockage, and mooring during normal weather patterns. The reefs form several protected embayments, including Grahams Harbor and Rice Bay in the north, Long Bay in the east, Snow Bay and French Bay in the south, and Fernandez Bay and Bonefish Bay in the west (Fig. 2).

Weather and Climate

The moderating effect of the Antilles Current, part of the North Atlantic Gyre flowing past San Salvador, cools in the summer when temperatures range from 22 to 32°C, and warms in the winter when temperatures range from 17 to 27°C (Fig. 3). Annual rainfall in the Bahamas ranges from 140 cm on the northern islands to 70 cm on the southern; San Salvador, in the center, averages 100 cm. Cold fronts from the north bring winter rains; as front systems progress southward across warm waters of the banks, winds moderate and it rains in the northern Bahamas. The summer rains (May-September) result from convection; the larger northern islands create more convection currents and receive more rain in the

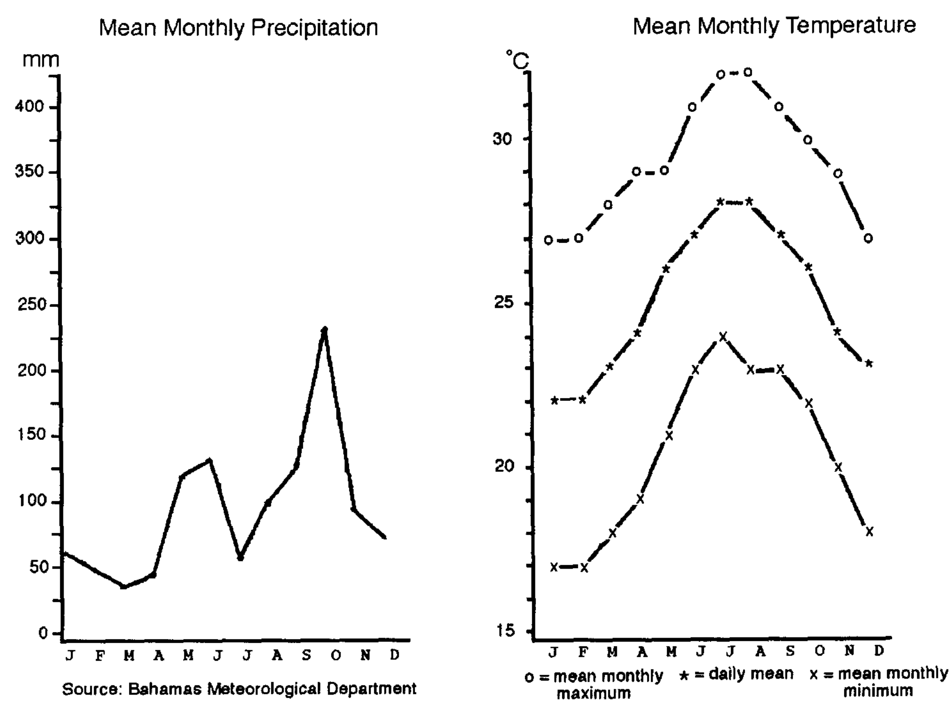


Fig. 3. Precipitation and temperatures in the Bahamas (Shaklee, 1994).

summer. The second rainy season is from September to November; it is caused by tropical depressions, tropical storms, and hurricanes and may account for up to one quarter of the total annual rainfall. All these weather conditions are unpredictable and produce years either with less than average rainfall on San Salvador or heavy rains that wash away exposed soils. Bahamian soils generally are shallow, poorly developed, and retain very little water. Land disturbed by cultivation erodes very quickly, and the lightweight humus occasionally present washes away even more easily.

Vegetation

San Salvador hosts only those species which can survive the hardships of poor soils, full sun, and periods of drought. Salt winds have led to 6 to 8% endemism in the plant communities. The vegetation of San Salvador is generally "scrub," with approximately 524 species of vascular plants in 265 genera, representing 96 families. Of these, about 60% are of Caribbean origin, approximately 30% are exotic Florida imports, and the rest are the 6 to 8% endemics (Smith, 1993).

As defined by Smith (1993), the vegetation of San Salvador can be categorized into three broad zones: coastal, nearshore, and inland. Coastal vegetation, in beach soil locations, is defined as the sea strand/sea oats community, consisting of sea oats (*Uniola*), sea grapes, and railroad vine, all of which assist in stabilization of the dunes. In rocky shore locations, the vegetation is 1 m high and includes *Mallotonia gnaphalodes* (bay lavender), *Erithalis diffusa* (black torch), *Scaevola plumieri* (ink berry), and *Gundlachia corymbosa* (horse bush). The nearshore vegetation is located farther inland and is more protected from salt spray. This "coastal coppice" community consists of thicket and silver-thatch or *Cocothrinax* shrub. The inland vegetation includes the mangrove community, the freshwater forests, the whiteland community, and the blackland community.

Mangrove swamps line the inland brackish lakes and are also found in protected basins such as Pigeon Creek and French Bay; the average height of the trees is 4 m. Vegetation is sparse in the mangrove flats; plants grow out of cracks in the rocks or in pits where soil has collected; average tree height is less than 0.3 m.

The blackland community is the most extensive plant community on the island. The soils are fertile light and dark loams. This community is characterized by dense vegetation with great species diversity but no dominant species.

Cultural History

It was probably San Salvador upon which Europeans (Columbus and his crew) first set foot in the New World. As described by Columbus in his log, the local Indians, called Lucayans, named the island Guanahani. These islands were completely depopulated by 1513 when Ponce de Leon passed through on his expedition to Florida. The Indians either were the victims of European diseases or were deported to the Greater Antilles as slaves. While the Spanish by-passed the Bahamas for more lucrative locations in their quest for gold and fertile lands, the British slowly took possession of this region, initially because of its strategic position on the perimeter of the Spanish colonies, and finally declared it a crown possession in 1629.

San Salvador was virtually unaffected by the encroachment of Europeans until American colonists loyal to Britain were forced from the United States and migrated to the Bahamas in 1783. They built impressive estates, using African slaves as a labor force. The "Loyalist Period" ended in 1834, when the Crown abolished slavery, capping an era that included many unsuccessful years for the planters because of drought, insect infestations, and soil depletion.

The descendants of San Salvador's slaves continued experimenting with agriculture under a sharecropping system throughout the 1800s, raising first citrus and livestock, then pineapples, and finally sisal. All of these large-scale agricultural enterprises apparently came to the same end as those of the Loyalists. Records show that just prior to and after World War I, the lifestyle of San Salvador's inhabitants was very poor, with everyone existing on subsistence farming.

Prosperity returned in 1951, with the establishment by the United States of a down-range missile-tracking base, a Coast Guard station, and a submarine tracking facility, all located on San Salvador. The majority of the US military departed the island in the late 1960s, leaving an infrastructure of well-constructed buildings, an electrical power station, and a 1,500 m paved airstrip. These facilities have all been put to good use by the Bahamas Government, now housing a Teachers' Training College, a high school, and the Bahamian Field Station. Prosperity has continued for San Salvador with a short-lived land development company in the 1970s and now a recently opened Club Med resort.

The local resident population of less than 800 persons lives in several small communities around the perimeter of the island. The capital is Cockburn Town, on the west coast of San Salvador, which houses the local government offices of the Commissioner and police, the post office, a telecommunications center, a government clinic, and electrical utilities company. Electricity is available for all but the smallest of communities on the rural southeastern side of the island; telephone service extends only along the west and north coasts. United Estates, located on the northeastern side of San Salvador, is home to the majority of the island's population and is also the site of the Dixon Hill Lighthouse, a major navigation aid in this section of the Atlantic.

Nearshore Waters

The Antilles Current, as part of the North Atlantic Gyre, brings warm waters as well as flotsam to the coast of San Salvador. However, the strongest current affecting the nearshore waters of the island is the long-shore current running north-south along the western shore. This current is strongest in the winter months when waves are forced around the island by the northeasterly winds. In summer, winds shift to predominantly southeasterly, resulting in the progradation of many beaches. Although long-term data on nearshore water conditions are not available, various measurements have been collected since 1992 by Thomas McGrath as part of a nearshore coral monitoring project. Table 1 shows the 1993 mean values at different times of the year for air and water temperatures, pH, salinity, and dissolved oxygen at different sites around San Salvador. Secchi disk depth varied from 21 m in July 1993 to less than 11 m in November 1993.

Table 1. Mean values for nearshore waters (McGrath, 1993).

Reef Site		Temperature (°C) Air	Water	pH	Salinity ‰	DO %
Rocky Point	March	23	24	8.3	3.5	6.0
	August	29	30	8.3	3.5	—
	November	26	25	8.3	3.5	6.0
Linday's Reef	March	24	24	8.3	3.5	6.0
	August	29	30	8.3	3.5	—
	November	26	25	8.3	3.5	6.0
Rice Bay	Site not established until August team					
	August	29	30	8.3	3.5	—
	November	26	25	8.3	3.5	6.0

Physical Measurements

The mangrove wetlands station is located in Blackwood Bay (Fig. 4); salinity and temperature measurements are taken 5 m offshore in order to obtain proper depth, interstitial water is measured 5 m landward of Quadrant 1. Seagrasses are sampled at two stations, the southern one in French Bay (Fig. 4), and the northern one in Grahams Harbor (Fig. 6), which also contains the climate sampling station. The coral reef station is located in Fernandez Bay (Fig. 8).

Mangrove Site

The mangrove site is located in an area called Blackwood Bay, part of a large embayment known as French Bay on the southern shore of San Salvador (Fig. 4).

Blackwood Bay has a low-energy shoreline, due to the fringing reef to the south which dampens waves coming from the Atlantic. Seaward of the reef, as described by Pace (1986), the bay platform passes through spur and groove topography and plunges almost vertically to abyssal depths (Fig. 5). The reef is a boulder rampart composed of coral rubble, bound by encrusting *Millepora*. The quiet lagoon located landward of the reef is a shallow platform of bedrock with mud mounds upon which *Thalassia* is growing on the lower mounds, *Halodule* on the higher. *Thalassia* traps sediments, causing the mounds to grow taller until they are exposed at low tides. *Thalassia*, having a low tolerance for aerial exposure, is then replaced by *Halodule*.

The platform shallows upward into an intertidal zone and continues to the mangroves of the upper intertidal zone. Red (*Rhizophora mangle*) and black (*Avicennia germinans*) mangroves are interspersed here, and the progression continues landward into white mangroves (*Laguncularia racemosa*) and buttonwood (*Conocarpus erectus*). Tree growth ends abruptly along a sandy beach ridge, or berm, which is basically treeless and covered primarily with dried *Thalassia* wrack along with *Sargassum* and swash debris. The berm parallels the shore and has all the appearance of an abandoned road; it represents the spring high tide and is marked with human detritus: bottles, styrofoam cups, plastic jugs, etc.

The sand beach extends 5 m inland to a gravel ridge of reef rubble and rock fragments. This ridge also parallels the coast and dips landward into several shallow ponds. Some of these ponds were dry in early April 1994, but there was evidence of flooding during the previous rainy season. The sand ridges probably represent successive storm beaches that were rapidly stabilized by mangroves (Kramer and Caputo, 1988). This may have been accelerated by tropical storms transporting materials to the gravel ridge and the shoreward sand berm.

The coastal red mangrove forest in Blackwood Bay is one of two habitats in which coastal mangroves exist on San Salvador; the other is in a lagoon/tidal flat complex in Snow Bay. The mangroves on San Salvador are typical of those on many of Bahamian islands. Mangroves are vulnerable to wave activity (Davies, 1980), which accounts for their absence on most of the coast, with the exception of these two low-energy environments. Lugo (1993) described the coastal mangroves of San Salvador as good examples of an ecosystem under stress. As he stated: "Short tree structure, small and rigid leaves, abundance of senescent leaves, vertical leaf orientation, thinned canopy, and high rates of albino seedlings are indicators of stress." Most of San Salvador's mangrove communities would be classified as "scrub" or "dwarf" as a result of scarce fresh water from rainfall and runoff, low nutrient availability, generally poor tidal exchange, lack of good substrate, and exposure to strong winds.

The mangrove sampling quadrants in Blackwood Bay consist of three 10 × 10 m plots located parallel to the shoreline, entirely within the intertidal zone. The substrate consists of calcium carbonate gravels and sands, with concentrations of organic-rich mud as the density of the mangrove prop roots increase. This site supports the growth of taller and greater diameter-at-breast-height (dbh) red mangroves than are typically found at other coastal communities on San Salvador. This may be due to seepage from the freshwater ponds located just landward of the sandy beach ridge, and/or to protection from prevailing winds.

Mangrove Quadrant 1 is located at 74°31'36"W, 23°57'12"N, entirely within the intertidal zone, and consists solely of red mangroves. The quadrant contains trees with maximum heights of 4.5 m and 4 with diameters greater than 2.5 cm just above the top prop roots. Numerous seedlings (diameter less than 2.5 cm) are dispersed throughout the quadrant.

Quadrant 2 is located 250 m east of Quadrant 1 and contains 22 trees more than 2.5 cm in diameter. The tallest mangrove reaches 4.5 m. This quadrant of red mangroves contains one large buttonwood tree, which may be a leftover from a lower sea-level stand.

Quadrant 3 is adjacent to the eastern side of Quadrant 2 and also parallels the shoreline. It contains 5 massive red mangrove trees whose prolific prop roots cover the entire 10 m^2 quadrant. The circumference at the top of the last prop root averages 22 cm. There are no seedlings in this quadrant, although it has the densest growth of the three. Tree heights reach 5.5 m.

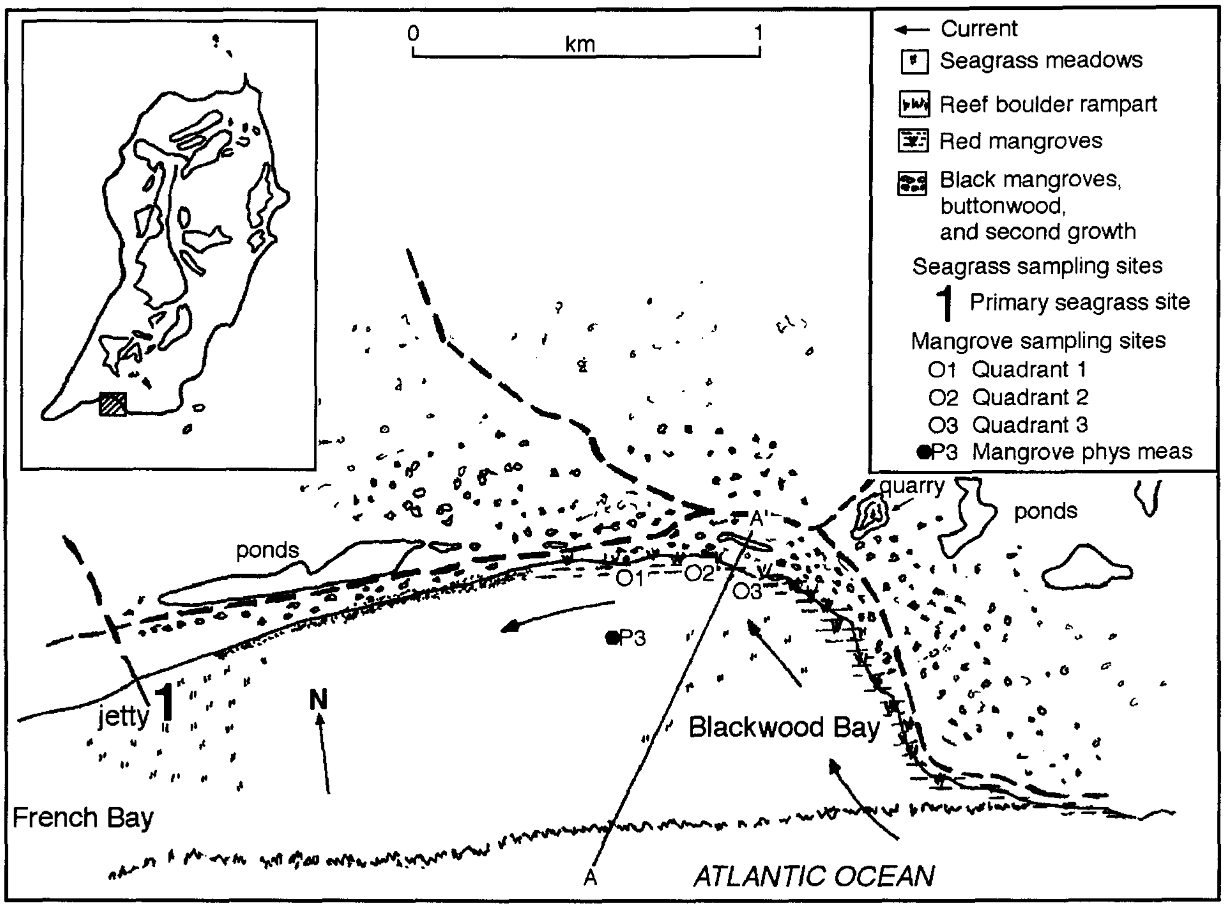
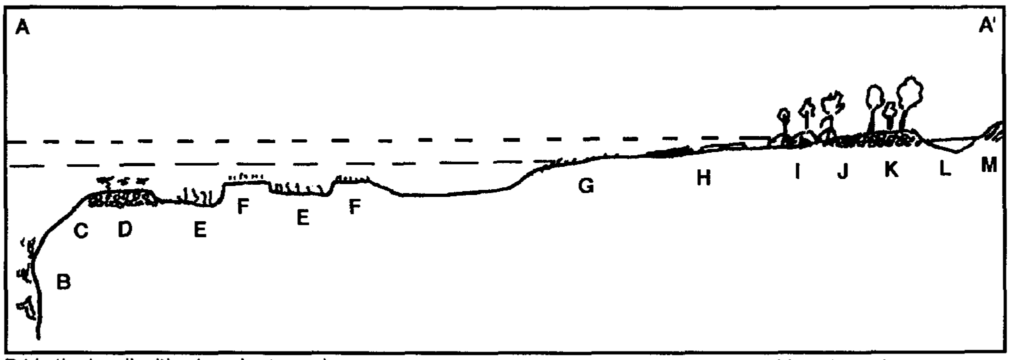


Fig. 4. Seagrass and mangrove sampling sites in southern San Salvador, Bahamas. Section A-A' is displayed in Fig. 5.



B Vertical well with abundant coral
C Fore-reef slope - smooth spur-and-groove structure
D Reef crest - encrusting *Millepora* boulder rampart
E Sandy intermound area with *Thalassia*
F Halodule
G Intertidal zone
H Pleistocene bedrock with paleosol
I Red mangrove
J Coarse sand beach back berm
K Coral rubble - black mangrove and buttonwood
L Pond
M Pleistocene dune

Fig. 5 Subenvironments of Blackwood Bay (not to scale); location of Section A- A' is shown in Fig. 4.

Seagrass Sites

Seagrass meadows occur in many marine coastal areas throughout the world (den Hartog, 1970). The diverse ecological roles played by seagrass in the marine environment have been well documented (Zieman, 1982; Thayer *et al.*, 1984). These plants provide fixed carbon to other trophic levels through direct herbivory and microbially transformed detritus (Ogden, 1976; Lewis, 1986; Kenworthy *et al.*, 1989). Seagrass also stabilizes marine sediments (Fonseca and Fisher, 1986; Fonseca, 1989) and provides a habitat for a variety of other organisms (Kenworthy *et al.*, 1988).

A number of environmental factors can have a profound influence on the growth and distribution of seagrass species in general. Among these are light intensity and quality (Dennison, 1987), temperature (Bulthuis, 1987), sediment nutrient status (Short, 1987), current velocity (Fonseca and Kenworthy, 1987), and microbial interactions (Smith, 1987). One or a combination of these factors may also account for seagrass declines in various geographical regions (den Hartog, 1987; Short *et al.*, 1987; Shepherd *et al.*, 1989). Although some decline may be attributed to point-source pollution, it is difficult to determine if they are local or widespread due to the lack of long-term, coordinated monitoring studies at key locations. Seagrass meadows occur off the northern, southern, and eastern coasts of San Salvador. They are particularly extensive in somewhat protected areas in the south (French Bay) and in Grahams Harbor in the north. French Bay was selected as a primary CARICOMP site because it has the highest potential growth rates for *Thalassia*, caused by the winds and currents providing high levels of nutrients (Fig. 4). The French Bay site is located 10 m east of and parallel to the French Bay jetty, which runs at 337° to the shore. The seagrass meadows near the mangrove sites are often exposed during low tides, while those chosen as CARICOMP studies are never exposed. Grahams Harbor was selected as

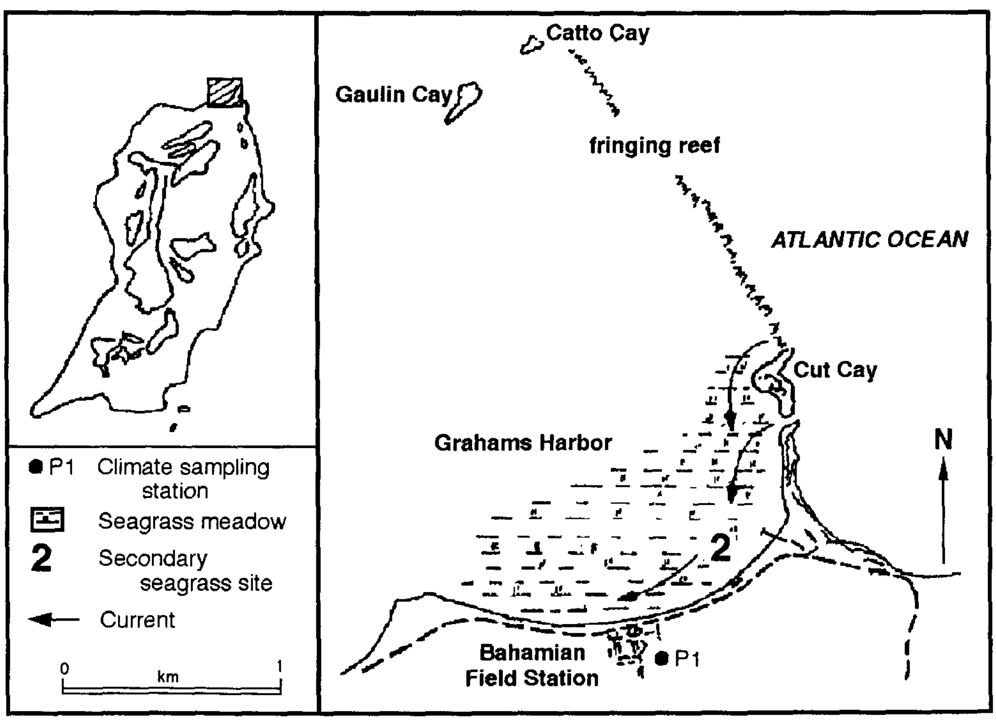


Fig. 6. Seagrass sampling site in Grahams Harbor, northern San Salvador, Bahamas.

the secondary site since it is most typical of the seagrass meadows around San Salvador. Grahams Harbor is a windward, high-energy lagoon located on the northeastern coast of San Salvador at 24°07' 24"N, 74°27'30"W (Fig. 6). This shallow basin is bounded by San Salvador to the south and North Point to the east. A barrier reef protects the lagoon along its northern margin; it is open to deeper waters to the west (Armstrong and Miller, 1988). Protected by fringing reefs, Grahams Harbor contains the most stable and the most extensive seagrass meadow around the island. It is buffered against extremes in water current velocity and is approximately 3 m deep at mean low tide. Beginning in 1988, samples of the seagrass beds in both French Bay and Grahams Harbor have been collected semiannually (mostly in July and December). The sampling protocol is given in Table 2 and resulting data are shown in Fig. 7 (next pages).

Table 2. Six year seagrass sampling protocol, 1988-1993.

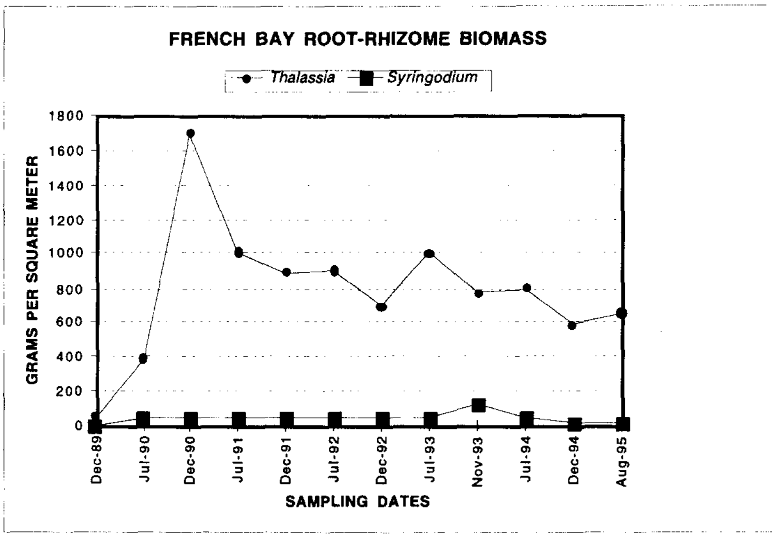
Site	Dates Sampled	No. of Cores	Species Present
French Bay	1, 4-12	285	T, S
Grahams Harbor	1-12	930	T, S, H

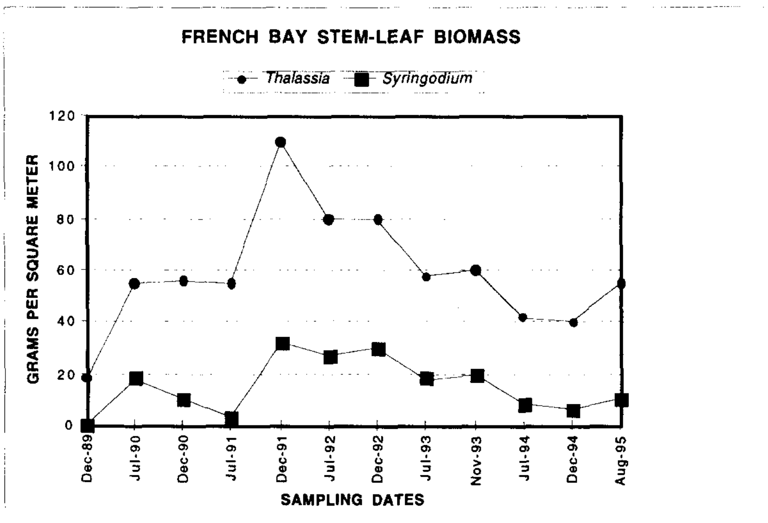
Sampling Dates				Seagrasses
1 = 07/88	4 = 12/89	7 = 07/91	10 = 12/92	T = *Thalassia*
2 = 12/88	5 = 07/90	8 = 12/91	11 = 07/93	S = *Syringodium*
3 = 07/89	6 = 12/90	9 = 07/92	12 = 11/93	H = *Halodule*

Seagrass cores were taken along 15 to 60 m transect lines at 2 m intervals with a 0.02 m^2 corer to a depth of 20 cm. Cores were placed in plastic bags upon removal from the substratum and washed free of adhering sediment on shore. Plants were then taken to the laboratory and washed in 0.1 N HCl, sorted by species and plant part, and leaf counts made. Contents of these cores were analyzed for seagrass species, above and below sediment biomass, and leaf count. The highest growth rates for *Thalassia* were observed at the French Bay site. Both *Thalassia* and *Syringodium* were found in more or less equal population densities (based on leaf counts), but biomass was much greater for *Thalassia*. Most of these measurements have remained stable over the past few years. At French Bay, huge mounds of seagrass wrack can be found on shore after heavy storms. At the Grahams Harbor site, population levels of *Syringodium* and *Halodule* were similar and relatively consistent until November 1993, when a significant increase was observed. Biomass measurements of *Thalassia* showed distinct seasonal fluctuations, with increases during the winter months.

Coral Reef Site

The coral reef site is located at 24°02'12"N, 74°31'57"W in Fernandez Bay, a gently curving shallow embayment along the west coast of San Salvador (Fig. 8). The bay is 4-5 km wide and extends from Cockburn Town in the north to the Sugar Loaf Rocks in the south, a distance of 6-8 km. The dominant feature of the irregularly shaped shoreline is the presence of large blocks of lithified beach sand which extend from the upper reaches of the intertidal zone (splash zone) through the lower intertidal zone and into the sandy bottom of the bay. The intertidal extends approximately 25 m into Fernandez





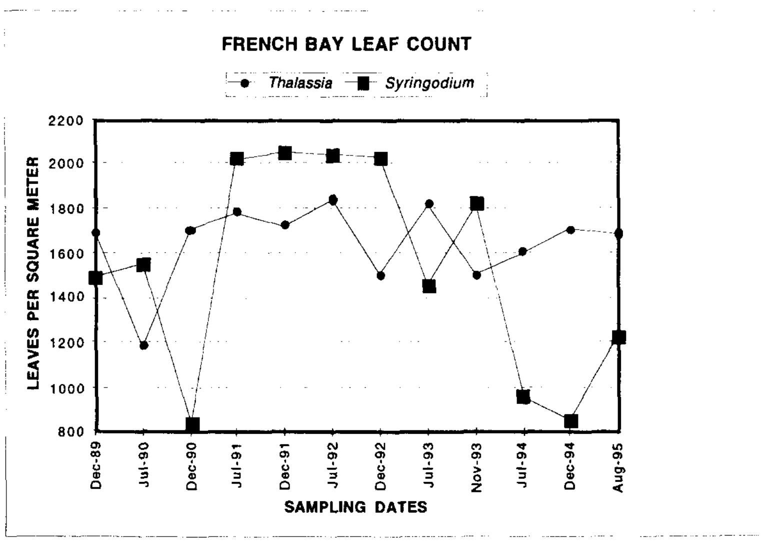


Fig. 7A. Seagrass analyses from the French Bay site, San Salvador, Bahamas.

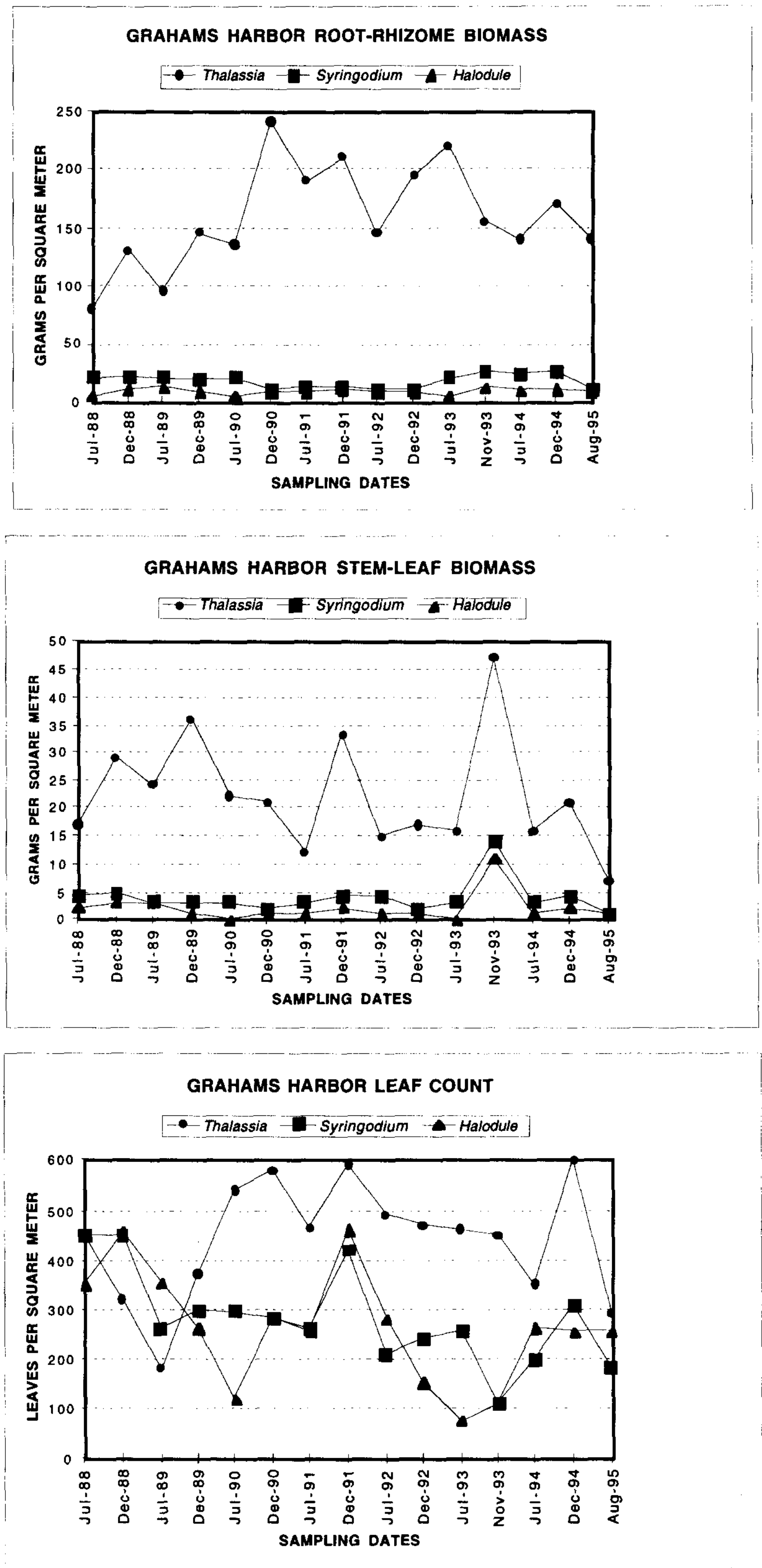


Fig. 7B. Seagrass analyses from the Grahams Harbor site, San Salvador, Bahamas.

Bay, with a mean depth of 1.5 m at high tide. The beach rock shoreline of Fernandez Bay grades into a predominantly calcium carbonate sand and extends outward from the shore 400-1,500 m to the "dropoff" or "wall," with a gradual downward slope such that the water reaches a maximum depth of 15-25 m at the top of the wall (Fig. 9). Numerous patch reefs of considerable size (>5,000 m^2, 3-5 m high) appear randomly on the floor of the bay. Water visibility remains good most of the year, with an average Secchi depth of 60 m. The mean water temperature is 28°C.

The wall is the predominant geological feature along the west coast of San Salvador Island; it has a near-vertical drop to 2,000-3,000 m. Running parallel to the shoreline and about 1,000 m from shore is

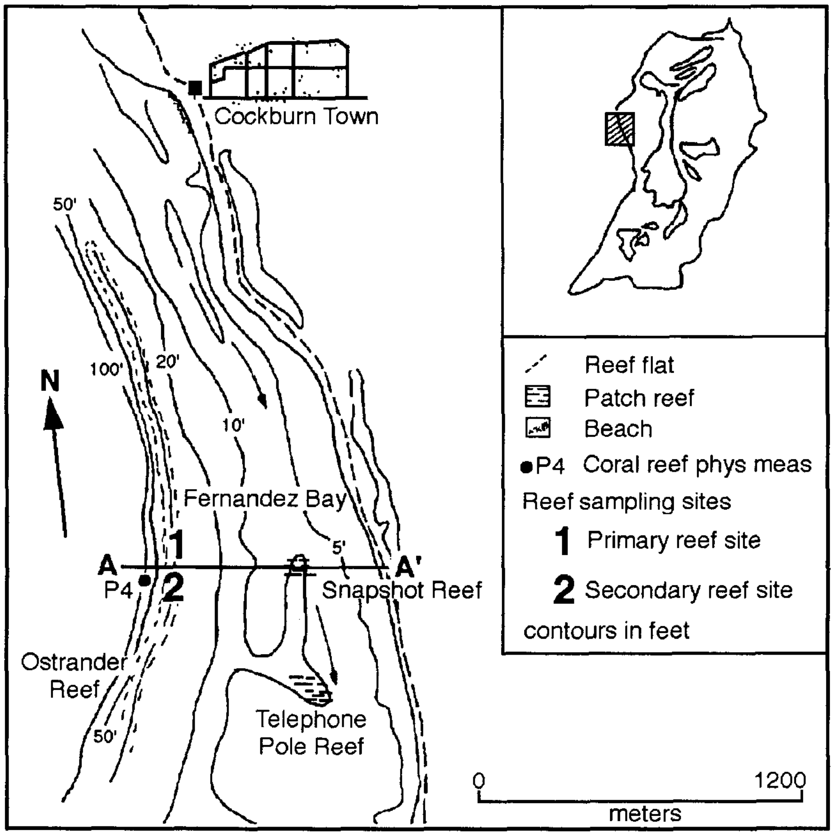


Fig. 8. Coral reef sampling site in Fernandez Bay, western cost of San Salvador, Bahamas. Section A-A' is displayed in Fig. 9.

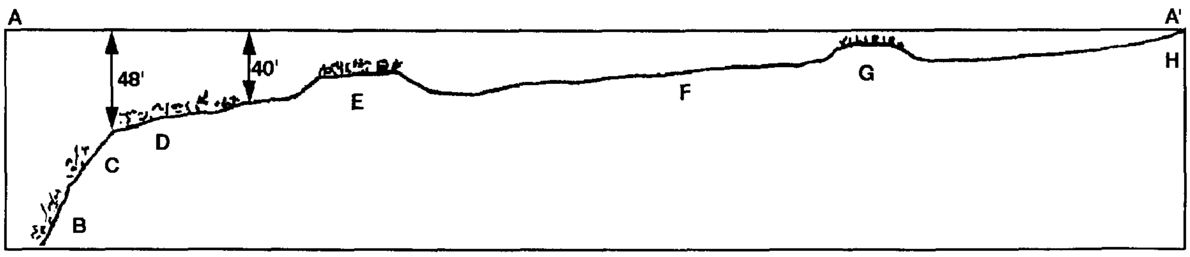


Fig. 9. Cross-section of Fernandez Bay (not to scale); location of section A-A' is shown in Fig. 8.

a minor secondary dropoff that descends toward the top of the wall. The sampling site at Ostrander Reef is located within a band of coral reefs situated on top of the wall and extending a considerable distance both north and south of the site.

The patch reefs scattered across the sandy bottom of the bay contain at least 100 species of fish and many more species of invertebrates. Hard corals include *Acropora cervicornis, Porites astreoides, P. porites, Monastrea annularis, M. cavernosa,* and *Dichocoenia stokesii.* The same soft coral species as described above predominate. In addition, significant numbers of colonies of *Millepora* sp. occur at a higher density on these reefs than on the surrounding substrate. The predominant algal species on the patch reefs include *Padina* and *Turbinaria.*

Primary anthropogenic activities in the vicinity of the coral reef site include occasional recreational divers and fishermen that visit the wall. However, this site is not in close proximity to any regular dive sites or fishing spots. Consequently, little human impact on any aspect of this coral reef ecosystem is anticipated over the course of these studies. The coral reef site is located a considerable distance from the seagrass and mangrove sites, and little interaction between the three ecosystems can be expected.

References

Adams, R. W. 1980. General guide to the geological features of San Salvador. **In:** *Field Guide to the Geology of San Salvador,* pp 1-66. Bahamian Field Station, San Salvador.

Armstrong, M. E., A. I. Miller. 1988. Modern carbonate sediment production and its relation to bottom variability, Grahams Harbor, San Salvador, Bahamas. **In:** *Proceedings of the Fourth Symposium on the Geology of The Bahamas* (edited by J. Mylroie), pp 23-32. Bahamian Field Station, San Salvador, 381 pp.

Bulthuis, D. A. 1987. Effects of temperature on photosynthesis and growth of seagrasses. *Aquatic Botany,* **27**:27-40.

Carew, J. L., J. E. Mylroie. 1994. *Geology and Karst of San Salvador Island, Bahamas: A Field Trip Guidebook.* Bahamian Field Station, San Salvador, 32 pp.

Colby, N. D., M. R. Boardman. 1988. Depositional evolution of windward, high-energy carbonate lagoon, San Salvador, Bahamas. **In:** *Proceedings of the Fourth Symposium on the Geology of The Bahamas* (edited by J. Mylroie), pp 95-105. Bahamian Field Station, San Salvador, 381 pp.

Davies, J. L. 1980. *Geographic Variation in Coastal Development, 2nd Edition.* Longmans Group Ltd, London, UK, 212 pp.

den Hartog, C. 1970. *The Seagrasses of the World.* North Holland Publishing, Amsterdam, 275 pp.

den Hartog, C. 1987. Wasting disease and other dynamic phenomena in *Zostera* beds. *Aquatic Botany,* **27**:3-14.

Dennison, W. C. 1987. Effect of light on seagrass photosynthesis, growth and depth distribution. *Aquatic Botany,* **27**:15-26.

Diehl, F., D. Mellon, R. Garrett, N. Elliott. 1988. *Field Guide to the Invertebrates of San Salvador.* Bahamian Field Station, San Salvador.

Fonseca, M. S. 1989. Sediment stabilization by *Halophila decipiens*. *Estuarine, Coastal and Shelf Science*, **29**:501-507.

Fonseca, M. S., J. S. Fisher. 1986. A comparison of canopy friction and sediment movement between four species of seagrasses with reference to their ecology and restoration. *Marine Ecology Progress Series*, **29**:15-22.

Fonseca, M. S., W. J. Kenworthy. 1987. Effects of current on photosynthesis and distribution of seagrasses. *Aquatic Botany*, **27**:59-78.

Kaplan, D. I., F. T. Short, G. W. Smith. 1990. Chemical interactions between seagrasses and carbonate sediments. **In:** *Proceedings of the Third Symposium on the Botany of The Bahamas* (edited by R. R. Smith), pp 41-45. Bahamian Field Station, San Salvador, 83 pp.

Kenworthy, W. J., G. W. Thayer, M. S. Fonseca. 1988. The utilization of seagrass meadows by fishery organisms. **In:** *Ecology and Management of Wetlands: Vol. 1, Ecology of Wetlands* (edited by D. D. Hook, W. H. McKee Jr, H.K. Smith, *et al.*), pp 548-560. Timber Press, Portland OR, USA, 592 pp.

Kenworthy, W. J., C. A. Currin, M. S. Fonseca, G. W. Smith. 1989. Production, decomposition and hetrotrophic utilization of the seagrass *Halophia decipiens* in a submarine canyon. *Marine Ecology Progress Series*, **71**:297-299.

Kramer, D. E., M. V. Caputo. 1988. Preliminary report on evolution of the coast along Blackwood Bay, San Salvador Island, Bahamas. **In:** *Proceedings of the Fourth Symposium on the Geology of The Bahamas* (edited by J. Mylroie), pp 177-189. Bahamian Field Station, San Salvador, 381 pp.

Lewis, S. M. 1986. The role of herbivorous fishes in the organization of a Caribbean reef community. *Ecology Monograph*, **56**:183-200.

Meyerhoff, A. A., C. W. Hatten. 1974. Bahamas salient of North America: Tectonic framework, stratigraphy and petroleum potential. *AAPG Bulletin*, **58**:1201-1239.

McGrath, T. A. 1993. *Coral Monitoring Project: Earthwatch Report*. Unpublished manuscript.

Mullins, H. T., G. W. Lynts. 1977. Origin of the northwestern Bahama platform: Review and reinterpretation. *GSA Bulletin*, **88**:1147-1161.

Ogden, J. C. 1976. Some aspects of herbivore-plant relationship on Caribbean reefs and seagrass beds. *Aquatic Botany*, **2**:103-116.

Pace, W. 1986. Preliminary investigation of a platform margin lagoon-tidal flat complex, Blackwood Bay, San Salvador Island, Bahamas. **In:** *Proceedings of the Third Symposium on the Geology of The Bahamas* (edited by H. A. Curran), pp 109-114. Bahamian Field Station, San Salvador, 254 pp.

Robblee, M. B., T. R. Barber, P. R. Carlson Jr., M. J. Durako, J. W. Fourqurean, L. K. Muehlstein, D. Porter, L. A. Yarbro, R. T. Zieman, J. C. Zieman. 1991. Mass mortality of the tropical seagrass *Thalassia testudinum* in Florida Bay. *Marine Ecology Progress Series*, **71**:297-299.

Shaklee, R. V. 1994. *In Columbus's Footsteps: Geography of San Salvador Island, The Bahamas*. Bahamian Field Station, San Salvador.

Shepherd, S. A., A. J. McComb, D. A. Bulthuis, V. Neverauskas, D. A. Steffensen, R. West. 1989. Decline of seagrasses. **In:** *Biology of Seagrasses* (edited by A. W. D. Larkam, A. J. McComb, S. A. Shepherd), pp 346-387. Elsevier Science, Amsterdam, 841 pp.

Short, F. T. 1987. Nutrient ecology of Bahamian seagrasses. **In:** *Proceedings of the First Symposium on the Botany of The Bahamas* (edited by R. R. Smith), pp 1-18. Bahamian Field Station, San Salvador, 165 pp.

Short, F. T., L. K. Muehlstein, D. Porter. 1987. Eelgrass wasting disease: Cause and recurrence of a marine epidemic. *Biological Bulletin [Woods Hole]*, **173**:557-562.

Smith, G. W. 1987. Microbial contributions to the growth and degradation of tropical seagrasses. **In:** *Proceedings of the Second Symposium on the Botany of The Bahamas* (edited by R. R. Smith), pp 45-53. Bahamian Field Station, San Salvador, 64 pp.

Smith, G. W., F. T. Short, D. I. Kaplan. 1990. Distribution and biomass of seagrasses in San Salvador, Bahamas. **In:** *Proceedings of the Third Symposium on the Botany of The Bahamas* (edited by R. R. Smith), pp 67-77. Bahamian Field Station, San Salvador, 83 pp.

Smith, R. R. 1993. *Field Guide to the Vegetation of San Salvador Island, The Bahamas, 2nd Edition.* Bahamian Field Station, 120 pp.

Thayer, G. W., W. J. Kenworthy, M. S. Fonseca. 1984. *The Ecology of Eelgrass Meadows of the Atlantic Coast: A Community Profile.* FWS/OBS-84/02, U.S. Fishery and Wildlife Service, 147 pp.

Zieman, J. C. 1982. *The Ecology of the Seagrasses of South Florida: A Community Profile.* FWS/OBS-82/85, U.S. Fishery and Wildlife Service, 123 pp.

Bermuda[1]

Struan R. Smith
Bermuda Biological Station for Research, Inc.
17 Biological Lane, Ferry Reach
St. George, Bermuda GE01

Bermuda is an isolated subtropical coral reef ecosystem in the North Atlantic. Shallow water carbonates cover an atoll-like volcanic seamount. The islands are emergent aeolianite limestone dunes that lie along the southeastern margin of the seamount. Extensive zones of coral reefs, dominated by massive corals (*Diploria* spp., *Montastraea* spp. and *Porites astreoides*), surround the central North Lagoon. Within the lagoon there is a complex of shallow patch reefs that support a higher diversity of corals, dominated by branching species (*Oculina* spp., *Madracis* spp.) and the hydrozoan *Millepora alcicornis*. Seagrass beds are distributed throughout the patch reefs, the inshore basins, and the shoreward margin of the outer rim reef. Three species of seagrasses, *Thalassia testudinum*, *Syringodium filiforme*, and *Halodule bermudensis*, are often intermixed or form monospecific beds. Mangrove forests have been reduced by foreshore development to small pockets and fringing communities, except at Hungry Bay. *Rhizophora mangal* and *Avicennia germinans* are the only species present. Seawater temperature fluctuates seasonally within the lagoon (14-31°C) and on the outer reef (18-29°C), which is moderated by the surrounding Sargasso Sea. Salinity remains close to oceanic values (36.5‰) due to low run-off from the porous limestone islands. Despite a high population density, human impacts are limited to over-fishing (now controlled through legislation), nutrient and trace metal loading of the inshore basins, and ship groundings.

Introduction

Bermuda is a unique island ecosystem located at a high latitude (32°N, 65°W) in the North Atlantic. The warming influence of the nearby Gulf Stream moderates the air and water temperature, allowing the development of subtropical marine and littoral communities (coral reefs, seagrass beds, mangrove forests). The islands of Bermuda are emergent aeolian dunes, formed during Pleistocene interglacial periods, located along the southeastern edge of the Bermuda Pedestal (Garret and Scoffin, 1977; Mackenzie and Vacher, 1975; Morris *et al.*, 1977).

[1] *CARICOMP — Caribbean Coral Reef, Seagrass and Mangrove Sites* (edited by B. Kjerfve), pp 247-257.
UNESCO, Paris, 1998, 347 pp.

The volcanic pedestal is covered by Pleistocene and Holocene carbonates, 15 to 100 m thick, and the upper surface is about 665 km^2 in size of which only 50 km^2 is covered by the islands. The bulk of the upper surface of the pedestal is a shallow lagoonal system (<20 m deep) with extensive shallow reefs, seagrass beds, and deeper muddy basins, referred to as the North Lagoon (Fig. 1). The islands form protected nearshore areas with further seagrass development and isolated pockets of mangroves. Extensive reef zones are developed at the seaward margin and flanks of the pedestal (Fig. 1). The outer reefs and lagoon areas, <20 m deep, are referred to collectively as the Reef Platform (Logan, 1988).

The marine biota is Caribbean in origin, with reduced species diversity and relatively little endemism (Sterrer, 1986). The cool winter water temperatures (14-18°C) are believed to be the limiting factor for the survival of some Caribbean species, although the degree of isolation of Bermuda (about 1200 km from The Bahamas and Florida) may limit larval dispersal from the Caribbean (Logan, 1988).

The islands were colonized in the early 17th Century and extensive development has taken place, primarily since 1940. At present, the population is about 60,000, distributed throughout the islands. The economy is based principally on tourism, international business, and finance (Hayward *et al.*,

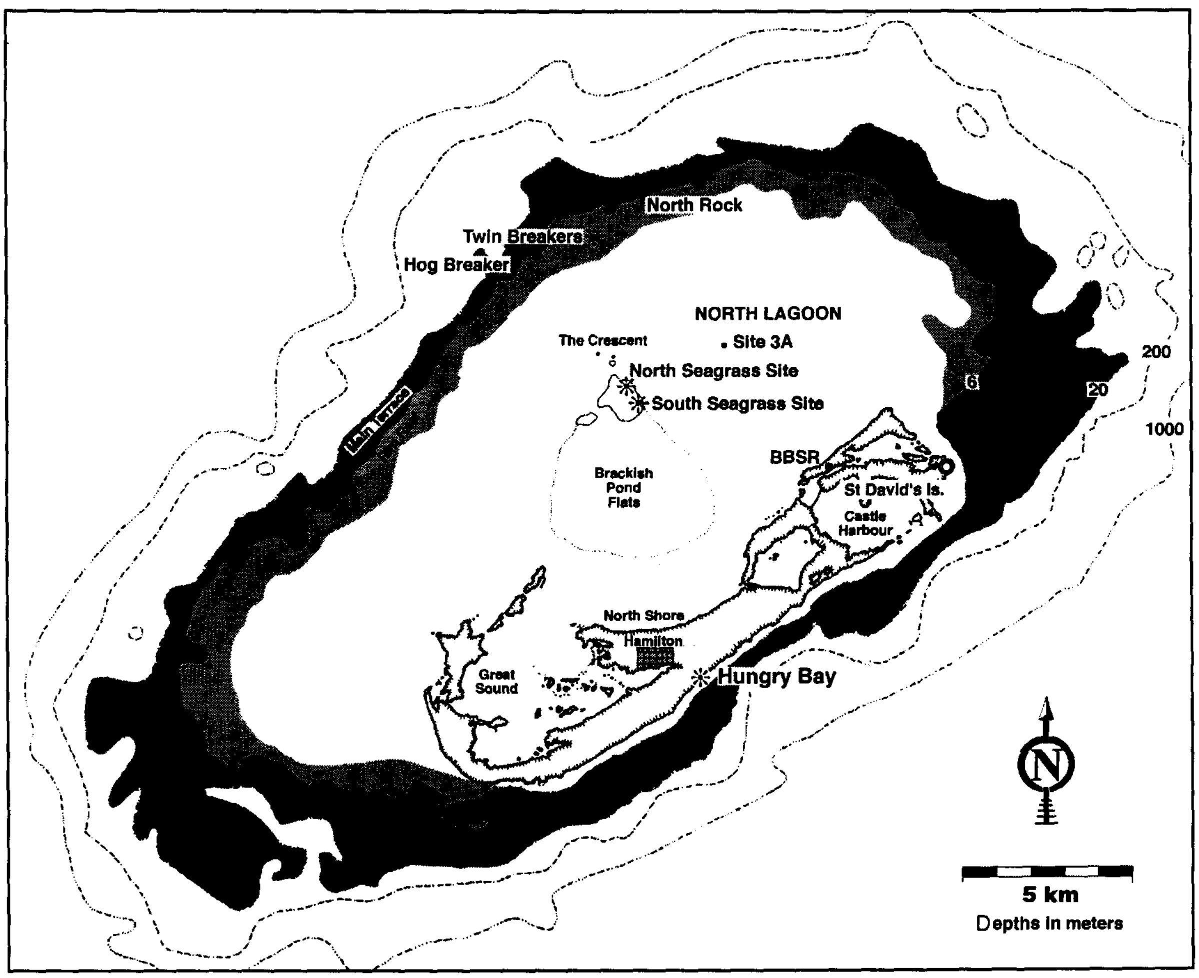


Fig. 1. Map of the Bermuda Platform, showing the outer reef zones surrounding the central North Lagoon, which contains numerous patch reefs (*e.g.*, Brackish Pond Flats and the Crescent) and muddy depressions. The CARICOMP study sites are marked with the symbol ✳. The site for climatic data collection on St. David's Island marked with the symbol ✪.

1981). The main settlements are the city of Hamilton in the center of the island and the town of St. George at the eastern end. Both urban areas have centralized sewage systems that discharge directly into the marine environment with little treatment; the Hamilton outfall is located on the South Shore and the St. George system empties into the North Lagoon.

Human impacts on the marine environment have been relatively limited. Fishing pressure on fish, conchs, and lobsters on the reefs has increased throughout the 20th Century and stocks have declined. A reasonably comprehensive management plan was introduced in 1990, including restricted areas and endangered species protection, to stabilize harvesting efforts (Butler *et al.*, 1993). The inshore coastal lagoons receive nutrient inputs derived from agriculture and sewage via both terrestrial runoff and groundwater seepage, and also trace metal contaminants (Bodungen *et al.*, 1982; Jickells *et al.*, 1986). Direct sewage inputs appear to have limited impact due to good flushing at the outfall sites. Foreshore development has been extensive, with the creation of commercial and naval port facilities. Also, shipping channels have been dredged and blasted through the North Lagoon for access to the capital city of Hamilton at the center of the island and to the naval bases at the western end of the island. The creation of an airfield by dredging and filling a large area in Castle Harbour eliminated coastal mangroves, caused coral mortality, and altered the ecology of the lagoon (Dodge and Vaisnys, 1977; Dryer and Logan, 1978).

Climate and Oceanography

Bermuda's climate and the oceanographic conditions on the Reef Platform and surrounding Sargasso Sea have been studied intensively for decades (Anon., 1984; Morris *et al.*, 1977). A comprehensive summary of many types of data pertaining to the Bermuda marine environment is given by Morris *et al.* (1977).

The high latitude of Bermuda (32°N) makes it susceptible to strong low-pressure systems from North America, bringing an average of 4-6 strong gales per winter (Anon., 1984; Garret and Scoffin, 1977). High seas (5-20 m) are generated over a long fetch and impinge on the outer reefs, qualifying them as high energy zones. The lagoonal reefs experience 1-2 m waves during gales. Hurricanes and tropical storms hit or pass by every 2-5 years and also produce extreme wave conditions on the outer reefs.

Air temperature fluctuates strongly with the seasons, dropping to 8°C with the passage of strong winter lows, while summer highs range to 35°C (Table 1; Anon., 1984). Spring and summer air flow is generally from the SE to SSW and usually less than 15 knots. ENE-N winds are common in the autumn; winter air flow is from SW-W-NW, often >15 knots, and frequently gale force (35 knots). Rainfall averages 147 cm per year and is evenly distributed throughout the year. Cloud cover varies seasonally, with more clear days in summer (35-40%) than winter (15-20%). Solar insolation ranges from a July average of 640 g cal^{-1} cm^{-2} d^{-1} to a December average of 240 g cal^{-1} cm^{-2} d^{-1}.

The North Lagoon and outer reef zones differ slightly in their oceanographic conditions (Boden and Kampa, 1953). The water temperatures on the outer reefs range from 18 to 28°C, moderated by the passage of Gulf Stream eddies in the surrounding Sargasso Sea (Hela *et al.*, 1953). Due to shallow depths, the North Lagoon warms and cools over a larger range; winter lows may reach 14°C, climbing to 31°C in the summer. There appear to have been record-setting highs in the past six years (Table 1; Cook *et al.*, 1990, 1993), but this may be the result of more frequent sampling and detection of short-term peaks.

The lagoonal waters are exchanged over the outer reef zones by semi-diurnal tides with a mean range of 0.75 m and a spring range of 1.0 m. Salinity varies little from the 36.5 ppt recorded in the North Lagoon and the outer reef zones. The more enclosed inshore basins do show modest departures (≈35.8 ppt) due to groundwater seepage, run-off, and rainfall.

Table 1. Summary of CARICOMP climatic, oceanographic, and biological data (average values).

	Maximum Monthly (Sampling Period)	Minimum Monthly (Sampling Period)
Cumulative rainfall	547 mm (09/1995)	19 mm (05/1993)
Air temperature	35.0°C (07/1995)	7.8°C (02/1993)
Sea temperature, reef site	29.2°C (07/1994)	18.7°C (02/1995)
Sea temperature, seagrass site	29.2°C (07/1994)	18.7°C (02/1995)
Secchi horizontal distance, reef site	50.0 m (05/1993)	11.0 m (10/1995)
Secchi horizontal distance, seagrass site	25.3 m (04/1995)	7.3 m (08/1995)

	Range of Averages		Sampling Period	
	Low	High	Low	High
Mangrove total litter fall (g m^{-2} $month^{-1}$)	15.00	250.00	01/1993	09/1993
Mangrove biomass (Cintron & Novelli) (kg m^{-2})	10.17	10.96	08/1993	09/1994
Thalassia leaf production rates (g^{-1} m^{-2} d^{-1})	0.52	1.48	09/1995	04/1994
Thalassia biomass (above+below) (g m^{-2})	658.00	1083.00	09/1993	04/1994
Total coral coverage (%)	16.70	24.20	09/1994	08/1993
Total algal coverage (%)	8.30	30.40	09/1995	09/1993

The lagoonal and inshore basins are more turbid than the surrounding oceanic waters, due to particle resuspension and higher water column productivity (Bodungen *et al.*, 1982; Jickells *et al.*, 1986; Morris *et al.*, 1977). Extinction coefficients are about 0.05 for the oceanic waters and range between 0.13 and 0.57 on the Reef Platform. Recent Secchi data show clear seasonal patterns at both the lagoonal seagrass site and the outer reef site, with generally clearer conditions in late spring/early summer, followed by a decline in water clarity through summer and fall (Table 1).

A water quality monitoring program (BIWI) has collected monthly surface water samples from the inshore waters and in the North Lagoon since 1977 (Bodungen *et al.*, 1982; Jickells *et al.*, 1986; Morris *et al.*, 1977). The program measures dissolved nutrients (NO_2+NO_3, NH_4, PO_4), pigment concentrations, temperature, and Secchi disc depths. Significant nitrogen enrichment was found in the inshore basins but not in the North Lagoon. One site (Site 3A) is located about 5 km east of the North Seagrass Site.

Climatic data are collected at two locations. Rainfall data are collected on St. David's Island as part of the AEROCE program. Air temperature data are collected at the Naval Oceanographic Command Facility, U.S. Naval Air Station, also on St. David's Island (see Fig. 1). oceanographic data are collected at the Hog Breaker Reef Site, the North Seagrass Site, and the Hungry Bay Mangrove Site.

Mangrove Ecosystems

Mangrove communities in Bermuda are the northernmost in the Atlantic and are limited in diversity and development (Thomas and Logan, 1992; Thomas, 1993). Bermuda's mangrove swamps have been reduced dramatically due to foreshore development, particularly in the last century (Sterrer and Wingate, 1981; Thomas and Logan, 1992). Approximately 16 ha of mangroves remain, perhaps less than half the pre-Colonial amount, and ~6 ha of the total are found associated with landlocked anachialine ponds (Thomas and Logan, 1992).

Mangrove swamp development was never very extensive due to the steeply sloped shoreline and lack of estuarine environments. Most of the current mangroves are classified as fringing communities and are composed of only two species, *Rhizophora mangale* and *Avicennia germinans*, that exist as narrow stands along the shore (Thomas and Logan, 1992). The distribution of the mangroves on Bermuda is disjunct, due to the character of the coastline. Most of the mangrove communities are small («1 ha) and there are no zonation patterns. Hungry Bay is the largest swamp (2.9 ha), with a creek system that has been channelized since the 1950s (Fig. 2). The seaward margin of the Hungry Bay swamp has retreated significantly due to sea-level rise over the past 100 years (Ellison, 1993).

The CARICOMP mangrove study is carried out in Hungry Bay (32°17.3'N; 64°45.5'W) on the southern shore of the island. Four 10 × 10 m vegetation study plots are located along the central axis of the swamp (Fig. 2) and the water sampling station is located near the mouth of the main drainage canal. CARICOMP results from 1992-93 indicate that salinity in the creek may drop to 33 ppm. The mangrove trees at the seaward margin are under stress, with reduced diameters, heights, and litter production compared to the plots in the interior of the swamp (CARICOMP data). Also, no seedlings are found at the seaward margin though they are abundant within the swamp. Ellison (1993) has demonstrated that the margin of the swamp is below mean sea level due to erosion and rising sea level, and this has contributed to the extensive retreat of the margin over the past 90 years.

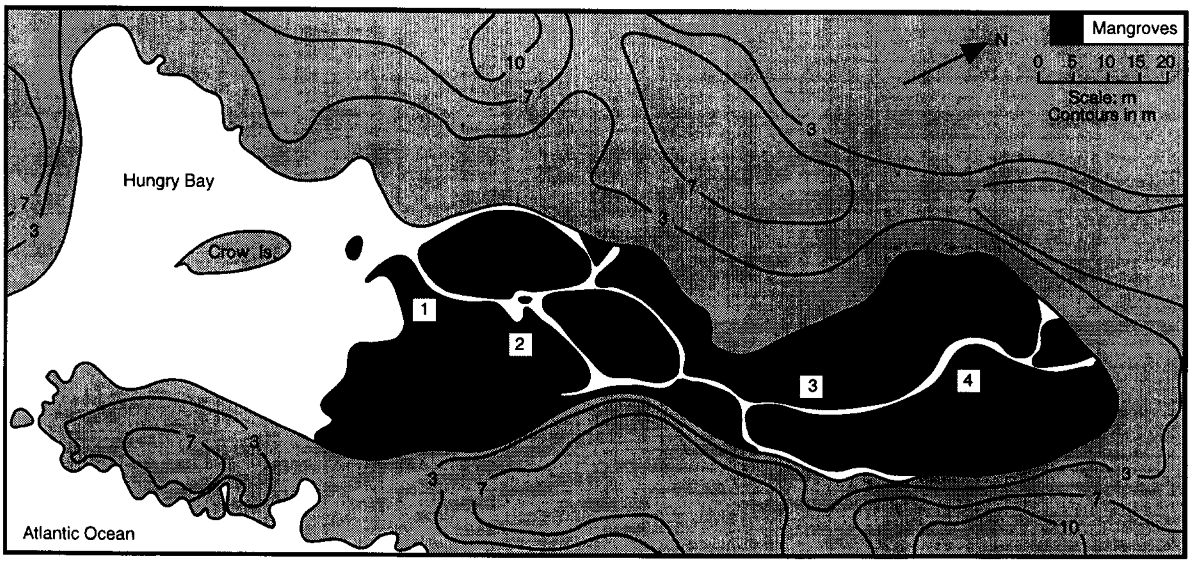


Fig. 2. Map of the mangrove forest at Hungry Bay (after J. Ellison, 1993). The locations of the four study plots are shown, as well as the principal channels within the forest.

Seagrass Ecosystems

Seagrass beds are distributed throughout the Reef Platform but they are generally limited in extent and have not been well studied (Thomas and Logan, 1992). The dominant species are *Thalassia testudinum* and *Syringodium filiforme*, which can form large monospecific stands. The most extensive *Thalassia* beds are located off the southwestern end of the island. A large bed of *Syringodium* is located along the North Shore (Knap *et al.*, 1991; Smith *et al.*, 1995). In the inshore basins, *Thalassia* and *Syringodium* usually occur in mixed stands along with a third species, *Halodule bermudensis*. These beds are generally small due to the limited shallow water areas surrounding the relatively deep inshore basins. Several small bays and sheltered coasts have been mapped (Morris *et al.*, 1977; Thomas and Logan, 1992). Seagrass beds are found associated with the patch reefs in the North Lagoon, either contained within the cellular and mini-atoll reefs (Logan, 1988) or on their flanks. Their distribution within the North Lagoon reef complex is patchy and has not been described. *T. testudinum* and *S. filiforme* are the most abundant species in these beds, occurring as either mixed beds or monospecific stands.

The two CARICOMP seagrass sites are located within a mini-atoll reef (Crescent Reef) in the center of the North Lagoon, south of the north shipping channel, in an area known as The Crescent (Figs. 1 and 3). Water depths off the reef reach 15-18 m. The North Seagrass Site (32°24'04"N; 64°47' 57"W) consists of a broad belt of *T. testudinum* adjacent to the eastern reef, which grades into an extensive mixed stand of *S. filiforme* and *H. bermudensis*. The South Seagrass Site (32°24'10"N; 64°48'20"W) is a monospecific stand of *T. testudinum*. The seagrass beds are surrounded by banks of reef that may shallow to 0.5 m depth but average 2-3 m in depth. Water depth at both seagrass beds is about 5 m. Shoot densities of *T. testudinum* are low (790 ± 190 [standard error] m^{-2}) and blade lengths short (5-11 cm), perhaps indicative of the relatively exposed condition of these beds. These sites appear to be pristine and undisturbed by human activities, apart from the CARICOMP study.

Thalassia beds are found at the lagoonward edge of the outer reef zone of the North Lagoon, known as the Rim Reef (see below and Fig. 1). These beds are small (<0.5 ha), patchy in distribution, and occur in relatively deep water (8-10 m). They are an important habitat for protected populations of the Queen Conch, *Strombus gigas* (Berg *et al.*, 1992).

Quantitative studies on seagrasses are limited primarily to the nearshore beds (Patriquin, 1973; Pitt, 1992; South, 1983; Smith *et al.*, 1995). Shoot densities for *T. testudinum* and *S. filiforme* range from 300 to 1600 per m^2. Leaf production estimates for *T. testudinum* range from 0.8 to 1.7 g m^{-2} d^{-1} dry weight (Pitt, 1992; CARICOMP data). Higher leaf growth rates are found in the nutrient-enriched inshore areas compared to the lagoonal beds (Pitt, 1992). Intensive studies of *T. testudinum* and *S. filiforme* beds along the North Shore have been carried out as part of an environmental monitoring study (Knap *et al.*, 1991; Smith *et al.*, 1995). *Syringodium* leaf production rates are 0.3-0.6 g m^{-2} d^{-1} dry weight (Smith *et al.*, 1995).

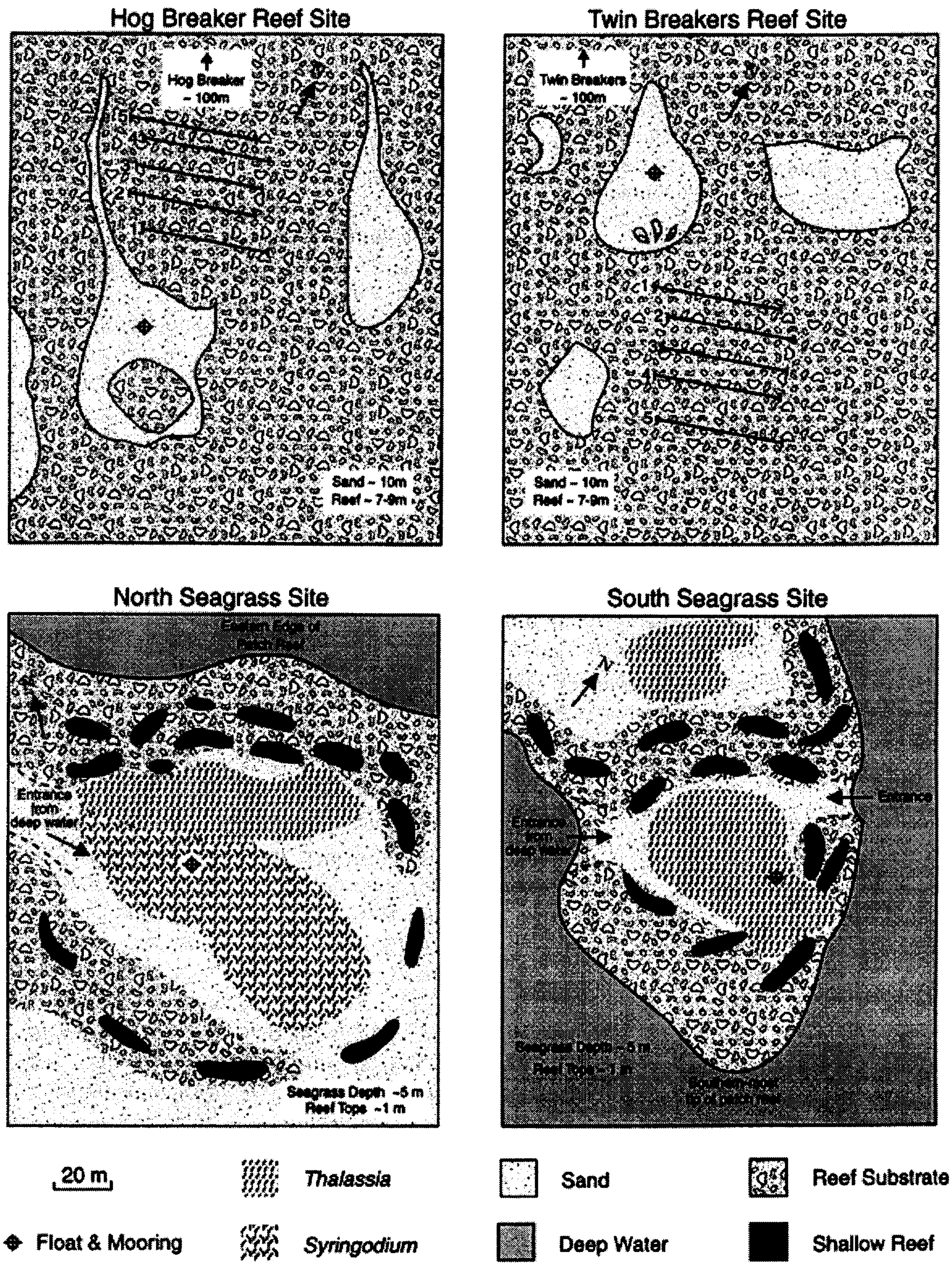


Fig. 3. Detailed maps of the two reef monitoring sites and the two seagrass study sites.

Coral Reef Zones

Extensive reef zones are developed at the margin and on the shallow flanks of the Bermuda Pedestal (Fig 1; Garret and Scoffin, 1977; Logan, 1988). The Rim Reef is a shallow (3-10 m) zone, about 0.5-1 km wide, that separates the ocean from the North Lagoon. This zone is reduced on the narrow southeastern edge of the pedestal adjacent to the islands, where a nearly continuous linear sequence of emergent algal-vermetid reefs ("boilers") separate the nearshore reef zone from the ocean (Meischner and Meischner, 1977). Seaward of the northern Rim Reef and southern boiler reefs is the extensive Main Terrace, sloping between 15-30 m, that surrounds the entire pedestal and may be up to 3 km in width. Below the Main Terrace reefs is the deep fore-reef that slopes sharply off and terminates at about 60 m (Fricke and Meischner, 1985). Within the North Lagoon is an extensive array of patch reefs varying in size and configuration (Garret *et al.*, 1971; Logan, 1988), interspersed with deep (15-18 m) muddy basins.

The Rim and Terrace Reefs have similar coral assemblages, made up of a few species, but coverage ranges from 25% in the former zone to 50% in the latter zone (Dodge *et al.*, 1982; Logan, 1988). *Diploria strigosa, D. labyrinthiformis, Montastraea franksi* (*sensu* Weil and Knowlton, 1994), *M. cavernosa*, and *Porites astreoides* are the dominant corals in these zones, along with the hydrozoan *Millepora alcicornis.* Less common species include *Stephanocoenia michelini, Favia fragum, Agaricia fragilis, Madracis decactis, Siderastrea* spp., *Scolymia cubensis*, and *Isophyllia sinuosa*. The deep fore-reef community is composed of *Montastraea* spp., *A. fragilis, S. michelini*, and *Madracis* spp. (Fricke and Meischner, 1985).

The lagoonal patch reefs have a similar *Diploria-Montastraea-Porites* community structure with lesser coverage (<20%) (Dodge *et al.*, 1982; Garrett *et al.*, 1971). However, the patch reefs closer to the island and within Castle Harbour support a different community of primarily branched species (*Madracis decactis, M. mirabilis, Oculina diffusa*) that grow on the vertical sides of the reefs (Dryer and Logan, 1978; Logan, 1988). This reef community may have developed as the result of higher sedimentation rates close to shore and the degree of protection from wave energy. Coral diversity is greatest on these reefs, along with other sessile invertebrates and benthic algae.

Coral growth rates appear to be seasonal, with faster growth in the summer months but reduced for some species compared to Caribbean congeners (Table 1; Logan and Tomascik, 1991). Higher growth rates for several coral species are found within the lagoonal reefs compared to the outer reef zones (Logan *et al.*, 1994).

Overall, Bermuda's reefs are in good health, despite repeated coral bleaching episodes (Cook *et al.*, 1993). The reefs have suffered direct human impact (ship groundings, dredging) but these have generally been limited in extent (Cook *et al.*, 1993). The potential effects of the over-harvesting of reef fishes have been mitigated by a new management plan that eliminates the use of non-selective traps and creates no-fishing zones (Butler *et al.*, 1993). Recent monitoring has noted the recovery of some fish stocks (Luckhurst, 1994).

The CARICOMP reef sites are located on the northern rim reef about 12 km from the island (Figs. 1 and 3). The Hog Breaker site (32°27'32"N; 64°49'54"W) and the Twin Reefs site (32°27'51"N; 64°48' 56"W) have been used for extensive investigation of coral recruitment, mortality, algal abundance, and fish grazing activity since 1986 (Smith, 1988, 1990, 1992; Hog Breaker = Smith's WC and Twin Reefs =

Smith's EC). Monitoring of coral bleaching on permanent transects at both sites has been carried out since 1990 (Cook *et al.*, 1993). Neither site shows any evidence of human interference apart from low-impact scientific endeavors (photography, algal collection, installation of marking stakes).

The reef sites are near the center of the Rim Reef zone, about 100-150 m shoreward from the transition of the Rim Reef to the Main Terrace; thus, these sites are exposed to oceanic swell and storm waves. Both sites are characterized as a bank of reef, average depth 7-9 m, interspersed with sediment-filled depressions at about 10 m depth. The reef surface is a fairly rugose relief of 1-2 m, due in part to the large sizes (0.5-1.5 m diameter) of the main framework-builder, *Diploria* spp. (Smith, 1988). An unusual feature is the presence of occasional biogenic carbonate pillars up to 4 m in height and 1-2 m in width, with sparse coral cover (Logan, 1988).

The coral communities at both sites are the *Diploria-Montastraea-Porites* assemblage typical of the Rim Reef. Gorgonian corals are common, primarily *Pseudoplexaura* spp., *Plexaura* spp., *Eunicea* spp., *Pseudopterogorgia* spp., and *Gorgonia ventalina*. Other common sessile invertebrates are coralliomorpharians, zoanthids, and anemones. Large erect sponges are rare. Reef turf algae are primarily *Polysiphonia* spp., *Ceramium* spp., *Herposiphonia secunda*, and *Sphacelaria* sp. The most common macroalgae are *Laurencia obtusa* and *Dictyota bartayresii*, although *Ceramium nitens* becomes seasonally dominant in the summer months (Smith, 1990).

Interaction of CARICOMP Sites and Relationship to the Caribbean Sites

The three CARICOMP study sites on Bermuda are separated physically and do not have any direct interactions. Bermuda's study sites are geographically unrelated to the Caribbean, with different climatic and oceanographic regimes. However, Bermuda's role as an outlier ecological system may be a valuable point of reference for future changes that may occur in the Caribbean.

Acknowledgements

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References

Anon. 1984. *Bermuda Environmental Scenario.* U.S. Naval Weather Service Detachment, Ashville NC, USA, 199 pp.

Berg Jr., J. C., F. Couper, K. Nisbet, J. Ward. 1992. Stock assessment of the Queen conch, *Strombus gigas*, and harbour conch, *S. costatus*, in Bermuda. *Proceedings of the Gulf and Caribbean Fisheries Institute*, **41**:433-438.

Boden, B. P., E. M. Kampa. 1953. Winter cascading from an oceanic island and it's biological implication. *Nature*, **171**:426.

Bodungen, B. von, T. D. Jickells, S. R. Smith, J. A. D. Ward, G. B. Hillier. 1982. *The Bermuda Marine Environment, Vol. III.* Special Publication 18, Bermuda Biological Station for Research, 123 pp.

Butler, J. N., J. Burnett-Herkes, J. A. Barnes, J. Ward. 1993. The Bermuda fisheries: A tragedy of the commons averted? *Environment*, **35**:7-15 and 25-33.

Cook, C. B., R. E. Dodge, S. R. Smith. 1993. Fifty years of impacts on coral reefs in Bermuda. **In:** *Global Aspects of Coral Reefs: Health, Hazards and History* (compiled by R. Ginsburg), pp 160-166. Rosenstiel School of Marine and Atmospheric Sciences, University of Miami, Miami FL, USA, 420 pp.

Cook, C. B., A. Logan, J. Ward, B. Luckhurst, J. C. Berg Jr. 1990. Elevated temperatures and bleaching on a high latitude coral reef: The 1988 Bermuda event. *Coral Reefs*, **9**:45-49.

Dodge, R. E., A. Logan, A. Antonius. 1982. Quantitative reef assessment studies in Bermuda: A comparison of methods and preliminary results. *Bulletin of Marine Science*, **32**:745-760.

Dodge, R. E., J. R. Vaisnys. 1977. Coral populations and growth patterns: Responses to sedimentation and turbidity associated with dredging. *Journal of Marine Research*, **35**:715-730.

Dryer, S., A. Logan. 1978. Holocene reefs and sediments of Castle Harbour, Bermuda. *Journal of Marine Research*, **36**:399-425.

Ellison, J. C. 1993. Mangrove retreat with rising sea-level, Bermuda. *Estuarine, Coastal and Shelf Science*, **37**:75-87.

Fricke, H., D. Meischner. 1985. Depth limits of Bermudian scleractinian corals. *Marine Biology*, **88**: 175-187.

Garret, P., T. P. Scoffin. 1977. Sedimentation on Bermuda's atoll rim. **In:** *Proceedings of the Third International Coral Reef Symposium* (edited by D. L. Taylor), Vol. 2, pp 87-95. Rosenstiel School of Marine and Atmospheric Sciences, University of Miami, Miami FL, USA, 628 pp.

Garret, P., D. L. Smith, O. A. Wilson, D. Patriquin, D. 1971. Physiography, ecology and sediments of two Bermuda patch reefs. *Journal of Geology*, **79**:647-668.

Hayward, S. J., V. H. Gomez, W. Sterrer (Editors). 1981. *Bermuda's Delicate Balance: People and the Environment.* Bermuda National Trust, Hamilton, Bermuda, 402 pp.

Hela, I., H. B. Moore, H. Owre. 1953. Seasonal changes in the surface water masses and their plankton in the Bermuda area. *Bulletin of Marine Science of the Gulf and Caribbean*, **3**:157-167.

Jickells, T. D., A. H. Knap, S. R. Smith. 1986. Trace metals and nutrient fluxes through the Bermuda inshore waters. **In:** *Rapports et Proces-Verbaux des Reunions* (edited by G. Kullenberg), pp 251-262. Report 186, Conseil Permanent Internationale pour l'Éxploration de la Mer, Copenhagen, Denmark, 485 pp.

Knap, A. H., C. B. Cook, S. B. Cook, J. A. K. Simmons, R. J. Jones, A. E. Murray. 1991. *Marine Environmental Studies to Determine the Impact of the Mass Burn Incinerator Proposed for Tynes Bay, Bermuda.* Report to the Ministry of Works and Engineering, Government of Bermuda, 256 pp.

Logan, A. 1988. *Holocene Reefs of Bermuda [Sedimenta XI].* University of Miami, Miami FL, USA, 63 pp.

Logan, A., T. Tomascik. 1991. Extension growth rates in two coral species from high latitude reefs of Bermuda. *Coral Reefs*, **10**:155-160.

Logan, A., L. Yang, T. Tomascik. 1994. Linear extension rates in two species of *Diploria* from high latitude reefs in Bermuda. *Coral Reefs*, **13**:225-242.

Luckhurst, B. E. 1994. A fishery-independent assessment of Bermuda's coral reef fish stocks by diver census following the fish pot ban — A progress report. *Proceedings of the Gulf and Caribbean Fisheries Institute*, **46**: 251-262.

Mackenzie, F. T., H. L. Vacher. 1975. Bermuda. **In:** *Encyclopedia of World Regional Geology, Part 1* (edited by R. Fairbridge), pp 117-121. Dowden, Hutchison and Ross, Stroudsburg PA, USA, 704 pp.

Meischner, D., U. Meischner. 1977. Bermuda south shore reef morphology — A preliminary report. **In:** *Proceedings of the Third International Coral Reef Symposium* (edited by D. L. Taylor), Vol. 2, pp 243-250. Rosenstiel School of Marine and Atmospheric Sciences, University of Miami, Miami FL , USA, 628 pp.

Morris, B., J. Barnes, F. Brown, J. Markham. 1977. *The Bermuda Marine Environment*. Special Publication 15, Bermuda Biological Station for Research, 120 pp.

Patriquin, D. G. 1973. Estimation of growth rate, production and age of the marine angiosperm *Thalassia testudinum* Konig. *Caribbean Journal of Science*, **13**:111-121.

Pitt, J. 1992. *An Investigation of Seagrass Productivity in Hamilton Harbour and Contrasting Areas*. Honours Thesis, University of Southampton (UK), 58 pp.

Smith, S. R. 1988. Recovery of a disturbed reef in Bermuda: Influence of reef structure and herbivorous grazers on algal and sessile invertebrate recruitment. **In:** *Proceedings of the Sixth International Coral Reef Symposium* (edited by J. H. Choat *et al.*), Vol. 2, pp 267-272. Sixth International Coral Reef Symposium Executive Committee, Townsville, Australia, 868 pp.

Smith, S. R. 1990. *The Influence of Herbivorous Grazers on the Recovery of a Disturbed Coral Reef in Bermuda*. Ph.D. Dissertation, University of Georgia, Athens GA, USA, 191 pp.

Smith, S. R. 1992. Patterns of coral recruitment and post-settlement mortality: Comparisons to Caribbean and Pacific reefs. *American Zoologist*, **32**:663-673.

Smith, S. R., T. Murdoch, T. Warren, D. Hayward. 1995. *Final Report of the Benthic Monitoring Programme Prior to the Operation of the Tynes Bay Incinerator*. Report to the Ministry of Works and Engineering, Government of Bermuda, 106 pp.

South, G. R. 1983. A note on two communities of seagrasses and rhizophytic algae in Bermuda. *Botanica Marina*, **26**:243-248.

Sterrer, W., D. B. Wingate. 1981. Wetlands and marine environments. **In:** *Bermuda's Delicate Balance* (edited by S. Hayward, V. H. Gomez, and W. Sterrer), pp 107-122. Bermuda National Trust, Hamilton, Bermuda, 402 pp.

Sterrer, W. E. 1986. *Marine Flora and Fauna of Bermuda*. Wiley, New York NY, USA, 742 pp.

Thomas, M. L. 1993. Mangrove swamps in Bermuda. *Atoll Research Bulletin*, **386**:1-17.

Thomas, M. L., A. Logan. 1992. *A Guide to the Ecology of the Shoreline and Shallow-Water Marine Communities of Bermuda*. Special Publication 30, Bermuda Biological Station for Research, 345 pp.

Weil, E., N. Knowlton. 1994. A multi-character analysis of the Caribbean coral *Montastraea annularis* (Ellis and Solander, 1786) and its two sibling species, *M. faveolata* (Ellis and Solander, 1786) and *M. franksi* (Gregory,1895). *Bulletin of Marine Science*, **55**:151-157.

The Data Management Centre and Data Summary[1]

Dulcie M. Linton and Jeremy D. Woodley
Centre for Marine Sciences
University of the West Indies-Mona
Kingston 7, Jamaica

The CARICOMP Data Management Centre is responsible for the collation, storage, and redistribution of data. At each CARICOMP site, data are entered into spreadsheet templates prepared for each of the fourteen CARICOMP Level One methods. These are sent to the Centre by various means, increasingly by e-mail. Regional data summaries are distributed to the network each year. After a period of internal review and use, these will be published, both in hard copy and on the World Wide Web. Final storage will be in a relational database program. Meanwhile, the Centre has coordinated Caribbean-wide research and discussion within the network.

Introduction

The Caribbean Coastal Marine Productivity Network is a cooperative effort to study and monitor three productive Caribbean coastal habitats, namely mangroves, seagrasses, and coral reefs. Twenty-one marine laboratories, parks, and reserves in nineteen countries are collecting data according to prescribed methods given in the *CARICOMP Methods Manual, Level 1* (1994, unpublished). These data are sent to the Data Management Centre (DMC) for collation, storage, and redistribution. The DMC was established in 1992, with grant funds from UNESCO, at the Centre for Marine Sciences, University of the West Indies (Mona), Kingston, Jamaica. The Centre became fully operational when a full-time Data Manager was employed, thanks to grant support from the MacArthur Foundation, in November 1994. The agreed functions of the DMC are:

- To receive and store all CARICOMP data, ultimately in a relational database, to be available for queries.
- To prepare regular summaries of the data and distribute them to the contributing sites.
- To prepare annual data reports, for publication one year after the data summary has been distributed to the sites.
- To perform analyses and summaries, as requested by the network.
- To be a focal point of communication between CARICOMP sites, relaying ideas and information on issues of concern to the participants.

[1] *CARICOMP — Caribbean Coral Reef, Seagrass and Mangrove Sites* (edited by B. Kjerfve), pp 259-336. UNESCO, Paris, 1998, 347 pp.

Receipt and Storage of CARICOMP Data

Data Entry. At each site, data are collected using fourteen methods, described in the CARICOMP manual and summarized in the first CARICOMP data report, which appears in this chapter. In 1992-93, raw data were sent to the DMC and entered into a specially written database program. In 1994, spreadsheet templates were designed (in Quattro Pro) for each of the above methods and distributed on disk to all participating sites for entry of their data.

The use of spreadsheets has several advantages (Ledgister *et al.*, 1995, 1997):

- paper data-collection forms can be printed;
- reports will be uniform in style (e.g., units of measurements);
- simple calculation formulas are built in, reducing errors;
- electronic entry at the local site facilitates error checking.

However, if Site Directors are unable to enter their data promptly, they are encouraged to send their raw data sheets to the DMC for entry.

In addition to the basic CARICOMP methods, data are being collected and stored electronically by automatic recording equipment: weather stations and Hobo temperature recorders.

Data Transfer. Completed spreadsheets have been returned to the DMC by courier, by mail or, increasingly, by e-mail. By October 1996, 19 of the 21 active CARICOMP sites had access to the Internet. So far, six have successfully transferred data to the DMC by e-mail, while others have yet to master the appropriate software.

Data Storage. Datasets received by the DMC are examined to ensure that the correct template has been used; they are then checked for obvious data entry errors. For HoboTemp data, which are presented in hundreds of rows, the DMC has designed macros (commands written in a software program that automates repetitive procedures) to speed up processing. All data received to date are stored in Quattro Pro spreadsheets on a 1.0 GB hard disk at DMC. Periodic backups are made to 120 MB data cartridges and stored at both on-site and off-site locations. Also, the original diskettes sent to the DMC are retained.

The entire CARICOMP database is now stored in hundreds of Quattro Pro spreadsheet files. This arrangement is part of a two-phase data management strategy of the DMC: to use spreadsheets at the data entry phase, with subsequent storage in a database management system. This strategy allows flexibility in data handling at the entry level, where the data are readily summarized and transferred to the CARICOMP network. Then the spreadsheets are imported into a relational database for ultimate storage in a more robust and versatile programme (Ledgister *et al.*, 1997).

The initial and most crucial stage of database development has been completed: sorting the data and designing data tables, in which the data are normalized (reduced to the simplest structure possible). The next phase, designing the data tables in an appropriate database, will take place after the pros and cons of various relational database programs have been fully explored. Meanwhile, a converter program has been written for the DMC, by which data will be extracted from the spreadsheets and entered into the database program.

Preparation and Distribution of Data Summaries. The schedule originally proposed was that the sites should send data every month to the DMC, which would return regional summaries to the network every quarter. This schedule has not been maintained, largely because of the irregular flow of data from the sites. All sites received copies of the 1993 dataset in January 1994, and annual summaries to date were mailed to all contributing sites in September 1995. Furthermore, copies were distributed at the Site Directors' Meeting in the Dominican Republic in December 1995. Abstracts of papers presented by CARICOMP at the 8th International Coral Reef Symposium (ICRS), held in Panama in June 1996, were drafted at that meeting, using the summaries provided.

Annual Data Reports. Site Directors agreed that their data should not be published until they had the opportunity to work with the data themselves. Therefore, the report for 1992-1995 in the following pages is the first to appear. The data herein will be made available on the CARICOMP home page on the World Wide Web, which was established in November 1997.

Analyses and Other Summaries. Specific datasets were distributed to members of working groups assigned to prepare the CARICOMP papers for presentation at the 8th ICRS. Those papers are listed in the 1992-95 report in this volume.

Communication Between CARICOMP Sites. All 25 participating sites are linked to the DMC by the traditional means of communication: telephone, fax, and mail service; at least 20 now use electronic mail, as do all members of the Steering Committee. No system is completely reliable, but the use of e-mail has made network communication much quicker and easier than even by fax.

In 1995-1996, the DMC organized a Caribbean-wide survey of coral bleaching and subsequent mortality, which was reported at the 8th ICRS. The DMC also played a role in the Caribbean-wide survey of a seafan sickness, the subject of another paper at the 8th ICRS. Reports of other mortality events, notably at the CARICOMP coral reef site in Moroccoy, Venezuela, were also distributed. In addition the DMC has facilitated discussions on CARICOMP methods and on future CARICOMP programs.

It is expected that the DMC will also be a focal point for communication with other individuals and agencies. So far, most of the enquiries received, especially from institutions wishing to join CARICOMP, have been passed to the Steering Committee for decision. Additional information is available to all interested persons at the CARICOMP website, which is maintained at the University of the West Indies–Mona, in Kingston, Jamaica: http://www.uwimona.edu.jm/centres/cms.

References

Cintrón, G., Y. Schaeffer-Novelli. 1984. Methods for studying mangrove structure. **In:** *The Mangrove Ecosystem* (edited by S. C. Snedaker and J. G. Snedaker), pp 91-113. UNESCO, 251 pp.

Golley, F., H. T. Odum, R. F. Wilson. 1962. The structure and metabolism of a Puerto Rican red mangrove forest in May. *Ecology*, **43**(1):9-19.

Ledgister, R., D. M. Linton, J. D. Woodley. 1995. *Data Collection and Management in CARICOMP, A Regional Programme of Long-Term Ecological Research*. Presented at the European Symposium of the International Society for Reef Studies (Newcastle UK, September 1995).

Ledgister, R., D. M. Linton, J. D. Woodley. 1997. Use of spreadsheet templates for general data entry and their integration into the database system. **In:** *Proceedings of the 8th International Coral Reef Symposium (Panama, June 1996)* (edited by H. A. Lessios and I. G. Macintyre), Vol. II, pp 1565-1568. Smithsonian Tropical Research Institute, Balboa, Republic of Panama.

CARICOMP Data Report 1992-1995

LIST OF TABLES

Table 1a. CARICOMP daily site measurements:
Monthly mean of daily maximum air temperatures (°C), 1992 -1995.

		BAHAMAS BFS		BARBADOS BRI		BELIZE CBC		BERMUDA BBS		BONAIRE BMP	
	Mo #	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1992											
Jan	1										
Feb	2										
Mar	3										
Apr	4										
May	5										
Jun	6										
Jul	7										
Aug	8										
Sep	9							29.9	1.0		
Oct	10							26.5	1.1		
Nov	11							24.3	1.4		
Dec	12			28.4*	1.3			21.9	1.7		
1993											
Jan	13			29.1	1.0	29.7	2.9	21.7	2.0		
Feb	14			29.5	0.9	29.1	2.5	20.1	2.4		
Mar	15			30.0	1.2	30.8	3.3	21.7	1.7		
Apr	16			31.0	0.9	32.6	1.5	22.8	1.3		
May	17			31.2	0.9	33.1	1.8	25.3	0.9		
Jun	18			31.2	1.0	32.4	1.7	26.6	1.5		
Jul	19			31.8	0.4	32.6	1.6	29.7	1.0		
Aug	20			31.7	0.7	32.6	1.7	30.5	1.4		
Sep	21			31.3*	1.7			30.3	0.8		
Oct	22			30.3*	1.0			28.0	1.3		
Nov	23			29.6	0.9	26.0*	1.9	25.6	1.5		
Dec	24			29.3*	0.2	27.4	1.9	23.4	1.5		
1994											
Jan	25			28.1	0.7	27.8	2.4				
Feb	26			28.2	0.9	30.2	1.7	21.1	2.3		
Mar	27			29.7	0.8	31.0	2.7	21.4	2.2		
Apr	28			30.7	0.8	32.9	1.8	24.0	1.8		
May	29			31.5	0.6	33.8	1.5	26.6	1.8		
Jun	30			30.9	0.8	33.0	1.9	29.0	1.8		
Jul	31			30.7	0.6	32.8	1.5	31.1	1.4		
Aug	32	34.4	1.3	31.2	0.6	33.6	1.7	31.2	1.5	31.7	0.9
Sep	33	34.5	0.6	30.5	0.9			30.4	1.8	32.1	0.5
Oct	34	32.7	2.1	30.5	1.1			25.3	2.5	31.9	0.8
Nov	35	31.6	2.5	30.1	0.7			23.8*	2.0	31.7*	0.6
Dec	36	29.0	1.2	29.1	0.9	28.0	2.2			31.1	0.6
1995											
Jan	37	28.7	1.3	29.0	0.9	28.5	1.9	21.6	3.0	30.8	0.5
Feb	38	28.7	1.9	29.5	0.8	28.8	2.5	20.9	2.5	30.6	0.4
Mar	39	30.0	1.2	30.1	0.8	31.4	2.1	20.1*	2.4	30.4	1.1
Apr	40	31.4	1.7	30.4	1.1	30.2	2.5			31.6	0.8
May	41	32.8	1.3	32.1	0.6	32.6	1.0	25.5	2.6	32.1	0.4
Jun	42	33.9	1.1	31.4	1.2	33.6	1.8	31.1	2.2	32.2	0.5
Jul	43	34.1	1.0	31.4	0.8	32.7	2.1	34.9	2.5	32.1	0.8
Aug	44	34.8	2.4	30.0	2.9	34.6	2.0	33.4	2.7	32.6	1.3
Sep	45	35.5	1.5	30.9	2.1	33.3	2.3	30.9	3.2	33.5	0.7
Oct	46	33.2	1.9	30.7	1.3	30.4	2.1	29.1	3.0	32.5	1.0
Nov	47	30.4	2.1	30.7	0.8	29.5	2.3	24.9	2.4	31.8	0.7
Dec	48	28.7	2.0	29.9	0.5	27.7	2.2	21.1	3.0	31.3	0.5

Mean = monthly mean of daily max temp. *Mean obtained from less than 20 days of data.

Table 1b. CARICOMP daily site measurements:
Monthly mean of daily maximum air temperatures (°C), 1992 -1995.

		CAYMAN P&CU		COLOMBIA INVEMAR		CUBA IOC		JAMAICA DBML		MEXICO PMOR	
	Mo #	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1992											
Jan	1	28.3									
Feb	2	28.9									
Mar	3	29.0									
Apr	4	29.8									
May	5	29.6									
Jun	6	31.6									
Jul	7	31.8									
Aug	8	31.9									
Sep	9	31.4								31.3*	0.9
Oct	10	31.1		29.8	1.0					30.1	1.0
Nov	11	27.9		30.2	1.2					29.3	1.9
Dec	12	27.8		30.3*	0.8					27.5	1.0
1993											
Jan	13	29.0		29.8	1.0			28.4	1.6	27.7	1.0
Feb	14	28.2		29.8	0.8			28.5*	0.9	27.5	1.7
Mar	15	28.7		30.2	0.6			28.8	1.0	27.0	1.6
Apr	16	30.4		30.5	0.7			30.0*	0.5	28.6	1.3
May	17	30.1		30.7	0.8			29.4	1.7	29.4	0.8
Jun	18	31.2		31.6	0.7			30.4*	0.6	30.1	0.7
Jul	19	32.1		31.5	0.6			30.6	0.7	31.0	0.5
Aug	20	32.3		30.9	1.0			31.1	0.6	31.3	0.4
Sep	21	31.6		29.9	1.3			31.1	0.7	31.0	0.9
Oct	22	31.1		30.3	1.1			31.1*	0.5	30.3	1.1
Nov	23	28.9		30.1	1.0			30.1	0.7	29.1	1.1
Dec	24	28.8		30.1	0.7			30.5	2.8	28.2	1.2
1994											
Jan	25	28.6	1.3	29.8	0.7			28.5	0.9	27.1	1.1
Feb	26	29.0	0.8	29.8	0.8			29.1	0.5	28.1	1.0
Mar	27	29.1	1.2	30.1	0.8	27.6	2.0	29.9	1.2	28.0	1.4
Apr	28	30.2	0.6	30.6	0.7	29.0	0.5	29.9	0.7	29.0	0.9
May	29	31.3	0.8	30.7	0.9	30.5	0.6	30.8	0.5	30.2	1.0
Jun	30	31.8	0.7	31.5	0.7	31.6	0.5	31.0	0.7	30.4	0.4
Jul	31	31.5	0.6	31.6	1.0	31.4	0.6	31.3	0.8	30.6	1.0
Aug	32	31.8	0.6	30.7	0.8	31.6	0.8	31.5	0.8	31.1	0.9
Sep	33	31.0	1.0	29.1	1.7	31.4	0.6	31.1	1.4	30.7	1.0
Oct	34	31.0	0.5	30.1	0.8	29.8	1.1	31.4	0.4	30.3	0.6
Nov	35	29.7	1.0	30.0	1.0	28.6	1.2	30.5	0.9	29.6*	0.9
Dec	36	28.9	1.3	30.1	1.2			29.5*	0.7	28.3*	1.3
1995											
Jan	37	27.9		30.7	0.7	26.2	2.2	29.0	1.0	27.2	3.0
Feb	38	27.9		29.9	0.7	26.2	2.6	29.0	1.2	26.7	1.7
Mar	39	28.8		30.1	1.0	27.4	1.4	29.2	0.5	27.6	1.1
Apr	40	30.4		31.0*	0.4	29.3	1.4	29.4	1.3	29.2	1.0
May	41	31.4		30.7	0.6	30.8	1.4	29.5	3.1	30.0	0.5
Jun	42	30.9		30.9	0.8	31.0	1.5	31.4	1.3	30.3	0.9
Jul	43	32.1		30.5	1.1	31.4	1.1	31.6	1.4	31.1	0.9
Aug	44	31.4		29.8	1.1	31.5	0.9	31.6	1.1	30.9	1.1
Sep	45	31.8		30.8	1.1	32.1	1.0	32.9	1.4	31.3	1.1
Oct	46	30.6		29.4	1.1	30.9	0.8	32.3	2.4	31.7*	1.0
Nov	47	29.7		30.4	1.0	27.9	1.8	32.5	3.3	29.8	1.5
Dec	48	28.7		29.9*	0.8	25.9	2.3	32.7	2.7	29.2	1.7

Mean = monthly mean of daily max temp. *Mean obtained from less than 20 days of data.

Table 1c. CARICOMP daily site measurements:
Monthly mean of daily maximum air temperatures (°C), 1992 -1995.

		PUERTO RICO UPR		SABA SMP		TRINIDAD IMA		VENEZUELA USB		VENEZUELA EDIMAR	
	Mo #	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1992											
Jan	1										
Feb	2										
Mar	3										
Apr	4										
May	5										
Jun	6										
Jul	7										
Aug	8										
Sep	9			31.6	1.3						
Oct	10			31.6	1.3						
Nov	11			28.4	1.8						
Dec	12			27.0	1.2						
1993											
Jan	13			26.2	0.9			29.9*	1.0	30.7	0.9
Feb	14			27.0	1.3			30.5	1.1	31.7	0.9
Mar	15			28.0	1.7	32.3	1.0	30.9	1.5	32.2	0.9
Apr	16			31.7	2.3	32.7	0.8	31.8	1.1	33.3	1.7
May	17			33.0	1.6	34.0	1.2	32.1	1.2	33.4	1.2
Jun	18			34.4	0.8	33.4	1.4	32.0	1.7	32.8	1.5
Jul	19			34.6	0.6	33.4	1.5	31.0	0.8	30.7	1.5
Aug	20			35.0	0.7	32.5	0.9	31.4	0.9	30.6	1.9
Sep	21			33.8	1.7	32.7	1.5	31.5	1.3	32.1	1.6
Oct	22					32.8	1.1	31.8	0.8	31.6	1.5
Nov	23					32.7*	0.5	31.2	1.0	31.1	0.8
Dec	24							30.7	1.1	29.4	0.6
1994											
Jan	25	31.5	0.9	26.9	1.5	30.4	0.7	29.6	1.1	29.2	0.7
Feb	26	31.6	0.7	26.1	1.2	30.5	0.4	28.5	1.0	30.0	0.8
Mar	27	30.8	1.2	28.1	1.6	31.1	0.6	29.7	0.7	30.4	0.5
Apr	28	31.2	1.0	30.3	1.9	31.2	0.7	29.7	1.0	32.5	0.6
May	29	32.6	0.8	33.8	2.6	31.7	0.6	31.2	1.0	32.5	0.9
Jun	30	33.3	0.3	34.1	1.9	30.6	1.0	29.9	0.9	31.4	0.8
Jul	31	32.6	1.2	33.5	2.6	30.7	0.7	29.7	0.8	31.4	0.8
Aug	32	33.1	0.6	33.5	1.8	30.7	1.1	30.7	0.9	32.1	1.3
Sep	33	32.7	1.6	31.7	1.8	30.5	1.4	31.1	1.0	32.2	0.9
Oct	34			30.5	2.0	31.1	1.1	31.7	1.2	32.6	0.7
Nov	35	31.8	1.3	29.6	1.4	30.7	1.3	32.3	1.4	31.6	1.3
Dec	36	31.2	1.4	27.5	1.1	29.9	0.7			30.5	0.7
1995											
Jan	37	30.8	1.1	27.4	1.3	30.1	1.0			31.0	0.6
Feb	38	31.3	0.8	28.9	1.9	30.7	0.4			31.6	1.0
Mar	39	30.2	1.5	28.0	2.0	30.8	0.8			32.0	1.5
Apr	40	31.4	1.0	31.5	2.4	31.0	0.8			32.5	1.2
May	41	32.5	1.4	32.4	2.9	32.0	0.6			33.3	1.1
Jun	42	33.3	0.9	33.8	2.0	31.6	0.8			32.4	0.9
Jul	43	33.2	1.4	33.1	2.9	31.2	0.8			32.1	1.0
Aug	44	33.3	1.2	32.5	2.3	31.3	1.0			31.9	1.2
Sep	45	32.5	2.0	31.9	2.1	31.7	1.0			33.0	1.0
Oct	46	32.7	0.9	29.8	2.1	31.1	1.4			32.0	1.0
Nov	47	31.5	2.4	28.7	1.7	31.1	0.8			31.6	0.7
Dec	48			27.9	1.8	30.9	0.6			31.2	0.7

Mean = monthly mean of daily max temp. *Mean obtained from less than 20 days of data.

Table 2a. CARICOMP daily site measurements:
Monthly mean of daily minimum air temperatures (°C), 1992 -1995.

		BAHAMAS BFS		BARBADOS BRI		BELIZE CBC		BERMUDA BBS		BONAIRE BMP	
	Mo #	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1992											
Jan	1										
Feb	2										
Mar	3										
Apr	4										
May	5										
Jun	6										
Jul	7										
Aug	8										
Sep	9							24.5	1.4		
Oct	10							21.9	1.4		
Nov	11							20.4	1.6		
Dec	12			23.0*	1.6			17.6	2.2		
1993											
Jan	13			23.1	1.1	24.5	1.8	17.8	2.3		
Feb	14			22.4	0.9	24.1	1.9	15.8	2.8		
Mar	15			22.9	1.4	24.5	2.3	17.3	2.0		
Apr	16			23.8	0.8	26.1	1.4	18.7	1.5		
May	17			24.0	0.8	25.3	1.7	20.4	1.0		
Jun	18			25.1	1.0	27.6	1.2	22.1	1.6		
Jul	19			24.6	1.9	27.4	0.8	25.4	1.3		
Aug	20			24.2	1.4	27.5	1.2	25.9	1.2		
Sep	21			23.7*	0.9			25.4	0.8		
Oct	22			24.1*	1.6			23.8	1.2		
Nov	23			23.7	1.1	23.0*	1.0	21.6	1.7		
Dec	24			23.4*	1.7	23.9	1.2	18.5	2.5		
1994											
Jan	25			22.4	1.1	24.1	2.2				
Feb	26			22.7	1.0	25.4	1.3	17.0	2.5		
Mar	27			22.5	1.6	25.3	2.2	16.0	2.5		
Apr	28			24.0	1.4	27.2	1.8	17.3	1.4		
May	29			25.2	1.2	27.1	1.2	20.3	1.8		
Jun	30			25.1	1.1	27.9	1.1	23.2	1.3		
Jul	31			25.1	0.9	27.4	0.8	24.5	1.2		
Aug	32	25.2	1.4	24.6	1.2	27.5	1.0	24.8	1.5	26.9	0.7
Sep	33	25.2	1.2	23.6	1.2			23.2	1.1	27.2	0.6
Oct	34	24.5	1.0	23.6	1.0			20.4	1.5	26.7	1.0
Nov	35	23.6	1.9	23.6	1.0			19.1*	2.3	26.6*	1.3
Dec	36	22.1	1.9	22.7	1.6	24.4	1.4			25.5	1.4
1995											
Jan	37	20.7	2.0	22.2	1.3	24.3	1.2	16.1	2.4	25.4	1.3
Feb	38	19.8	2.9	22.3	1.2	24.1	1.9	15.1	2.9	25.1	0.6
Mar	39	19.6	2.0	22.7	1.0	25.3	1.9	15.9*	2.3	25.4	0.8
Apr	40	21.7	1.3	23.2	1.2	27.3	0.8			26.4	0.8
May	41	22.5	1.0	23.8	1.8	30.7	1.3	17.9	2.7	27.1	0.5
Jun	42	24.5	1.0	25.1	1.2	28.5	1.8	22.3	0.9	27.3	0.6
Jul	43	25.5	1.4	24.7	1.2	27.8	1.0	24.3	1.2	26.8	1.1
Aug	44	24.7	1.1	25.9	2.7	28.3	1.8	24.2	1.7	27.1	1.3
Sep	45	24.9	1.3	25.8	2.8	27.2	1.0	23.5	1.3	27.5	1.4
Oct	46	23.8	1.1	24.1	1.1	26.1	1.1	22.1	1.0	26.6	1.6
Nov	47	22.4	1.5	23.7	1.1	25.5	1.6	18.0	2.2	25.9	1.1
Dec	48	20.4	2.1	22.9	1.1	24.5	1.4	14.5	2.6	25.3	1.2

Mean = monthly mean of daily min temp. *Mean obtained from less than 20 days of data.

Table 2b. CARICOMP daily site measurements:
Monthly mean of daily minimum air temperatures (°C), 1992 -1995.

		CAYMAN P&CU		COLOMBIA INVEMAR		CUBA IOC		JAMAICA DBML		MEXICO PMOR	
	Mo #	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1992											
Jan	1	21.8									
Feb	2	22.6									
Mar	3	22.7									
Apr	4	24.1									
May	5	23.3									
Jun	6	24.6									
Jul	7	25.2									
Aug	8	25.3									
Sep	9	24.8								24.2*	1.8
Oct	10	24.8		27.2	1.0					24.2	2.2
Nov	11	23.7		27.5	1.0					24.9	2.7
Dec	12	22.5		27.0*	0.4					23.4	2.8
1993											
Jan	13	22.7		26.5	0.7			21.9	1.8	22.6	3.5
Feb	14	21.2		26.8	0.4			21.3*	1.1	21.5	3.2
Mar	15	22.4		27.3	0.5			20.9	0.6	22.4	4.3
Apr	16	23.2		27.7	0.4			21.8*	0.8	23.9	3.3
May	17	24.6		27.3	1.4			23.7	1.6	25.0	2.0
Jun	18	25.6		27.9	0.9			24.9*	1.1	26.2	1.9
Jul	19	26.0		28.0	0.8			24.6	0.7	27.3	1.5
Aug	20	25.8		28.0	0.9			25.2	1.2	26.6	2.4
Sep	21	25.2		27.2	1.4			24.8	1.0	25.8	1.9
Oct	22	24.6		27.8	0.9			24.5*	0.9	25.6	2.3
Nov	23	24.6		26.9	1.1			23.3	1.1	22.6	3.4
Dec	24	22.6		27.5	0.7			22.3	2.0	21.1	3.3
1994											
Jan	25	23.1	1.1	26.8	0.5			21.7	1.2	21.8	3.6
Feb	26	22.8	1.4	26.5	0.3			21.3	0.8	23.8	2.4
Mar	27	22.7	1.7	27.3	0.7	21.2	3.1	21.2	0.9	23.0	4.1
Apr	28	23.5	1.0	27.8	0.6	23.5	1.3	22.3	0.7	25.7	1.8
May	29	24.4	1.3	27.6	0.8	23.4	1.5	22.9	1.0	25.5	3.3
Jun	30	26.2	0.9	28.4	0.4	25.2	1.8	23.8	1.0	27.3	1.6
Jul	31	25.4	1.5	28.2	0.8	26.0	1.4	23.9	0.8	25.9	2.1
Aug	32	25.2	1.2	27.5	0.9	25.9	1.6	24.4	2.0	26.5	1.7
Sep	33	25.1	1.1	28.5	1.4	24.8	1.9	24.3	0.6	24.7	2.1
Oct	34	24.7	1.3	26.5	0.9	24.1	1.4	23.7	0.7	25.9	2.4
Nov	35	24.4	1.2	26.6	1.1	23.8	1.8	23.0	0.8	22.3*	2.9
Dec	36	23.1	2.5	26.9	0.9			22.3*	1.1	22.4*	5.0
1995											
Jan	37	22.2		27.3	0.6	20.4	2.3	21.5	0.9	21.5	3.7
Feb	38	22.0		26.9	0.5	20.5	2.8	21.4	0.9	20.8	4.4
Mar	39	22.3		27.4	0.8	20.9	1.9	21.1	1.2	23.3	3.9
Apr	40	24.2		28.0*	0.6	22.9	1.6	23.9	2.3	24.9	2.5
May	41	25.8		27.6	1.0	23.6	1.2	25.9	2.9	27.4	1.5
Jun	42	25.6		27.6	0.7	24.7	1.6	24.2	1.5	26.4	1.8
Jul	43	26.0		27.0	1.3	24.9	1.6	23.8	1.8	26.1	1.7
Aug	44	25.4		26.7	1.2	24.9	1.6	24.4	1.3	25.2	1.8
Sep	45	25.6		27.2	0.9	24.9	1.2	24.5	1.8	23.7	2.1
Oct	46	25.2		26.4	0.9	25.0	1.2	24.4	0.8	26.6*	1.5
Nov	47	25.0		27.3	0.8	23.7	1.8	24.4	0.8	23.5	3.4
Dec	48	24.0		27.2*	0.3	21.9	2.1	23.5	1.2	22.3	2.9

Mean = monthly mean of daily min temp. (°C) *Mean obtained from less than 20 days of data.

Table 2c. CARICOMP daily site measurements:
Monthly mean of daily minimum air temperatures (°C), 1992 -1995.

	Mo #	PUERTO RICO UPR Mean	PUERTO RICO UPR SD	SABA SMP Mean	SABA SMP SD	TRINIDAD IMA Mean	TRINIDAD IMA SD	VENEZUELA USB Mean	VENEZUELA USB SD	VENEZUELA EDIMAR Mean	VENEZUELA EDIMAR SD
1992											
Jan	1										
Feb	2										
Mar	3										
Apr	4										
May	5										
Jun	6										
Jul	7										
Aug	8										
Sep	9			25.9	0.9						
Oct	10			26.0	1.2						
Nov	11			25.1	1.2						
Dec	12			25.0	0.8						
1993											
Jan	13			24.1	1.3			22.2*	1.2	24.3	0.8
Feb	14			24.1	1.3			22.5	1.4	24.0	0.6
Mar	15			24.1	1.1	22.1	1.3	23.2	1.7	24.5	0.9
Apr	16			24.8	1.5	24.1	1.1	25.0	0.9	25.6	0.7
May	17			24.9	1.1	24.4	1.1	25.1	0.7	26.0	1.2
Jun	18			26.3	1.1	24.3	1.2	24.4	0.8	25.4	1.4
Jul	19			26.3	1.0	22.8	1.0	23.7	0.7	25.7	0.5
Aug	20			27.1	1.1	22.5	1.2	23.6	0.9	26.0	0.7
Sep	21			26.1	1.1	22.8	1.2	23.9	0.5	26.3	0.8
Oct	22					22.5	0.7	24.1	1.0	25.9	0.9
Nov	23					22.5*	0.5	23.3	0.9	26.3	0.5
Dec	24							22.6	1.0	25.0	0.7
1994											
Jan	25	20.3	0.9	23.5	1.2	23.2	0.9	21.5	0.9	24.7	0.6
Feb	26	20.4	1.0	23.3	1.1	23.5	1.1	22.6	1.4	24.0	0.5
Mar	27	21.4	0.8	24.2	1.2	23.9	1.0	23.1	1.5	25.5	0.6
Apr	28	21.6	1.3	25.1	2.3	24.1	1.3	24.0	1.1	25.7	0.4
May	29	24.2	2.0	27.1	3.3	25.5	0.7	25.1	0.7	25.6	0.4
Jun	30	24.3	0.9	26.8	2.5	24.7	0.8	24.3	0.7	25.2	0.6
Jul	31	22.7	1.4	27.4	3.2	24.8	0.6	23.3	0.6	25.3	0.5
Aug	32	22.5	3.0	28.1	2.6	25.0	0.6	23.6	0.6	25.9	0.7
Sep	33	22.6	3.4	27.3	2.6	24.3	1.2	23.8	1.0	26.4	0.4
Oct	34			26.9	2.0	24.2	0.6	23.9	0.8	26.7	0.6
Nov	35	23.2	2.4	26.3	1.0	24.4	0.9	23.6	1.0	25.9	1.1
Dec	36	21.1	1.0	24.6	1.0	23.8	1.0	22.8	0.9	25.4	0.7
1995											
Jan	37	20.5	1.0	23.7	1.2	23.4	1.0	22.2	1.2	25.2	0.3
Feb	38	21.4	1.5	24.1	1.3	23.4	0.9	22.0	1.1	24.6	0.6
Mar	39	20.1	1.1	23.8	1.2	24.3	0.9	23.1	1.1	25.3	0.8
Apr	40	21.8	1.5	24.8	3.4	25.0	0.8	24.0	2.2	25.9	0.7
May	41	23.8	1.0	27.8	2.8	25.6	1.1	24.8	0.9	26.1	0.4
Jun	42	25.1	1.4	29.5	2.2	25.4	0.8	24.1	0.8	26.2	0.6
Jul	43	24.8	0.8	29.1	2.0	25.3	0.8	23.4	0.7	26.5	0.4
Aug	44	24.5	1.2	27.3	1.9	25.6	1.2	24.0	0.9	26.3	0.8
Sep	45	24.5	1.7	27.7	2.1	25.8	0.9	24.2	0.7	27.2	0.8
Oct	46	22.9	2.6	25.9	1.6	25.3	1.0			26.7	0.9
Nov	47	22.9	2.0	25.2	1.5	24.5	0.6			26.2	0.6
Dec	48			24.3	1.4	23.9	0.7			25.6	0.8

Mean = monthly mean of daily min temp. (°C) *Mean obtained from less than 20 days of data.

Table 3a. CARICOMP daily site measurements:
Cumulative monthly rainfall (mm) 1992 -1995.

	Mo #	BAH: BFS	BAR: BRI	BEL: CBC	BER: BBSR	BON: BMP	CAY: P&CU	COL: INV	CUB: IOC
1992									
Jan	1				136.5		18.9		
Feb	2				153.0		128.8		
Mar	3				66.3		86.1		
Apr	4				79.5*		19.8		
May	5				99.1		78.9		
Jun	6				235.8		195.0		
Jul	7				26.1		107.5		
Aug	8				75.9		238.8		
Sep	9				122.1		295.0		
Oct	10				58.1		155.2	7.5	
Nov	11				71.9		39.9	33.6	
Dec	12		11.5*		170.6		9.5	3.4	
12 Months					1294.9		1373.4		
1993									
Jan	13		95.0	37.6	105.7		67.0	2.2	
Feb	14		94.0	19.2	223.3		11.5	0.0	
Mar	15		38.7	110.4	96.2		33.6	0.0	
Apr	16		17.2	18.1	136.0		8.7	1.8	
May	17		75.9	71.1	18.8		197.6	163.0	
Jun	18		66.5	55.7	80.0		178.9	3.7	
Jul	19		96.4	134.8	58.7		88.5	3.3	
Aug	20		120.1	22.7	131.9		63.1	19.3	
Sep	21		18.9*		78.5		166.8	45.5	
Oct	22		10.9*		167.3		159.3	32.0	
Nov	23		9.8	18.4*	171.6		293.1	47.0	
Dec	24		0.4*	393.2	101.5		35.9	0.0	
12 Months			643.8		1369.5		1304.0	317.8	
1994									
Jan	25		120.0	204.8	126.2		59.7	0.0	
Feb	26		50.6	45.5	116.6		68.0	0.0	
Mar	27		18.7	34.1	88.4		14.5	0.0	4.1
Apr	28		5.9	25.8	80.0		70.4	0.0	48.6
May	29		21.9	29.4	85.1		109.3	60.0	83.6
Jun	30		37.7	72.1	79.0		37.0	0.0	116.2
Jul	31		74.2	68.2	197.1		155.3	5.9	21.8
Aug	32	65.4	126.5	196.9	190.2	18.0*	183.9	50.1	13.7
Sep	33	63.6	260.0		169.4	44.2	193.1	8.5	234.0
Oct	34	106.0	81.6		197.6	143.2	6.5	52.4	124.9
Nov	35	419.6	69.0		32.3*	21.6*	110.7	55.0	60.7
Dec	36	164.4	96.4	161.6		9.4	33.0	0.0	
12 Months			962.5		1361.9		1041.4	231.9	
1995									
Jan	37	93.4	30.5	123.9	109.2	26.8	67.3	0.0	23.2
Feb	38	27.8	18.3	70.3	98.5	14.8	19.2	0.0	16.6
Mar	39	61.9	169.7	28.2	95.2	52.0	30.2	0.0	51.7
Apr	40	132.8	57.9	102.0	77.0	17.6	9.8	2.2	31.1
May	41	98.0	2.3	0.0	69.6	0.0	69.9	23.7	108.4
Jun	42	71.6	123.1	147.8	104.1	10.4	444.7	6.8	267.4
Jul	43	130.8	117.8	163.6	72.0	75.1	200.4	85.5	139.4
Aug	44	314.2	358.3	180.4	150.0	108.2	182.9	64.8	128.4
Sep	45	113.6	171.0	222.8	70.1	30.2	206.7	132.0	131.9
Oct	46	79.5	172.3	208.6	188.2	76.1	348.8	113.3	95.8
Nov	47	133.0	56.0	240.4	203.2	56.6	44.0	0.0	92.0
Dec	48	84.1	47.6	203.3	153.9	32.8	117.9	4.8*	61.8
12 Months		1340.7	1324.8	1691.3	1391.0	500.6	1741.8	433.1	1147.7

*Cumulative monthly rainfall obtained from less than 20 days of data.

Table 3b. CARICOMP daily site measurements: Cumulative monthly rainfall (mm) 1992 -1995.

	Mo #	JAM	MEX	PUE	SAB	TRI	VEN	VEN
1992								
Jan	1				71.4			
Feb	2				19.6			
Mar	3				93.0			
Apr	4				117.7			
May	5				140.9			
Jun	6				28.4			
Jul	7				48.5			
Aug	8				54.5			
Sep	9		62.4*		30.2			
Oct	10		227.9		30.2			
Nov	11		143.7		191.3			
Dec	12		123.5		53.0			
12 Months					878.7			
1993								
Jan	13	57.0	123.5		66.6		1.0*	6.6
Feb	14	55.3*	31.9		30.8		22.4	0.0
Mar	15	115.8	144.0		46.4		2.3	0.0
Apr	16	240.0*	13.8		78.3	7.4	32.7	1.4
May	17	250.0	291.8		213.3	8.4	108.4	86.7
Jun	18	33.0*	221.1		38.8	13.4	29.1	17.6
Jul	19	44.0	20.9		72.8	161.2	30.9	5.2
Aug	20	38.0	58.2		49.1	119.0	119.1	58.4
Sep	21	68.0	100.7		68.5	188.0	21.3	54.8
Oct	22	61.0*	126.4		63.2	175.0	18.0	8.6
Nov	23	161.0	117.4		68.3	130.0	39.4	9.4
Dec	24	47.8	109.2		62.6	63.0*	0.3	19.5
12 Months		1170.9	1358.9		858.7		424.9	268.2
1994								
Jan	25	126.7	77.0	21.6	22.8	26.3	0.2	9.8
Feb	26	36.2	51.7	2.3	44.8	9.1	0.5	10.1
Mar	27	40.2	124.9	94.7	6.0	17.0	0.0	0.0
Apr	28	32.9	6.2	26.2	16.0	37.8	16.1	0.0
May	29	163.4	54.9	1.8	12.3	23.5	1.3	8.2
Jun	30	27.8	44.8	23.1	70.2	145.4	14.3	18.4
Jul	31	29.6	46.3	58.9	15.0	114.2	46.8	26.4
Aug	32	47.2	90.6	14.2	60.8	151.5	86.5	48.5
Sep	33	34.6	190.1	157.0	57.3	220	26.2	84.4
Oct	34	74.6	22.1		58.2	123.1	60.3	27.5
Nov	35	144.4	112.9*	58.7	56.2	259.4	48.0	67.4
Dec	36	61.4*	24.3*	83.5	32.3	92.6	11.2	9.2
12 Months		819.0	845.8		451.9	1219.9	311.4	309.9
1995								
Jan	37	87.5	59.4	21.1	22.7	26.2	7.5	0.5
Feb	38	172.4	5.4	62.4	30.6	18.9	0.0	0.0
Mar	39	34.2	64.1	6.1	30.7	39.3	79.8	0.0
Apr	40	31.6	31.1	16.0	64.1	108.1	38.3	0.0
May	41	19.8	0.7	29.5	71.3	22.0	22.9	0.0
Jun	42	7.8	158.0	18.3	39.6	146.1	55.4	11.2
Jul	43	47.5	60.7	39.4	35.8	131.5	331.6	10.2
Aug	44	118.6	44.3	143.5	79.1	222.9	85.7	93.4
Sep	45	13.2	200.6	96.5	300.5	65.9	15.6	15.8
Oct	46	74.7	260.2	34.5	34.4	229.2		120.8
Nov	47	253.7	53.0	100.6	127.3	86.5		20.5
Dec	48	137.6	202.9		73.7	121.8		18.7
12 Months		998.6	1140.4		909.8	1218.4		291.1

*Cumulative monthly rainfall obtained from less than 20 days of data.

Table 4a. CARICOMP weekly site measurements:
Monthly mean of weekly water temperatures (°C at 0.5 m depth), 1992 -1995.

		BAHAMAS: BFS						BARBADOS: BRI					
		Coral Reef		Seagrass		Mangrove		Coral Reef		Seagrass		Mangrove	
	Mo #	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1992													
Jan	1												
Feb	2												
Mar	3												
Apr	4												
May	5												
Jun	6												
Jul	7												
Aug	8												
Sep	9												
Oct	10												
Nov	11							28.9*		28.7*		29.8*	
Dec	12							28.3	0.5	28.2	0.4	28.6	0.5
1993													
Jan	13							27.1	0.3	27.3	0.4	27.2	0.3
Feb	14							27.0	0.1	27.0	0.3	28.1	0.2
Mar	15							27.3	0.2	27.6	0.5	28.4	0.5
Apr	16							29.0	0.0	29.1	0.1	28.9	0.1
May	17							29.1	0.3	29.1	0.3	29.1	0.1
Jun	18												
Jul	19							28.8	0.7	29.5	0.5	30.1	0.2
Aug	20							28.9	0.4	29.5	0.7	30.0	0.4
Sep	21							28.9	0.2	29.8	0.8	30.6	0.7
Oct	22							28.7	0.3	29.1	0.9	29.9	1.1
Nov	23							28.3	0.3	28.8	0.5	29.1	1.0
Dec	24									28.2*	0.4	28.3*	0.0
1994													
Jan	25							26.6	0.4	27.3	0.1	27.4*	0.1
Feb	26							26.8	0.3	26.8	0.1		
Mar	27							26.8	0.3	27.0	0.5		
Apr	28							27.0*	0.0	27.5*	0.7		
May	29							27.6	0.0	27.8	0.7		
Jun	30							28.2	0.2	28.5	0.5		
Jul	31							28.1	0.3	28.7	0.5		
Aug	32							28.9	0.8	29.1	0.7		
Sep	33							28.9	0.1	29.5	0.7		
Oct	34							28.7	0.2	28.8	0.6		
Nov	35							28.7	0.1	29.0	0.5		
Dec	36							26.9	0.5	27.1*	1.3		
1995													
Jan	37	25.7	0.4					26.6	0.4	27.1	0.9		
Feb	38	25.5	0.2					26.7	0.1	26.7	0.2		
Mar	39	25.8	0.4					26.9	0.1	27.5	0.9		
Apr	40	25.9	0.5					28.5	0.5	28.8	0.6		
May	41	27.5	0.7					28.9*	0.0	29.0*	0.1		
Jun	42	28.3*	0.1					29.0*	0.1	29.2*	0.2		
Jul	43	29.0*											
Aug	44	30.0*						29.4	0.1	30.8	0.2		
Sep	45	29.0*								28.9*	1.3		
Oct	46	28.5*	0.7	28.0*				29.3	0.1	30.0	0.1		
Nov	47	26.6	0.3	26.3	0.9			29.3	0.2	30.1	0.5		
Dec	48							28.0*	1.5	28.9*	0.5		

*Monthly mean values calculated from less than 3 weeks data; values without SD indicate only 1 week's measurement, values with SD indicate 2 weeks' measurements.

Table 4b. CARICOMP weekly site measurements:
Monthly mean of weekly water temperatures (°C at 0.5 m depth), 1992 -1995.

		BELIZE: CARRIE BOW CAY						BERMUDA: BIOL STATION					
		Coral Reef		Seagrass		Mangrove		Coral Reef		Seagrass		Mangrove	
	Mo #	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1992													
Jan	1												
Feb	2												
Mar	3												
Apr	4												
May	5												
Jun	6												
Jul	7												
Aug	8												
Sep	9							27.1	0.5	27.3	0.4		
Oct	10							24.3*	0.8	23.7	0.8	24.4	0.6
Nov	11							22.6	0.7	22.0	0.7	22.4	0.8
Dec	12							20.6*	0.1	19.7*	0.1	20.5*	
1993													
Jan	13	27.6	0.5	26.9	2.1	26.5*	2.2	20.7	0.7	19.5	0.8	19.8	1.9
Feb	14	26.9	0.6	27.0	1.3	28.0	1.3	19.8*	0.1	18.8	0.4	19.4	1.9
Mar	15	27.8	1.6	27.4	0.9	28.2	1.7	19.6	0.4	19.0	1.0		
Apr	16	27.9	0.6	28.5	0.6	29.4	0.6			20.2*			
May	17	28.7	0.6	29.2	1.3	30.2	1.0	22.3*	0.4	22.5	0.6	23.0*	0.7
Jun	18	29.3	0.4	30.0	1.2	30.7	1.3	23.9	0.6	24.9	0.8	25.3	1.3
Jul	19	29.0	0.6	29.9	0.3	30.5	0.3	26.4	0.7	26.9	0.5	26.8*	0.8
Aug	20	29.2	0.2	29.7	0.1	30.3	0.6	27.8	1.0	27.9	0.9	27.2	0.5
Sep	21							27.3	0.2	27.7	0.6	27.8	0.5
Oct	22											25.2*	
Nov	23							23.2*		23.2*		24.0*	
Dec	24	26.8*		27.2*		27.5*		22.4*		21.3*	0.7		
1994													
Jan	25	27.5	0.0	27.5	0.0	28.3	0.3	20.0*	0.2	19.5*	0.1		
Feb	26	27.3	0.3	27.5	0.8	27.8	0.9	20.2*		19.3*	1.0	19.7*	
Mar	27	28.0	0.6	28.6	1.0	28.2	1.0	20.0*		18.9*	0.4	19.0*	
Apr	28	29.4	0.8	29.6	1.3	29.8	0.7	20.4*	0.7	20.4*	0.8		
May	29	28.6*	0.3	29.4*	0.2	28.9*	0.1	22.9	0.1	23.2	0.3		
Jun	30	28.8	0.3	29.0	0.9	30.2	2.3	26.3*	1.8	26.6*	1.7	19.0*	
Jul	31	28.7	0.1	29.1	0.3	29.8	0.7	29.2*	0.5	29.1	0.3	28.0*	
Aug	32	29.0*	0.1	29.6*	0.6	29.9*	0.2	28.9	0.6	29.2	0.5	28.0*	
Sep	33							27.6*	0.7	27.5	0.7		
Oct	34							24.7*	1.4	23.9	1.2		
Nov	35									21.4*			
Dec	36	27.9*	0.1	27.2*	1.8								
1995													
Jan	37	27.5	0.1	26.7	0.3			20.4*		18.5*			
Feb	38	26.9*	0.1	26.3	0.9			18.7*		18.5*			
Mar	39	27.4	0.7	27.7	0.3			18.8	0.6	18.6	0.7		
Apr	40	28.2	0.2	28.7	0.6			18.9*		20.0*	1.1		
May	41	29.6	0.3	29.9	0.7			21.4*		21.9*			
Jun	42	30.1	0.3	30.9	0.8			25.3*	0.1	26.2*	0.0		
Jul	43	29.3	0.2	29.6	0.6			27.6	1.0	27.9*	0.1		
Aug	44	30.0	0.7	30.5	0.9					26.8*	0.0		
Sep	45	30.2	0.6	30.4	1.2			26.8*	0.4	27.2*	0.4		
Oct	46	27.8	1.7	27.9	1.3			26.5*		27.0*	0.3		
Nov	47	29.0	0.7	28.9	1.2			23.2*	1.5	22.7*	1.8		
Dec	48	28.2	0.4	27.1*	1.4			21.1*		21.3*			

*Monthly mean values calculated from less than 3 weeks data; values without SD indicate only 1 week's measurement, values with SD indicate 2 weeks' measurements.

Table 4c. CARICOMP weekly site measurements:
Monthly mean of weekly water temperatures (°C at 0.5 m depth), 1992 -1995.

		BONAIRE: BONAIRE MARINE PARK						COLOMBIA: INVEMAR					
		Coral Reef		Seagrass		Mangrove		Coral Reef		Seagrass		Mangrove	
	Mo #	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1992													
Jan	1												
Feb	2												
Mar	3												
Apr	4												
May	5												
Jun	6												
Jul	7												
Aug	8												
Sep	9							29.1*		29.5*		30.0*	
Oct	10							28.3	0.4	28.3	0.5	28.6	0.7
Nov	11							27.9	0.5	28.1	0.3	28.2	0.2
Dec	12							27.6*	0.6	27.6*	0.6	27.4*	0.2
1993													
Jan	13							25.5*	0.7	26.1*	0.1	26.1*	0.1
Feb	14							26.1	0.4	26.6	0.2	27.1	1.2
Mar	15							26.0	0.6	27.0	0.6	27.6	0.9
Apr	16							27.0	1.5	28.5	1.5	30.0	1.2
May	17							28.8	1.4	29.1	1.3	30.3	1.6
Jun	18							28.0	1.4	29.0	0.7	30.7	0.8
Jul	19							26.4	0.8	27.7	0.9	28.2	0.9
Aug	20							27.3	1.1	28.8	0.7	31.3	2.4
Sep	21							28.1	0.6	28.6	0.6	29.4	0.9
Oct	22							28.4	0.5	29.1	0.3	31.0	1.5
Nov	23							27.2	1.5	27.7	1.3	28.3	1.6
Dec	24							27.1	0.6	27.2	0.5	27.0	0.6
1994													
Jan	25							25.0	0.5	25.3	0.6	25.9	1.3
Feb	26							24.0	1.2	24.7	0.7	25.2	1.0
Mar	27							25.8	0.1	26.5	0.2	26.9	0.8
Apr	28							25.6	0.9	26.7	0.7	27.9	1.1
May	29							26.8	0.4	27.5	0.2	29.6	0.8
Jun	30							26.4	0.7	27.7	0.8	28.9	0.6
Jul	31							25.5	0.5	26.8	0.2	28.0	0.5
Aug	32	28.1	0.3					27.2	0.4	27.8	0.4	29.0	0.5
Sep	33	27.6	0.5					28.4	0.6	29.2	0.3	30.2	0.5
Oct	34	28.5	0.2					28.9	0.1	29.2	0.0	29.9	0.4
Nov	35							27.6	0.9	28.1	1.0	28.3	1.3
Dec	36							25.1	0.6	26.0	0.6	26.8	0.2
1995													
Jan	37	27.3	0.2					25.3	0.5	25.6	0.8	25.0	1.4
Feb	38	26.7	0.1					25.5	0.6	25.9	0.2	26.4	0.9
Mar	39	26.9	0.6					25.8	0.8	26.7	0.8	27.5	1.2
Apr	40	27.6	1.0					26.4	0.6	27.7	0.8	28.9	1.4
May	41	28.3	1.0					27.8	0.3	28.8	0.5	29.8	1.4
Jun	42	28.2	0.1					28.6	1.3	29.3	1.0	30.3	1.2
Jul	43	28.0	0.2					27.1	0.5	27.4	0.5	28.7	1.2
Aug	44	28.9	0.5					29.6	0.9	29.8	0.9	31.1	1.2
Sep	45	29.4	0.1					29.6	0.4	30.0	1.0	31.1	0.6
Oct	46	28.7	0.4					30.0	0.7	30.4	1.0	30.5	1.1
Nov	47	28.4	0.2					28.1	0.6	28.5	0.4	29.0	0.6
Dec	48	27.6	0.2					26.6	0.6	27.2	0.4	27.8	0.8

*Monthly mean values calculated from less than 3 weeks data; values without SD indicate only 1 week's measurement, values with SD indicate 2 weeks' measurements.

Table 4d. CARICOMP weekly site measurements:
Monthly mean of weekly water temperatures (°C at 0.5 m depth), 1992 -1995.

		JAMAICA: DBML, UWI						MEXICO: PUERTO MORELOS					
		Coral Reef		Seagrass		Mangrove		Coral Reef		Seagrass		Mangrove	
	Mo #	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1992													
Jan	1												
Feb	2												
Mar	3												
Apr	4												
May	5												
Jun	6												
Jul	7												
Aug	8												
Sep	9									29.8	0.9		
Oct	10							28.9*	0.6	28.4	0.8		
Nov	11							28.3	0.4	28.3	0.3		
Dec	12							27.3*	0.2	26.5	0.5		
1993													
Jan	13	27.5	0.2	27.6	0.1	26.3	0.7	26.7	0.4	26.3	1.0		
Feb	14	27.1	0.4	27.4	0.3	26.7	0.3	26.5	0.4	26.0	0.5		
Mar	15	27.1	0.2	27.5	0.6	26.7	0.6	25.9*	0.2	26.1	0.6		
Apr	16	27.3	0.3	27.6	0.6	26.5	0.6	27.3	0.3	27.5	0.3		
May	17	27.5*	0.7	27.8	0.8	25.9	0.2	27.9	0.5	28.2	0.5		
Jun	18	28.2	0.6	29.3	0.7	26.4	0.2	29.0	0.6	29.2	0.6		
Jul	19	28.5	0.4	28.9	0.3	26.8	0.3	29.2	0.5	29.7	0.3		
Aug	20	28.2	0.6	28.9	0.1	26.4	0.2	29.2	0.1	30.2	0.5		
Sep	21	28.9	0.8	29.3	0.5	26.6	0.1	29.2	0.4	30.2	1.0		
Oct	22	29.2	0.3	29.2	0.1	27.3	0.2	28.7	0.2	28.9	0.5		
Nov	23							28.2	0.4	27.9	1.0		
Dec	24							27.0	0.2	26.3	0.4		
1994													
Jan	25	28.1	0.8	28.4	1.4	26.7	0.9	26.4*	0.0	25.4	0.7		
Feb	26	28.3	0.2	27.7	0.3	27.1	0.4	26.7*	0.1	26.8	0.2		
Mar	27	27.2*		27.2*		26.2*		26.8	0.3	26.5	0.6		
Apr	28	28.6*		27.8*		25.5*		28.2*	0.0	28.0	0.8		
May	29	28.6	0.6	28.8	0.6	26.7	0.2	28.4	0.3	29.0	0.7		
Jun	30	28.6	0.2	29.0	0.3	26.6	0.3	29.2*	0.3	29.4	0.9		
Jul	31	28.5	0.2	29.0	0.2	26.6	0.1	29.3	0.1	29.5	0.3		
Aug	32	28.8	0.3	29.4	0.5	26.8	0.6	29.3	0.5	29.9	1.1		
Sep	33	29.2*		29.5*		27.0*		29.4*	0.1	30.7*	0.4		
Oct	34	29.1	0.1	29.3	0.4	26.1	0.1	29.0	0.2	29.3	0.4		
Nov	35	29.2*		29.4*		26.8*		28.0*		26.3*			
Dec	36							27.9*		27.9*	0.1		
1995													
Jan	37			28.4*		26.4*		26.7*	0.8	26.1	0.7		
Feb	38	27.4*	0.2	27.8*	0.6	26.3*	0.0	26.2*		25.8*	1.4		
Mar	39	27.1*	0.0	27.5*	0.4	26.6*	0.1	26.6	0.5	26.5	0.2		
Apr	40	27.5	0.4	28.2	0.3	26.4	0.1			28.0*	0.0		
May	41	28.2	0.6	28.4	0.3	26.5	0.1	29.1	0.4	29.6	0.5		
Jun	42	29.0	0.1	29.5	0.4	26.7	0.3	29.1*	0.1	29.7	0.5		
Jul	43	28.9	0.5	29.4	1.1	26.8	0.8	29.2*	0.0	29.1*	0.1		
Aug	44	29.8	0.7	30.8	1.8	27.3	0.3	30.0	0.0	31.0	0.5		
Sep	45	30.9	1.4	30.8	0.8	27.2	0.4	30.1	0.3	30.0	0.9		
Oct	46	29.7*	0.1	29.9*	0.1	27.3*	0.6			28.6*			
Nov	47	29.2	0.5	29.1	0.9	27.0	0.6	28.9	0.3	28.4	0.9		
Dec	48	28.4	0.5	28.6	0.5	26.4	0.2	27.5	0.3	26.0	0.7		

*Monthly mean values calculated from less than 3 weeks data; values without SD indicate only 1 week's measurement, values with SD indicate 2 weeks' measurements.

Table 4e. CARICOMP weekly site measurements:
Monthly mean of weekly water temperatures (°C at 0.5 m depth), 1992 -1995.

		PUERTO RICO: University of PR						SABA, NA: Saba Marine Park					
		Coral Reef		Seagrass		Mangrove		Coral Reef		Seagrass		Mangrove	
	Mo #	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1992													
Jan	1												
Feb	2												
Mar	3												
Apr	4												
May	5												
Jun	6												
Jul	7												
Aug	8												
Sep	9												
Oct	10												
Nov	11												
Dec	12												
1993													
Jan	13	26.0*	0.0										
Feb	14	27.2*											
Mar	15	27.7	1.1										
Apr	16	28.0*	1.4					27.0	0.0	27.0	0.0		
May	17	28.5*	0.7					27.8	1.0	27.8	1.0		
Jun	18	29.4*	0.6					28.8	0.3	28.8	0.3		
Jul	19	29.3*	0.4					28.6	0.1	28.5	0.1		
Aug	20	29.0*	0.0					28.8	0.1	28.8	0.1		
Sep	21	29.2*	0.5					29.0	0.2	29.0	0.2		
Oct	22	29.0*	0.0					28.8*		28.8*			
Nov	23	28.9*	0.1										
Dec	24	28.0*											
1994													
Jan	25												
Feb	26												
Mar	27							26.5*		26.6*	0.1		
Apr	28							26.7	0.2	27.0	0.4		
May	29							27.1	0.1	26.9	0.3		
Jun	30							27.8	0.5	27.8	0.5		
Jul	31							27.8	0.3	27.8	0.3		
Aug	32							28.3	0.3	28.4	0.3		
Sep	33			29.1	0.1			28.6	0.2	28.6	0.1		
Oct	34			29.6	0.3			28.9	0.1	28.9	0.1		
Nov	35			29.0	0.2			28.5	0.4	28.5	0.4		
Dec	36			27.9*	0.4			27.4	0.6	27.4	0.6		
1995													
Jan	37	27.5*	0.2	28.0*	0.1			27.0	0.1	27.0	0.1		
Feb	38	27.0*		27.8	0.2			26.8	0.3	26.8	0.3		
Mar	39	26.8*		27.9	0.5			26.6	0.4	26.6	0.4		
Apr	40			29.0*	0.6			27.0	0.9	27.0	0.9		
May	41	28.4*		29.8*	0.4			28.4	0.3	28.4	0.3		
Jun	42							28.4	0.3	28.4	0.3		
Jul	43							29.0*	0.4	29.0*	0.4		
Aug	44			31.6*				29.1	0.1	29.1	0.1		
Sep	45	30.0*		30.3*	1.3								
Oct	46	29.4	0.6	29.5	0.7			28.2*		28.2*			
Nov	47			29.4*	1.3			28.4*	0.1	28.4*	0.1		
Dec	48	27.7*		27.9*	0.4			27.7	0.4	27.9*	0.5		

*Monthly mean values calculated from less than 3 weeks data; values without SD indicate only 1 week's measurement, values with SD indicate 2 weeks' measurements.

Table 4f. CARICOMP weekly site measurements:
Monthly mean of weekly water temperatures (°C at 0.5 m depth), 1992 -1995.

		TRINIDAD & TOBAGO: IMA						VENEZUELA: Universidad de Simon Bolivar					
		Coral Reef		Seagrass		Mangrove		Coral Reef		Seagrass		Mangrove	
	Mo #	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1992													
Jan	1												
Feb	2												
Mar	3												
Apr	4												
May	5												
Jun	6												
Jul	7												
Aug	8												
Sep	9							26.0*		27.0*			
Oct	10							29.8*		30.0*			
Nov	11									29.5*			
Dec	12												
1993													
Jan	13							27.2*		29.0*		31.0*	
Feb	14												
Mar	15							27.4*		28.7*		28.2*	
Apr	16							27.1*		28.4*		27.4*	
May	17							28.5*		29.8*		28.1*	
Jun	18							31.4*		32.5*		31.7*	
Jul	19							28.6*		30.3*		29.4*	
Aug	20							29.8*		31.5*		31.4*	
Sep	21							28.1*		31.2*		29.4*	
Oct	22												
Nov	23							28.0*		30.5*		29.3*	
Dec	24							30.1*		29.5*		29.0*	
1994													
Jan	25	26.7*	0.2	27.5*	0.6	27.4*	0.6	26.7*		27.8*		27.4*	
Feb	26							28.0*		27.9*		26.3*	
Mar	27	27.0*		28.0*		28.0*		26.8*		28.8*		27.8*	
Apr	28	26.0*		26.0*		26.0*		27.6*		28.5*		28.5*	
May	29	28.8*	0.0	28.5*	0.7	29.0*	0.7	28.0*				30.5*	
Jun	30	28.0*		28.0*		28.5*							
Jul	31	29.0*		29.0*		29.0*		27.5*		28.7*		28.3*	
Aug	32							28.1*		31.5*		30.1*	
Sep	33							28.1*		30.1*			
Oct	34							30.1*		31.1*			
Nov	35							30.1*		31.9*		31.0*	
Dec	36							27.5*		29.0*		28.4*	
1995													
Jan	37							28.7*		28.9*		27.7*	
Feb	38							27.9*		28.5*		27.2*	
Mar	39							27.5*		29.2*		28.3*	
Apr	40												
May	41							29.1*		30.5*		29.9*	
Jun	42							28.5*		30.5*		29.0*	
Jul	43							29.8*		31.2*		29.5*	
Aug	44												
Sep	45												
Oct	46												
Nov	47												
Dec	48												

*Monthly mean values calculated from less than 3 weeks data; values without SD indicate only 1 week's measurement, values with SD indicate 2 weeks' measurements.

Table 4g. CARICOMP weekly site measurements:
Monthly mean of weekly water temperatures (°C at 0.5 m depth), 1992 -1995.

VENEZUELA: EDIMAR

		Coral Reef		Seagrass		Mangrove	
	Mo #	Mean	SD	Mean	SD	Mean	SD
1992							
Jan	1						
Feb	2						
Mar	3						
Apr	4						
May	5						
Jun	6						
Jul	7						
Aug	8						
Sep	9						
Oct	10						
Nov	11						
Dec	12						
1993							
Jan	13			26.2	0.6	26.3	0.4
Feb	14			26.0	0.2	25.8	0.1
Mar	15			27.0	0.7	26.6	0.4
Apr	16			27.0	0.1	27.9	0.9
May	17			28.7	0.7	29.3	0.8
Jun	18			28.2	1.3	28.1	1.4
Jul	19			28.0	0.7	28.3	0.8
Aug	20			28.1	0.8	28.0*	0.6
Sep	21			28.3	0.5	29.2	0.7
Oct	22			28.1	0.3	28.2	0.6
Nov	23			27.9	0.9	27.8	0.9
Dec	24			27.0	0.4	27.1	0.6
1994							
Jan	25			26.0*	0.2	26.4*	0.2
Feb	26			25.1*	0.7	24.9*	0.6
Mar	27			26.3	0.6	26.6	0.5
Apr	28			26.8*	0.1	26.7*	0.1
May	29			26.7*	0.4	26.9*	0.1
Jun	30			27.1	0.3	27.5	0.7
Jul	31			27.1*	0.8	28.1*	2.0
Aug	32			28.3	0.4	30.6	2.9
Sep	33			28.2*	0.5	28.6*	0.3
Oct	34			28.3*	1.0	28.9*	1.0
Nov	35			28.2	1.0	28.6	0.9
Dec	36			26.9*		27.2*	
1995							
Jan	37			26.7*	0.3	27.1*	0.1
Feb	38			25.5*	0.1	25.7*	1.1
Mar	39			27.0	1.1	27.1	0.9
Apr	40			28.2*	0.2	29.0*	0.1
May	41			28.2	0.3	28.8	0.4
Jun	42			27.8*	0.1	28.5*	0.4
Jul	43			28.0*	0.3	28.9*	1.4
Aug	44			29.9*	0.4	29.9*	0.9
Sep	45			30.4*	0.7	30.8*	1.7
Oct	46			29.3*	0.6	29.3*	0.1
Nov	47			27.9	0.7	27.7	1.0
Dec	48			27.4*	0.9	27.2*	0.9

*Monthly mean values calculated from less than 3 weeks data; values without SD indicate only 1 week's measurement, values with SD indicate 2 weeks' measurements.

Table 5a. CARICOMP HOBO measurements: Monthly mean water temperatures (°C), 1994 -1995.

	BAHAMAS: Bahamian Field Station						BELIZE: Carrie Bow Cay			
	Ostrander Reef		Grahams Harbor		French Bay		Coral Reef		Seagrass Bed	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1994										
Jan										
Feb										
Mar										
Apr										
May										
Jun										
Jul										
Aug										
Sep			27.26	0.71						
Oct										
Nov					26.65	1.03				
Dec					25.59	0.93				
1995										
Jan	25.34	0.29	24.05	0.95	24.72	0.91				
Feb	24.93	0.23	24.02	1.51	24.86	1.32				
Mar	24.88	0.68	24.75	0.95	24.89	1.31				
Apr			26.22	0.90	26.53	1.20				
May			28.20	0.97	28.21	1.11				
Jun			29.07	0.80	29.34	1.09				
Jul			29.56	0.86	29.99	1.07				
Aug	28.95	0.49	29.39	0.99	29.76	1.10	29.80	0.16	29.96	0.12
Sep	29.53	0.18					29.69	0.15	29.86	0.52
Oct							28.76	0.51	28.64	0.74
Nov	27.62	0.52					28.52	0.40	27.98	1.17
Dec	26.05	0.58	24.65	1.30	25.27	1.20	27.74	0.28	26.67	0.64

	BERMUDA: Biological Station for Research					
	Coral Reef		Seagrass Bed		Mangrove	
	Mean	SD	Mean	SD	Mean	SD
1994						
Jan						
Feb						
Mar						
Apr	20.66	0.73	20.98	0.93		
May	22.39	0.38	23.31	0.35		
Jun	25.25	1.33	26.32	1.21		
Jul	28.58	0.46	29.55	0.31	27.15	0.43
Aug	28.90	0.50	29.08	0.48	27.15	0.43
Sep	27.46	0.54	27.41	0.63	26.15	0.90
Oct	24.72	1.14	24.48	1.30	21.92	1.30
Nov	22.24	0.61	21.67	0.73	19.39	2.21
Dec	21.44	0.55	20.39	0.41	18.53	1.49
1995						
Jan						
Feb						
Mar						
Apr						
May						
Jun						
Jul						
Aug						
Sep						
Oct						
Nov						
Dec						

Table 5b. CARICOMP HOBO measurements: Monthly mean water temperatures (°C), 1994 -1995.

COLOMBIA INVEMAR

	Reef Site		Seagrass Bed		Mangrove Site		Laboratory Site	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1994								
Jan								
Feb	23.99	0.82	25.54	1.09	25.60	0.32	28.18	0.80
Mar	25.16	0.28	26.62	0.84	26.16	0.45	28.55	0.88
Apr	25.02	0.58	26.62	0.97	26.39	0.39	29.00	0.79
May	26.14	0.68	27.45	0.94	27.57	0.49	29.06	0.98
Jun	25.89	0.74	27.65	0.85	27.80	0.27	29.74	0.77
Jul	24.64	0.78	26.82	0.81	27.06	0.26	29.80	0.95
Aug	26.46	0.69	27.16	0.79	28.00	0.32	28.85	1.03
Sep	27.21	0.49	27.21	0.49	28.56	0.32	29.11	1.03
Oct	27.78	0.49	28.80	1.00	28.37	0.36	28.58	0.98
Nov	27.14	0.83	28.26	1.07	27.48	0.54	28.22	0.99
Dec	24.62	0.99	26.43	1.03	26.24	0.25	28.33	0.95
1995								
Jan	24.88	0.67	25.81	0.88	25.80	0.31	28.61	0.70
Feb	24.80	0.60	25.89	0.83	25.43	0.21	28.21	0.73
Mar	25.17	1.01	26.84	1.24	26.00	0.56	28.56	0.98
Apr	24.91	0.73	27.10	0.95	26.73	0.31	28.78	0.78
May	26.88	0.51	28.25	0.73	28.10	0.27	29.04	0.88
Jun	27.51	0.54	28.88	0.93	28.47	0.25	29.19	1.01
Jul	26.65	0.78	27.57	0.96	27.99	0.37	28.24	1.09
Aug	28.40	0.39	28.96	0.93	28.67	0.46	28.11	1.18
Sep	28.69	0.54	29.94	0.74	29.02	0.46	28.84	1.07
Oct	29.34	0.34	30.02	0.61	28.61	0.53	27.57	1.01
Nov	27.06	0.48	27.32	0.62	27.72	0.23	28.45	0.74
Dec	26.00	0.72	26.55	0.86	26.82	0.35	28.22	0.64

CUBA: IOC/CIEC

	Reef Site		Seagrass Bed		Mangrove Site		Laboratory Site	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1994								
Jan								
Feb								
Mar								
Apr								
May								
Jun								
Jul								
Aug								
Sep								
Oct								
Nov								
Dec								
1995								
Jan								
Feb								
Mar	25.18	0.95	25.68	1.07	25.74	1.00	25.37	1.12
Apr	25.45	0.28	26.74	0.70	26.64	0.91	25.71	0.87
May	26.50	0.50	28.30	1.06	28.22	1.03	26.72	0.97
Jun	27.20	0.54	28.97	1.00	29.04	1.19	27.45	1.22
Jul	27.98	0.35	29.67	1.13	29.68	1.05	28.04	1.03
Aug	28.19	0.50	29.31	1.13	29.55	1.11	27.95	1.12
Sep	29.04	0.11	30.00	0.12	30.47	0.13	27.72	0.80
Oct								
Nov								
Dec								

Table 5c. CARICOMP HOBO measurements: Monthly mean water temperatures (°C), 1994 -1995.

	JAMAICA: Discovery Bay Marine Lab					
	Coral Reef		Seagrass Bed		Mangrove	
	Mean	SD	Mean	SD	Mean	SD
1994						
Jan						
Feb						
Mar			27.42	0.32	25.76	0.10
Apr	27.32	0.62	27.54	0.60	25.81	0.17
May	28.19	0.32	28.68	0.26	26.05	0.11
Jun	28.31	0.13	28.56	0.21	26.51	0.10
Jul	28.26	0.16	28.22	0.22	26.48	0.04
Aug	28.31	0.24	28.51	0.38	26.21	0.30
Sep	28.49	0.08	28.72	0.20	26.08	0.06
Oct	28.72	0.25	28.70	0.29	26.31	0.32
Nov	28.65	0.21	28.24	0.22	26.49	0.05
Dec	26.08	2.82	27.49	0.42	25.90	0.49
1995						
Jan	26.35	1.43	26.96	0.31	25.24	0.04
Feb	26.70	0.12	26.72	0.23	25.21	0.05
Mar						
Apr	27.27	0.05	27.13	0.29	25.20	0.15
May	27.75	0.36	27.84	0.40	25.31	0.10
Jun	28.24	0.21	28.00	0.33	25.30	0.07
Jul	28.99	0.24	28.79	0.21	26.64	0.16
Aug	29.15	0.27	28.80	0.32	26.71	0.09
Sep	29.56	0.15	29.28	0.31	26.67	0.12
Oct	28.92	0.02	28.47	0.29	26.50	0.05
Nov	28.36	0.16	27.94	0.24	26.28	0.15
Dec	28.11	0.01	27.86	0.28	26.10	0.02

	MEXICO: Puerto Morelos						MEXICO: CINVEST			
	Coral Reef		Seagrass Bed		Met. Station		Seagrass Bed		Mangrove	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1994										
Jan										
Feb										
Mar										
Apr	27.33	0.45	27.73	0.83	26.99	0.82				
May	27.80	0.42	27.24	3.11	27.00	2.24				
Jun	27.94	0.56	28.56	0.81						
Jul	28.23	0.58	28.52	0.45	28.09	1.24				
Aug	27.24	1.24			28.19	1.29				
Sep					25.60	2.36				
Oct	28.08	0.38	27.80	0.60	25.49	1.70				
Nov	27.28	0.37	26.50	0.75						
Dec	26.52	0.58	25.57	1.35						
1995										
Jan	23.36	0.49	24.85	1.72	23.60	2.91				
Feb	24.66	1.30	25.11	0.93	23.59	3.15				
Mar	25.80	0.56	24.12	1.33	24.47	2.47				
Apr	26.83	0.30	24.62	1.49	25.45	1.62				
May	26.39	1.05	28.36	1.41						
Jun	25.58	0.70	28.66	0.99			26.76	1.38	27.30	1.76
Jul	28.72	0.44			27.19	1.31	26.43	0.99	26.92	0.70
Aug	28.41	0.81	29.34	0.71	27.66	1.71	26.94	0.61	28.02	0.78
Sep	28.75	0.36	28.93	0.60	27.92	2.10	27.77	1.03	28.93	0.62
Oct			28.45	0.39	27.37	1.55	25.70	1.32	25.92	1.43
Nov			27.51	0.81	25.54	2.71				
Dec			26.21	0.72	23.88	2.66				

Table 5d. CARICOMP HOBO measurements: Monthly mean water temperatures (°C), 1994 -1995.

	SABA: Park		TRINIDAD: IMA							
	Coral Reef		Coral Reef		Seagrass Bed		Mangrove		Weather Station	
	Mean	SD	Mean	SD	Mean	SD				
1994										
Jan										
Feb										
Mar	26.08	0.14								
Apr	26.22	0.17								
May	26.92	0.30								
Jun	27.34	0.09								
Jul	27.51	0.22								
Aug	28.02	0.21								
Sep	28.25	0.13	26.78	0.33	28.02	0.50				
Oct	25.72	0.87	27.04	0.33	28.31	0.36				
Nov	25.62	0.99	26.53	0.32	27.59	0.58				
Dec	26.11	0.25	26.68	0.22	27.13	0.24				
1995										
Jan	24.51	0.92								
Feb	23.95	1.26								
Mar	23.64	1.26					26.42	2.01		
Apr							25.73	1.51		
May	27.56	0.41					26.44	1.46		
Jun	28.03	0.17					26.11	1.15		
Jul							26.41	1.53		
Aug							26.31	1.65		
Sep							26.45	1.44		
Oct							26.20	1.41	26.95	2.78
Nov							25.23	1.25	26.43	2.67
Dec							24.24	1.29	25.78	2.77

	VENEZUELA: INTECMAR						VENEZUELA: EDIMAR			
	Coral Reef		Seagrass Bed		Mangrove		Mangrove		Met. Station	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1994										
Jan										
Feb										
Mar					26.57	0.48				
Apr			27.88	0.39	27.16	0.59				
May			28.38	1.17	27.38	0.93				
Jun			27.94	0.14	27.30	0.20				
Jul			27.67	0.17	27.11	0.31				
Aug										
Sep	24.38	2.74			28.36	0.95				
Oct	28.36	0.47			29.25	0.35				
Nov	28.49	0.41	18.86*	2.97	28.06	1.01				
Dec	27.38	0.26	17.85*	0.32	26.23	0.33				
1995										
Jan	24.42	0.24	27.63	0.21	26.25	0.64	25.63	1.12		
Feb	24.09	0.10	27.46	0.24	26.16	0.23	25.31	1.21	26.60	2.42
Mar	23.21	2.04	27.85	0.28	25.56	2.01	28.06	1.16	27.24	2.39
Apr			28.38	0.13			27.59	1.39	28.00	2.29
May							27.72	1.17	28.25	2.30
Jun							28.22	1.07	28.00	2.10
Jul							29.04	1.33	28.22	2.04
Aug							29.88	1.47	28.24	1.97
Sep							29.75	1.39	29.05	2.02
Oct							29.05	1.14	28.24	2.03
Nov							28.02	1.13	27.80	2.14
Dec							27.11	1.02	27.06	2.15

Table 6a. CARICOMP weekly habitat measurements: Monthly mean of weekly salinity (‰ at 0.5 m depth), 1992 -1995.

		BAHAMAS: BAHAMIAN FIELD STATION						BARBADOS: BELLAIRS RESEARCH INST					
		Coral Reef		Seagrass		Mangrove		Coral Reef		Seagrass		Mangrove	
	Mo #	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1992													
Jan	1												
Feb	2												
Mar	3												
Apr	4												
May	5												
Jun	6												
Jul	7												
Aug	8												
Sep	9												
Oct	10												
Nov	11							35.0*		35.0*		2.0*	
Dec	12							35.0	0.0	35.4	0.4	2.0	0.0
1993													
Jan	13							35.0	0.0	35.0	0.0	2.0	0.0
Feb	14							35.5	0.4	35.1	0.3	2.5	0.6
Mar	15							35.0	0.4	35.1	0.5	3.4	0.5
Apr	16							34.2	0.3	33.8	0.8	4.5	0.0
May	17							34.0	0.0	33.1	0.6	4.9	0.3
Jun	18												
Jul	19							33.9	0.9	33.9	1.1	5.0	0.0
Aug	20							34.5	0.5	33.5	0.6	4.5	0.6
Sep	21							34.0	0.7	33.8	0.8	4.4	0.7
Oct	22							34.2	0.3	34.0	0.0	3.8	0.5
Nov	23							34.5	0.4	34.5	0.6	3.6	0.5
Dec	24									34.5*	0.0	3.5*	0.0
1994													
Jan	25							35.2	0.3	34.7	0.6	5.0*	0.0
Feb	26							34.0	0.0	34.0	0.0		
Mar	27							34.0	0.0	33.4	0.5		
Apr	28							34.0*	0.0	33.0*	0.0		
May	29							34.0	0.0	33.7	0.6		
Jun	30							31.8	1.0	32.3	0.5		
Jul	31							32.5	0.6	32.8	1.0		
Aug	32							32.8	1.3	32.5	0.9		
Sep	33							34.6	0.5	34.0	0.7		
Oct	34							34.0	0.0	34.3	0.5		
Nov	35							33.3	0.6	33.9	0.6		
Dec	36							35.3*	0.4	35.8	0.3		
1995													
Jan	37	35.0	0.0	36.3	0.6			34.8	1.4	35.5	0.9		
Feb	38	32.7	6.7	37.7	0.6			34.3	0.6	35.7	0.6		
Mar	39	37.0	1.0	37.4	0.9			35.5	0.6	35.8	0.5		
Apr	40	37.8	0.5	37.5	0.6			35.0	0.0	35.2	0.3		
May	41	36.8	0.4	37.2	0.4			34.0*	0.0	35.0*	0.0		
Jun	42	37.0	0.0	37.5	0.6			35.0*	0.0	35.0*	0.0		
Jul	43	37.0*	0.0	37.0	0.0								
Aug	44	36.5*	0.7	37.3	0.5			35.0	0.0	34.5	0.6		
Sep	45									32.0*	0.0		
Oct	46	37.5*	0.7	37.5*	0.7			35.0	0.0	34.3	1.2		
Nov	47	38.0*	0.0	37.8	0.4			35.0	0.0	34.8	0.3		
Dec	48							35.0*	0.0	35.0	0.0		

*Monthly mean values calculated from less than 3 weeks data; values without SD indicate only 1 week's measurement, values with SD indicate 2 weeks' measurements.

Table 6b. CARICOMP weekly habitat measurements: Monthly mean of weekly salinity (‰ at 0.5 m depth), 1992 -1995.

		BELIZE: CARRIE BOW CAY						BERMUDA: BIOL STATION					
		Coral Reef		Seagrass		Mangrove		Coral Reef		Seagrass		Mangrove	
	Mo #	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1992													
Jan	1												
Feb	2												
Mar	3												
Apr	4												
May	5												
Jun	6												
Jul	7												
Aug	8												
Sep	9							35.5	0.6	35.5	0.6		
Oct	10							35.8*	0.4	36.0	0.0	35.0	1.0
Nov	11							36.0	0.0	36.0	0.0	34.3	1.5
Dec	12							36.0*	0.0	36.0*	0.0	33.5*	0.7
1993													
Jan	13	34.7	2.3	34.7	2.3	36.5*	0.7	36.0*	0.0	36.0*	0.0	35.0*	0.0
Feb	14	35.8	0.5	35.9	0.9	36.3	1.3	36.0*	0.0	36.0	0.0	35.2	1.3
Mar	15	35.2	0.3	35.7	0.4	35.6	0.7	36.0	0.0	36.0	0.0		
Apr	16	36.9	1.3	36.0	0.0	36.0	0.0			35.0*			
May	17	36.0	1.0	35.7	0.6	35.3	1.2	35.0	1.7	36.0*	0.0	33.0*	
Jun	18	36.0	0.0	36.0	0.0	36.0	0.0	36.0	0.0	36.0	0.0	34.7	1.5
Jul	19	36.8	1.3	36.5	1.0	36.0	0.8	36.0	0.0	36.0	0.0	34.5*	2.1
Aug	20	35.8	0.5	35.8	0.5	35.8	0.5	36.0	0.0	36.0	0.0	35.4	0.9
Sep	21							36.1	0.3	36.0	0.0	35.6	0.5
Oct	22											35.0*	
Nov	23							36.0*		36.0*		34.0*	
Dec	24	34.0*		34.0*		34.0*		36.0*		36.0*	0.0		
1994													
Jan	25	36.3	0.3	35.0	0.0	35.0	0.0	36.0*	0.0	36.0*	0.0	35.0*	
Feb	26	35.8	0.5	35.5	0.6	34.9	0.3	36.0*		36.0*	0.0	36.0*	0.0
Mar	27	35.8	0.5	35.9	0.3	35.8	0.4	36.0*		36.0*	0.0	35.3*	0.4
Apr	28	35.3	0.6	35.3	0.6	35.3	0.6	36.0	0.0	36.0*	0.0		
May	29	38.0*	0.0	35.5*	0.7	35.5*	0.7	36.2	0.3	36.2	0.3		
Jun	30	37.3	1.9	36.5	1.0	36.0	0.0	36.0*		36.0*	0.0	34.5*	
Jul	31	36.3	0.6	36.0	0.0	36.0	1.0	36.0	0.0	36.3*	0.4	35.5*	
Aug	32	36.0*	0.0	36.0*	0.0	36.5*	0.7	36.0*		36.0*		35.5*	
Sep	33							36.0	0.0	35.5	0.0		
Oct	34												
Nov	35												
Dec	36												
1995													
Jan	37	35.8	0.3	32.5	5.2			36.0*		35.5*			
Feb	38	35.5*		36.0*				36.5*		38.0*			
Mar	39	36.2	0.8	35.6	0.9			36.3	0.6	36.3	0.6		
Apr	40	36.1	1.0	35.5	0.9			37.0*		36.5*	0.7		
May	41	34.9	0.2	34.6	0.2								
Jun	42	35.0	1.4	35.3	0.5								
Jul	43	35.3	0.6	35.3	0.6					36.0*	0.0		
Aug	44	34.0	1.4	34.3	1.0	34.0	2.6			36.0*	0.0		
Sep	45	32.8	1.7	32.8	1.0	32.0	1.4	36.0*		36.0*	0.0		
Oct	46	35.0	1.4	35.3	1.5	34.8	1.0			36.0*			
Nov	47	35.0	1.0	34.3	0.6	36.7	2.1	35.5*	0.7	35.3*	0.4		
Dec	48	36.3	1.0	36.3	2.1	34.5*	0.7	35.5*		36.0*			

*Monthly mean values calculated from less than 3 weeks data; values without SD indicate only 1 week's measurement, values with SD indicate 2 weeks' measurements.

Table 6c. CARICOMP weekly habitat measurements: Monthly mean of weekly salinity (‰ at 0.5 m depth), 1992 -1995.

		BONAIRE: BONAIRE MARINE PARK						COLOMBIA: INVEMAR					
		Coral Reef		Seagrass		Mangrove		Coral Reef		Seagrass		Mangrove	
	Mo #	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1992													
Jan	1												
Feb	2												
Mar	3												
Apr	4												
May	5												
Jun	6												
Jul	7												
Aug	8												
Sep	9							36.0*		35.0*		34.0*	
Oct	10							34.7	0.6	34.7	0.6	34.7	0.6
Nov	11							35.2	0.1	35.2	0.1	35.1	0.3
Dec	12							35.3*	0.2	35.2*	0.1	35.1*	0.3
1993													
Jan	13							36.0*	0.0	36.0*		35.5*	0.7
Feb	14							35.9	0.3	36.0	0.0	36.6	0.8
Mar	15							36.0	0.0	36.0	0.0	38.0	0.0
Apr	16							36.0	0.0	36.0	0.0	38.2	0.3
May	17							34.0	1.0	33.3	2.5	33.7	4.0
Jun	18							35.8	1.3	36.3	1.5	38.0	1.4
Jul	19							36.3	0.6	37.7	0.6	40.0	0.0
Aug	20							36.3	0.6	37.0	1.0	39.3	1.2
Sep	21							35.6	1.1	35.6	1.1	36.6	1.3
Oct	22							36.0	0.0	36.0	0.0	37.1	1.2
Nov	23							35.8	1.3	36.0	0.8	36.5	1.3
Dec	24							36.5	0.6	36.5	0.6	36.8	1.5
1994													
Jan	25							36.3	0.5	36.8	0.5	38.0	0.8
Feb	26							37.0	0.0	37.5	0.6	38.8	1.0
Mar	27							36.0	0.0	37.0	0.0	39.3	1.2
Apr	28							36.8	0.5	37.5	0.6	40.0	1.6
May	29							35.5	1.0	35.0	1.8	36.8	2.2
Jun	30							35.2	1.1	36.0	1.0	37.8	2.3
Jul	31							36.3	0.5	37.0	0.8	38.5	1.0
Aug	32	34.5	1.3					36.0	0.0	36.0	0.0	38.0	1.7
Sep	33	34.3	0.6					35.3	1.5	35.3	1.5	37.8	1.3
Oct	34	33.5	0.6					33.5	1.9	34.0	1.6	34.8	1.5
Nov	35							35.2	1.8	35.0	2.2	34.6	1.7
Dec	36							36.0*	0.0	36.0*	0.0	36.5*	0.7
1995													
Jan	37	34.0	0.0					36.0	0.0	36.2	0.3	37.8	0.3
Feb	38	34.0	0.0					36.8	0.5	37.5	0.6	38.8	1.0
Mar	39	34.0	0.0					36.4	0.5	36.6	0.5	38.8	1.1
Apr	40	34.8	0.5					36.8	0.5	37.0	0.0	40.0	0.8
May	41	34.3	0.5					35.8	0.4	36.0	0.0	37.2	1.1
Jun	42	34.3	0.5					34.0	2.2	34.5	2.6	37.8	2.1
Jul	43	34.3	1.0					36.0	0.7	36.4	1.0	38.2	0.5
Aug	44	34.0	0.0					33.6	2.0	33.7	1.9	33.6	1.6
Sep	45	34.5	0.6					35.4	1.3	35.8	0.2	34.8	3.3
Oct	46	34.5	0.6					34.0	2.6	34.0	2.6	33.3	2.5
Nov	47	34.6	0.5					37.6	0.5	27.8	0.5	37.9	1.0
Dec	48	35.0	0.0					37.7	1.5	38.0	1.5	39.3	0.3

*Monthly mean values calculated from less than 3 weeks data; values without SD indicate only 1 week's measurement, values with SD indicate 2 weeks' measurements.

Table 6d. CARICOMP weekly habitat measurements: Monthly mean of weekly salinity (‰ at 0.5 m depth), 1992 -1995.

		JAMAICA: DBML, UWI						MEXICO: PUERTO MORELOS					
		Coral Reef		Seagrass		Mangrove		Coral Reef		Seagrass		Mangrove	
	Mo #	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1992													
Jan	1												
Feb	2												
Mar	3												
Apr	4												
May	5												
Jun	6												
Jul	7												
Aug	8												
Sep	9									35.0*	1.4		
Oct	10							36.3	0.6	35.5	0.6		
Nov	11							35.3	1.2	35.3	1.0		
Dec	12							35.0*	0.0	35.6	0.9		
1993													
Jan	13	36.0	0.2	34.7	0.7	26.9	0.4	35.7	0.6	36.0	0.0		
Feb	14	35.9	0.1	34.8	0.2	27.2	0.1	36.0	0.0	36.0	0.0		
Mar	15	35.8	0.5	34.8	1.1	25.3	3.2	36.0*	0.0	36.0	0.0		
Apr	16	35.5	0.5	33.0	1.3	26.2	1.5	36.0	0.0	36.0	0.0		
May	17	35.3*	0.5	34.4	1.3	23.6	4.9	36.0	0.0	36.0	0.0		
Jun	18	36.2	0.5	32.5	2.3	27.1	0.3	36.0	0.0	36.0	0.0		
Jul	19	35.9	0.9	34.0	1.3	26.0	2.2	36.0	0.0	36.0	0.0		
Aug	20	35.4	0.8	34.0	1.0	23.9	5.3	36.0	0.0	36.0	0.0		
Sep	21	35.7	0.3	34.3	0.4	25.4	2.5	36.3	0.5	36.3	0.5		
Oct	22	35.3	0.8	34.1	2.0	24.6	4.9	35.5	0.6	35.8	0.5		
Nov	23							36.3	0.6	35.5	0.6		
Dec	24							36.0	0.0	36.0	0.0		
1994													
Jan	25	35.2	0.6	33.9	1.5	27.0	0.8	36.0*	0.0	36.0	0.0		
Feb	26	35.2	0.6	34.0	1.3	27.6	0.3	36.0*	0.0	36.0	0.0		
Mar	27	35.6*		33.8*		25.8*		36.0	0.0	36.0	0.0		
Apr	28	34.5*		27.0*		26.5*		36.0*	0.0	36.0	0.0		
May	29	35.0	0.7	33.3	0.4	27.2	0.5	36.0	0.0	35.3	0.6		
Jun	30	35.2	0.6	34.6	0.8	27.7	0.2	36.0*	0.0	36.0	0.0		
Jul	31	36.0	0.1	35.2	0.3	27.9	0.2	36.0	0.0	36.0	0.0		
Aug	32	35.8	0.4	34.9	0.7	25.4	2.4	36.0	0.0	36.0	0.0		
Sep	33	36.0*		35.5*		28.0*		36.0*		36.0*	0.0		
Oct	34	35.8	0.2	34.0	0.8	27.3	0.3	36.0*	0.0	36.0	0.0		
Nov	35	35.5*		34.5*		27.5*		36.0*		36.0*			
Dec	36							36.0*		36.0*	0.0		
1995													
Jan	37			33.0*		27.5*		36.0*	0.0	36.0	0.0		
Feb	38	37.4*	1.2	35.3	0.4	27.5*	0.0	36.0*		36.0*	0.0		
Mar	39	37.4*	1.2	34.3*	0.4	23.5*	5.7	36.0	0.0	36.0	0.0		
Apr	40	36.3	1.4	34.5	0.0	27.6	0.9			36.0	0.0		
May	41	35.6	1.0	33.8	0.5	25.5	3.3	36.0	0.0	34.0	4.5		
Jun	42	36.8	2.4	35.2	0.3	27.1	0.3	36.0*	0.0	36.0	0.0		
Jul	43	35.3	0.5	35.3	0.5	25.5	3.7	36.0*	0.0	36.0*	0.0		
Aug	44	36.1	0.5	35.6	0.5	27.3	1.3	36.0	0.0	36.0	0.0		
Sep	45	36.0	0.0	35.8	0.5	26.3	1.5	36.0	0.0	35.8	0.5		
Oct	46	36.0*	0.7	35.5*	0.7	28.5*	2.1			34.0*			
Nov	47	36.0	1.0	36.0	1.0	26.3	2.9	36.0	0.0	35.8	0.5		
Dec	48	35.2	0.3	33.7	5.1	27.7	1.2	36.0	0.0	36.0	0.0		

*Monthly mean values calculated from less than 3 weeks data; values without SD indicate only 1 week's measurement, values with SD indicate 2 weeks' measurements.

Table 6e. CARICOMP weekly habitat measurements: Monthly mean of weekly salinity (‰ at 0.5 m depth), 1992 -1995.

		PUERTO RICO: University of PR						SABA, NA: Saba Marine Park					
		Coral Reef		Seagrass		Mangrove		Coral Reef		Seagrass		Mangrove	
	Mo #	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1992													
Jan	1												
Feb	2												
Mar	3												
Apr	4												
May	5												
Jun	6												
Jul	7												
Aug	8												
Sep	9							39.1	0.9	39.0	0.8		
Oct	10							35.3	0.5	35.8	1.5		
Nov	11							34.8	0.5	35.0	0.0		
Dec	12							35.0	0.0	35.0	0.0		
1993													
Jan	13	35.0*	0.0					35.0	0.0	35.0	0.0		
Feb	14	36.0*						35.0	0.0	35.0	0.0		
Mar	15	35.5	0.9					35.0	0.0	35.0	0.0		
Apr	16	36.5*	0.7					34.8	0.5	34.8	0.5		
May	17	35.5*	0.7					35.0	0.0	35.0	0.0		
Jun	18	34.0*	1.4					35.0	0.0	35.2	0.4		
Jul	19	35.0*	0.0					35.0	0.0	35.0	0.0		
Aug	20	34.8*	0.0					35.0	0.0	35.0	0.0		
Sep	21	34.6*	0.8					35.0	0.0	35.0	0.0		
Oct	22	34.1*	0.1					35.0*		35.0*			
Nov	23	36.0*	0.0										
Dec	24	36.0*											
1994													
Jan	25							35.0*		35.0*			
Feb	26							35.4	0.8	35.0	0.0		
Mar	27							35.0	0.0	35.0	0.0		
Apr	28							35.0	0.0	35.0	0.0		
May	29							35.0	0.0	35.0	0.0		
Jun	30							35.0	0.0	35.0	0.0		
Jul	31							35.0	0.0	35.0	0.0		
Aug	32							35.0	0.0	35.0	0.0		
Sep	33			32.3	0.6			35.0	0.0	35.0	0.0		
Oct	34			33.0	0.0			34.7	0.6	34.7	0.6		
Nov	35			33.0	0.0			35.0	0.0	35.0	0.0		
Dec	36			33.0*	0.0			35.0	0.0	35.0	0.0		
1995													
Jan	37	33.0*	0.0	33.0*	0.0			35.0	0.0	35.0	0.0		
Feb	38	33.0*		33.5	1.0			35.0	0.0	35.0	0.0		
Mar	39	33.0*		34.0	0.0			35.0	0.0	35.0	0.0		
Apr	40			34.0*	0.0			35.0	0.0	35.5	1.0		
May	41	34.0*		34.0*	0.0			35.0	0.0	35.0	0.0		
Jun	42							35.0	0.0	35.0	0.0		
Jul	43							35.0*	0.0	35.0*	0.0		
Aug	44			34.0*				35.0	0.0	35.0	0.0		
Sep	45	34.0*		34.0*	0.0								
Oct	46	34.0	0.0	34.0	0.0			35.0*		35.0*			
Nov	47			34.0*	0.0			35.0*	0.0	35.0*	0.0		
Dec	48	34.0*	0.0	34.0*				35.0	0.0	35.0*	0.0		

*Monthly mean values calculated from less than 3 weeks data; values without SD indicate only 1 week's measurement, values with SD indicate 2 weeks' measurements.

Table 6f. CARICOMP weekly habitat measurements: Monthly mean of weekly salinity (‰ at 0.5 m depth), 1992 -1995.

		TRINIDAD & TOBAGO: IMA						VENEZUELA: Universidad de Simon Bolivar					
		Coral Reef		Seagrass		Mangrove		Coral Reef		Seagrass		Mangrove	
	Mo #	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1992													
Jan	1												
Feb	2												
Mar	3												
Apr	4												
May	5												
Jun	6												
Jul	7												
Aug	8												
Sep	9							38.0*		38.0*			
Oct	10							35.0*		38.0*			
Nov	11									38.0*			
Dec	12												
1993													
Jan	13							36.0*		36.0*		36.0*	
Feb	14												
Mar	15							36.0*		39.0*		39.0*	
Apr	16							37.0*		37.0*		38.0*	
May	17							37.0*		38.0*		37.0*	
Jun	18							37.0*		36.0*		37.0*	
Jul	19							38.0*		38.0*		37.0*	
Aug	20							36.0*		36.0*		37.0*	
Sep	21							36.0*		38.0*		36.0*	
Oct	22									38.0*		36.0*	
Nov	23							38.0*		38.0*		38.0*	
Dec	24							36.0*		36.0*		36.0*	
1994													
Jan	25	35.0	0.0	35.0	0.0	34.0	1.7	36.9*		35.8*		35.0*	
Feb	26	34.7	0.6	35.0	0.0	35.0	0.0	36.0*		38.0*		36.0*	
Mar	27	35.0*	0.0	35.0*	0.0	35.0*	0.0	36.0*		37.0*		36.0*	
Apr	28	34.5*		34.0*		34.0*		36.0*		36.0*		36.0*	
May	29	35.0*	0.0	37.0*	4.2	35.0*	0.0	36.0*				37.0*	
Jun	30	35.0*		32.0*		35.0*							
Jul	31	35.0*		35.0*		35.0*		37.0*		36.0*		36.0*	
Aug	32							35.0*		36.0*		36.0*	
Sep	33							36.0*		36.0*			
Oct	34							36.0*		36.0*			
Nov	35							35.0*		35.0*		35.0*	
Dec	36							36.0*		35.0*		36.0*	
1995													
Jan	37							37.0*		36.0*		37.0*	
Feb	38							37.0*		38.0*		35.0*	
Mar	39							38.0*		37.0*		36.0*	
Apr	40												
May	41							38.0*		38.0*		36.0*	
Jun	42							37.5*		38.0*		35.5*	
Jul	43							38.0*		38.0*		38.0*	
Aug	44												
Sep	45												
Oct	46												
Nov	47												
Dec	48												

*Monthly mean values calculated from less than 3 weeks data; values without SD indicate only 1 week's measurement, values with SD indicate 2 weeks' measurements.

Table 6g. CARICOMP weekly habitat measurements: Monthly mean of weekly salinity (‰ at 0.5 m depth), 1992 -1995.

VENEZUELA: EDIMAR

		Coral Reef		Seagrass		Mangrove	
	Mo #	Mean	SD	Mean	SD	Mean	SD
1992							
Jan	1						
Feb	2						
Mar	3						
Apr	4						
May	5						
Jun	6						
Jul	7						
Aug	8						
Sep	9						
Oct	10						
Nov	11						
Dec	12						
1993							
Jan	13			37.8	1.0	37.8	0.5
Feb	14			37.5	0.6	38.5	0.6
Mar	15			37.2	0.4	38.4	0.5
Apr	16			37.8	1.0	38.3	0.5
May	17			37.3	0.5	38.5	1.0
Jun	18			37.8	0.4	39.2	0.8
Jul	19			38.3	0.5	38.8	0.5
Aug	20			38.3	1.2	38.0*	0.0
Sep	21			37.3	1.0	37.5	1.0
Oct	22			37.3	0.5	38.0	0.0
Nov	23			37.0	0.0	38.0	0.0
Dec	24			37.0	0.0	38.0	0.0
1994							
Jan	25			37.0*	0.0	37.5*	0.7
Feb	26			37.0*	0.0	37.5*	0.7
Mar	27			37.3	0.6	38.0	0.0
Apr	28			37.0*	0.0	38.0*	0.0
May	29			37.0*	0.0	38.0*	0.0
Jun	30			37.3	0.6	38.3	0.6
Jul	31			37.0*	0.0	38.5*	0.7
Aug	32			36.7	0.6	37.0	1.7
Sep	33			37.0*	0.0	38.5*	0.7
Oct	34			37.5*	0.7	38.0*	0.0
Nov	35			36.3	0.6	37.0	0.0
Dec	36			39.0*		39.0*	
1995							
Jan	37			38.0*	1.4	38.5*	0.7
Feb	38			37.5*	0.7	38.0	1.4
Mar	39			37.0	0.0	37.7	0.6
Apr	40			37.5*	0.7	37.5*	0.7
May	41			38.3	0.6	39.3	0.6
Jun	42			38.0*	0.0	38.5*	0.7
Jul	43			36.5*	0.7	37.0*	1.4
Aug	44			37.0	0.0	37.3	0.6
Sep	45			37.5*	0.7	37.5*	0.7
Oct	46			37.5*	0.7	37.5*	0.7
Nov	47			37.0	1.0	37.7	1.5
Dec	48			37.0*	0.0	38.0*	0.0

*Monthly mean values calculated from less than 3 weeks data; values without SD indicate only 1 week's measurement, values with SD indicate 2 weeks' measurements.

Table 7a. CARICOMP weekly habitat measurements: Monthly mean of light attenuation (Secchi disk), 1992 -1995.

		BAHAMAS: Bahamian Field Station						BARBADOS: Bellairs Research Institute					
	Month #	Coral Reef	SD	Sea-grass	SD	Man-grove	SD	Coral Reef	SD	Sea-grass	SD	Man-grove	SD
1992													
Jan	1												
Feb	2												
Mar	3												
Apr	4												
May	5												
Jun	6												
Jul	7												
Aug	8												
Sep	9												
Oct	10												
Nov	11							20.3*		9.0*			
Dec	12							11.5	10.0	3.8*	0.8		
1993													
Jan	13							12.3*		5.5	1.6		
Feb	14							17.3*	2.1	7.4	5.2		
Mar	15							18.9	3.6	8.6	5.3		
Apr	16							18.7	1.5	5.1	4.8		
May	17							18.4	2.4	10.0	3.5		
Jun	18												
Jul	19							19.6	1.5	9.1	4.8		
Aug	20							17.8	2.6	9.5	4.0		
Sep	21							19.4	2.5	4.9	1.6		
Oct	22							18.1	0.9	5.0	1.9		
Nov	23							17.2	2.9	4.2	1.8		
Dec	24									6.6*	3.4		
1994													
Jan	25							18.4	1.3	5.7	3.1		
Feb	26							16.7	1.1	6.6	0.4		
Mar	27							18.8	1.2	6.1	0.5		
Apr	28							19.0*	0.1	7.3*	5.8		
May	29							11.7	4.3	7.3*	3.8		
Jun	30							11.0	1.0	5.3	0.7		
Jul	31							11.9	4.0	4.2	1.0		
Aug	32							10.6*	2.5	5.8	2.1		
Sep	33							15.3	1.4	7.7	2.4		
Oct	34							11.2	2.8	5.1	1.6		
Nov	35							7.1	1.7	5.1	1.3		
Dec	36							7.1*	2.1	5.7*	0.5		
1995													
Jan	37	44.7	11.6					11.7	2.8	3.6	0.5		
Feb	38	41.3	5.1					13.2	0.8	4.3	2.0		
Mar	39	42.2	2.8					13.3	2.2	5.0	1.8		
Apr	40	44.3	5.9	8.8*				13.6	0.7	6.8	2.0		
May	41	43.0	8.7	13.6	0.9			18.4*	8.0	7.0*	2.9		
Jun	42	37.0*	12.7	17.6	1.2			14.1*	0.1	5.3*	0.5		
Jul	43	37.0*		14.6	2.5								
Aug	44	34.0*		10.9	3.8			13.5	0.6	3.6	0.5		
Sep	45	34.0*								2.9*	0.1		
Oct	46	37.0*		9.6*	0.4			14.0	2.0	4.1	0.4		
Nov	47	32.0	2.8	10.2	2.4			10.9	5.5	2.9	2.1		
Dec	48							8.1*	2.1	4.2	1.2		

*Denotes Monthly Mean Values calculated from less than 3 weeks data; values without Standard Deviation indicate only 1 week's measurement; values with Standard Deviation indicate 2 weeks' measurement.

Table 7b. CARICOMP weekly habitat measurements: Monthly mean of light attenuation (Secchi disk), 1992 -1995.

	Month #	BELIZE: Smithsonian Institution (Carrie Bow Cay) Coral Reef	SD	Sea-grass	SD	Man-grove	SD	BERMUDA: Biological Station for Research Coral Reef	SD	Sea-grass	SD	Man-grove	SD
1992													
Jan	1												
Feb	2												
Mar	3												
Apr	4												
May	5												
Jun	6												
Jul	7												
Aug	8												
Sep	9							39.4	10.5	11.2	4.0		
Oct	10							25.0*		11.1	1.5		
Nov	11							30.2	11.0	16.7	2.9		
Dec	12							45.9*	6.9	13.9*	0.4		
1993													
Jan	13	24.5	0.7	12.7	2.5			40.5*	10.6	17.0*	4.9		
Feb	14	21.6	2.3	14.0	4.2					15.3*	0.0		
Mar	15	20.8	4.4	12.1	2.7			50.0*		18.1	2.1		
Apr	16	22.5	4.1	15.8	1.3					14.0*			
May	17	21.7	0.3	11.0	1.7			41.0*		12.8	1.1		
Jun	18	16.6	4.7	10.9	1.3			34.4	4.7	23.3	2.4		
Jul	19	19.5	0.4	10.3	2.2			31.7	5.0	15.4	2.1		
Aug	20	21.7	2.0	15.3	1.2			29.4	1.2	12.2	0.2		
Sep	21							33.2	4.3	11.6	2.8		
Oct	22												
Nov	23									12.0*			
Dec	24	14.0*		14.0*				15.0*		12.8*	2.3		
1994													
Jan	25	17.3	0.6	14.0	1.0			36.6*	1.3	14.1*	5.2		
Feb	26	16.3	1.8	15.4	0.5			36.3*		13.7*	0.4		
Mar	27	17.8	6.8	9.3	3.6					12.5*	3.0		
Apr	28	25.7	1.3	12.7	2.1			34.5*	3.5	14.0*	2.8		
May	29	20.5*	1.4	8.0*	1.4			39.7	6.7	13.9	0.3		
Jun	30	22.1	4.7	12.8	4.6			34.0*	15.6	14.1*	1.3		
Jul	31	26.7	1.9	14.9	0.9			27.0*	2.8	13.0*			
Aug	32	23.4*	3.3	14.3*	1.8			26.5	3.4	10.3	2.4		
Sep	33							25.1*	10.0	12.8	0.6		
Oct	34							15.5*		11.4	1.7		
Nov	35									8.0*			
Dec	36	21.5*	6.4	13.0*	0.0								
1995													
Jan	37	19.0	4.0	7.0	3.7			39.8*		14.4*			
Feb	38	16.0*	2.8	8.7	4.9			30.0*		12.0*			
Mar	39	23.0	6.9	13.3	3.0			29.8	4.5	21.7	3.9		
Apr	40	21.8	6.2	10.9	1.2			17.0*		25.3*	12.3		
May	41	21.6	0.9	14.3	1.0			50.0*		12.8*			
Jun	42	34.8	3.4	13.0	3.2			33.5*	10.6	13.0*	2.5		
Jul	43	35.5*	3.5	11.0	2.0			43.0	7.5	17.4*	2.1		
Aug	44	22.6	10.1	13.9	3.0					7.3*	1.3		
Sep	45	17.8	2.5	10.5	2.7			19.7*	2.8	11.3*	2.8		
Oct	46	11.4	4.5	9.4	5.3			29.0*		11.6*	0.8		
Nov	47	23.2	9.3	8.8	5.1			32.0*	14.3	13.5*	3.1		
Dec	48	25.3	2.1	9.0*	5.7			42.5*		12.6*			

*Denotes Monthly Mean Values calculated from less than 3 weeks data; values without Standard Deviation indicate only 1 week's measurement; values with Standard Deviation indicate 2 weeks' measurement.

Table 7c. CARICOMP weekly habitat measurements: Monthly mean of light attenuation (Secchi disk), 1992 -1995.

	Month #	BONAIRE, NA: Bonaire Marine Park Coral Reef	SD	Sea-grass	SD	Man-grove	SD	COLOMBIA: INVEMAR Coral Reef	SD	Sea-grass	SD	Man-grove	SD
1992													
Jan	1												
Feb	2												
Mar	3												
Apr	4												
May	5												
Jun	6												
Jul	7												
Aug	8												
Sep	9							14.0*		9.0*			
Oct	10							16.2	4.6	7.2	2.6		
Nov	11							14.0	5.7	4.9	2.6		
Dec	12							17.0*	1.4	3.0*	0.7		
1993													
Jan	13							7.0*		3.5*			
Feb	14							10.8	1.0	5.7	2.0		
Mar	15							12.3	3.2	6.8	2.1		
Apr	16							15.7	4.9	6.7	0.3		
May	17							8.0	2.6	3.8	1.6		
Jun	18							12.4	5.0	5.1	1.8		
Jul	19							10.3	1.3	4.2	1.5		
Aug	20							14.5	5.1	6.0	4.3		
Sep	21							11.5	3.3	7.9	2.0		
Oct	22							15.8	3.8	6.8	2.3		
Nov	23							11.6	2.5	6.1	5.8		
Dec	24							12.8	1.6	4.7	4.6		
1994													
Jan	25							11.5	0.6	3.0	1.9		
Feb	26							12.9	1.7	6.6	3.1		
Mar	27							14.7	4.0	7.3	0.4		
Apr	28							12.5	5.6	6.6	4.3		
May	29							15.5	3.4	7.5	3.7		
Jun	30							12.7	2.9	3.9	1.3		
Jul	31							11.8	1.1	3.0	0.9		
Aug	32	21.6	4.9					16.0	1.0	7.3	4.9		
Sep	33	21.2	2.3					14.6	4.9	6.2	1.9		
Oct	34	22.0	4.1					9.0	4.8	6.7	3.1		
Nov	35							15.8	4.2	7.5	3.5		
Dec	36							13.0	3.6	3.0	1.9		
1995													
Jan	37	24.7	2.5					13.1	0.1	3.2	1.8		
Feb	38	25.5	1.0					13.0	2.2	5.7	3.3		
Mar	39	26.4	4.3					15.7	3.9	4.6	2.1		
Apr	40	26.9	3.9					16.8	1.7	4.9	2.8		
May	41	25.9	3.3					18.2	3.7	10.2	4.5		
Jun	42	27.4	3.0					11.5	4.8	4.9	2.1		
Jul	43	27.4	1.9					14.3	0.5	4.3	0.9		
Aug	44	26.9	1.1					10.8	4.2	5.3	1.5		
Sep	45	29.2	1.8					14.0	2.6	6.2	1.7		
Oct	46	27.7	1.4					11.1	4.2	5.5	1.0		
Nov	47	24.1	1.3					15.8	2.4	3.8	2.7		
Dec	48	25.8	1.4					14.7	0.8	3.9	3.2		

*Denotes Monthly Mean Values calculated from less than 3 weeks data; values without Standard Deviation indicate only 1 week's measurement; values with Standard Deviation indicate 2 weeks' measurement.

Table 7d. CARICOMP weekly habitat measurements: Monthly mean of light attenuation (Secchi disk), 1992 -1995.

	Month #	JAMAICA: Discovery Bay Marine Lab Coral Reef	SD	Seagrass	SD	Mangrove	SD	MEXICO: ICMyL, UAM (Puerto Morelos) Coral Reef	SD	Seagrass	SD	Mangrove	SD
1992													
Jan	1												
Feb	2												
Mar	3												
Apr	4												
May	5												
Jun	6												
Jul	7												
Aug	8												
Sep	9									17.0*			
Oct	10							25.7*	8.6	13.8	2.6		
Nov	11							22.9	4.1	20.5	2.7		
Dec	12							22.1	1.6	19.7	3.8		
1993													
Jan	13	31.0	1.3	19.5	2.0			18.8	1.0	19.9	0.8		
Feb	14	29.1	1.4	17.5	1.0			25.1	4.3	21.4	1.6		
Mar	15	29.7	2.9	17.1	1.7			21.0*	2.8	17.3	5.6		
Apr	16	28.8	4.5	12.1	2.2			22.0	2.7	16.1	4.9		
May	17	20.8*	9.5	14.2	2.9			20.4	5.0	15.8	2.2		
Jun	18	26.4	6.3	15.2	3.0			18.6	4.6	16.1	0.8		
Jul	19	30.9	0.4	14.0	1.7			18.7	0.6	15.3	1.9		
Aug	20	31.5	7.8	11.5	1.6			19.0	2.5	15.2	1.0		
Sep	21	31.2	6.3	13.3	1.1			21.1	1.9	14.6	1.8		
Oct	22	36.1	5.6	12.9	1.4			20.0	4.3	14.4	1.8		
Nov	23							21.3	8.1	11.4	2.0		
Dec	24							20.7	2.1	11.9	0.6		
1994													
Jan	25	22.2	7.3	14.5	2.2			17.0*	5.7	12.9	3.1		
Feb	26	25.3	4.8	13.4	0.7			18.1*	4.4	17.9	1.9		
Mar	27	22.5*		17.1*				19.3	1.8	17.2	2.9		
Apr	28	25.0*		11.3*				20.7*	1.2	15.1	0.6		
May	29	21.0	5.4	13.1	2.1			20.7	2.1	13.8	0.9		
Jun	30	25.6	5.0	11.3	2.1			22.0*	1.4	14.1	0.9		
Jul	31	20.4	0.2	12.2	2.1			21.5	1.4	16.5	1.8		
Aug	32	22.0	3.1	12.8	1.8			23.8	3.9	15.0	1.2		
Sep	33	22.0*		14.2*				23.7*	2.8	13.8*	0.1		
Oct	34	26.0	1.0	12.0	0.7			22.1*	0.1	14.3*	0.1		
Nov	35	15.0*		12.0*				24.0*		16.2*			
Dec	36							15.3*		12.9*	0.8		
1995													
Jan	37			11.0*				22.5*	0.0	15.4	2.4		
Feb	38	24.3*	0.4	13.0*				22.6*		16.2*	4.9		
Mar	39	17.0*	4.2	13.1*	0.1			21.9	2.1	15.0	0.4		
Apr	40	20.1	4.2	11.7	2.9					13.1*	0.1		
May	41	19.8	2.3	10.0*				21.6	5.4	15.3	0.8		
Jun	42	19.0	1.5	13.8	1.8			21.8*	2.5	16.7	2.1		
Jul	43	23.2	8.1	10.8	1.9			22.1*	2.7	17.6*	0.7		
Aug	44	27.9	5.2	10.0	1.5			23.5	3.9	15.3	2.3		
Sep	45	24.0	1.7	10.7	1.0			25.9	1.7	14.1	1.5		
Oct	46	24.0*		12.8*	3.9					8.0*			
Nov	47	22*	4.2	8.7	1.3			23.7	5.8	15.8	2.2		
Dec	48	22.7	1.8	12.8	2.8			26.6	5.3	17.3	4.0		

*Denotes Monthly Mean Values calculated from less than 3 weeks data; values without Standard Deviation indicate only 1 week's measurement; values with Standard Deviation indicate 2 weeks' measurement.

Table 7e. CARICOMP weekly habitat measurements: Monthly mean of light attenuation (Secchi disk), 1992 -1995.

		PUERTO RICO, USA: University of Puerto Rico						SABA, NA: Saba Marine Park					
	Month #	Coral Reef	SD	Sea-grass	SD	Man-grove	SD	Coral Reef	SD	Sea-grass	SD	Man-grove	SD
1992													
Jan	1												
Feb	2												
Mar	3												
Apr	4												
May	5												
Jun	6												
Jul	7												
Aug	8												
Sep	9							25.3	1.5	19.4	5.9		
Oct	10							30.3	3.9	29.2	4.7		
Nov	11							12.5	4.1	13.3	3.8		
Dec	12							19.0	1.0	17.7	0.6		
1993													
Jan	13	12.8*	1.1					21.7	2.5	19.6	1.4		
Feb	14	13.5*						24.0	2.8	22.5	3.0		
Mar	15	12.5	5.5					22.0	6.9	22.0	5.3		
Apr	16	13.0*	4.2					25.5	3.8	25.0	4.8		
May	17	6.5*	2.1					25.3	3.8	25.0	4.2		
Jun	18	10.5*	0.7					18.5	2.0	17.7	1.2		
Jul	19	12.5*	0.7					25.8	11.1	21.8	5.2		
Aug	20	9.5*	2.1					24.5	1.7	23.0	2.4		
Sep	21	10.0*	2.8					22.8	2.6	21.5	3.5		
Oct	22	15.3*	6.7					24.0*		24.0*			
Nov	23	9.0*	1.4										
Dec	24	12.0*											
1994													
Jan	25												
Feb	26												
Mar	27							15.0*					
Apr	28							23.0	2.7				
May	29							22.0	1.6				
Jun	30							19.8	1.3				
Jul	31							19.0	1.2				
Aug	32							18.8	4.4				
Sep	33			10.2	1.1			22.3	2.2				
Oct	34			12.9	1.5			21.3	9.3	19.8	5.9		
Nov	35			10.9	0.7			23.3	2.2	23.3	2.2		
Dec	36			12.7*	0.8			23.8	1.5	23.4	2.2		
1995													
Jan	37	10.3*	0.4	9.0*	1.6			24.5	1.0	24.5	1.0		
Feb	38	6.0*		9.6	3.6			22.0	3.5	22.0	3.5		
Mar	39	10.9*		8.5	1.0			23.8	1.8	23.8	1.8		
Apr	40			7.4*	0.9			21.3	1.2	22.0	1.6		
May	41	15.0*		9.0*	2.1			21.6	2.5	21.6	2.5		
Jun	42							19.7	0.6	19.7	0.6		
Jul	43												
Aug	44			5.3*				17.3	3.1	17.3	3.1		
Sep	45			10.1*									
Oct	46	7.3	2.6	7.2	1.3			21.0*		20.0*			
Nov	47			8.9*	2.8			20.0*	0.0	20.0*	0.0		
Dec	48	6.0*		8.0*	1.4			20.3	1.5	20.5*	2.1		

*Denotes Monthly Mean Values calculated from less than 3 weeks data; values without Standard Deviation indicate only 1 week's measurement; values with Standard Deviation indicate 2 weeks' measurement.

Table 7f. CARICOMP weekly habitat measurements: Monthly mean of light attenuation (Secchi disk), 1992 -1995.

		TRINIDAD & TOBAGO: Institute of Marine Affairs						VENEZUELA: Universidad de Simon Bolivar					
	Month #	Coral Reef	SD	Sea-grass	SD	Man-grove	SD	Coral Reef	SD	Sea-grass	SD	Man-grove	SD
1992													
Jan	1												
Feb	2												
Mar	3												
Apr	4												
May	5												
Jun	6												
Jul	7												
Aug	8												
Sep	9							6.0*		3.6*			
Oct	10							10.7*		5.2*			
Nov	11									4.7*			
Dec	12												
1993													
Jan	13							6.9*		4.2*			
Feb	14												
Mar	15							8.0*		7.0*			
Apr	16							10.0*		3.0*			
May	17							10.0*		4.0*			
Jun	18							7.5*		10.0*			
Jul	19							9.0*		7.5*		4.0*	
Aug	20							9.0*		5.0*		3.8*	
Sep	21							11.0*		7.0*		3.0*	
Oct	22									9.9*		3.4*	
Nov	23							8.4*		4.0*		4.0*	
Dec	24									3.0*		3.8*	
1994													
Jan	25	15.5	0.9	3.5	2.8			10.0*		11.9*		3.0*	
Feb	26	14.2	2.8	4.8	2.0			11.5*		9.0*		2.0*	
Mar	27	11.8*	0.4	7.5*	0.7			10.0*		8.0*		3.8*	
Apr	28	7.0*		7.0*				8.0*		5.0*		2.0*	
May	29	12.5*	4.9	8.5*	4.9			12.0*					
Jun	30	17.0*		7.0*									
Jul	31	14.0*		8.0*				8.5*		4.5*		2.5*	
Aug	32							15.5*		5.8*		3.5*	
Sep	33							9.5*		7.5*			
Oct	34							9.0*		9.0*			
Nov	35							6.0*		7.0*		5.6*	
Dec	36							10.5*		8.5*		3.0*	
1995													
Jan	37							11.5*		10.5*		5.0*	
Feb	38							15.0*		9.0*		4.0*	
Mar	39							7.4*		5.5*		2.1*	
Apr	40												
May	41							9.0*		7.0*		3.0*	
Jun	42							8.0*		4.0*		3.0*	
Jul	43							10.0*		11.0*			
Aug	44												
Sep	45												
Oct	46												
Nov	47												
Dec	48												

*Denotes Monthly Mean Values calculated from less than 3 weeks data; values without Standard Deviation indicate only 1 week's measurement; values with Standard Deviation indicate 2 weeks' measurement.

Table 7g. CARICOMP weekly habitat measurements: Monthly mean of light attenuation (Secchi disk), 1992 -1995.

	Month #	Coral Reef	SD	Sea-grass	SD	Man-grove	SD
			VENEZUELA: EDIMAR				
1992							
Jan	1						
Feb	2						
Mar	3						
Apr	4						
May	5						
Jun	6						
Jul	7						
Aug	8						
Sep	9						
Oct	10						
Nov	11						
Dec	12						
1993							
Jan	13			1.8	1.0		
Feb	14			3.2	2.3		
Mar	15			2.2	1.0		
Apr	16			1.8	0.6		
May	17			2.9	0.5		
Jun	18			1.5	0.4		
Jul	19			1.6	0.2		
Aug	20			4.0	3.4		
Sep	21			3.3	1.6		
Oct	22			2.7	0.8		
Nov	23			2.2	0.3		
Dec	24			2.9	0.7		
1994							
Jan	25			4.2*	0.9		
Feb	26			1.8*	1.1		
Mar	27			2.1	0.5		
Apr	28			2.5*	0.7		
May	29			2.2*	0.0		
Jun	30			3.6	2.5		
Jul	31			4.3*	0.4		
Aug	32			4.7	2.5		
Sep	33			3.5*	0.0		
Oct	34			2.2*	1.2		
Nov	35			3.3	1.2		
Dec	36			4.0*			
1995							
Jan	37			3.1*	1.3		
Feb	38			2.1*	0.5		
Mar	39			2.8	1.0		
Apr	40			4.7*	2.4		
May	41			2.4	0.6		
Jun	42			2.0*	0.9		
Jul	43			4.4*	2.3		
Aug	44			5.2*			
Sep	45			3.5*	0.7		
Oct	46			2.9*	1.9		
Nov	47			3.3	1.6		
Dec	48			3.9*	2.3		

*Denotes Monthly Mean Values calculated from less than 3 weeks data; values without Standard Deviation indicate only 1 week's measurement; values with Standard Deviation indicate 2 weeks' measurement.

Table 8a. CARICOMP mangrove forest measurements, 1992-1995.

COUNTRY and Institution	Number	Basal Area		Number of		Trunk Volume	
	of	(m^2/ha)		Trees		(m^3)	
Sampling Date	Plots	Mean	SD	Mean	SD	Mean	SD
BAHAMAS: Bahamian Field Station							
July 1994	3	3.93	2.97	10.3	10.1	0.150	0.096
July 1995	3	4.33	2.65	12.0	13.0	0.178	0.085
BARBADOS: Bellairs Research Institute							
February 1994	3	33.10	19.07	24.0	7.2	4.870	3.960
February 1995	3	33.54	18.89	23.0	6.1		
BELIZE: Smithsonian Institution — Carrie Bow Cay							
August 1993	5	15.44	4.47	43.8	12.9	0.662	0.367
February 1995	2	1.17	1.06	31.0	27.9	0.050	0.050
BELIZE: Hol Chan Marine Reserve							
October 1995	3	36.83	7.29	56.3	21.9	1.320	0.530
BERMUDA: Bermuda Biological Station for Research							
August 1992	4	28.01	8.40	41.5	27.5	2.390	0.860
August 1993	4	28.73	8.41	41.0	27.1	2.160	0.680
August 1994	4	27.09	10.11	41.0	27.1	2.070	0.760
August 1995	4	28.42	8.22	40.0	26.0	2.130	0.630
BONAIRE: Bonaire Marine Park							
November 1994	4	16.54	3.45	12.0	9.7	1.298	0.450
CAYMAN: Department of the Environment, Protection & Conservation Unit							
March 1994	5	30.64	12.94	48.0	13.6	2.897	1.540
April 1995	5	30.77	13.04	48.0	13.6		
COLOMBIA: Instituto de Investigaciones Marinas y Costeras							
February 1995	3	42.60	6.20	34.7	4.2	3.630	0.940
CURAÇAO: CARMABI Foundation							
June 1994	5	18.60	6.10	28.2	14.1	0.942	0.220
September 1995	5	18.75	6.22	28.2	14.2	0.944	0.220
DOMINICAN REPUBLIC: Centro de Investigaciones de Biología Marina							
November 1995	1	16.68		87.0		0.808	
MEXICO: Centro de Investigación y Estudios Avanzados de IPN							
September 1994	3	52.70	24.48	31.3	7.5	3.713	1.560
PUERTO RICO: UPR Department of Marine Sciences							
October 1994	3	20.40	5.54	23.7	8.1	1.400	0.410
TRINIDAD & TOBAGO: Institute of Marine Affairs							
October 1993	1	21.39		11.0	9.8	2.506	
Mar & Sep 1994	4	16.23	4.34	9.8	3.5	2.087	0.884
Mar & Sep 1995	7	17.76	5.29	15.9	12.4	1.943	1.164
VENEZUELA: Universidad de Simon Bolivar, INTECMAR							
September 1994	3	17.10	10.76	45.3	28.1	1.720	1.010
VENEZUELA: Fundación La Salle de Ciencias Naturales, EDIMAR							
May 1992	1	31.21		5.0		3.760	
June 1994	1	31.77		5.0		3.830	
July 1995	2	34.54	25.99	9.0	1.4	4.620	4.720

Table 8b. CARICOMP mangrove forest measurements, 1992-1995.

COUNTRY and Institution / Sampling Date	Number of Plots	Total Biomass[a] (kg m^{-2}) Mean	SD	Total Biomass[b] (kg m^{-2}) Mean	SD	Biomass[a] Per Tree Mean	SD	Biomass[b] Per Tree Mean	SD
BAHAMAS: Bahamian Field Station									
July 1994	3	1.07	0.73	2.23	1.89	0.104		0.217	
July 1995	3	1.27	0.71	2.55	2.15	0.106		0.213	
BARBADOS: Bellairs Research Institute									
February 1994	3	23.88	17.81	10.05	4.08	0.995		0.419	
February 1995	3			9.98	4.01			0.434	
BELIZE: Smithsonian Institution — Carrie Bow Cay									
August 1993	5	4.49	1.99	8.85	1.67	0.103		0.202	
February 1995	2	0.66	0.62	2.03	1.83	0.021		0.065	
BELIZE: Hol Chan Marine Reserve									
October 1995	3	8.50	2.79	15.75	1.48	0.151		0.280	
BERMUDA: Bermuda Biological Station for Research									
August 1992	4	12.84	4.80	10.59	5.17	0.309		0.255	
August 1993	4	11.84	4.20	10.78	5.23	0.289		0.263	
August 1994	4	11.61	4.54	10.70	5.42	0.283		0.261	
August 1995	4	11.73	3.89	10.59	5.04	0.293		0.265	
BONAIRE: Bonaire Marine Park									
November 1994	4	6.75	1.66	4.78	1.81	0.563		0.398	
CAYMAN: Department of the Environment, Protection & Conservation Unit									
March 1994	5	113.98	6.70	10.38	2.55	0.291		0.216	
April 1995	5			10.40	2.55			0.217	
COLOMBIA: Instituto de Investigaciones Marinas y Costeras									
February 1995	3	19.37	4.21	13.48	0.83	0.558		0.388	
CURAÇAO: CARMABI Foundation									
June 1994	5	5.94	1.42	8.08	3.19	0.211		0.287	
September 1995	5	5.94	1.42	8.07	3.27	0.211		0.286	
DOMINICAN REPUBLIC: Centro de Investigaciones de Biología Marina									
November 1995	1	13.32		6.09		0.153		0.070	
MEXICO: Centro de Investigación y Estudios Avanzados de IPN									
September 1994	3	17.42	5.84	11.65	3.25	0.557		0.372	
PUERTO RICO: UPR Department of Marine Sciences									
October 1994	3	8.26	2.50	7.82	2.45	0.349		0.330	
TRINIDAD & TOBAGO: Institute of Marine Affairs									
October 1993	1	11.84		5.25		1.085		0.477	
Mar & Sep 1994	4	9.94	3.72	4.36	0.86	1.019		0.447	
Mar & Sep 1995	7	9.70	4.80	5.66	2.02	0.610		0.356	
VENEZUELA: Universidad de Simon Bolivar, INTECMAR									
September 1994	3	9.02	5.48	6.88	4.47	0.199		0.152	
VENEZUELA: Fundación La Salle de Ciencias Naturales, EDIMAR									
May 1992	1	15.30		4.30		3.060		0.860	
June 1994	1	15.30		4.37		3.116		0.874	
July 1995	2	19.48	17.68	6.17	2.00	2.164		0.686	

[a]Cintrón and Schaeffer-Novelli (1984); [b]Golley *et al.* (1962).

Table 9a. CARICOMP mangrove measurements: Monthly mean litterfall (g m^{-2} d^{-1}), 1992 -1995.

	BAHAMAS			BELIZE			BERMUDA		
	Mean	SD	SE	Mean	SD	SE	Mean	SD	SE
1992									
May									
Jun							2.53	0.87	0.62
Jul							6.07	1.80	1.04
Aug							3.95	0.60	0.35
Sep							3.31	0.80	0.46
Oct							5.40	2.19	1.26
Nov							4.34	2.89	1.67
Dec							1.62	0.54	0.31
1993									
Jan				0.89	0.41	0.18	0.90	0.17	0.10
Feb				0.99			0.97	0.17	0.10
Mar				0.99			0.69	0.20	0.11
Apr				0.94	0.46	0.21			
May				1.46	0.98	0.44	1.84	0.51	0.29
Jun				1.64	0.95	0.42	2.81	0.89	0.51
Jul				1.69	0.88	0.39	4.33	0.72	0.42
Aug				1.95	0.78	0.35	3.97	0.56	0.32
Sep				2.68	0.67	0.30	4.84	1.94	1.12
Oct				2.01	0.88	0.39			
Nov				0.58	0.05	0.02	4.29	1.48	0.85
Dec				0.82	0.28	0.12			
1994									
Jan							1.45	1.03	0.59
Feb							0.62	0.24	0.14
Mar							0.52	0.11	0.06
Apr									
May							2.59	0.67	0.38
Jun							3.99	1.02	0.59
Jul							3.74	0.94	0.54
Aug							3.40	0.34	0.20
Sep	3.22						4.52	0.88	0.51
Oct	1.46						5.47	1.85	1.07
Nov	0.25								
Dec	0.25								
1995									
Jan	0.54	0.22	0.13						
Feb	0.48	0.30	0.18						
Mar	0.62	0.27	0.16						
Apr	0.65								
May	1.18								
Jun	1.18								
Jul	1.73	1.40	0.81						
Aug									
Sep									
Oct									
Nov									
Dec									

Table 9b. CARICOMP mangrove measurements: Monthly mean litterfall (g m^{-2} d^{-1}), 1992 -1995.

	CAYMAN			COLOMBIA			CURAÇAO		
	Mean	SD	SE	Mean	SD	SE	Mean	SD	SE
1992									
May									
Jun									
Jul									
Aug									
Sep									
Oct									
Nov									
Dec									
1993									
Jan									
Feb									
Mar									
Apr									
May									
Jun									
Jul									
Aug									
Sep									
Oct									
Nov									
Dec									
1994									
Jan									
Feb	1.17	0.27	0.14						
Mar	1.74	0.37	0.17						
Apr	1.90	0.38	0.17						
May	2.38	0.50	0.22						
Jun	3.81	0.80	0.86						
Jul	4.12	0.89	0.40				3.15	1.95	0.87
Aug	4.12	1.45	0.65				3.16	0.28	0.13
Sep	3.95	0.82	0.37				3.46	0.37	0.17
Oct	3.47	1.21	0.54				2.98	0.52	0.23
Nov	2.20	0.88	0.39				2.72	0.56	0.25
Dec	1.33	0.61	0.28				1.71	0.44	0.20
1995									
Jan	1.64	0.57	0.25				2.02	0.25	0.11
Feb							2.06	0.66	0.29
Mar							2.11	0.80	0.36
Apr							2.75	0.83	0.37
May							2.86	1.00	0.45
Jun							3.81	0.42	0.19
Jul	4.61	1.57	0.70	5.83	1.18	0.68	3.68	0.73	0.33
Aug	5.13	2.41	1.08	5.40	0.95	0.55			
Sep				5.66	0.64	0.37			
Oct				5.17	0.90	0.52			
Nov				5.05	0.35	0.20			
Dec				4.43	0.47	0.27			

Table 9c. CARICOMP mangrove measurements: Monthly mean litterfall (g m^{-2} d^{-1}), 1992 -1995.

	PUERTO RICO			TRINIDAD			VENEZUELA: EDIMAR*		
	Mean	SD	SE	Mean	SD	SE	Mean	SD	SE
1992									
May							8.66		
Jun							8.97		
Jul							7.03		
Aug							7.43		
Sep							5.32		
Oct							5.30		
Nov							4.10		
Dec							3.54		
1993									
Jan							4.02		
Feb							3.20		
Mar							5.51		
Apr							5.09		
May							7.07		
Jun							6.65		
Jul							6.60		
Aug							5.59		
Sep							4.70		
Oct							4.66		
Nov							4.20		
Dec							4.65		
1994									
Jan				2.80	0.54	0.38	3.94		
Feb				3.70	1.21	0.85	5.49		
Mar				4.14	0.98	0.44	4.39		
Apr				5.15	1.60	0.72	7.16		
May				5.66	1.66	0.74	6.82		
Jun				5.26	1.83	0.82	8.99		
Jul				3.76	0.93	0.41	9.77		
Aug				3.68	0.88	0.39	7.71		
Sep				3.51	1.85	0.83	7.89		
Oct				3.34	1.16	0.52	7.12		
Nov	5.19	0.51	0.29	3.39	0.93	0.42	7.72		
Dec	6.64	0.39	0.23	2.61	0.70	0.31	3.33		
1995									
Jan	2.68	0.47	0.27	2.79	1.30	0.58	3.83		
Feb	2.95	0.60	0.35	3.54	1.50	0.67	4.00	0.46	0.32
Mar	3.72	0.83	0.48	3.22	1.26	0.56	3.23	1.09	0.77
Apr	3.99	0.37	0.21				4.30	1.10	0.78
May	5.72	1.13	0.65				5.18	1.28	0.90
Jun							4.85	1.23	0.87
Jul							4.78	0.71	0.41
Aug							6.06	0.56	0.32
Sep							4.72	0.76	0.44
Oct							3.92	0.56	0.32
Nov							3.26	0.29	0.16
Dec							3.18	0.70	0.40

*EDIMAR: Plot A only, 1992-1994.

Table 10. CARICOMP interstitial water salinity measurements at mangrove sites, 1994-1995.

	BELIZE Salinity			COLOMBIA Salinity			CURAÇAO Salinity		
	%	SD	SE	%	SD	SE	%	SD	SE
1994									
Jan									
Feb									
Mar									
Apr									
May									
Jun							40.36	1.29	0.58
Jul							F		
Aug							42.98	2.67	1.19
Sep							39.24	2.92	1.30
Oct							39.62	4.68	2.09
Nov								flooded	
Dec							37.10	3.22	1.44
1995									
Jan							38.76	4.27	1.91
Feb							39.62	5.11	2.29
Mar							38.42	4.39	1.96
Apr							40.46	6.12	2.74
May							39.44	5.25	2.35
Jun								flooded	
Jul				43.13	3.35	1.93	34.50	2.51	1.12
Aug	41.50	12.77	5.21	44.17	3.71	2.14	28.50	3.59	1.60
Sep	35.92	12.38	3.57	43.47	4.37	2.52			
Oct	39.42	8.26	2.39	37.47	0.97	0.56			
Nov	36.11	2.57	0.86	42.97	2.80	1.62			
Dec	31.50	2.07	0.85	43.03	2.07	1.20			

	PUERTO RICO Salinity			VENEZUELA:EDIMAR Salinity		
	%	SD	SE	%	SD	SE
1994						
Jan						
Feb						
Mar						
Apr						
May						
Jun						
Jul						
Aug						
Sep						
Oct	35.50	1.64	0.67			
Nov						
Dec						
1995						
Jan						
Feb						
Mar						
Apr						
May				49.00	1.41	1.00
Jun						
Jul				43.50	2.12	1.50
Aug				46.33	0.58	0.33
Sep						
Oct				40.00	3.46	2.00
Nov				41.33	2.08	1.20
Dec						

Table 11a. CARICOMP seagrass biomass measurements, 1993-1995.

COUNTRY: Institution Site	Date	Biomass of Turtle Grass & Others g m^{-2} Mean	SD	SE	Biomass of Turtle Grass g m^{-2} Mean	SD	SE
BAHAMAS: *Bahamian Field Station*							
French Bay	Jul 1994	1982.4	761.8	380.9	1805.7	661.7	330.8
Grahams Harbour	Jul 1994	235.7	125.1	62.5	159.2	128.7	64.3
French Bay	Aug 1995	1671.8	308.6	154.3	1589.4	302.5	151.2
Grahams Harbour	Aug 1995	272.2	108.3	54.2	238.5	74.2	37.1
BARBADOS: *Bellairs Research Institute*							
East Lagoon	Apr 1993	7558.2	3339.6	1669.8	4920.9	1644.5	822.3
West Lagoon	Mar 1993	4343.4	2152.9	1076.5	3183.1	799.9	400.0
East Lagoon	Oct 1993	2310.2	305.0	152.5	1335.3	312.2	156.1
West Lagoon	Oct 1993	2468.8	141.4	70.7	1776.6	299.3	149.6
East Lagoon	Mar 1994	2578.7	637.3	318.7	1296.1	479.9	239.9
West Lagoon	Mar 1994	2772.4	425.2	212.6	1583.0	298.4	149.2
East Lagoon	Sep 1994	2574.3	401.2	200.6	1994.2	797.6	398.8
West Lagoon	Sep 1994	2723.7	369.2	213.2	1964.0	302.2	174.5
East Lagoon	Mar 1995	2360.2	533.6	266.8	1449.8	214.5	107.2
West Lagoon	Mar 1995	1981.6	505.1	252.6	800.0	358.9	179.4
BELIZE: *Smithsonian Institution*							
Carrie Bow Cay I	Aug 1993	4430.4	608.8	304.4	4279.7	621.9	310.9
Carrie Bow Cay II	Aug 1993	2380.3	469.2	234.6	2249.5	505.7	252.9
Carrie Bow Cay I	Dec 1993	3953.4	838.8	419.4	3492.9	594.4	297.2
Carrie Bow Cay II	Dec 1993	3343.3	782.6	391.3	3210.7	674.9	337.5
Carrie Bow Cay I	Aug 1994	4137.1	389.2	194.6	3967.0	406.7	203.3
Carrie Bow Cay II	Aug 1994	3432.4	1178.7	589.3	3358.7	1186.2	593.1
Carrie Bow Cay I	Dec 1994	4300.0	460.1	230.1	4177.6	463.9	232.0
Carrie Bow Cay II	Dec 1994	3619.2	764.9	382.5	3553.2	750.0	375.0
Carrie Bow Cay I	Aug 1995	4265.3	630.8	315.4	4197.9	643.3	321.6
Carrie Bow Cay II	Aug 1995	4243.5	564.5	282.2	4201.6	600.7	300.4
Carrie Bow Cay I	Dec 1995	3247.2	597.3	298.6	3075.5	627.4	313.7
Carrie Bow Cay II	Dec 1995	4362.6	734.8	367.4	4321.9	687.4	343.7
BERMUDA: *Bermuda Biological Station for Research*							
North Seagrass	Apr 1993	970.7	278.0	160.5	970.7	278.0	160.5
South Seagrass	May 1993	1089.9	220.7	127.4	1089.9	220.7	127.4
North Seagrass	Aug 1993	907.7	50.1	28.9	907.7	50.1	28.9
South Seagrass	Sep 1993	878.0	277.2	160.0	878.0	277.2	160.0
North Seagrass	Apr 1994	1083.8	77.6	44.8	1083.8	77.6	44.8
South Seagrass	Apr 1994	965.8	106.6	61.5	965.8	106.6	61.5
North Seagrass	Sep 1994	1152.8	350.0	202.1	1152.8	350.0	202.1
South Seagrass	Sep 1994	858.6	367.3	212.1	858.6	367.3	212.1
COLOMBIA: *Instituto de Investigaciones Marinas y Costeras (INVEMAR)*							
Chengue Bay I	Mar 1994	1356.0	536.3	268.2	1293.2	538.6	269.3
Chengue Bay II	Mar 1994	1073.1	44.8	22.4	1009.3	77.4	38.7
Chengue Bay I	Nov 1994	1262.1	379.0	189.5	1176.9	408.2	204.1
Chengue Bay II	Nov 1994	984.5	39.1	19.6	934.6	60.7	30.4
Chengue Bay I	Mar 1995	903.9	340.5	170.2	851.8	351.3	175.6
Chengue Bay II	Mar 1995	970.9	116.5	58.2	891.6	145.9	72.9
CUBA: *Instituto de Oceanología (CIEC)*							
Cayo Coco A	Mar 1994	2449.3	610.2	305.1	2396.3	518.7	259.4
Cayo Coco B	Mar 1994	2251.2	615.0	307.5	2251.2	615.0	307.5
Cayo Coco A	Oct 1994	1782.4	661.5	330.7	1753.7	618.2	309.1
Cayo Coco B	Oct 1994	2019.3	571.0	285.5	1870.3	704.8	352.4
Cayo Coco A	Apr 1995	934.0	291.4	145.7	931.9	287.5	143.8
Cayo Coco B	Apr 1995	1522.7	332.4	166.2	1522.7	332.4	166.2
Cayo Coco A	Aug 1995	1329.3	658.7	329.3	1325.6	657.2	328.6
Cayo Coco B	Aug 1995	1237.3	235.5	117.8	1204.7	214.7	107.4

Table 11b. CARICOMP seagrass biomass measurements, 1993-1995.

COUNTRY Institution Site	Date	Biomass of Turtle Grass & Others g m^{-2} Mean	SD	SE	Biomass of Turtle Grass g m^{-2} Mean	SD	SE
CURAÇAO: *Carmabi Foundation*							
Spanish Water	Mar 1994	668.9	155.2	77.6	504.1	230.0	115.0
Spanish Water	Mar 1995	565.2	278.5	139.2	452.6	216.6	108.3
Spanish Water	Sep 1995	575.6	108.5	54.3	192.7	18.2	9.1
JAMAICA: *Discovery Bay Marine Lab, University of the West Indies*							
Back Reef	Aug 1993	839.3	174.3	87.2	783.7	185.3	92.7
Back Reef	Jun 1994	1037.2	93.3	46.7	956.7	113.3	56.7
Back Reef	Jun 1995	1151.0	248.6	124.3	1045.1	224.0	112.0
MEXICO: ICMyL, *Universidad Autónoma de Mexico*							
Puerto Morelos I	Sep 1992	1383.7	231.6	115.8	1274.5	209.9	105.0
Puerto Morelos II	Sep 1992	859.2	251.1	125.5	691.5	155.0	77.5
Puerto Morelos I	Feb 1993	1526.0	88.1	44.0	1365.1	82.7	41.3
Puerto Morelos II	Mar 1993	776.4	173.0	86.5	690.9	185.1	92.6
Puerto Morelos I	Aug 1993	1588.9	210.7	105.3	1409.7	250.5	125.3
Puerto Morelos II	Aug 1993	1078.9	271.3	135.6	971.4	244.8	122.4
Puerto Morelos I	Feb 1994	1487.8	101.6	58.7	1277.8	123.4	71.2
Puerto Morelos II	Feb 1994	942.2	169.7	98.0	809.6	197.0	113.7
Puerto Morelos I	Aug 1994	1083.5	175.5	101.3	942.5	169.0	97.6
Puerto Morelos II	Aug 1994	872.2	289.9	167.4	719.9	258.5	149.2
Puerto Morelos I	Jan 1995	1386.3	170.2	98.3	1268.0	178.5	103.1
Puerto Morelos II	Jan 1995	930.5	96.2	55.6	749.9	63.9	36.9
Puerto Morelos I	Aug 1995	1233.8	210.6	121.6	1000.4	227.4	131.3
Puerto Morelos II	Aug 1995	1044.6	264.0	152.4	852.3	178.1	102.8
MEXICO: CINVESTAV, *Merida*							
Celestun I	Sep 1994	917.6	552.6	276.3	917.6	552.6	276.3
Celestun II	Oct 1994	4756.0	2469.8	1234.9	4756.0	2469.8	1234.9
Celestun I	Jun 1995	2766.6	478.1	239.1	2731.7	483.3	241.6
Celestun II	Jul 1995	3069.9	1571.1	785.6	3069.9	1571.1	785.6
PUERTO RICO, USA: *Department of Marine Sciences, University of Puerto Rico*							
La Parguera I	Sep 1994	700.4	160.1	80.0	700.4	160.1	80.0
La Parguera II	Sep 1994	1007.2	128.4	64.2	1007.2	128.4	64.2
La Parguera I	Mar 1995	768.8	174.6	87.3	768.8	174.6	87.3
La Parguera II	Mar 1995	830.0	170.7	85.4	830.0	170.7	85.4
TRINIDAD & TOBAGO: *Institute of Marine Affairs (IMA)*							
Bon Accord Lagoon	Oct 1992	408.6	90.5	45.3	408.6	90.5	45.3
Bon Accord Lagoon	Sep 1994	436.1	30.7	15.4	423.7	39.0	19.5
Bon Accord Lagoon	Mar 1995	504.1	16.8	8.4	495.5	11.4	5.7
VENEZUELA: *Universidad de Simón Bolívar*							
Las Luisas	Jun 1993	661.3	270.4	156.1	661.3	270.4	156.1
Tumba Cuatro	Sep 1993	1088.8	186.2	107.5	1088.8	186.2	107.5
Las Luisas	Mar 1994	1060.0	454.8	227.4	1060.0	454.8	227.4
Tumba Cuatro	Mar 1994	890.6	578.5	289.3	890.6	578.5	289.3
Las Luisas	Sep 1994	1650.1	301.6	150.8	1650.1	301.6	150.8
Tumba Cuatro	Sep 1994	1459.8	298.4	149.2	1459.8	298.4	149.2
Las Luisas	Mar 1995	836.1	148.6	74.3	836.1	148.6	74.3
VENEZUELA: *Fundación La Salle de Ciencias Naturales, EDIMAR, Margarita Island*							
Punta de Mangle	Dec 1993	2257.50	400.30	283.06			
Punta de Mangle	Jan 1994	2630.00	422.69	298.89			
Punta de Mangle	Feb 1994	2013.05	858.35	606.94			
Punta de Mangle	Mar 1994	3061.11	1865.98	1319.44			
Punta de Mangle	Apr 1994	1527.78	526.40	372.22			
Punta de Mangle	Jun 1994	1416.67	447.83	316.67			
Punta de Mangle	Nov 1995	1029.10	403.60	201.80			

Table 12a. CARICOMP turtle grass (*Thalassia testudinum*) growth measurements, 1993-1995: Percent per day.

Country and Institution Site	Date	Mean Areal Productivity Mean	SD	SE	Mean Turnover per Biomass of Plant Mean	SD	SE
BAHAMAS: *Bahamian Field Station*							
French Bay	Jul 1994	0.35	0.16	0.06	4.35	1.04	0.42
Grahams Harbour	Jul 1994	0.46	0.22	0.09	3.10	0.94	0.38
French Bay	Jan 1995	1.11	0.54	0.22	2.97	0.43	0.18
Grahams Harbour	Jan 1995	0.70	0.45	0.18	3.16	1.91	0.78
French Bay	Jul 1995	2.29	0.43	0.25	3.26	0.60	0.35
Grahams Harbour	Jul 1995	0.94	0.16	0.09	2.98	0.09	0.05
BARBADOS: *Bellairs Research Institute*							
East Lagoon	Apr 1993	2.88	0.49	0.20	3.58	0.62	0.25
West Lagoon	Apr 1993	5.09	2.42	0.99	3.32	0.46	0.19
East Lagoon	Oct 1993	3.33	1.03	0.42	3.18	0.22	0.09
West Lagoon	Oct 1993	2.43	0.63	0.26	3.98	0.33	0.13
East Lagoon	Mar 1994	3.83	0.76	0.31	5.48	0.67	0.27
West Lagoon	Mar 1994	5.29	1.05	0.43	5.16	0.99	0.41
East Lagoon	Sep 1994	2.90	0.80	0.36	3.44	0.43	0.19
West Lagoon	Sep 1994	3.01	2.43	1.40	3.05	0.19	0.11
East Lagoon	Mar 1995	3.08	0.36	0.15	3.09	0.42	0.17
West Lagoon	Mar 1995	2.47	0.79	0.32	3.36	0.53	0.22
East Lagoon	Nov 1995	2.61	1.07	0.48	3.89	0.61	0.27
West Lagoon	Nov 1995	4.16	1.27	0.52	3.01	0.54	0.22
BELIZE: *Smithsonian Institution*							
Carrie Bow Cay I	Aug 1993	2.52	0.52	0.21	2.52	0.29	0.12
Carrie Bow Cay II	Aug 1993	2.73	0.83	0.34	2.79	0.57	0.23
Carrie Bow Cay I	Dec.1993	2.41	1.19	0.49	2.75	0.51	0.21
Carrie Bow Cay II	Dec.1993	2.41	0.79	0.32	2.35	0.19	0.08
Carrie Bow Cay I	Aug 1994	2.75	1.38	0.56	2.22	0.26	0.11
Carrie Bow Cay II	Aug 1994	2.41	0.69	0.28	2.27	0.37	0.15
Carrie Bow Cay I	Dec 1994	1.61	0.30	0.12	1.66	0.18	0.08
Carrie Bow Cay II	Dec 1994	1.80	0.53	0.21	1.60	0.11	0.05
Carrie Bow Cay I	Aug 1995	4.19	1.24	0.50	2.48	0.10	0.04
Carrie Bow Cay II	Aug 1995	2.67	1.01	0.41	2.49	0.25	0.10
Carrie Bow Cay I	Dec 1995	2.65	1.31	0.53	3.03	0.56	0.23
Carrie Bow Cay II	Dec 1995	2.66	0.87	0.36	2.59	0.21	0.09
BERMUDA: *Bermuda Biological Station for Research*							
North Seagrass	Apr 1993	1.19	0.40	0.16	2.93	0.28	0.11
South Seagrass	Apr 1993	1.15	0.29	0.13	2.85	0.35	0.16
North Seagrass	Aug 1993	1.06	0.23	0.09	2.67	0.27	0.11
South Seagrass	Aug 1993	1.38	0.45	0.19	3.41	0.45	0.18
North Seagrass	Apr 1994	1.48	0.47	0.19	4.74	0.40	0.16
South Seagrass	Apr 1994	1.35	0.44	0.18	5.07	0.29	0.12
North Seagrass	Sep 1994	1.12	0.34	0.14	2.54	0.60	0.25
South Seagrass	Sep 1994	0.96	0.46	0.19	2.34	0.50	0.21
North Seagrass	Apr 1995	1.15	0.21	0.08	3.64	0.43	0.18
South Seagrass	Apr 1995	1.45	0.42	0.17	3.72	0.53	0.22
North Seagrass	Sep 1995	0.64	0.32	0.13	4.08	1.15	0.47
South Seagrass	Sep 1995	0.52	0.10	0.04	2.14	0.25	0.10
COLOMBIA: *Instituto de Investigaciones Marinas y Costeras (INVEMAR)*							
Chengue Bay I	Mar 1994	4.20	0.68	0.28	3.23	0.44	0.18
Chengue Bay II	Mar 1994	3.07	1.23	0.50	4.81	1.91	0.78
Chengue Bay I	Nov 1994	2.71	0.49	0.20	3.23	0.40	0.16
Chengue Bay II	Nov 1994	3.42	0.48	0.20	3.14	0.28	0.11
Chengue Bay I	Mar 1995	3.89	1.21	0.49	3.55	0.43	0.18
Chengue Bay II	Mar 1995	3.56	1.03	0.42	3.43	0.20	0.08
CUBA: *Instituto de Oceanología (CIEC)*							
Cayo Coco A	Mar 1994	1.76	0.37	0.15	2.01	0.16	0.07
Cayo Coco B	Mar 1994	2.07	0.52	0.21	2.06	0.13	0.05
Cayo Coco A	Oct 1994	1.64	0.43	0.18	2.40	0.26	0.10
Cayo Coco B	Oct 1994	1.04	0.23	0.09	2.94	0.42	0.17

Table 12b. CARICOMP turtle grass (*Thalassia testudinum*) growth measurements, 1993-1995: Percent per day.

Country and Institution		Mean Areal Productivity			Mean Turnover per Biomass of Plant		
Site	Date	Mean	SD	SE	Mean	SD	SE
CUBA: *Instituto de Oceanología (CIEC)*							
Cayo Coco A	Apr 1995	2.24	0.70	0.28	3.68	0.42	0.17
Cayo Coco B	Apr 1995	1.83	0.20	0.08	2.40	0.41	0.17
Cayo Coco A	Aug 1995	2.65	0.32	0.13	2.07	0.61	0.25
Cayo Coco B	Aug 1995	1.70	0.45	0.18	2.52	0.60	0.25
CURAÇAO: *Carmabi Foundation*							
Spanish Water	Mar 1994	1.22	0.31	0.13	2.29	0.33	0.14
Spanish Water	Mar 1995	0.60	0.25	0.10	3.14	0.31	0.13
Spanish Water	Sep 1995	0.14	0.09	0.04	2.44	0.73	0.30
JAMAICA: *Discovery Bay Marine Lab, University of the West Indies*							
Discovery Bay I	Feb 1993	2.97	0.98	0.40	4.27	0.73	0.30
Discovery Bay II	Feb 1993	3.79	1.16	0.47	3.32	0.37	0.15
Discovery Bay I	Aug 1993	1.87	0.54	0.22	3.61	0.69	0.28
Discovery Bay II	Aug 1993	1.35	0.45	0.18	3.37	0.94	0.38
Discovery Bay I	Jun 1994	3.76	2.48	1.11	2.56	0.89	0.40
Discovery Bay I	Aug 1995	2.48	0.65	0.27	2.91	1.05	0.43
Discovery Bay II	Aug 1995	3.42	0.74	0.33	3.32	0.54	0.24
MEXICO: *ICMyL, Universidad Autónoma de Mexico*							
Puerto Morelos I	Feb 1993	2.07	0.90	0.37	2.32	0.23	0.09
Puerto Morelos II	Feb 1993	0.55	0.28	0.12	2.17	0.70	0.29
Puerto Morelos I	Aug 1993	2.15	1.12	0.46	3.24	0.22	0.09
Puerto Morelos II	Aug 1993	1.38	0.61	0.25	3.26	0.56	0.23
Puerto Morelos I	Feb 1994	1.64	0.22	0.09	2.66	0.23	0.09
Puerto Morelos II	Feb 1994	0.80	0.27	0.11	3.16	0.62	0.25
Puerto Morelos I	Aug 1994	2.17	1.22	0.50	2.99	1.27	0.52
Puerto Morelos II	Aug 1994	1.13	0.45	0.18	3.08	0.82	0.34
Puerto Morelos I	Jan 1995	1.13	0.33	0.13	2.18	0.24	0.10
Puerto Morelos II	Jan 1995	0.87	0.41	0.17	2.65	0.49	0.20
Puerto Morelos I	Aug 1995	1.76	0.58	0.24	2.80	0.51	0.21
Puerto Morelos II	Aug 1995	1.13	0.49	0.20	2.88	0.40	0.16
MEXICO: *CINVESTAV, Merida*							
Celestun I	Jun 1995	7.56	4.87	2.81	4.30	1.20	0.70
PUERTO RICO, USA: *Department of Marine Sciences, University of Puerto Rico*							
La Parguera I	Sep 1994	2.74	1.09	0.77	5.13	0.16	0.11
La Parguera II	Sep 1994	3.57	1.67	1.18	5.27	0.29	0.20
La Parguera I	Mar 1995	2.21	0.30	0.21	3.65	0.20	0.14
La Parguera II	Mar 1995	1.46	0.50	0.36	4.60	0.32	0.23
La Parguera I	Nov 1995	3.14	1.12	0.79	5.08	0.11	0.08
La Parguera II	Nov 1995	2.46	0.43	0.31	5.62	1.06	0.75
TRINIDAD: *Institute of Marine Affairs (IMA)*							
Bon Accord Lagoon	Mar 1993	2.60	1.12	0.46	3.69	0.56	0.23
Bon Accord Lagoon	Sep 1994	1.09	0.25	0.10	2.41	0.40	0.16
Bon Accord Lagoon	Mar 1995	1.97	0.22	0.09	3.74	0.68	0.28
VENEZUELA: *Universidad de Simón Bolívar*							
Las Luisas	Mar 1994	2.53	0.11	0.06	2.12	0.23	0.13
Tumba Cuatro	Mar 1994	1.53	0.28	0.16	3.02	0.41	0.24
Las Luisas	Sep 1994	1.36	0.27	0.16	2.17	0.41	0.24
Tumba Cuatro	Sep 1994	0.84	0.48	0.28	2.55	0.50	0.29
Las Luisas	Mar 1995	2.14	0.86	0.43	2.03	0.50	0.25
VENEZUELA: *Fundación La Salle de Ciencias Naturales, EDIMAR*							
Punta de Mangle	Dec 1993	2.88	0.17	0.10	5.16	1.73	1.00
Margarita Island	Jan 1994	7.32	0.40	0.28	5.20	0.30	0.21
	Feb 1994	5.28	1.18	0.68	4.84	1.16	0.67
	Mar 1994	4.09	2.16	1.08	4.57	0.71	0.35
	Apr 1994	8.29	1.30	0.65	3.78	0.27	0.14
	1 Jun 1994	5.19	1.36	0.96	3.04	1.08	0.76
	16 Jun 1994	4.28	0.84	0.42	4.23	1.29	0.65
	Nov 1995	1.49	0.70	0.31	5.06	0.66	0.30

Table 13. CARICOMP turtle grass (*Thalassia testudinum*) leaf measurements, 1993-1995.

Country and Institution Site	Date	Shoots/ Quadrat Mean	Mean Leaf Length (cm) Mean	SD	SE	Mean Leaf Width (mm) Mean	SD	SE	Leaf Area Index (m^2 leaf per m^2 surface) Index	SD	SE
BELIZE: *Smithsonian Institution*											
Carrie Bow Cay I	Dec 1994	21.0	16.83	8.30	2.14	12.00	0.93	0.24	6.44	0.91	0.41
Carrie Bow Cay I	Aug 1995	21.5	18.92	11.76	3.14	11.93	0.92	0.25	6.84	3.69	1.65
Carrie Bow Cay II		18.7	15.90	8.21	2.12	11.87	0.92	0.24	5.31	0.38	0.17
Carrie Bow Cay I	Dec 1995	19.0	20.69	12.40	3.20	12.80	1.94	0.50	7.72	2.70	1.21
Carrie Bow Cay II		17.0	20.20	10.73	3.10	11.08	1.08	0.31	4.68	1.68	0.75
BERMUDA: *Bermuda Biological Station for Research*											
North Bermuda	Sep 1994	15.7	8.18	3.98	1.03	8.53	0.92	0.24	1.68	0.62	0.28
South Bermuda		13.8	6.12	2.85	0.76	6.14	1.35	0.36	0.74	0.24	0.11
COLOMBIA: *Instituto de Investigaciones Marinas y Costeras (INVEMAR)*											
Chengue Bay 1	Mar 1994	11.0	15.81	12.71	2.54	15.04	1.31	0.26	6.59	1.15	0.52
Chengue Bay II		11.0	17.72	12.02	2.56	14.77	0.43	0.09	6.33	0.89	0.40
Chengue Bay 1	Nov1994	10.8	16.12	9.20	2.17	16.22	2.05	0.48	5.12	0.49	0.22
Chengue Bay II		17.3	20.07	8.70	2.25	15.20	1.37	0.36	7.97	0.96	0.43
Chengue Bay 1	Mar 1995	12.5	20.50	9.58	2.32	15.06	2.16	0.53	6.60	2.07	0.93
Chengue Bay II		17.5	22.28	10.97	2.59	15.39	0.50	0.12	10.75	1.83	0.82
CUBA: *Instituto de Oceanología (CIEC)*											
Cayo Coco A	Mar 1994	ND	12.65	4.06	0.98	9.59	1.18	0.29	ND		
Cayo Coco B		ND	11.41	5.34	1.20	10.20	1.40	0.31	ND		
Cayo Coco A	Oct 1994	ND	14.54	7.47	2.16	8.44	0.78	0.22	ND		
Cayo Coco B		ND	10.29	4.98	1.29	9.63	1.60	0.41	ND		
Cayo Coco A	Apr 1995	13.0	21.94	8.23	1.75	9.23	1.45	0.31	5.91	1.67	0.75
Cayo Coco B		13.2	13.03	4.84	1.01	8.30	2.18	0.46	3.41	0.95	0.43
Cayo Coco A	Sep 1995	18.5	25.16	9.34	2.14	8.81	0.24	0.06	7.80	1.66	0.74
Cayo Coco B		15.7	13.45	7.39	1.51	7.75	1.48	0.30	4.61	1.56	0.70
CURAÇAO: *Carmabi Foundation*											
Spanish Water	Mar 1995	3.5	16.71	6.40	1.65	10.53	1.46	0.38	0.93	0.40	
Spanish Water	Oct 1995	2.7	14.25	5.12	1.48	9.42	0.79	0.23	0.43	0.21	
MEXICO: *Instituto de Ciencias Marinas y Limnología, Estación Puerto Morelos*											
High Prod.	Aug 1993	10.2	11.54	6.66	1.92	11.67	3.03	0.87	1.70	0.92	0.41
Typical		10.3	8.38	4.21	1.22	7.42	2.02	0.58	0.74	0.30	0.13
High Prod.	Feb 1994	9.3	8.94	5.04	1.40	10.92	0.76	0.22	1.18	0.30	0.14
Typical		9.7	9.78	3.91	1.13	8.42	0.79	0.23	0.97	0.35	0.15
High Prod.	Aug 1994	8.0	12.18	8.45	2.34	10.69	1.93	0.54	1.40	0.76	0.34
Typical		12.0	8.08	5.23	1.58	8.09	1.64	0.50	0.89	0.53	0.24
High Prod.	Jan 1995	9.5	10.97	6.52	2.06	10.80	0.79	0.25	1.15	0.50	0.22
Typical		11.0	8.09	5.51	1.59	8.83	0.72	0.21	0.95	0.33	0.15
High Prod.	Aug 1995	9.8	14.69	6.34	1.91	12.27	1.10	0.33	1.95	0.28	0.13
Typical		10.7	14.93	6.41	2.14	8.78	1.39	0.47	1.28	0.58	0.26
MEXICO: *CINVESTAV*											
Celestun	Sept 1994	ND	13.27	6.11	1.22	10.84	3.76	0.75	ND		
PUERTO RICO, USA: *Department of Marine Sciences, University of Puerto Rico*											
Isla Magueyes A	Mar 1995	22.0	10.38	5.54	1.34	9.29	1.15	0.28	3.66	1.64	0.73
Isla Magueyes B		9.5	9.10	4.47	1.15	8.60	0.51	0.13	1.11	0.16	0.07
VENEZUELA: *INTECMAR*											
Las Luisas	Sept 1994	ND	14.77	6.56	1.37	9.44	0.59	0.12	ND		
Las Luisas	Mar 1995	ND	15.37	9.53	1.95	10.96	1.20	0.24	ND		
VENEZUELA: *EDIMAR*											
Punta de Mangle	Nov 1995	8.2	12.75	6.56	1.40	16.00	1.41	0.30	3.74	1.03	0.46

ND: Leaf Area Index could not be calculated as the mean number of shoots/quadrat was not measured.

Table 14a. CARICOMP coral reef transect measurements, 1993-1995: Percentage cover at 10 m depth.

COUNTRY	BAHAMAS					
Reef Site	Fernandez Bay, San Salvador					
Date of Survey	Nov 1994		4-8 Feb 1995		19-22 Nov 1995	
Number of Transects and Std Dev	T 1-10	SD	T 1-10	SD	T 1-10	SD
ALGAE						
Calcareous algae	0.31	0.73	0.00	0.00	0.00	0.00
Encrusting algae	1.48	1.43	1.89	2.53	3.28	3.04
Fleshy algae	10.17	3.45	21.02	7.37	13.34	4.31
Turf algae	5.56	4.04	7.31	6.10	11.12	4.16
TOTAL	17.51	6.26	30.22	7.08	27.74	7.03
HARD CORALS						
Branching corals	0.34	0.49	0.14	0.20	0.10	0.14
Massive corals	2.18	1.66	1.36	1.36	2.68	1.90
Encrusting corals	4.97	2.42	6.11	3.50	3.47	1.87
Foliaceous	2.09	2.37	1.11	0.94	0.81	1.17
Milleporine	0.12	0.38	0.01	0.04	0.00	0.00
TOTAL	9.69	4.68	8.74	3.81	7.05	2.95
SOFT CORALS						
Gorgonians	0.10	0.13	0.21	0.18	0.04	0.04
Encrusting gorgonians	0.00	0.00	0.00	0.00	0.00	0.00
Anemones	0.00	0.00	0.00	0.00	0.00	0.00
Zoanthids	0.00	0.00	0.00	0.00	0.00	0.00
Coralliomorpharians	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	0.10	0.13	0.21	0.18	0.04	0.04
SPONGES						
Erect sponges	1.25	2.15	2.14	2.94	3.06	2.62
Encrusting sponges	3.64	1.33	2.04	1.63	0.51	0.88
Other organisms	0.02	0.06	0.00	0.00	0.10	0.02
TOTAL	4.90	3.14	4.18	2.42	3.58	2.59
ABIOTIC						
Bare rock	16.71	8.76	5.78	4.93	8.12	6.00
Bare rubble	8.52	8.14	14.01	10.20	8.43	3.77
Bare boulders	7.90	8.52	0.21	0.48	6.21	4.10
Holes, gaps	27.93	6.89	29.35	7.46	36.55	7.29
Sand	2.89	4.70	1.48	2.60	2.29	3.28
Dead coral	3.92	3.46	5.83	8.31	0.00	0.00
TOTAL	67.86	5.19	56.66	7.96	61.61	5.97
Total Chain Links	1219.90	181.20	1226.70	154.10	1349.20	141.20
Rugosity	1.72	0.26	1.73	0.22	1.90	0.20
Percent Hard & Soft Coral in Biotic	30.86	14.78	20.74	7.19	18.73	7.76

Table 14b. CARICOMP coral reef transect measurements, 1993-1995: Percentage cover at 10 m depth.

COUNTRY	BARBADOS					
Reef Site	North and South Bellairs					
Date of Survey	April 1993		March 1994		September -October 1994	
Number of Transects and Std Dev	T 1-10	SD	T 1-10	SD	T 1-9	SD
ALGAE						
Calcareous algae	0.00	0.00	0.01	0.04	0.00	0.00
Encrusting algae	2.86	2.89	8.04	5.50	11.94	5.23
Fleshy algae	0.02	0.06	0.11	0.29	0.04	0.12
Turf algae	57.74	17.56	51.40	11.36	40.08	17.59
TOTAL	60.62	16.26	59.57	11.28	52.05	18.16
HARD CORALS						
Branching corals	0.60	1.05	1.03	2.07	0.83	1.08
Massive corals	7.31	7.10	7.81	7.99	7.21	5.61
Encrusting corals	8.51	3.30	4.91	3.43	7.89	3.46
Foliaceous	0.00	0.00	0.00	0.00	0.00	0.00
Milleporine	1.19	1.47	0.94	0.68	1.45	0.85
TOTAL	17.60	6.65	14.69	10.06	17.38	9.10
SOFT CORALS						
Gorgonians	0.00	0.00	0.00	0.00	0.00	0.00
Encrusting gorgonians	0.00	0.00	0.00	0.00	0.00	0.00
Anemones	0.00	0.00	0.24	0.59	0.00	0.00
Zoanthids	0.00	0.00	0.00	0.00	0.00	0.00
Coralliomorpharians	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	0.00	0.00	0.24	0.59	0.00	0.00
SPONGES						
Erect sponges	0.50	1.53	0.00	0.00	0.13	0.35
Encrusting sponges	0.15	0.47	0.08	0.21	0.00	0.00
Other organisms	0.71	1.68	0.00	0.00	0.00	0.00
TOTAL	1.36	2.09	0.08	0.21	0.13	0.35
ABIOTIC						
Bare rock	0.00	0.00	0.00	0.00	0.11	0.33
Bare rubble	9.24	7.84	0.00	0.00	0.00	0.00
Bare boulders	0.00	0.00	0.00	0.00	0.00	0.00
Holes, gaps	7.03	7.08	20.57	6.83	21.22	8.89
Sand	4.15	5.18	4.85	4.69	9.11	5.71
Dead coral	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	20.42	13.99	25.43	7.45	30.44	11.03
Total Chain Links	1499.20	220.70	1370.40	97.30	1200.90	126.50
Rugosity	2.11	0.31	1.93	0.14	1.69	0.18
Percent Hard & Soft Coral in Biotic	23.05	9.43	19.95	12.54	24.23	17.78

Table 14c. CARICOMP coral reef transect measurements, 1993-1995: Percentage cover at 10 m depth.

COUNTRY	BELIZE					
Reef Site	Carrie Bow Cay I and II					
Date of Survey	August 1993		August 1994		December 1994	
Number of Transects and Std Dev	T 1-10	SD	T 1-10	SD	T 1-10	SD
ALGAE						
Calcareous algae	14.17	4.04	12.72	3.79	15.92	4.02
Encrusting algae	6.45	2.46	4.60	1.40	7.53	2.22
Fleshy algae	13.38	5.29	23.52	7.68	12.54	5.09
Turf algae	19.02	2.51	17.12	4.92	21.97	4.66
TOTAL	53.01	5.25	57.95	8.53	57.96	9.01
HARD CORALS						
Branching corals	3.32	2.59	4.46	3.12	3.87	3.48
Massive corals	2.63	1.49	3.36	2.08	3.56	2.28
Encrusting corals	2.34	2.08	5.82	3.66	3.66	1.94
Foliaceous	5.52	5.24	4.95	7.14	6.18	7.03
Milleporine	0.25	0.40	0.26	0.24	0.29	0.38
TOTAL	14.06	5.95	18.85	6.94	17.56	7.70
SOFT CORALS						
Gorgonians	1.76	0.86	1.13	0.79	1.15	0.79
Encrusting gorgonians	0.00	0.00	0.00	0.00	0.06	0.19
Anemones	0.08	0.19	0.03	0.08	0.03	0.07
Zoanthids	0.02	0.06	0.00	0.00	0.06	0.18
Coralliomorpharians	0.12	0.19	0.15	0.32	0.20	0.47
TOTAL	1.98	0.88	1.31	0.85	1.50	1.04
SPONGES						
Erect sponges	1.29	1.97	1.62	2.17	1.40	2.35
Encrusting sponges	1.51	0.96	0.91	0.76	0.76	0.64
Other organisms	0.89	1.12	0.11	0.28	0.16	0.23
TOTAL	3.69	2.61	2.65	2.02	2.32	2.49
ABIOTIC						
Bare rock	2.69	2.10	4.29	2.49	3.03	1.18
Bare rubble	6.70	6.12	2.97	2.82	2.77	5.25
Bare boulders	0.00	0.00	0.00	0.00	0.00	0.00
Holes, gaps	15.76	4.18	9.99	4.03	13.87	4.31
Sand	2.21	2.94	1.55	2.62	0.64	0.74
Dead coral	0.00	0.00	0.44	1.20	0.36	1.13
TOTAL	27.36	5.83	19.25	6.26	20.66	5.07
Total Chain Links	1170.10	76.00	1172.90	70.20	1174.20	76.60
Rugosity	1.65	0.11	1.65	0.10	1.66	0.11
Percent Hard & Soft Coral in Biotic	21.92	6.22	24.97	7.39	23.99	8.74

Table 14d. CARICOMP coral reef transect measurements, 1993-1995: Percentage cover at 10 m depth.

COUNTRY	BELIZE			
Reef Site	Carrie Bow Cay I and II			
Date of Survey	August 1995		December 1995	
Number of Transects and Std Dev	T 1-10	SD	T 1-10	SD
ALGAE				
Calcareous algae	18.91	5.85	15.97	3.98
Encrusting algae	6.56	2.20	10.21	3.34
Fleshy algae	16.09	3.57	13.59	4.53
Turf algae	17.67	9.57	18.03	5.39
TOTAL	59.23	8.67	57.81	9.14
HARD CORALS				
Branching corals	3.34	3.04	3.92	3.28
Massive corals	4.41	2.89	4.00	2.98
Encrusting corals	2.92	1.79	4.33	2.05
Foliaceous	5.48	6.65	4.83	7.35
Milleporine	0.44	0.47	0.35	0.34
TOTAL	16.59	6.51	17.43	8.05
SOFT CORALS				
Gorgonians	1.30	1.04	1.16	0.79
Encrusting gorgonians	0.00	0.00	0.00	0.00
Anemones	0.02	0.04	0.00	0.00
Zoanthids	0.02	0.06	0.01	0.03
Coralliomorpharians	0.27	0.45	0.30	0.56
TOTAL	1.61	1.31	1.58	1.22
SPONGES				
Erect sponges	1.63	2.60	2.11	2.94
Encrusting sponges	0.68	0.51	0.89	0.63
Other organisms	0.06	0.13	0.21	0.31
TOTAL	2.37	2.80	3.21	2.93
ABIOTIC				
Bare rock	2.33	1.44	3.15	1.20
Bare rubble	2.66	2.14	1.19	0.91
Bare boulders	0.00	0.00	0.00	0.00
Holes, gaps	13.28	3.08	12.86	3.41
Sand	1.61	3.43	2.43	3.77
Dead coral	0.32	0.63	0.37	0.58
TOTAL	20.21	5.57	19.99	3.02
Total Chain Links	1216.70	58.20	1186.30	65.10
Rugosity	1.72	0.08	1.67	0.09
Percent Hard & Soft Coral in Biotic	22.84	7.00	23.78	9.00

Table 14e. CARICOMP coral reef transect measurements, 1993-1995: Percentage cover at 10 m depth.

COUNTRY	BERMUDA					
Reef Site	Hog Breaker West and Twin Breaker					
Date of Survey	September 1993		August-October 1994		September 1995	
Number of Transects and Std Dev	T 1-10	SD	T 1-10	SD	T 1-10	SD
ALGAE						
Calcareous algae	0.50	1.02	0.33	0.65	0.00	0.00
Encrusting algae	0.35	1.01	2.25	3.31	0.00	0.00
Fleshy algae	7.87	6.13	9.61	3.31	4.44	2.78
Turf algae	14.91	10.09	10.56	7.29	6.74	4.12
TOTAL	23.63	14.10	22.75	10.15	11.18	3.71
HARD CORALS						
Branching corals	0.38	1.03	0.00	0.00	0.00	0.00
Massive corals	19.44	5.86	16.78	4.80	9.63	4.87
Encrusting corals	3.12	4.14	2.42	3.26	10.15	3.78
Foliaceous	0.00	0.00	0.00	0.00	0.02	0.06
Milleporine	0.32	0.34	0.52	0.68	0.76	0.76
TOTAL	23.25	5.49	19.71	4.51	20.56	5.21
SOFT CORALS						
Gorgonians	0.49	0.60	0.53	0.42	0.70	0.66
Encrusting gorgonians	0.00	0.00	0.00	0.00	0.00	0.00
Anemones	0.00	0.00	0.00	0.00	0.00	0.00
Zoanthids	0.00	0.00	0.00	0.00	0.00	0.00
Coralliomorpharians	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	0.49	0.60	0.53	0.42	0.70	0.66
SPONGES						
Erect sponges	0.00	0.00	0.03	0.08	0.00	0.00
Encrusting sponges	0.06	0.20	0.10	0.21	0.09	0.14
Other organisms	0.23	0.66	0.00	0.00	0.00	0.00
TOTAL	0.30	0.86	0.12	0.22	0.09	0.14
ABIOTIC						
Bare rock	25.80	17.02	27.00	12.36	39.44	8.29
Bare rubble	0.64	2.02	2.02	2.34	0.22	0.71
Bare boulders	0.00	0.00	0.00	0.00	0.00	0.00
Holes, gaps	22.84	7.14	24.22	6.65	22.85	7.03
Sand	3.06	5.90	3.66	4.08	5.02	3.63
Dead coral	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	52.34	14.56	56.90	10.19	67.48	4.91
Total Chain Links	1116.00	87.40	1186.20	82.20	1173.80	125.50
Rugosity	1.57	0.12	1.67	0.12	1.66	0.18
Percent Hard & Soft Coral in Biotic	53.06	16.59	48.77	12.14	65.06	11.45

Table 14f. CARICOMP coral reef transect measurements, 1993-1995: Percentage cover at 10 m depth.

COUNTRY	BONAIRE				CAYMAN	
Reef Site	Barcadera Reef Sites				Andes and Pinnacle	
Date of Survey	October 1994		March 1995		October 1995	
Number of Transects and Std Dev	T 1-10	SD	T 1-10	SD	T 1-10	SD
ALGAE						
Calcareous algae	3.65	2.21	0.00	0.00	3.60	3.43
Encrusting algae	0.01	0.04	3.90	2.85	3.67	6.23
Fleshy algae	1.58	1.02	2.04	1.43	10.32	12.87
Turf algae	27.43	7.91	31.51	5.54	39.87	11.91
TOTAL	32.67	9.19	37.44	5.70	57.45	13.67
HARD CORALS						
Branching corals	1.10	1.13	0.70	0.95	0.37	0.79
Massive corals	26.22	8.38	26.30	6.79	16.04	7.02
Encrusting corals	0.14	0.45	0.70	0.76	0.17	0.47
Foliaceous	1.12	1.58	1.39	1.82	2.47	0.60
Milleporine	1.08	1.94	0.84	1.18	0.04	0.12
TOTAL	29.67	8.94	29.91	8.53	19.09	7.54
SOFT CORALS						
Gorgonians	0.00	0.00	0.00	0.00	2.40	2.30
Encrusting gorgonians	2.39	2.17	2.67	2.17	0.07	0.22
Anemones	0.00	0.00	0.01	0.02	0.00	0.00
Zoanthids	0.00	0.00	0.00	0.00	0.00	0.00
Coralliomorpharians	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	2.39	2.17	2.68	2.16	2.47	2.49
SPONGES						
Erect sponges	0.16	0.51	0.05	0.16	0.10	0.33
Encrusting sponges	0.58	0.77	0.58	0.67	2.46	2.14
Other organisms	0.08	0.19	0.09	0.16	0.02	0.07
TOTAL	0.81	1.19	0.72	0.67	2.59	2.25
ABIOTIC						
Bare rock	0.29	0.91	0.00	0.00	7.49	7.45
Bare rubble	1.56	1.17	0.82	1.00	0.05	0.15
Bare boulders	0.00	0.00	0.00	0.00	0.00	0.00
Holes, gaps	15.16	7.57	12.11	5.33	6.22	8.05
Sand	17.44	8.29	16.32	6.79	3.23	3.90
Dead coral	0.00	0.00	0.00	0.00	1.43	3.03
TOTAL	34.45	5.17	29.25	5.32	18.41	14.56
Total Chain Links	1441.00	163.50	1460.20	161.00	1212.40	129.40
Rugosity	2.03	0.23	2.06	0.23	1.71	0.18
Percent Hard & Soft Coral in Biotic	49.13	13.28	45.74	9.41	26.75	9.64

Table 14g. CARICOMP coral reef transect measurements, 1993-1995: Percentage cover at 10 m depth.

COUNTRY	COLOMBIA			
Reef Site	Chengue Bay Reef Sites			
Date of Survey	April 1993		October 1993	
Number of Transects and Std Dev	T 1-10	SD	T 1-10	SD
ALGAE				
Calcareous algae	0.20	0.58	0.39	0.61
Encrusting algae	8.00	4.06	11.12	5.18
Fleshy algae	25.64	9.37	11.16	5.95
Turf algae	22.43	10.49	30.58	8.49
TOTAL	56.27	13.20	53.25	13.70
HARD CORALS				
Branching corals	0.48	1.43	0.59	1.69
Massive corals	31.90	12.73	32.59	14.27
Encrusting corals	0.58	1.25	0.71	0.78
Foliaceous	0.42	0.63	0.52	0.85
Milleporine	0.58	0.65	0.73	0.47
TOTAL	33.96	12.10	35.14	13.55
SOFT CORALS				
Gorgonians	0.00	0.00	0.00	0.00
Encrusting gorgonians	0.00	0.00	0.00	0.00
Anemones	0.04	0.13	0.05	0.15
Zoanthids	0.00	0.00	0.00	0.00
Coralliomorpharians	0.00	0.00	0.00	0.00
TOTAL	0.04	0.13	0.05	0.15
SPONGES				
Erect sponges	0.07	0.11	0.25	0.29
Encrusting sponges	0.20	0.37	0.28	0.42
Other organisms	0.04	0.08	0.04	0.08
TOTAL	0.30	0.47	0.57	0.48
ABIOTIC				
Bare rock	0.09	0.29	0.00	0.00
Bare rubble	0.52	0.56	1.65	3.52
Bare boulders	0.00	0.00	0.00	0.00
Holes, gaps	5.85	2.54	6.60	3.12
Sand	2.98	3.53	2.75	3.41
Dead coral	0.00	0.00	0.00	0.00
TOTAL	9.44	4.74	11.00	6.01
Total Chain Links	1074.80	100.40	1073.80	69.10
Rugosity	1.61	0.15	1.61	0.10
Percent Hard & Soft Coral in Biotic	37.65	13.43	39.47	15.00

Table 14h. CARICOMP coral reef transect measurements, 1993-1995: Percentage cover at 10 m depth.

COUNTRY	COLOMBIA			
Reef Site	Chengue Bay Reef Sites			
Date of Survey	October 1994		November 1995	
Number of Transects and Std Dev	T 1-10	SD	T 1-10	SD
ALGAE				
Calcareous algae	0.62	1.02	0.48	0.66
Encrusting algae	10.57	6.33	14.99	6.97
Fleshy algae	19.24	11.17	3.14	2.59
Turf algae	19.81	8.34	25.71	4.28
TOTAL	50.24	12.31	44.32	7.38
HARD CORALS				
Branching corals	0.21	0.41	0.22	0.38
Massive corals	26.71	12.02	28.77	12.22
Encrusting corals	4.88	4.13	4.14	2.79
Foliaceous	0.38	0.68	0.64	1.10
Milleporine	1.14	0.83	1.37	1.25
TOTAL	33.32	13.37	35.14	13.02
SOFT CORALS				
Gorgonians	0.96	1.69	1.14	1.58
Encrusting gorgonians	0.00	0.00	0.00	0.00
Anemones	0.22	0.27	0.35	0.47
Zoanthids	0.08	0.25	0.01	0.03
Coralliomorpharians	0.03	0.09	0.04	0.14
TOTAL	1.29	1.77	1.55	1.78
SPONGES				
Erect sponges	0.10	0.13	0.16	0.20
Encrusting sponges	0.22	0.49	0.33	0.41
Other organisms	0.00	0.00	0.03	0.08
TOTAL	0.31	0.55	0.51	0.49
ABIOTIC				
Bare rock	0.03	0.09	0.11	0.34
Bare rubble	1.34	2.49	1.34	2.65
Bare boulders	0.00	0.00	0.00	0.00
Holes, gaps	8.14	3.68	11.59	5.39
Sand	5.34	6.29	5.44	6.30
Dead coral	0.00	0.00	0.00	0.00
TOTAL	14.85	7.67	18.47	8.50
Total Chain Links	1129.30	79.60	1059.10	100.60
Rugosity	1.69	0.12	1.67	0.10
Percent Hard & Soft Coral in Biotic	40.39	14.74	44.18	12.09

Table 14i. CARICOMP coral reef transect measurements, 1993-1995: Percentage cover at 10 m depth.

COUNTRY	CUBA					
Reef Site	Cayo Coco — Reefs A and B					
Date of Survey	March & June 1994		October 1994		April 1995	
Number of Transects and Std Dev	T 1-10	SD	T 1-10	SD	T 1-10	SD
ALGAE						
Calcareous algae	2.11	1.20	1.94	1.21	2.28	0.91
Encrusting algae	1.38	2.00	0.22	0.26	0.27	0.31
Fleshy algae	31.97	9.88	37.75	11.91	24.43	12.17
Turf algae	24.31	16.09	14.09	5.69	24.60	9.05
TOTAL	59.77	14.13	54.00	10.73	51.58	10.44
HARD CORALS						
Branching corals	1.22	1.54	0.94	1.14	0.50	0.44
Massive corals	4.83	4.17	4.93	3.85	4.09	2.62
Encrusting corals	0.61	0.55	0.65	0.65	0.77	0.62
Foliaceous	0.08	0.25	0.08	0.26	0.14	0.24
Milleporine	0.25	0.45	0.13	0.21	0.07	0.14
TOTAL	6.99	4.15	6.72	3.67	5.56	2.73
SOFT CORALS						
Gorgonians	0.14	0.33	0.11	0.14	0.11	0.35
Encrusting gorgonians	0.03	0.09	0.00	0.00	0.00	0.00
Anemones	0.21	0.37	0.23	0.29	0.39	0.39
Zoanthids	0.00	0.00	0.00	0.00	0.00	0.00
Coralliomorpharians	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	0.38	0.51	0.33	0.33	0.50	0.63
SPONGES						
Erect sponges	2.13	0.85	1.20	1.04	1.39	1.52
Encrusting sponges	0.65	0.78	0.59	0.68	0.67	0.60
Other organisms	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	2.78	1.26	1.79	1.00	2.06	1.45
ABIOTIC						
Bare rock	8.50	9.02	4.25	2.52	2.44	3.18
Bare rubble	1.43	2.11	3.90	2.80	5.09	5.62
Bare boulders	0.00	0.00	0.00	0.00	2.74	2.94
Holes, gaps	9.34	6.93	22.83	7.88	22.41	6.53
Sand	10.82	9.46	6.17	5.36	7.20	5.11
Dead coral	0.00	0.00	0.00	0.00	0.42	0.93
TOTAL	30.09	13.70	37.15	9.70	40.30	9.90
Total Chain Links	1081.70	77.50	1083.20	84.30	1128.60	93.58
Rugosity	1.53	0.11	1.53	0.12	1.59	0.13
Percent Hard & Soft Coral in Biotic	10.94	6.93	11.61	6.15	10.55	5.14

Table 14j. CARICOMP coral reef transect measurements, 1993-1995: Percentage cover at 10 m depth.

COUNTRY	CURAÇAO					
Reef Site	Santa Barbara Reef Sites					
Date of Survey	October 1994		March 1995		September 1995	
Number of Transects and Std Dev	T 1-5	SD	T 1-10	SD	T 1-10	SD
ALGAE						
Calcareous algae	0.30	0.67	2.00	2.14	1.30	2.81
Encrusting algae	3.90	2.48	4.35	3.08	5.66	4.41
Fleshy algae	1.27	1.71	6.51	3.71	3.76	3.35
Turf algae	21.65	10.82	23.12	10.95	27.26	8.99
TOTAL	27.12	14.70	35.98	8.91	37.97	7.32
HARD CORALS						
Branching corals	4.16	3.52	4.32	3.84	4.75	4.07
Massive corals	24.03	2.34	18.59	6.85	19.66	6.49
Encrusting corals	1.07	1.09	2.33	2.24	2.84	3.60
Foliaceous	1.90	1.37	1.08	1.02	0.71	1.01
Milleporine	8.23	5.48	6.27	4.36	7.98	5.88
TOTAL	39.39	9.27	32.58	7.52	35.94	7.78
SOFT CORALS						
Gorgonians	1.64	1.46	0.53	0.69	0.45	0.67
Encrusting gorgonians	0.04	0.09	0.04	0.08	0.33	0.95
Anemones	0.43	0.38	0.30	0.47	0.18	0.24
Zoanthids	1.90	3.01	3.13	2.62	3.42	2.88
Coralliomorpharians	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	4.02	2.87	4.00	2.30	4.38	2.76
SPONGES						
Erect sponges	0.07	0.15	0.09	0.12	0.07	0.17
Encrusting sponges	0.13	0.12	0.28	0.50	0.04	0.07
Other organisms	0.13	0.14	0.00	0.00	0.03	0.09
TOTAL	0.33	0.32	0.36	0.51	0.13	0.20
ABIOTIC						
Bare rock	9.57	10.05	1.80	1.98	0.47	1.14
Bare rubble	3.05	3.50	0.64	0.75	0.42	0.80
Bare boulders	0.24	0.53	0.00	0.00	0.00	0.00
Holes, gaps	10.81	6.50	19.62	7.51	15.21	5.41
Sand	5.48	4.81	5.04	3.43	5.47	2.42
Dead coral	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	29.15	16.69	27.09	7.88	21.58	5.67
Total Chain Links	942.60	60.30	1000.40	121.88	955.70	79.10
Rugosity	1.33	0.09	1.41	0.17	1.35	0.11
Percent Hard & Soft Coral in Biotic	62.90	14.27	50.27	9.83	51.25	9.51

Table 14k. CARICOMP coral reef transect measurements, 1993-1995: Percentage cover at 10 m depth.

COUNTRY	DOMINICAN REPUBLIC	
Reef Site	Boca Chica	
Date of Survey	November 1994	
Number of Transects and Std Dev	T 1-4	SD
ALGAE		
Calcareous algae	5.11	4.43
Encrusting algae	0.97	1.20
Fleshy algae	12.62	3.55
Turf algae	30.84	8.90
TOTAL	49.54	13.38
HARD CORALS		
Branching corals	1.04	0.71
Massive corals	3.58	3.29
Encrusting corals	0.00	0.00
Foliaceous	3.19	1.39
Milleporine	0.00	0.00
TOTAL	7.81	4.20
SOFT CORALS		
Gorgonians	0.23	0.17
Encrusting gorgonians	0.00	0.00
Anemones	0.00	0.00
Zoanthids	0.00	0.00
Coralliomorpharians	0.00	0.00
TOTAL	0.23	0.17
SPONGES		
Erect sponges	0.71	0.49
Encrusting sponges	8.59	4.64
Other organisms	0.00	0.00
TOTAL	9.30	4.33
ABIOTIC		
Bare rock	9.87	17.54
Bare rubble	4.17	4.50
Bare boulders	0.00	0.00
Holes, gaps	3.30	1.25
Sand	15.80	12.76
Dead coral	0.00	0.00
TOTAL	33.13	15.36
Total Chain Links	1023.00	101.60
Rugosity	1.44	0.14
Percent Hard & Soft Coral in Biotic	12.20	5.29

Table 141. CARICOMP coral reef transect measurements, 1993-1995: Percentage cover at 10 m depth.

COUNTRY			JAMAICA			
Reef Site			Site A			
Date of Survey	August 1993		August 1994		October 1995	
Number of Transects and Std Dev	T 1-5	SD	T 1-5	SD	T 1-5	SD
ALGAE						
Calcareous algae	1.57	2.09	10.12	3.85	17.71	1.57
Encrusting algae	0.00	0.00	0.03	0.08	3.61	2.91
Fleshy algae	26.19	7.19	28.20	8.68	28.46	4.88
Turf algae	2.84	3.38	0.38	0.55	7.81	5.75
TOTAL	30.60	7.22	38.73	11.06	57.59	8.10
HARD CORALS						
Branching corals	0.93	0.72	0.08	0.17	0.16	0.36
Massive corals	13.29	2.77	8.98	7.05	5.68	4.87
Encrusting corals	0.21	0.47	0.46	0.32	3.12	1.78
Foliaceous	2.53	2.12	0.00	0.00	0.52	0.71
Milleporine	0.77	0.44	0.00	0.00	0.00	0.00
TOTAL	17.73	4.44	9.52	7.06	9.59	4.78
SOFT CORALS						
Gorgonians	0.00	0.00	0.09	0.13	0.15	0.34
Encrusting gorgonians	0.00	0.00	0.28	0.30	0.46	0.69
Anemones	0.00	0.00	0.00	0.00	0.45	0.76
Zoanthids	0.00	0.00	0.00	0.00	0.00	0.00
Coralliomorpharians	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	0.00	0.00	0.37	0.20	1.06	1.02
SPONGES						
Erect sponges	0.52	1.05	0.00	0.00	0.04	0.08
Encrusting sponges	0.07	0.16	0.00	0.00	0.24	0.42
Other organisms	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	0.59	1.02	0.00	0.00	0.28	0.40
ABIOTIC						
Bare rock	23.86	4.47	17.18	6.51	10.33	3.79
Bare rubble	0.00	0.00	0.00	0.00	3.06	3.08
Bare boulders	0.00	0.00	0.00	0.00	0.00	0.00
Holes, gaps	12.81	8.26	19.97	6.40	7.77	3.21
Sand	14.41	5.61	14.22	5.07	10.35	6.37
Dead coral	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	51.08	11.18	51.38	14.99	31.51	10.48
Total Chain Links	1184.80	157.50	1161.20	230.20	1233.40	146.20
Rugosity	1.67	0.22	1.64	0.32	1.74	0.21
Percent Hard & Soft Coral in Biotic	36.12	2.43	19.22	8.80	15.13	5.99

Table 14m. CARICOMP coral reef transect measurements, 1993-1995: Percentage cover at 10 m depth.

COUNTRY			MEXICO			
Reef Site			Puerto Morelos			
Date of Survey	March 1993		September 1993		April 1994	
Number of Transects and Std Dev	T 1-4	SD	T 1-5	SD	T 1-5	SD
ALGAE						
Calcareous algae	14.55	5.59	11.77	1.32	5.95	4.58
Encrusting algae	0.00	0.00	0.00	0.00	0.00	0.00
Fleshy algae	26.48	3.55	19.10	8.46	46.52	4.83
Turf algae	6.93	3.24	13.99	10.41	32.62	8.90
TOTAL	47.95	8.60	44.86	5.78	85.10	4.53
HARD CORALS						
Branching corals	0.00	0.00	0.00	0.00	0.00	0.00
Massive corals	0.61	0.67	0.89	0.74	0.62	0.86
Encrusting corals	0.48	0.40	0.06	0.14	0.27	0.42
Foliaceous	0.00	0.00	0.00	0.00	0.03	0.06
Milleporine	0.90	1.26	0.74	0.50	0.63	0.95
TOTAL	1.99	1.37	1.69	0.32	1.54	0.45
SOFT CORALS						
Gorgonians	5.95	0.88	4.44	1.11	2.39	1.11
Encrusting gorgonians	0.00	0.00	0.00	0.00	0.00	0.00
Anemones	0.00	0.00	0.00	0.00	0.07	0.16
Zoanthids	0.00	0.00	0.00	0.00	0.00	0.00
Coralliomorpharians	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	5.95	0.88	4.44	1.11	2.47	1.24
SPONGES						
Erect sponges	0.09	0.19	1.65	2.72	0.19	0.43
Encrusting sponges	8.78	4.16	2.40	1.01	2.83	0.64
Other organisms	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	8.87	4.35	4.06	2.88	3.02	0.95
ABIOTIC						
Bare rock	0.00	0.00	7.53	16.85	1.61	1.53
Bare rubble	0.00	0.00	0.00	0.00	0.00	0.00
Bare boulders	0.00	0.00	0.00	0.00	0.00	0.00
Holes, gaps	0.00	0.00	0.00	0.00	0.00	0.00
Sand	35.24	11.30	37.42	10.54	6.27	4.43
Dead coral	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	35.24	11.30	44.96	8.14	7.88	3.76
Total Chain Links	825.80	15.80	855.00	57.20	806.20	42.20
Rugosity	1.16	0.02	1.21	0.08	1.14	0.06
Percent Hard & Soft Coral in Biotic	12.68	3.67	11.22	1.71	4.41	1.71

Table 14n. CARICOMP coral reef transect measurements, 1993-1995: Percentage cover at 10 m depth.

COUNTRY	MEXICO			
Reef Site	Puerto Morelos			
Date of Survey	October 1994		May 1995	
Number of Transects and Std Dev	T 1-5	SD	T 1-5	SD
ALGAE				
Calcareous algae	7.26	1.52	6.72	3.65
Encrusting algae	0.05	0.12	0.00	0.00
Fleshy algae	41.77	4.94	46.79	8.43
Turf algae	37.87	7.50	40.79	8.75
TOTAL	86.95	1.94	94.30	2.82
HARD CORALS				
Branching corals	0.00	0.00	0.00	0.00
Massive corals	0.99	0.86	0.79	0.49
Encrusting corals	0.37	0.57	0.30	0.23
Foliaceous	0.00	0.00	0.08	0.17
Milleporine	0.32	0.21	0.39	0.31
TOTAL	1.68	0.37	1.56	0.12
SOFT CORALS				
Gorgonians	1.82	0.65	1.38	1.10
Encrusting gorgonians	0.00	0.00	0.00	0.00
Anemones	0.00	0.00	0.00	0.00
Zoanthids	0.00	0.00	0.00	0.00
Coralliomorpharians	0.00	0.00	0.00	0.00
TOTAL	1.82	0.65	1.38	1.10
SPONGES				
Erect sponges	1.39	1.62	0.88	1.73
Encrusting sponges	1.83	1.84	1.31	1.01
Other organisms	0.00	0.00	0.00	0.00
TOTAL	3.22	2.67	2.19	1.64
ABIOTIC				
Bare rock	0.89	0.80	0.06	0.13
Bare rubble	0.00	0.00	0.00	0.00
Bare boulders	0.00	0.00	0.00	0.00
Holes, gaps	0.00	0.00	0.00	0.00
Sand	5.44	2.75	0.51	0.78
Dead coral	0.00	0.00	0.00	0.00
TOTAL	6.33	2.75	0.57	0.90
Total Chain Links	818.40	30.00	714.80	32.74
Rugosity	1.15	0.04	1.01	0.05
Percent Hard & Soft Coral in Biotic	3.74	1.05	2.96	1.08

Table 14o. CARICOMP coral reef transect measurements, 1993-1995: Percentage cover at 10 m depth.

COUNTRY	NICARAGUA			
Reef Site	Great Corn Island			
Date of Survey	August 1993		October 1995	
Number of Transects and Std Dev	T 1-5	SD	T 1-5	SD
ALGAE				
Calcareous algae	7.46	8.45	11.18	5.37
Encrusting algae	5.87	3.32	8.05	3.14
Fleshy algae	30.68	7.68	13.02	5.13
Turf algae	4.01	1.70	5.87	7.57
TOTAL	48.01	5.56	38.11	5.58
HARD CORALS				
Branching corals	2.07	1.17	2.18	1.94
Massive corals	15.98	6.45	11.17	5.90
Encrusting corals	2.16	3.53	8.66	2.59
Foliaceous	7.20	1.51	0.00	0.00
Milleporine	0.35	0.42	0.08	0.08
TOTAL	27.76	5.23	22.09	6.11
SOFT CORALS				
Gorgonians	1.99	2.45	1.21	0.97
Encrusting gorgonians	0.00	0.00	0.00	0.00
Anemones	0.00	0.00	0.00	0.00
Zoanthids	0.00	0.00	0.00	0.00
Coralliomorpharians	0.00	0.00	0.00	0.00
TOTAL	1.99	2.45	1.21	0.97
SPONGES				
Erect sponges	0.29	0.64	0.02	0.05
Encrusting sponges	1.98	1.48	1.05	1.05
Other organisms	0.02	0.04	0.01	0.03
TOTAL	2.28	1.47	1.09	1.01
ABIOTIC				
Bare rock	0.06	0.09	0.00	0.00
Bare rubble	1.07	1.95	1.47	2.60
Bare boulders	0.00	0.00	0.00	0.00
Holes, gaps	8.61	3.95	22.12	11.41
Sand	2.72	4.05	2.48	2.77
Dead coral	7.49	5.26	11.42	8.01
TOTAL	19.95	2.15	37.50	6.24
Total Chain Links	1406.80	207.60	1431.80	206.30
Rugosity	1.98	0.29	2.02	0.29
Percent Hard & Soft Coral in Biotic	37.24	6.37	37.02	9.58

Table 14p. CARICOMP coral reef transect measurements, 1993-1995: Percentage cover at 10 m depth.

COUNTRY	PUERTO RICO, USA					
Reef Site	Media Luna & Turrumote		Media Luna		Media Luna & Turrumote	
Date of Survey	October 1994		April 1995		August 1995	
Number of Transects and Std Dev	T 1-10	SD	T 1-5	SD	T 1-10	SD
ALGAE						
Calcareous algae	0.79	0.94	0.14	0.23	0.29	0.48
Encrusting algae	0.00	0.00	0.00	0.00	0.00	0.00
Fleshy algae	0.02	0.07	0.13	0.29	1.15	1.84
Turf algae	28.62	7.88	31.54	5.16	27.76	7.05
TOTAL	29.43	7.48	31.81	5.38	29.26	7.24
HARD CORALS						
Branching corals	4.04	2.79	3.25	1.32	5.79	3.10
Massive corals	34.02	11.06	35.05	5.25	34.36	8.96
Encrusting corals	3.76	3.77	2.15	1.49	0.60	0.89
Foliaceous	0.22	0.52	0.73	1.49	1.69	1.56
Milleporine	0.40	0.58	0.44	0.78	0.19	0.26
TOTAL	42.44	8.95	41.63	4.58	42.64	7.34
SOFT CORALS						
Gorgonians	0.11	0.18	0.30	0.23	0.25	0.24
Encrusting gorgonians	8.49	6.25	7.16	7.89	9.19	5.78
Anemones	0.23	0.36	0.61	0.35	0.63	0.70
Zoanthids	2.32	3.23	4.05	3.39	2.63	3.03
Coralliomorpharians	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	11.15	6.58	12.12	6.36	12.69	5.92
SPONGES						
Erect sponges	0.64	1.26	1.37	1.54	0.16	0.31
Encrusting sponges	0.87	1.15	1.15	1.29	1.56	1.68
Other organisms	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	1.51	1.67	2.52	1.20	1.72	1.86
ABIOTIC						
Bare rock	0.32	0.69	0.00	0.00	0.00	0.00
Bare rubble	0.00	0.00	0.00	0.00	0.19	0.40
Bare boulders	0.12	0.27	0.00	0.00	0.00	0.00
Holes, gaps	12.48	4.34	9.55	2.94	10.26	4.05
Sand	2.57	5.27	2.37	3.43	3.26	5.66
Dead coral	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	15.49	7.35	11.93	3.87	13.70	7.65
Total Chain Links	1308.40	94.90	1219.00	62.20	1213.50	91.50
Rugosity	1.57	0.11	1.46	0.07	1.46	0.11
Percent Hard & Soft Coral in Biotic	63.41	9.07	61.17	4.70	64.22	7.69

Table 14q. CARICOMP coral reef transect measurements, 1993-1995: Percentage cover at 10 m depth.

COUNTRY	SABA, NETHERLANDS ANTILLES					
Reef Site	Ladder Labyrinth					
Date of Survey	October 1993		May 1994		November 1994	
Number of Transects and Std Dev	T 1-5	SD	T 1-5	SD	T 1-5	SD
ALGAE						
Calcareous algae	0.00	0.00	3.03	4.60	1.98	2.76
Encrusting algae	5.30	3.85	0.00	0.00	0.05	0.12
Fleshy algae	25.10	7.86	18.50	14.15	12.33	8.08
Turf algae	11.72	5.99	23.72	8.62	24.26	5.84
TOTAL	42.13	11.11	45.25	18.91	38.62	9.91
HARD CORALS						
Branching corals	1.84	1.67	0.16	0.22	0.07	0.10
Massive corals	13.92	4.72	10.20	8.55	7.43	3.41
Encrusting corals	0.34	0.61	6.00	5.04	6.97	5.30
Foliaceous	3.24	2.38	0.00	0.00	0.00	0.00
Milleporine	0.24	0.15	0.40	0.41	0.06	0.09
TOTAL	19.58	7.45	16.76	9.39	14.53	7.21
SOFT CORALS						
Gorgonians	1.82	1.38	0.00	0.00	0.15	0.10
Encrusting gorgonians	0.00	0.00	0.00	0.00	0.00	0.00
Anemones	0.00	0.00	0.00	0.00	0.00	0.00
Zoanthids	0.26	0.58	0.06	0.13	0.10	0.21
Coralliomorpharians	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	2.08	1.54	0.06	0.13	0.25	0.26
SPONGES						
Erect sponges	6.66	5.35	1.96	2.41	8.13	6.95
Encrusting sponges	1.08	0.77	1.14	1.01	2.32	0.83
Other organisms	0.84	0.76	0.50	0.87	0.00	0.00
TOTAL	8.58	5.18	3.60	2.84	10.45	7.11
ABIOTIC						
Bare rock	0.04	0.09	1.92	3.81	0.11	0.24
Bare rubble	0.62	1.00	0.70	1.17	4.96	5.59
Bare boulders	0.00	0.00	0.00	0.00	0.00	0.00
Holes, gaps	9.68	3.75	4.80	5.50	7.17	2.70
Sand	17.38	14.36	26.94	20.62	23.90	24.06
Dead coral	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	27.72	12.71	34.36	19.36	36.14	18.98
Total Chain Links	1198.20	97.60	1159.60	56.10	1012.60	66.30
Rugosity	1.69	0.14	1.64	0.08	1.43	0.09
Percent Hard & Soft Coral in Biotic	29.91	6.36	25.13	14.07	22.58	8.71

Table 14r. CARICOMP coral reef transect measurements, 1993-1995: Percentage cover at 10 m depth.

COUNTRY	SABA, NETHERLANDS ANTILLES			
Reef Site	Ladder Labyrinth			
Date of Survey	May 1995		November 1995	
Number of Transects and Std Dev	T 1-4	SD	T 1-3 & 5	SD
ALGAE				
Calcareous algae	0.00	0.00	0.00	0.00
Encrusting algae	0.00	0.00	0.00	0.00
Fleshy algae	12.78	15.73	17.89	17.93
Turf algae	30.68	13.76	32.53	18.79
TOTAL	43.46	10.53	50.42	12.28
HARD CORALS				
Branching corals	0.09	0.18	0.00	0.00
Massive corals	5.32	2.84	3.66	3.25
Encrusting corals	6.32	4.48	7.69	4.70
Foliaceous	0.05	0.10	0.15	0.17
Milleporine	0.20	0.34	0.10	0.12
TOTAL	11.97	5.17	11.60	7.31
SOFT CORALS				
Gorgonians	0.03	0.05	0.00	0.00
Encrusting gorgonians	0.00	0.00	0.00	0.00
Anemones	0.00	0.00	0.00	0.00
Zoanthids	0.00	0.00	0.00	0.00
Coralliomorpharians	0.00	0.00	0.00	0.00
TOTAL	0.03	0.05	0.00	0.00
SPONGES				
Erect sponges	7.94	7.73	1.19	0.95
Encrusting sponges	2.51	1.21	1.24	1.16
Other organisms	0.00	0.00	0.00	0.00
TOTAL	10.45	7.95	2.43	1.97
ABIOTIC				
Bare rock	0.98	1.95	0.19	0.28
Bare rubble	3.27	2.17	4.94	7.32
Bare boulders	0.00	0.00	0.00	0.00
Holes, gaps	6.03	0.61	5.90	4.35
Sand	23.81	23.44	24.53	14.94
Dead coral	0.00	0.00	0.00	0.00
TOTAL	34.09	20.67	35.55	19.81
Total Chain Links	1068.00	101.10	1043.80	188.60
Rugosity	1.51	0.14	1.47	0.27
Percent Hard & Soft Coral in Biotic	17.47	4.43	16.17	8.30

Table 14s. CARICOMP coral reef transect measurements, 1993-1995: Percentage cover at 10 m depth.

COUNTRY	TRINIDAD & TOBAGO			
Reef Site	Eastern and Outer Buccoo Reef			
Date of Survey	September 1994		March 1995	
Number of Transects and Std Dev	T 1-10	SD	T 1-10	SD
ALGAE				
Calcareous algae	0.00	0.00	0.00	0.00
Encrusting algae	40.17	26.11	36.03	14.79
Fleshy algae	0.00	0.00	0.00	0.00
Turf algae	14.38	23.82	21.66	10.59
TOTAL	54.55	13.23	57.69	12.82
HARD CORALS				
Branching corals	0.02	0.06	0.02	0.07
Massive corals	6.42	6.25	9.28	7.35
Encrusting corals	8.47	8.73	14.61	13.43
Foliaceous	7.70	11.39	0.00	0.00
Milleporine	1.22	2.09	1.43	2.75
TOTAL	23.82	16.91	25.34	16.19
SOFT CORALS				
Gorgonians	0.86	1.39	0.31	0.62
Encrusting gorgonians	5.24	4.73	5.48	5.02
Anemones	0.00	0.00	0.00	0.00
Zoanthids	1.35	2.29	0.82	1.33
Coralliomorpharians	0.00	0.00	0.00	0.00
TOTAL	7.45	4.45	6.62	5.09
SPONGES				
Erect sponges	0.05	0.05	0.00	0.00
Encrusting sponges	0.05	0.17	0.00	0.00
Other organisms	0.05	0.05	0.00	0.00
TOTAL	0.05	0.17	0.00	0.00
ABIOTIC				
Bare rock	0.62	1.51	0.00	0.00
Bare rubble	0.00	0.00	0.00	0.00
Bare boulders	0.00	0.00	0.00	0.00
Holes, gaps	13.51	9.25	9.77	6.61
Sand	0.00	0.00	0.14	0.45
Dead coral	0.00	0.00	0.43	0.73
TOTAL	14.12	9.51	10.35	6.24
Total Chain Links	1168.00	72.00	1162.10	174.74
Rugosity	1.65	0.10	1.64	0.25
Percent Hard & Soft Coral in Biotic	35.61	17.63	35.07	16.44

Table 14t. CARICOMP coral reef transect measurements, 1993-1995: Percentage cover at 10 m depth.

COUNTRY	VENEZUELA, USB					
Reef Site	Playa Caiman					
Date of Survey	October 1994		April 1995		September 1995	
Number of Transects and Std Dev	T 1-5	SD	T 1-10	SD	T 1-9	SD
ALGAE						
Calcareous algae	0.00	0.00	0.00	0.00	0.00	0.00
Encrusting algae	0.00	0.00	0.78	1.67	0.14	0.31
Fleshy algae	0.00	0.00	0.05	0.15	0.00	0.00
Turf algae	11.04	6.96	12.89	9.13	15.43	9.59
TOTAL	11.04	6.96	13.71	10.45	15.58	9.69
HARD CORALS						
Branching corals	0.00	0.00	0.00	0.00	0.00	0.00
Massive corals	49.30	17.68	36.36	11.22	41.12	15.98
Encrusting corals	0.00	0.00	0.00	0.00	0.00	0.00
Foliaceous	0.00	0.00	1.12	2.39	0.31	0.40
Milleporine	1.14	1.24	3.63	3.90	4.94	7.64
TOTAL	50.44	17.91	41.10	12.35	46.37	11.29
SOFT CORALS						
Gorgonians	2.34	0.84	4.09	3.09	2.85	3.22
Encrusting gorgonians	13.54	13.09	21.79	8.61	10.93	7.35
Anemones	0.04	0.09	0.02	0.06	0.03	0.09
Zoanthids	0.00	0.00	0.00	0.00	0.00	0.00
Coralliomorpharians	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	15.92	12.70	25.89	9.52	13.81	8.21
SPONGES						
Erect sponges	0.62	0.52	1.18	1.28	0.54	0.79
Encrusting sponges	0.14	0.19	0.03	0.08	0.43	0.95
Other organisms	0.22	0.44	0.36	0.46	0.16	0.33
TOTAL	0.98	0.71	1.57	1.23	1.12	1.09
ABIOTIC						
Bare rock	1.74	2.50	2.11	3.21	1.25	1.45
Bare rubble	0.00	0.00	0.00	0.00	0.00	0.00
Bare boulders	0.00	0.00	0.00	0.00	0.00	0.00
Holes, gaps	10.82	4.60	8.22	5.25	15.37	12.84
Sand	9.04	8.75	7.40	8.52	6.50	9.46
Dead coral	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	21.60	8.27	17.72	9.96	23.11	10.52
Total Chain Links	1383.40	330.20	1127.60	98.40	1146.20	190.20
Rugosity	1.95	0.47	1.59	0.14	1.62	0.27
Percent Hard & Soft Coral in Biotic	84.98	7.68	82.19	10.75	78.53	11.75

Table 14u. CARICOMP coral reef transect measurements, 1993-1995: Percentage cover at 10 m depth.

COUNTRY	VENEZUELA, EDIMAR	
Reef Site	Punta Ballena, Pampatar	
Date of Survey	April 1995	
Number of Transects and Std Dev	T 1-10	SD
ALGAE		
Calcareous algae	0.00	0.00
Encrusting algae	2.04	1.59
Fleshy algae	2.40	1.59
Turf algae	16.98	10.47
TOTAL	21.42	11.78
HARD CORALS		
Branching corals	0.04	0.13
Massive corals	2.50	4.51
Encrusting corals	0.30	0.26
Foliaceous	0.00	0.00
Milleporine	9.11	10.58
TOTAL	11.95	10.03
SOFT CORALS		
Gorgonians	2.96	1.97
Encrusting gorgonians	0.00	0.00
Anemones	0.18	0.28
Zoanthids	2.42	4.01
Coralliomorpharians	0.00	0.00
TOTAL	5.56	4.90
SPONGES		
Erect sponges	1.11	2.18
Encrusting sponges	3.09	2.00
Other organisms	9.00	6.21
TOTAL	13.20	7.58
ABIOTIC		
Bare rock	8.48	6.91
Bare rubble	4.98	6.36
Bare boulders	7.97	15.22
Holes, gaps	5.20	3.09
Sand	21.24	21.57
Dead coral	0.00	0.00
TOTAL	47.86	25.96
Total Chain Links	1023.50	110.70
Rugosity	1.44	0.16
Percent Hard & Soft Coral in Biotic	30.60	10.71

Table 15a. CARICOMP gorgonian measurements, 1994-1995.

COUNTRY	BAHAMAS											
Reef Site	Fernandez Bay, San Salvador											
Date of Survey		November 1994						November 1995				
Five 10 m^2 tran-		Site 1			Site 2			Site 1			Site 2	
sects/site	Total	Mean	SD	Total	Mean	SD	Total	Mean	SD	Total	Mean	SD
Rod	0	0.00	0.00	1	0.20	0.45	0	0.00	0.00	0	0.00	0.00
Feather	58	11.60	5.90	23	4.60	1.67	18	3.60	2.70	10	2.00	1.58
Fan	5	1.00	1.41	1	0.20	0.45	6	1.20	1.64	2	0.40	0.89
Whip	0	0.00	0.00	2	0.40	0.89	0	0.00	0.00	0	0.00	0.00
Site Totals	63			27			24			12		
Total Gorgonians	90						36					

COUNTRY	BELIZE											
Reef Site	Carrie Bow Cay											
Date of Survey		August 1994						December 1994				
Five 10 m^2 tran-		Site 1			Site 2			Site 1			Site 2	
sects/site	Total	Mean	SD	Total	Mean	SD	Total	Mean	SD	Total	Mean	SD
Rod	27	5.40	2.30	23	4.60	3.91	26	5.20	1.79	26	5.20	3.42
Feather	27	5.40	4.98	26	5.20	5.76	22	4.40	3.65	23	4.60	4.56
Fan	1	0.20	0.45	1	0.20	0.45	1	0.20	0.45	1	0.20	0.45
Whip	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
Site Totals	55			50			49			50		
Total Gorgonians	105						99					

COUNTRY	BELIZE											
Reef Site	Carrie Bow Cay											
Date of Survey		August 1995						December 1995				
Five 10 m^2 tran-		Site 1			Site 2			Site 1			Site 1	
sects/site	Total	Mean	SD	Total	Mean	SD	Total	Mean	SD	Total	Mean	SD
Rod	32	6.40	1.34	30	6.00	4.30	335	7.00	1.22	35	7.00	5.70
Feather	20	4.00	2.92	28	5.60	6.58	31	6.20	4.44	31	6.20	6.02
Fan	1	0.20	0.45	1	0.20	0.45	0	0.00	0.00	2	0.40	0.55
Whip	0	0.00	0.00	0	0.00	0.00	4	0.80	0.00	14	2.80	0.00
Site Totals	53			0			66			68		
Total Gorgonians	112						134					

Total = number of individuals in 5 x 10 m^2
Mean = number of individuals/transect (10m^2)

Table 15b. CARICOMP gorgonian measurements, 1994-1995.

COUNTRY	BERMUDA						COLOMBIA					
Reef Site	Twin & Hog Breaker Reefs						Chengue Bay					
Date of Survey	August 1994						October 1994					
Five 10 m^2 transects/site	Site 1			Site 2			Site 1			Site 2		
	Total	Mean	SD	Total	Mean	SD	Total	Mean	SD	Total	Mean	SD
Rod	72	14.40	3.51	157	31.40	6.19	120	20.80	15.98	15	3.00	1.58
Feather	13	2.60	1.14	20	4.00	2.35	0	0.00	0.00	0	0.00	0.00
Fan	0	0.00	0.00	5	1.25	0.71	0	0.00	0.00	0	0.00	0.00
Whip	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
Site Totals	85			182			120			15		
Total Gorgonians	267						135					

COUNTRY	CUBA											
Reef Site	Cayo Coco											
Date of Survey	March and June 1994						October 1994					
Five 10 m^2 transects/site	Site 1			Site 2			Site 1			Site 2		
	Total	Mean	SD	Total	Mean	SD	Total	Mean	SD	Total	Mean	SD
Rod	21	4.20	2.49	26	5.20	1.30	22	4.40	1.67	22	4.40	1.82
Feather	9	1.80	1.30	6	1.20	1.10	8	1.60	1.14	7	1.40	1.14
Fan	1	0.20	0.45	0	0.00	0.00	2	0.40	0.55	0	0.00	0.00
Whip	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
Site Totals	31			32			32			29		
Total Gorgonians	63						61					

COUNTRY	CUBA						CURAÇAO					
Reef Site	Cayo Coco						Santa Barbara					
Date of Survey	April 1995						March 1995					
Five 10 m^2 transects/site	Site 1			Site 2			Site 1			Site 2		
	Total	Mean	SD	Total	Mean	SD	Total	Mean	SD	Total	Mean	SD
Rod	16	3.20	1.30	20	4.00	2.00	37	7.40	5.59	23	4.60	3.36
Feather	8	1.60	1.14	8	1.60	1.14	21	4.20	3.11	9	1.80	1.79
Fan	1	0.20	0.40	0	0.00	0.00	6	1.20	1.64	4	0.80	0.84
Whip	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
Site Totals	25			28			64			36		
Total Gorgonians	53						100					

Total = number of individuals in 5 x 10 m^2
Mean = number of individuals/transect (10m^2)

Table 15c. CARICOMP gorgonian measurements, 1994 -1995.

COUNTRY	JAMAICA						TRINIDAD					
Reef Site	West Forereef						Outer and Eastern Buccoo Reefs					
Date of Survey	November 1995						March 1995					
Five 10 m² transects/site	Site 1			Site 2			Site 1			Site 2		
	Total	Mean	SD	Total	Mean	SD	Total	Mean	SD	Total	Mean	SD
Rod	25	5.00	1.87	0	0.00	0.00	4	0.80	0.84	10	2.00	2.12
Feather	0	0.00	0.00	0	0.00	0.00	7	1.40	1.14	0	0.00	0.00
Fan	1	0.20	0.45	0	0.00	0.00	4	0.80	0.84	3	0.60	0.89
Whip	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
Site Totals	26			0			15			13		
Total Gorgonians	26						28					

COUNTRY	VENEZUELA					
Reef Site	Punta Ballena, Isla de Margarita					
Date of Survey	November 1995					
Five 10 m² transects/site	Site 1			Site 2		
	Total	Mean	SD	Total	Mean	SD
Rod	79	15.80	2.77	29	5.80	5.93
Feather	22	4.40	3.21	17	3.40	3.36
Fan	0	0.00	0.00	0	0.00	0.00
Whip	0	0.00	0.00	0	0.00	0.00
Site Totals	101			46		
Total Gorgonians	147					

Total = number of individuals in 5 x 10 m²
Mean = number of individuals/transect (10m²)

Table 16a. CARICOMP urchin measurements, 1994-1995.

Country and Institution	Reef Site	Site #	Date	# Diadema Total	# Diadema Density	# Echino Total	# Echino Density	# Trip Total	# Trip Density
BAHAMAS: Bahamian Field Station									
	Fernandez Bay	1	Nov 1994	1	0.02	0	0.00	0	0.00
	Ostrander Reef	2	Nov 1994	6	0.12	0	0.00	0	0.00
		1	Nov 1995	4	0.08	6	0.12	0	0.00
		2	Nov 1995	3	0.06	1	0.02	0	0.00
BARBADOS: Bellairs Research Institute									
	Bellairs	1	Mar 1994	153	3.06	0	0.00	0	0.00
		2	Mar 1994	171	3.42	0	0.00	0	0.00
BELIZE: Smithsonian Institution									
	Carrie Bow Cay	1	Aug 1994	3	0.06	0	0.00	0	0.00
		2	Aug 1994	3	0.06	0	0.00	0	0.00
		1	Dec 1994	3	0.06	35	0.70	2	0.04
		2	Dec 1994	1	0.02	26	0.52	0	0.00
		1	Aug 1995	8	0.16	49	0.98	0	0.00
		2	Aug 1995	1	0.02	66	1.32	0	0.00
		1	Dec 1995	5	0.10	27	0.54	0	0.00
		2	Dec 1995	2	0.04	24	0.48	0	0.00
CUBA: Academia de Ciencias									
	Cayo Coco	A	Apr 1995	0	0.00	4	0.08	0	0.00
		B	Apr 1995	6	0.12	3	0.06	0	0.00
CURAÇAO: Carmabi Foundation									
	Sta. Barbara	1	Mar 1995	0	0.00	0	0.00	0	0.00
		2	Mar 1995	0	0.00	0	0.00	0	0.00
JAMAICA: Discovery Bay Marine Lab									
	Discovery Bay	1	Aug 1994	0	0.00	12	0.24	1	0.02
		1	Oct 1995	0	0.00	0	0.00	0	0.00
VENEZUELA: EDIMAR									
	Punta Ballena	1	Apr 1995	0	0.00	37	0.74	0	0.00
		2	Apr 1995	0	0.00	154	3.08	0	0.00

Total = number of individuals in 5 x $10m^2$
Density = number of individuals per m^2

Table 16b. CARICOMP urchin measurements, 1994-1995.

Country and Institution	Reef Site	Site #	Date	# Lyt Total	# Lyt Density	# Other Total	# Other Density	Total # Urchins
BAHAMAS: Bahamian Field Station								
	Fernandez Bay	1	Nov 1994	0	0.00	0	0.00	
	Ostrander Reef	2	Nov 1994	0	0.00	0	0.00	7
		1	Nov 1995	0	0.00	0	0.00	
		2	Nov 1995	0	0.00	0	0.00	14
BARBADOS: Bellairs Research Institute								
	Bellairs	1	Mar 1994	0	0.00	0	0.00	
		2	Mar 1994	0	0.00	0	0.00	324
BELIZE: Smithsonian Institution								
	Carrie Bow Cay	1	Aug 1994	0	0.00	0	0.00	
		2	Aug 1994	0	0.00	0	0.00	6
		1	Dec 1994	0	0.00	13	0.26	
		2	Dec 1994	0	0.00	1	0.02	81
		1	Aug 1995	0	0.00	9	0.18	
		2	Aug 1995	0	0.00	1	0.02	134
		1	Dec 1995	0	0.00	3	0.06	
		2	Dec 1995	0	0.00	0	0.00	61
CUBA: Academia de Ciencias								
	Cayo Coco	A	Apr 1995	0	0.00	0	0.00	
		B	Apr 1995	0	0.00	0	0.00	13
CURAÇAO: Carmabi Foundation								
	Santa Barbara	1	Mar 1995	0	0.00	0	0.00	
		2	Mar 1995	0	0.00	0	0.00	0
JAMAICA: Discovery Bay Marine Lab								
	Discovery Bay	1	Aug 1994	0	0.00	10	0.20	23
		1	Oct 1995	0	0.00	0	0.00	0
VENEZUELA: EDIMAR								
	Punta Ballena	1	Apr 1995	0	0.00	3	0.06	
		2	Apr 1995	0	0.00	0	0.00	194

Total = number of individuals in 5 x $10m^2$
Density = number of individuals per m^2

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