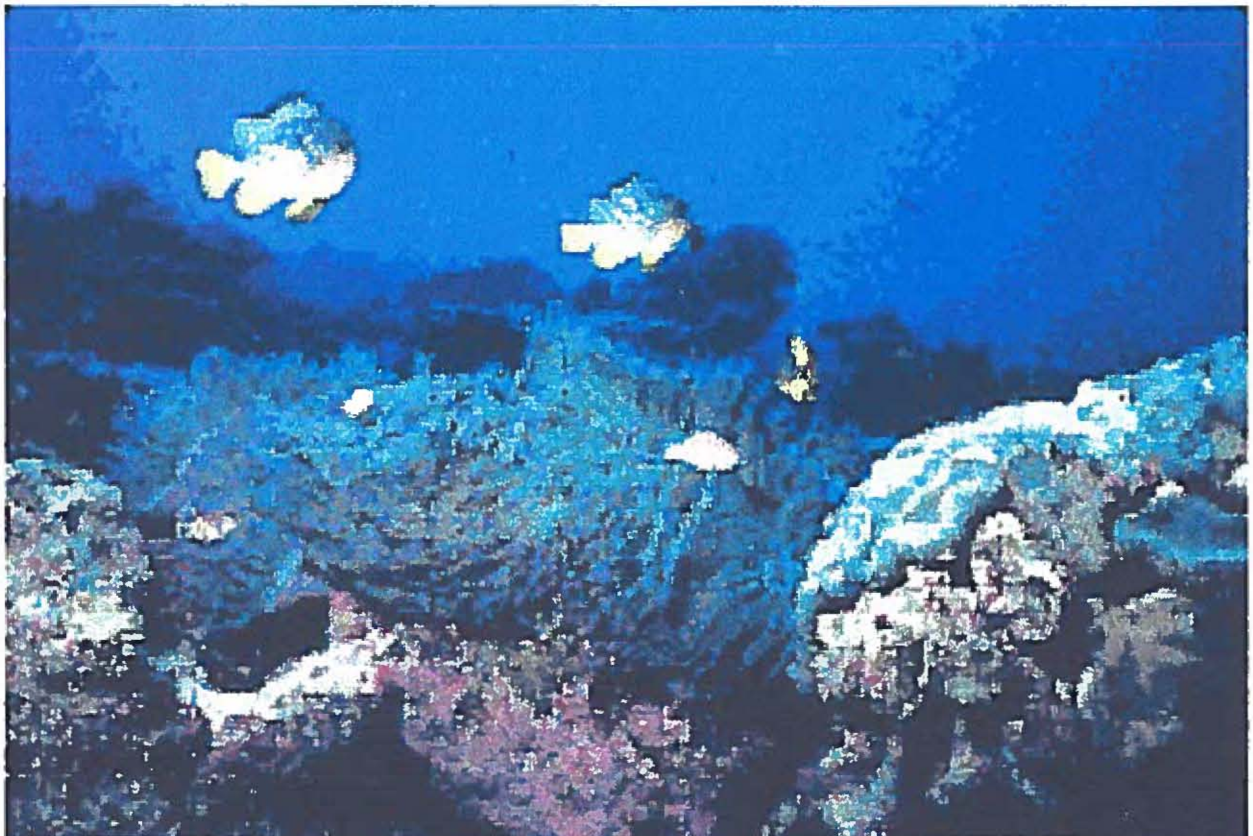
# GUAM CORAL REEF INITIATIVE



*Guam Coral Reef Initiative Policy Advisory Committee*

**Background and Briefing Book**

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**Planning Information Program**

# Introduction and Welcome

As a member of the Guam Coral Reef Initiative Policy Advisory Committee, you have been asked to make decisions which will determine whether or not Guam succeeds as a community, into the Twenty First Century. For a variety of reasons, we find ourselves at the brink of a failure too great to even imagine, but with the opportunity to achieve a success which can lead the Pacific.

All human activities on Guam affect our coral reefs. A single family home in Babulao affects the reefs. A storage yard in Harmon affects the reefs. A road winding past Mount Humuyong Manglo affects the reefs. We have not been good stewards of the reefs and they are in serious jeopardy, making the task of this Committee a daunting effort.

We must all remember, in this effort, that the economy of Guam and her environment are not separable. If our economy is weak, our environment will suffer. If our environment fails, our economy fails. The economy and the environment support each other. It is our job to look beyond the simplicity of single issue problems and solutions. It is our job to provide holistic solutions which understand not only the impacts of our actions, but the cumulative impacts of our actions.

This briefing book is just a beginning. The libraries and offices of the Bureau of Planning, Department of Agriculture, Guam Environmental Protection Agency, and University of Guam Marine Laboratory hold volumes of material on Guam's reefs. You are encouraged to utilize these resources to continue your education about the coral reefs, and you are encouraged to visit, call, fax, email or write the government representatives on the Committee in order to keep abreast of the pressures we place on the reefs.

Welcome to the Committee. Your selection reflects the high esteem with which this community holds your opinions. You have already contributed greatly to your community, and now you are asked to give more. Your participation on the Guam Coral Reef Policy Advisory Committee may well be the most important role you will ever play in determining the future our children will inherit.

## GUAM CORAL REEF INITIATIVE POLICY ADVISORY COMMITTEE MEMBERSHIP

| | | |
|---|---|---|
| **Honorable Carl T.C. Gutierrez**<br>**Governor of Guam** | P.O. Box 2950, Agana Guam 96932 | Tel. No. 472-8931-2<br>Fax No. 477-GUAM |
| **Ms. Ginger C. Cruz**<br>**Director of Communications, Office of the Governor**<br>**Representative for Governor Gutierrez** | **Chairperson**<br>P.O. Box 2950, Agana Guam 96932 | Tel. No. 475-9309<br>Fax No. 472-7549 |
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| Mr. Joseph C. Cruz<br>Director, Department of Commerce | 102 M. Street<br>Tiyan, Guam 96913 | Tel. No. 475-0321<br>Fax No. 477-9031 |
| Mr. Sonny Shelton<br>Director, Depr. of Parks and Recreation | 13-8 Seagull Avenue, Tiyan<br>P.O. Box 2950, Agana Guam 96932 | Tel. No. 475-6296/7<br>Fax No. 472-9626 |
| Mr. James Nelson<br>General Manager, Guam Visitor's Bureau | P.O. Box 3520, Agana Guam 96932<br>E-Mail gvbrm@ite.net | Tel. No.646-5278<br>Fax No. 646-8861 |
| Mr. Michael Gawel<br>Planner IV<br>Member, Guam CRICC, representing theAdministrator, Guam Environmental Protection Agency | 15-6101 Mariner Ave., Tiyan<br>P.O. Box 22439, Barrigada Guam 96921 | Tel.No. 475-1649<br>Fax No. .477-9402 |
| Mr. Lee P. Webb er<br>Publisher, Pacific Daily News, Representative for the News Media | 238 Archbishop Flores St. Agana<br>P.O. Box DN, Agana Guam 96932 | Tel. No. 477-9711<br>Fax No. 472-1512<br>Email - lwebber@gannett.guam.com |
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## GUAM CORAL REEF INITIATIVE POLICY ADVISORY COMMITTEE MEMBERSHIP

**Honorable Carl T.C. Gutierrez** — **Governor of Guam**

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**Ms. Ginger Cruz** — **Chairperson**
**Director of Communications, Office of the Governor**
**Representative for Governor Gutierrez**

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**Mr. Michael Ham** — **Vice-Chairperson**
**Administrator, Guam Coastal Management Program**
**Chairperson, Guam Coral Reef Initiative Coordinating Committee**
**Guam Point of Contact, U.S. Coral Reef Initiative**

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**Honorable**
**Senator, 24th Guam Legislature**
**Representative for 24th Guam Legislature**

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**Mr. Gerry Davis**
**Fisheries Biologist**
**Member, Guam Coral Reef Initiative Coordinating Committee** — **representing**
**Director, Department of Agriculture**

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**Mr. Joe Cruz**
**Director, Department of Commerce**

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**Mr. Sonny Shelton**
**Director, Department of Parks and Recreation**

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**Mr. James Nelson**
**General Manager, Guam Visitor's Bureau**

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**Mr. Michael Gawel**
**Planner IVrepresenting**
**Member, Guam Coral Reef Initiative Coordinating Committee** — **representing**
**Administrator, Guam Environmental Protection Agency**

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**Mr. Lee Webber**
**Publisher, Pacific Daily News**
**Representative for the News Media**

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**Mr. Bruce Kloppenburg**
**Kloppenburg Enterprises (Nautilus Submarines)**
**Representative for the Recreational Craft Industry**

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**Mr. Fred Quinene**
**Reef Fisherman**
**Representative for the Reef Fisheries Interests**

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**Mr. Pete Peterson**
**Owner, Microneian Divers Association**
**Representative for the Divers and Dive Shops**

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**Ms. Janette Deagle**
**Coordinator, Kids for Coral**
**Representative for Guam's Non-Governmental Organizations**

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**Mr. John Benavente**

**Representative for Guam's Deep Water Fisheries Interests**

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**Mr. Tom Ahillen**
**Matson Shipping**
**Representing the Maritime Industry**

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**Dr. Robert Richmond**
**Marine Biologist, University of Guam Marine Laboratory**
**Member, Guam Coral Reef Initiative Coordinating Committee representing**
**Director, University of Guam Marine Laboratory**

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**Mr. Vincent P. Arriola**
**Director, Bureau of Planning**
**Member, Guam Coral Reef Initiative Coordinating Committee**

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# *REEF FACT SHEET*

## EROSION OF SOIL ONTO GUAM'S REEFS

☞ Between 1983 -1993 59,950 acres were burned in wildland fires. It is estimated that soil lost through erosion as a result totalled 600 million pounds - or 300,000 tons. This is the equivalent of almost 34,000 dump truck loads of soil on the reefs from wildland fires alone.

☞ For one watershed, the Ugum, the average annual erosion from roads is 10,304 tons of soil, or 1,040 dump truck loads. The erosion rate for 1993 was double that for 1975, and the rate of erosion for sloped roads is 5 times higher than for level roads.

☞ Stream bank erosion in the Ugum is estimated at 1,132 tons of soil per year, adding another 114 dump truck loads per year onto the reef.

☞ Total sediment yield from erosion in the Ugum (fine grain only) is 23,368 tons per year, or 2,360 dump truck loads.

☞ The total sediment load from the Ugum watershed would cover, each year, 14.2 acres in 1 foot of soil.

The Ugum watershed is only 4,691 acres in size and represents less than 4% of the islands total land mass. Erosion rates are higher in more developed areas.

# ***REEF FACT SHEET***

## VALUE OF GUAM'S REEFS

☞ Guam's waters contain 179 square kilometers of coral reefs; 69 square kilometers in waters immediately adjacent to Guam's shores and 110 square kilometers in off-shore banks and reefs. This is a total of 179,000,000 square meters, or 44,295 acres of coral reef.

☞ Guam's coral reefs, based on the federal fine values which are conservative, are worth a minimum of **$143.2 billion dollars** for tourism, recreation, storm protection, fisheries (both subsistence and commercial), and aesthetics.

☞ Guam certifies more divers per year than any other location except the United States.

☞ Guam certifies upwards to 4,000 divers per year. In addition, Guam provides approximately 70,000 introductory dives (tourist dives) per year. **Diving alone accounts for more than $1.5 million dollars a month in economic activity.** *This activity requires a healthy reef or the activity will cease to exist.*

☞ It is estimated that the passive activities dependent upon the coral reefs, with direct dollar benefits to Guam's economy (diving, tourist submarines, dolphin watch boats, observatiory), account for upwards to **$10.5 million a month in Guam's economy.**

## *HISTORY OF THE CORAL REEF INITIATIVE*
Important Benchmarks

⏩ **1992:** At United Nations Conference on Environment and Development (UNCED) in Brazil, nations adopted Agenda 21. Chapter 17 of Agenda 21 on the Environment identifies coral reefs, mangroves and seagrass beds as ecosystems of high biodiversity and production, and it recommends that they be accorded high priority for identification and protection.

⏩ **December 1993:** Notice that a meeting would be held in Washington D.C. in January 1994, with the purpose of developing a *United States Coral Reef Initiative.*

Guam's response: Notice was too late to allow us to attend, but keep us informed.

⏩ **Janurary 1994:** The meeting was held and the *United States Coral Reef Initiative* was drafted. There were 76 participants, as follows:

- 37 representatives from federal agencies. 36 from D.C., one from Florida.
- 24 representatives of NonGovernmental Organizations. 16 from D.C., 7 from east coast U.S., 1 from Hawaii (Greenpeace)
- 2 from State of Florida government
- 4 private individuals or corporations. 3 from D.C., one from Florida
- 8 from east coast U.S. academia. (Universities of Rhode Island, Florida, New Hampshire, Yale, and William and Mary).
- 1 from International Center for Living Aquatic Resources Management (ICLARM) in Philippines.

There were 55 repesentatives from Washington D.C., only 2 from the Pacific, and neither of them representing any government.

⏩ **March 1994:** A package of funding proposals for Pacific coral reef *science* initiatives was sent to D.C. by University of Hawaii and Pacific Island Network as leads.

⏩ **April 1994:** First draft of *U.S. Coral Reef Initiative* transmitted to Guam. This initiative placed major emphasis on Florida and Caribbean area, with bare mention of Pacific. When mentioned, activities in Pacific were to be initiated between federal government and NGO's, with island governments to be included sometime in the future.

⏩ **April 1994:** At Coastal Program Manager's Meeting in Washington D.C., the Coastal Program Manager's for Guam and Hawaii, supported by CNMI and American Samoa, complained very loudly about the *Initiative* and the lack of island input into its creation. Personnel from NOAA International Office and Office of Ocean and Coastal Resource Management met with the Program Managers, and at this point the U.S. Initiative was, for all intents and purposes, put on hold.

⏩ **July 1996:** Guam submitted a series of proposals for Coral Reef Initiative related research and action projects to be funded through NOAA. These included video development for very wide distribution (UOG Marine Lab/Department of Agriculture), coral distribution and recruitment success test (UOG Marine Lab), and coral reseeding test using Planula Larvae (UOG Marine Lab/Department of Agriculture).

⏩ **1997:** Year of the Coral Reef Declared at international conference in Canada, adopted by U.S. and by Guam (through Proclamation by Governor Gutierrez).

⏩ **1997:** NOAA approves all Guam projects for funding.

⏩ **May 1997:** 24th Guam Legislature passed Bill 49" An act To Establish Rules And Regulations For The Control Of Fisheries By The Department Of Agriculture" (also establishing five Marine Preserves on Guam), which was signed into law (P.L. 24-21) by Governor Gutierrez.

⏩ **May 1997:** Governor Gutierrez signs Executive Order 97-10, adopting the Guam Coral Reef Initiative, and establishing the Guam Coral Reef Initiative Policy Advisory Committee.

TERRITORY OF GUAM

OFFICE OF THE GOVERNOR

AGAÑA, GUAM 96910

U.S.A.

# EXECUTIVE ORDER NO. 97-10

## ADOPTION OF THE GUAM CORAL REEF INITIATIVE (CRI) TO ESTABLISH A POLICY DEVELOPMENT MECHANISM FOR THE PROTECTION OF GUAM'S CORAL REEFS

WHEREAS, protection of Guam's ocean resources, including our coral reefs is vital to the residents of Guam and to the many people who visit our island; and

WHEREAS, the government of Guam recognizes that the increased demand and use of our ocean waters by residents and visitors has resulted in the occurrence of environmental damage to our reef ecosystems; and

WHEREAS, the percentage of live coral covering Guam's reefs has declined from 60% of all reefs just fifteen years ago to only 28% today, vividly illustrating the urgent need to protect our reefs; and

WHEREAS, existing Guam laws and policies are insufficient to manage and to protect its ocean natural resources and underlying ecosystem for the interests of future generations; and

WHEREAS, Guam has taken a leadership role and has contributed significant language and direction in the development of the United States Coral Reef Initiative, the United States Coral Reef Initiative Draft Strategy, the International Coral Reef Initiative Call to Action and Framework for Action, and the Pacific Region Coral Reef Initiative Work Program; and

WHEREAS, Coral Reef Initiatives have been adopted by a number of jurisdictions including Palau, the United States, and the state of Hawaii, emphasizing the global effort to conserve, restore, and effectively manage coral reef ecosystems, including, where appropriate, mangroves and seagrass beds; and

WHEREAS, a Guam Coral Reef Initiative Coordinating Committee has been organized to deal with these coral reef issues as they relate to our environment; and

WHEREAS, that Committee has prepared a comprehensive initiative to address the needs for proper management and protection of Guam's coral reefs and associated resources.

NOW, THEREFORE, I, CARL T. C. GUTIERREZ, Governor of Guam, by virtue of the authority vested in me by the Organic Act do order:

1. Creation of the Guam Coral Reef Initiative Coordinating Committee (CRICC). The Guam Coral Reef Initiative Coordinating Committee is hereby created, consisting of the following members:

    a) the Administrator of the Guam Coastal Management Program, Bureau of Planning;

    b) the Director of the Bureau of Planning, or designee;

    c) the Director of the University of Guam Marine Laboratory, or designee;

    d) the Director of the Department of Agriculture, or designee;

    e) the Administrator of the Guam Environmental Protection Agency, or designee.

2. **Chairperson of the CRICC.** The Administrator of the Guam Coastal Management Program, Bureau of Planning shall serve as Chairperson of the CRICC.

3. **Creation of the Guam Coral Reef Initiative Policy Advisory Committee (CRIPAC).** The Guam Coral Reef Initiative Policy Advisory Committee is hereby created, consisting of the following members:

   a) representative of the Governor's Office to be appointed by the Governor;

   b) representative of the Guam Legislature to be appointed by the Speaker of the Legislature;

   c) the Director of the Department of Parks & Recreation, or designee;

   d) the Director of the Department of Commerce, or designee;

   e) the General Manager of the Guam Visitors Bureau, or designee;

   f) representative of deep water commercial fisheries to be appointed by the Governor;

   g) representative of reef commercial fisheries to be appointed by the Governor;

   h) representative of the maritime industry (shipping) to be appointed by the Governor;

   i) representative from among Guam's dive shop operators to be appointed by the Governor;

   j) representative from among Guam's recreational water craft operators to be appointed by the Governor;

   k) representative from each locally based and registered environmental non-governmental organization to be appointed by the Governor; and

4. **Chairperson of the CRIPAC.** The representative of the Governor's Office shall serve as Chairperson of the CRIPAC; and

5. **Vice Chairperson of the CRIPAC.** The Point of Contact shall serve as Vice Chairperson of the CRIPAC and shall provide administrative support; and

6. **Additional members of the CRIPAC.** Other members may be added to the CRIPAC membership as determined by the Committee.

7. **Implementation of the Guam Coral Reef Initiative.** The provisions of the attached Guam Coral Reef Initiative shall be implemented.

SIGNED AND PROMULGATED at Agana, Guam this 12th day of May, 1997.

CARL T. C. GUTIERREZ
Governor of Guam

COUNTERSIGNED:

MADELEINE Z. BORDALLO
Lieutenant Governor of Guam

## THE GUAM CORAL REEF INITIATIVE
## TAKING RESPONSIBILITY FOR OUR ENVIRONMENT AND FUTURE

Guam's coral reefs are the very essence of the economic, cultural, political, and social viability of the island. Our coral reefs, including the associated mangroves and seagrass beds, provide shelter for the land from typhoons and tsunamis, shelter for the shallow bays and lagoons which offer recreation and sustenance, nourishment for our beaches which support our economy, and habitat for the biodiversity which defines the soul of our community. Guam's coral reefs provided our forefathers with the majority of their food and the materials for their lattes, tools and implements.

There is evidence that Guam's coral reefs are under stress and are being degraded, both from natural climatological and man induced causes. Sea level rise, global warming, ozone depletion and coral bleaching affect coral reefs world wide. Guam's reefs are additionally stressed by inadequately designed and placed sewage outfalls, polluted runoff from increased impervious surfaces, siltation from poorly planned grading and land clearing practices, overloaded sewage treatment facilities located on or near reefs, poor agricultural practices including, lack of proper controls for animal wastes or over use of herbicides and fertilizers, and improper disposal of hazardous wastes such as oils and household cleaning products. Inadequate education and control of visitors has resulted in a destructive level of coral removal for souvenirs.

Degradation of Guam's reefs and near shore waters may have resulted in or abetted in the toxification of seaweeds and fishes which has led to human fatalities. Coral reproduction and recruitment in some areas has been significantly reduced. Noxious and obnoxious over-growths of algae in near shore and estuarine waters, and over-production of species such as Acanthaster signal damage to water quality on reefs which negatively react beyond extremely narrow ranges of water quality variation. Reef fish stocks, like open ocean fish stocks, have been significantly reduced in part by poor reef and ocean management (over-fishing) and in part by poor land management (allowance of poor land use practices).

While every anthropogenic cause of reef and near shore water degradation can be prevented or significantly reduced, the failure to address "downstream", cumulative, or long term impacts of human actions, coupled with a governmental structure that encourages immediacy over sustainability, makes a failure to prevent and an economic incapacity to correct unavoidable. The coral reefs and associated systems on Guam present the opportunity for ecosystem management difficult to achieve in terrestrial ecosystems.

Guam has taken initial steps to declare and implement its responsibility to properly manage its coral reefs through preservation, conservation and sustainable resource use and management. Guam's Commonwealth Draft Act iterates the right of the people of Guam to prevent marine pollution, to intelligently exploit the living and non-living resources in sustainable fashion, and to have an effective voice in national and international policy which may impact on Guam's rights and responsibilities. Additionally, Guam has taken a leadership role and has contributed significant language and direction in the development of the United States Coral Reef Initiative, the United States Coral Reef Initiative Draft Strategy, the International Coral Reef Initiative Call to Action and Framework for Action, and the Pacific Region Coral Reef Initiative Work Program.

This paper outlines a Coral Reef Initiative to address the challenge of the conservation and sustainable use of Guam's coral reefs and related ecosystems through the strategies of partnerships, coordination, integration, and capacity-building.

## THE GUAM CORAL REEF INITIATIVE: VISION AND STRATEGIES

The long-term vision for the Guam Coral Reef Initiative is to build a comprehensive program for the conservation and effective management of Guam's coral reef ecosystem, including mangroves and sea-grass beds, utilizing existing activities, programs, laws and expertise to be augmented when necessary with new supports. The unifying concept is the principle of *sustainable* use and wise preservation in the present to maximize management opportunities for all future generations. This program is intended to reverse patterns of destructive practices through public and private partnerships in policy development, program implementation, and conflict resolution.

The implementation of the Initiative will depend on four strategies: partnerships, coordination, integration, and capacity-building.

**Partnerships:** This Initiative will build partnerships, ensuring that the full range of concerned parties are involved in the management of Guam's coral reef ecosystem. These parties include, but are not limited to, federal and Guam government agencies, organizations of commercial users, community representatives, non-governmental organizations, scientists, and tourism representatives. The primary objective is to foster innovative cross-disciplinary approaches to sustainable management of reef ecosystems through the development of cooperative relationships among the various stakeholders.

Because relationships between coral ecosystems exist on regional and international levels as well as the immediate local level, and because management regimes and policies are being developed at regional, national and international levels as well, partnerships between Guam and these other levels will also be built and supported through implementation of this Initiative. While such partnerships are premised on cooperation and experience sharing, they will continue to recognize the legal authority and responsibility of Guam to manage coral reefs within her jurisdiction.

**Coordination:** The Initiative will strive to ensure that existing and new activities among all players are fully coordinated to ensure that resources are used as effectively as possible to preserve, protect, and manage the coral reef ecosystems of Guam.

**Integration:** The Initiative will endeavor to ensure that all critical ecosystem components and linkages are taken into account, and that all elements of the problems and their solutions, including research, assessment, monitoring and management will be considered in a comprehensive manner.

**Capacity Building:** The Initiative will seek to strengthen local technical and human resources through cooperative education, training and infrastructure development (including the installation and use of new monitoring technologies as available). Particular attention will be given to the stimulation and enhancement of community-level efforts aimed at the sustainable management of coral reef ecosystems and sustainable use of coral reef resources.

In employing these strategies, the Initiative will undertake the full range of activities needed for the conservation and sustainable use of these ecosystems. These activities include research, mapping and resource assessment, monitoring, management for sustainable use (including protection and integrated coastal zone management, environmental damage assessment and restoration, and capacity building).

## THE INITIATIVE AS A RESPONSE TO RECOGNIZED CONCERNS

The Initiative is being undertaken to address such environmental concerns as loss of biodiversity, land-based sources of marine pollution, and sustainable development.

**Biodiversity:** The Initiative recognizes that the maintenance of the biological diversity of the coral reef ecosystems and associated ecosystems is imperative for the quality of life and choices in today's generation, and for the protection of choices and opportunities for future generations. As part of the world community, Guam also recognizes the importance of biodiversity in reef ecosystems to address national concerns iterated through the U.S. International Biodiversity Strategy and to address international concerns iterated through the Biodiversity Chapter of Agenda 21.

**Land-Based Sources of Marine Pollution:** The Government of Guam has recognized that land-based sources of pollution, both point and nonpoint, are major causes of the degradation of coral reefs and related ecosystems. The Initiative provides a platform for addressing the inter-connectiveness of land-based practices to marine water and biological quality.

**Sustainable Development:** The call, in Chapter 17 of Agenda 21, for the sustainable use and conservation of marine living resources echoes the fundamental understanding underlying the environmental management of resources on Guam, as has been growing since 1984. Extraordinary explosions in population, development and economy have resulted in a resource demand and usage level which will be unsustainable even into the next generation. The Initiative will support efforts to control, rather than be controlled by, circumstances of human development.

## ELEMENTS OF THE GUAM CORAL REEF INITIATIVE

**A Program for Coral Reef Research and Monitoring:** The quantitative environmental data necessary to understand the causes of coral reef degradation and to predict and respond to future changes are currently limited. This limitation on data often results in management and policy decisions being made without an adequate understanding of the problem or full range of solutions. There is an urgent need to develop long-term monitoring sites as part of an integrated research agenda to provide:

- The data necessary to show how Guam's reef systems are changing

- The environmental data needed to identify sources of stress in disturbed reef areas.

- The environmental data needed for proper resource management.

An expanded coral reef research program will be initiated, building on research data compiled by and existing partnerships between Guam, National Science Foundation, National Oceanic and Atmospheric Administration and the National Biological Survey. Components of this research program will focus on areas of biological diversity and sustainable use, and would include:

- Ecosystem function, including research on the biology and ecology of "keystone" organisms (crown of thorns, etc.).

- Eutrophication, to provide information on the input of nutrients from upland sources; and,

- Sustainable use, including research on the sustainability of fisheries in order to understand the value of management areas for the conservation of fishery resources in these ecosystems.

The Initiative will foster the development of a monitoring program that will establish a coordinated monitoring network involving scientists and managers to facilitate the exchange of physical, chemical, biological and socio-economic data.

**A Program for Improving the Health of Guam's Coral Reef Ecosystems:** A second element of the Initiative is the establishment of a coordinated program to address problems facing Guam's coral reef system. Guam's corals are being increasingly stressed as development and visitor arrivals continue to increase. Important sources of stress include nutrient enrichment from sewage and agriculture, over-fishing, sedimentation from deforestation, earth moving, agriculture, vessel traffic and coastal runoff. Tourist related and navigational damage, urban pollution, harvesting of non-renewable reef resources, and destructive fishing have further aggravated reefs already stressed by natural disturbances and disease.

A comprehensive coral reef program will necessarily include both improved protection and proactive and innovative approaches to accelerating recovery rates of degraded habitats. This program element would include activities for assessing and restoring coral reef ecosystems damaged through anthropogenic events such as oil spills, ship groundings, etc. In addition, environmental economic valuation of reefs for both assessment and resource management activities is needed.

Specific tasks to accomplish this element of the Initiative, including; implementation of elements in the Guam Nonpoint Source Management Plan; development of plans for the creation of marine protected areas; support for efforts to increase mariculture/aquaculture technologies for purposes of reseeding stocks and/or to provide alternate food fish sources to relieve stress on reef fish resources; amendments to existing fisheries management plans to address corals and reef associated plants and invertebrates, and to address management of live rock harvests; development of a habitat restoration program, and; development of a model for the sustainable use of coral reef ecosystem resources, will be developed by the partnerships described in this Initiative.

**A Program of Capacity Building (Partnerships for Effective Management):** Capacity building, focusing particularly on the concept of integrated coastal zone management, is basic to reef management. The overall objective of the capacity-building program as part of the Initiative is to improve the management of coral reefs and associated coastal ecosystems by:

■ Developing education and outreach capabilities to elevate public awareness of the value of marine resources and thereby establishing the necessary support for their protection.

■ Facilitating the development of necessary legislative frameworks, implementation and enforcement capabilities.

■ Facilitating the development of private/public partnerships to develop educational and marketing programs for tourists and standard operating procedures for tour operators.

■ Developing mechanisms to allow for the training and the participation of community residents and schools in the processes of monitoring, research, analysis, and priority setting for coral reefs and associated resources.

■ Development, up-dating, expansion, or corrections to reef geologic, geographic and biologic mapping and GIS development.

## IMPLEMENTING THE GUAM CORAL REEF INITIATIVE

Implementation of the Guam Coral Reef Initiative shall be accomplished through a Point of Contact, the Guam Coral Reef Coordinating Committee, and the Guam Coral Reef Initiative Policy Advisory Committee.

**Point of Contact:** The Administrator for the Guam Coastal Management Program shall serve as Point of Contact for Coral Reef Initiative efforts. Guam's continued participation and coordination in regional, national and international Initiative's have created a history and precedence for Initiative related activities. On both the domestic and international levels, local Coastal Zone Management officials serve as local contacts, as these programs not only are developed to address these issues, but are established as coordinating mechanisms.

As Point of Contact, the Administrator will serve as a clearinghouse/dispersement point for CRI information on all levels, and shall be responsible for setting meetings for the Committees. The Point of Contact shall serve as chair for the Guam Coral Reef Initiative Coordinating Committee.

**Guam Coral Reef Initiative Coordinating Committee (CRICC):** The CRICC shall be composed of the following members, in addition to the Point of Contact.

Representatives for:

Director, Bureau of Planning
Director, University of Guam Marine Laboratory
Director, Department of Agriculture
Administrator, Guam Environmental Protection Agency

The CRICC shall meet at least once per month and shall be responsible for implementation of the Initiative. The CRICC may request other participants from the Government of Guam or private sector to participate in meetings as required.

**Guam Coral Reef Initiative Policy Advisory Committee (CRIPAC):** The CRIPAC shall provide suggestions for policy and direction to the CRICC. The CRIPAC would provide a forum for the development of specific proposals to strengthen coral reef management efforts. The CRIPAC shall meet once per quarter, and shall be comprised of the following members:

Members of the CRICC

Designated representatives for:

Governor's Office
Guam Legislature
Director, Department of Parks and Recreation
Director, Department of Commerce
Director, Guam Visitor's Bureau
Commercial Fisheries (deep water)
Commercial Fisheries (reef fisheries)
Maritime Industry (shipping)
Dive Shop Operators
Recreational Water Craft Operators
Locally based and registered Environmental NGO's

Other members may be added as determined by the Committee. The representative for the Governor's Office shall serve as Chair of the CRIPAC. The Point of Contact shall serve as Vice-Chair and provide administrative support.

**ASSOCIATION OF MARIANA ISLANDS' MAYORS, VICE MAYORS AND ELECTED MUNICIPAL COUNCIL MEMBERS (AMIM)**
**FIFTH GENERAL ASSEMBLY 1996**

Resolution No. 96-04

Introduced by: Committee on Environmental and Natural Resources

RELATIVE TO EXPRESSING GRAVE CONCERN OVER THE DAMAGE TO THE ISLAND CORAL REEFS AND URGING STEPS TO BE TAKEN TO RESTORE AND PRESERVE OUR CORAL REEFS FOR FUTURE GENERATIONS.

WHEREAS, erosion, sedimentation and runoff are problems many tropical islands are experiencing as they come under development pressure from the construction of hotels, resorts, condominiums, golf courses, roads, and increased housing; and

WHEREAS, coral reefs are precious resources, provide the limestone material upon which many tropical islands are built, protect shorelines from erosion and wave damage and produce the white sand for tropical beaches; and

WHEREAS, coral reefs sustain fisheries of economic value and cultural importance; and

WHEREAS, the beauty of coral reefs has been a major attraction for tourists and recreational scuba divers; and

WHEREAS, the ecological system on most islands is seriously threatened by poachers who steal coral as well as by the careless discharge of chemicals; and

WHEREAS, strong reefs serve a variety of purposes, such as habitats for fish and other organisms that provide a source of food, and protection from damaging storms; and

WHEREAS, once destroyed, it takes several generations for reefs to be restored to their full vitality, and in some instances, they never fully recover; and

WHEREAS, many island areas that have suffered reef damage have been forced to build artificial reefs from concrete stones, and other material, but have met with limited success in restoring the natural function of reefs; and

WHEREAS, preservation is a great deal than restoration, so every effort should be made to protect the reefs before severe damage occurs; now, therefore, be it

RESOLVED, by the Fifth General Assembly of the Association of Mariana Islands' Mayors, Vice Mayors and Elected Municipal Council Members (AMIM), that grave concern be and hereby is expressed over the damage to the island reefs, and be it urged that steps be taken to restore and preserve our reefs for future generations and develop a monitoring system with strict enforcement; and, be it

FURTHER RESOLVED, that government agencies charged with such responsibilities be tasked to diligently seek Federal assistance or funding for immediate implementation; and, be it

FURTHER RESOLVED, that the President certify and the Secretary attest to the adoption hereof, and thereafter transmit certified copies to the Governor of Guam and the Governor of the Commonwealth of the Northern Mariana Islands.

DULY ADOPTED BY THE AMIM GENERAL ASSEMBLY ON THE 26TH DAY OF NOVEMBER, 1996, PITI, GUAM.

ISABEL S. HAGGARD
President

ATTESTED:

FRANCISCO N. LIZAMA
Secretary

CONTENS

# AMERICAN FLAG PACIFIC ISLANDS
# CORAL REEF INITIATIVE
# MANAGEMENT PROGRAM PLANNING MEETING
# SUMMARY REPORT

February 1995

Prepared on behalf of the American Flag Pacific Islands Governments
by
Pacific Basin Development Council
711 Kapiolani Boulevard, Suite 1075
Honolulu, Hawaii 96813

## I. VISION STATEMENT

**Coral reef ecosystems are vital natural resources in the American Flag Pacific Islands. These beautiful and biodiverse systems are essential to residents as sources of food and enhancement for social and cultural activities important to our heritage and tourism, the largest industry in the Commonwealth of the Northern Mariana Islands, Guam, and Hawaii. Moreover, coral reefs protect nearshore areas from storm waves, build new land masses and are a source of natural products for the food and pharmaceutical industries. The sustainable use of coral reef ecosystems and the perpetuation of their economic, cultural and environmental functions should be the guiding principles in planning and managing growth in the American Flag Pacific Islands.**

## II. GOALS

**To maintain the high biodiversity, health, and beauty of coral reef ecosystems, the Coral Reef Initiative Management Program in the American Flag Pacific Islands will:**

- **Increase public support for the perpetuation of coral reef ecosystems and instilling stewardship for future generations;**
- **Maintain and enhance the high quality of coral reef ecosystems and insure that their quality and use are sustainable for future generations; and**
- **Build effective public-private sector partnerships among regional governments and organizations, educational and research institutions, and non-governmental organizations to plan and manage land and water use activities that affect coral reef ecosystems.**

# AMERICAN FLAG PACIFIC ISLANDS
# CORAL REEF INITIATIVE MANAGEMENT PROGRAM

The US Territories of American Samoa and Guam, the Commonwealth of the Northern Mariana Islands, and the State of Hawaii have established initiatives aimed at addressing the unique problems they face in managing coral reef ecosystems. These initiatives are a response to the establishment of a Coral Reef Initiative (CRI) being planned by the US Federal government and announced by the US delegation to the UN Conference on Sustainable Development in Small Island Developing States in March of 1994.

In June 1994, Coastal Zone Management Program administrators from the American Flag Pacific Islands (AFPI) met in Kihei, Maui with representatives of the US Department of State and the Office of Ocean and Coastal Resources Management of NOAA to develop a plan for the involvement of their governments in the planning of the US Coral Reef Initiatives. They recommended to the AFPI Governors at the Annual Meeting of the Board of Directors of the Pacific Basin Development Council (PBDC) in August that the Governors endorse the CRI and pledge their commitment to a partnership with the Federal government in developing the initiative. To that end, the Governors designated points of contact in each of their governments to work with PBDC staff and Federal officials to continue the dialogue.

In September, October, and November PBDC staff facilitated a series of teleconferences among the points of contact to develop a plan for the AFPI Coral Reef Initiative. They also maintained an on-going dialogue with the Office of Territorial and International Affairs at Department of the Interior, NOAA's Office of Ocean and Coastal Resource Management and the Office of Oceans, Science and Technology in the Department of State on developments at the national level.

The points of contact reaffirmed the need for a AFPI Coral Reef Initiative planning meeting involving the AFPI governments, major research and scientific institutions in the region, representatives from non-governmental organizations (NGOs) and Federal officials. In preparation for the meeting, PBDC staff were asked to conduct a series of surveys on current resource management activities aimed at protecting coral reefs and on coral reef management problems and management needs that might be met with additional resources that might be provided under the Coral Reef Initiative.

The points of contact agreed that each of the AFPI governments should initiate a local coral reef initiatives as a basis for involvement in regional, national, and international coral reef initiative activities. Each jurisdiction established a working group consisting of agencies responsible for coastal zone management, natural resources, and water quality, and representatives of research institutions and non-governmental organizations. The working groups contributed to the surveys developed by PBDC and provided input on the development of the planning meeting agenda.

Federal officials from the Office of Territorial and International Affair, the Office of Ocean and Coastal Resource Management, and the Office of Oceans, Science and Technology invited the American Flag Pacific Islands Governments to send a representative to a planning meeting for an International Coral Reef Initiative Workshop schedule for mid-1995. The points of contact designated the Administrator of the American Samoa coastal zone management program to represent the AFPI at that planning meeting.

PBDC was asked to convene the AFPI Coral Reef Initiative management planning meeting on behalf of the four governments. The Office of Territorial and International Affairs generously offered to fund the meeting which was held December 5-7, 1994. The remainder of this reports summarizes the results of that meeting. It consists of a recommended vision statement and goals for the AFPI Coral Reef Initiative Management Program, matrixes summarizing existing coral reef management efforts in the AFPI, the coral reef management problems facing the AFPI and the common problems agreed upon by planning meeting participants, agreed upon recommended AFPI Coral Reef Initiative Management Program elements, potential contributions of the AFPI to the international coral reef initiative, and agreed upon next steps.

III. EXISTING RESOURCE MANAGEMENT ACTIVITIES IN THE AMERICAN FLAG PACIFIC ISLANDS THAT CONTRIBUTE TO THE PROTECTION OF CORAL REEF ECOSYSTEMS

Existing coastal zone, marine resource protection and water quality management efforts in the American Flag Pacific Islands contribute to the protection of coral reef ecosystems. They are presented here in summary form. [Achronyms are used extensively for agency names, statutes, and other components of the existing management systems. A glossary is included on page 11.

| Protection & Regulations | American Samoa | Northern Marianas | Guam | Hawaii |
|---|---|---|---|---|
| 1. General Laws & Regulations | DMWR: Manage, protect & preserve marine resources, including coral reef ecosystems.<br><br>EPA: Water quality regulation of activities in the water.<br><br>FBNMS: Prohibits gathering, taking, breaking, cutting, destroying or possessing corals and other invertebrates. Fishing restrictions also apply<br><br>ASCMP: Protect unique areas and resources; develop strategies for coastal hazards; conservation of marine resources; coordination of planning, monitoring, and enforcement by govt. agencies. | CRM: Coastal use permitting, enforcement & education.<br><br>DEQ: Environmental quality, earthmoving, stormwater control permitting, pesticide application certification, wastewater disposal system permitting; water quality standards & permitting; recreation water quality monitoring.<br><br>DLNRM: Submerged lands leasing.<br><br>Div. of Fish & Wildlife: Fishing regulations.<br><br>Historic Preservation Office: Submerged historic property protection.<br><br>CUC: Wastewater system use regulations. | DOA: Preservation and protection of fish & wildlife; protection of endangered species & habitats.<br><br>DLM: Seashore protection act review for development on shoreline to 10 fathoms. Territorial Seashore Protection Commission reviews & approves or disapproves development in Seashore Reserves.<br><br>Parks & Recreation: Recreation water use mgt. plan implementation.<br><br>GCMP: Reviews, approves or disapproves activities requiring Federal action in coral reef areas through Federal consistency.<br><br>GEPA: Water Pollution Control Act, Water Quality Standards, and Soil Control & Sedimentation Regulations protect water quality and aquatic resources. Clearing and Grading permits designed to protect coral reefs and habitats. | CZM: Preservation of valuable coral reef resources; Federal consistency review.<br><br>DLNR: Establish & Manage Marine Life Conservation Districts in which taking of coral or altering substrate normally prohibited.<br><br>DOH: rules prohibit discharge pollutant into state waters. NPDES permit required.<br><br>Admin. Rules 11-54 requires conservation of coral reefs and wilderness areas in AA waters. |

| Protection & Regulations | American Samoa | Northern Marianas | Guam | Hawaii |
|---|---|---|---|---|
| Prohibiting or Restricting Taking of Corals | DMWR: Regulations prohibit collecting of coral in less than 60 feet of water; commercial harvest below 60 ft requires permit; dynamite fishing illegal; willfull destruction of coral while fishing is illegal; destruction of fish habitat illegal.<br><br>FBNMS: Regulations state that no corals can be taken; damage prohibited; NMFS enforces--agreement with DMWR for enforcement pending.<br><br>ASCMP: Rules prohibit dredging or filling of coral reefs & other submerged lands unless public need demonstrated, no environ. preferable alternatives available, and adverse impacts minimized; protect marine resources and unique areas including reefs; only dependent uses permitted. | Division of Fish & Wildlife: Fishing regulations prohibit taking of live or dead coral except for betel lime--all types of coral covered. | DOA: Specific statutes prohibit taking of coral without permit--"need for revision."<br><br>Seashore Protection Act: Permit required for removal. Only removal for scientific purposes permitted.<br><br>GEPA: Water Pollution Control Act and Water Quality Standards provide general protecttion of coral reefs and marine resources (successful out-of-court settlement in coral damage from ship grounding). | DLNR: HRS 188-68 prohibits the intentional taking of, breaking or damaging any live stony coral including any live reef or mushroom coral. Eight species are identified in the statute. Exceptions may be granted for certain scientific, educational or other public purpose if adverse impacts are minimized. |

| Protection & Regulation | American Samoa | Northern Marianas | Guam | Hawaii |
|---|---|---|---|---|
| 3. Prohibiting Drilling, Blasting, and/or Dredging | ASCMP: Project Notification & Review System reviews all projects in AS. Board's concern in avoiding or mitigating damage to environ., including coral reefs. Enforcement provided by ASCMP (2 wetland conservation officers & 2 compliance officers). Violations result in stop orders; continued violations referred to AG.<br><br>DMWR: Prohibit use of explosives on reefs and destruction of fish habitat. Regs enforced by DMWR enforcement officers.<br><br>EPA: Water Quality Standards require Certificate for any of these activities.<br><br>FBNMS: Drilling, dredging, blasting, and any other alteration of the seabed prohibited. | CRM: Actions affecting reefs subject to CRM permitting. Enforcement via permitting programs by CRM staff. | DLM Territorial Seashore Protection Commission: Permits required for all such activities within Seashore Reserve (to 10 fathoms). Requirement for EA or EIS which must be approved by Guam EPA. Environmental Protection Plan required and must be approved by GEPA before DPW permit can be issued.<br><br>GEPA:<br>-Section 401 cetification required;<br>-All operators would require an approved Environmental Protection Plan;<br>-Blasting would require approved blasting plan to limit fish kill radius to 100' maximum.<br><br>Enforcement done by inspectors from DPW, GEPA, and DLM. | DLNR: HRS 188-23 prohibits possession of explosive for taking of aquatic life. Drilling, dredging and blasting in nearshore waters requires Conservation District Use Permit. Because ACOE permit also required, CZM would conduct Federal consistency review. If permit based on CWA 404 permit, Water Quality Certification from DOH also mandatory. |

| Protection & Regulation | American Samoa | Northern Marianas | Guam | Hawaii |
|---|---|---|---|---|
| 4. Prohibiting or Restricting Anchoring | FBNMS: Anchoring must be done so that there is no damage to bottom formations. Mooring buoys have been installed in the past, but currently none.<br><br>No restrictions exist in other parts of the Territory. | No restrictions.<br><br>DNR has placed moorings buyos in 17 locations. | No law address anchor damage to coral reefs.<br><br>DAWR developing stage of providing moorings. | DLNR: HRS 190 authorizes regulation of anchoring & mooring in Marine Life Conservation Districts; HRS 200 restricts boats in certain reef areas; Day mooring exist in some areas and rules to curb anchoring in coral rich areas has been proposed.<br><br>CZM: HRS 205A restricts anchoring on coral reefs because of likely adverse environmental & ecological impacts. |
| 5. Prohibiting or Restricting Vessel Discharge | ASEPA: AS law prohibits discharge of oil or hazardous substances from boats. Fines $100-$1,000.<br><br>USCG also enforces discharge regs (OPA 90) and levies fines for oil and sewage spills<br><br>Marine Sanctuary: Discharge prohibited. | No local regulations.<br><br>USCG has regulations under OPA 90 and DEQ is a first responder to a spill. | EPA: Local water quality standards regulations restrict vessel discharges in local waters; Police Department, GEPA, and DAWR have enforcement authority under Guam Safe Boating Act, Rec. Water Use Mgt. Rules and Regs, Endangered Species Act, Guam Clean Water Act, and Guam Litter Control Act. | DOH: All vessel discharges are prohibited in State waters.<br><br>USCG: Has OPA 90 rules in effect.<br><br>DPS Marine Patrol and USCG enforce discharge regulations cooperatively. |
| 6. Control of Other Point Source Pollution | ASCMP: PNRS provides for review of all projects and compliance with Federal and Territorial laws and regs.<br><br>ASEPA: NPDES permits required for all discharges. AS Environmental Quality Act provides for standards at and distances from discharges Marine Sanctuary: Discharges | CRM: Permitting program; enforcement vial field monitoring & enforcment program. | USCG: Has OPA 90 rules and enforcement authority.<br><br>GEPA: NPDES permit required for point source discharges; Section 401 certification required for discharges; water quality monitoring for discharges. | DOH: NPDES permit is primary regulation and control of discharges in coral reef areas. Applications are reviewed for their impact of aquatic ecosystems by DLNR and for consistency with CZM objectives and policies by CZM program. US Fish & Wildlife Service and NMFS have programmatic monitoring and |

| Protection & Regulation | American Samoa | Northern Marianas | Guam | Hawaii |
|---|---|---|---|---|
| 7. Control of Non-Point Source Pollution | ASEPA: AS Water Quality Act (see question 1); Regulations for use of septic tanks, pesticides, activities resulting in soil erosions, litter and solid waste disposal. ASCMP + other agencies: PNRS requires permits for new projects. Admin. rules prohibit discharge of untreated sewage, petroleum products and other pollutants or hazardous material; taking of sand and aggregate material outside designated sites; destruction of reef matter not assoc. w/ permitting; disposal of trash; un-permitted dredge and fill activities. Non-regulatory measures include public education aimed at reducing erosion and impact of piggeries; TA provided when required; solid waste & oil collection facilities provided. | CRM: project permitting, plan approvals; new best management practices evaluation starting.<br><br>DEQ: Water quality monitoring. | GEPA: Construction Site Erosion and Sediment Controls required. New rules in formative stage including vegetative control and landscaping standards. | DOH: Limited control over npsp. Storm water runoff from county and industrial sources requires NPDES permit. Have programs that promote methods for controlling npsp.<br><br>Counties have promulgated requirements for construction sites.<br><br>County and other State agencies within the CZM network of agencies have other regulatory and non-regulatory measures that contribute to control of non-point source pollution. Non-regulatory measures include use of siltation basins, grassing, and prohibition of motorized traffic. |
| 8. Proposed Non-Point Source Pollution Measures | ASCMP: Current policy of stream bank buffer of 25 ft for private and 50 ft. for commercial project now used in environmental review will be made part of ASCMP Admin. Rules. Non-regulatory measures include demo project, voluntary compliance on proposals, public education, tax incentives and subsidies for those using BMPs. | CRM & DEQ now developing coastal non-point source pollution plan. 6217 marina measures expected to be incorporated. Additional mgt. measures to be developed for golf course development and wildfires. DEQ existing requirements cover storm water. Marine water quality monitoring expected to be upgraded. | Land-Use Master Plan for Guam contains performance standards designed to reduce non-point source pollution. | Numerous non-regulatory provisions are being considered for marina, agricultural forestry, urban, and other activities.<br><br>State dedicated to developing a workable npsp plan for the Hawaiian context. Conflicting perspectives & values of Feds & State may make it difficult to complete program. Legislative action will drive schedule. |
| 9. CZMA 6217 Plan Completed | Draft to be submitted summer 1995 | November 1994 | On or before July 19, 1995 | Anticipate July 1997 at earliest. |

| Monitoring & Research | American Samoa | Northern Marianas | Guam | Hawaii |
|---|---|---|---|---|
| 0. Inventory or Database of Past Monitoring & Research | DMWR: Developed database of coral reef information to 1990 and maintains natural resource information on nearshore and land based resources for American Samoa.<br><br>ASCMP: Has compilation of most surveys and monitoring activity.<br><br>FBNMS: Has reports of two resource surveys at Fagatele Bay and other locations around Tutuila. | No. | UOG Marine Lab (UOGML) has a data base that includes 99 tech. reports, 5 proceedings, 27 environ. survey reports, 68 misc. reports and 82 MA theses. Computerized inventory of local coral reef flora & fauna being established--now contains over 3,500 species. GEPA & DAWR had additional studies. PBDC completed database w/ 560 entries on river, stream, and nearshore waters quality & habitat. Bureau of Planning has library w/ reports & published Inventory of Planning Info. SPC recently completed bibliography on fisheries & ocean resource project. | Not for resource managers. Numerous bibliographies exist and many studies have been conducted by the UH and have been funded by DLNR. Some areas are very well studied (eg Kaneohe Bay). CZM funded a DOT assessment of nearshore marine uses. CZM also funded the first phase of a comprehensive coastal resource project and information on coral reefs is being incorporated into the State GIS. |
| 1. Comprehensive Assessment of Coral Reefs | Coral Reef Inventory completed by ACOE in 1980 and by Sea Grant and others in 1992.DMWR: Quantitative, comprehensive assessment of condition of coral reefs now being done. | No. | UOGML has much of this info. Recent review paper on effects of anthropogenic disturbances summarizes this data. Other studies have been done.<br>UOGML has several established sites that are monitored periodically. | There are studies of the health of corals of specific sites (eg, Kaneohe Bay and Na Pali Coast) but no comprehensive assessment. The State is unsure how this could be accomplished. |
| 2. Monitoring Done on Regular Basis | DMWR has sponsored periodic, qualitative surveys. Current quant. survey aimed at providing baseline for future monitoring. Frequency and regularity of future surveys uncertain. FBNMS: Recording thermographs in place for past 3 years at Fagatele and an offshore site. Water quality monitoring since 1994 by ASEPA. | Impact analysis being done for dredging of port by developer. Monitoring locations identified by island resource agencies. Schedule is both weekly (plan & water quality) and monthly (photo stations) | GEPA: Island-wide water qualtiy monitoring established 1977. Monthly physical/chemical samples for selected watersheds and coastal stations. Includes marine piological (coral stations). GEPA collects water quality samples from around Guam for analysis. DAWR conducts 8 monthly fisheries surveys to monitor | DLNR routinely conducts survey of fish and habitats in Marine Life Conservation Districts and other protected areas. UH's HIMB has conducted monitoring in Kaneohe Bay. |

| Monitoring & Research | American Samoa | Northern Marianas | Guam | Hawaii |
|---|---|---|---|---|
| 13. Studies of Coral Health | J. Maragos et al of Hawaii done numerous qualitative assessment. Damage assessments done after hurricanes (eg Fagatele Bay by NOAA after Val). Damage assessment following crown of thorns starfish damage: Surveys conducted done by Birkeland in 1984 and 1987. | No. | Yes. Variety of studies done by UOGML, GEPA, and DAWR since 1970. GEPA: Monthly analysis of island-wide monitoring network since 1977. | Numerous studies done of specific sites by UH scientists. DLNR has supported surveys in State parks and protected areas. Partisan studies have been conducted as part of environmental impact assessments. |
| 14. Water Quality Monitoring | DMWR currently conducting rigorous quantitative surveys.<br><br>ASEPA focuses on Pago Harbor. 18 stations monitor a range of parameters. Two fish toxicity studies have been done. Water quality monitoring also started in Fagatele in 1994. | DEQ: Recreational water quality monitoring done weekly for most populated beaches; quarterly in less populated areas. | GEPA: Performs weekly analysis of water quality for chloroform at recreational beaches. UOGML have several projects that include water quality monitoring at sewage outfalls and effluent discharge pipes at power plants. | DOH has monitored water quality for bacteria counts in knee-deep water at public swimming beaches for many years. Monitoring stations have been added to their program in harbors and bays. Does not have protocols that discriminate water quality parameter values associated with heathy reef ecosystems. |
| 15. Restoration, Rehabilitation, or Seeding Program | No. Giant clam re-seeding desired by DMWR. | Minor seeding/transplant program from port project. | UOGML w/ DAWR & GEPA working on re-seeding including cultivation of coral larvae. Research ongoing for 3 years. Restoration of Apra harbor done in '89; local environmental and business groups have conducted "reef relief" clean-up activities since '90. GEPA required restoration of 2.5 acres of mangroves following spill incident in 1980. | DLNR has had an artificial reef program. UH has fairly large coral research program but if seeding work done not known. |
| 16. Coral Breeding | No | No. | UOGML now working with reproduction for seeding. Success in spawning & settling of some species. | Not within State government. |

| Education & Public Awareness | American Samoa | Northern Marianas | Guam | Hawaii |
|---|---|---|---|---|
| 17 General Programs | ASEPA: Anti-litter campaign & non-point source pollution public education program.<br><br>DMWR: will begin campaign aimed at informing leaders, general public and school children on value of coral reef resources. Will include distribution of 10,000 runs of two posters and 32 page information book. DMWR has also developed 3 dimensional display. | CRM and Division of Fish & Wildlife have public education program. | UOGML, DAWR, GEPA, and GCMP all conducted educational outreach or public information aimed at coral reef protection. GCMP has funded publication of books on fishes, corals, fishing techniques on Guam. Dr. Birkeland (UOGML) now editing book on The Life & Death of Coral Reefs. Educational video in production as cooperative effort of UOGML, DAWR & GCMP. GCMP produces monthly newsletter (4,000 copies). | CZM: Jointly funded SeaSearch: Exploring Hawaii's Marine Life. DLNR produces a poster about prohibition on taking corals.<br><br>EWC, PSA, UH and local environmental groups have had several recent workshops on coral reefs and coral reef protection and research. |
| 18. Programs About Laws & Regs | Workshop on traditional fisheries in 1990. Workshop for commercial fishermen held 10/94 with posters exhibits, public presentations, & news paper columns. | In 1984 did a CRM OCRM Ocean Resources work book. Interviews given to press on timely basis. Yearly tidal calendar (with fisheries regulations) published. | DAWR has several programs designed to educate tourists, foreign laborers, and local community on Guam's laws and regulations protecting corals. | Education emphasis on increasing awareness and understanding of the resources. |
| **International Technical Assistance** | | | | |
| 19. Involved in International TA | Not at present. DMWR coordinating with Western Samoa on visual assessment of stocks of coral reef fishes. | No. | UOGML faculty involved in regional technical assistance in Micronesia, Asia, Central & South America, American Samoa, Hawaii, & Papua New Guinea. | No State programs that deal with TA or research on coral reefs. CZM discussion of ocean & coastal issues for 15 years. UH, EWC, and NGO scientists are extensively involved research and technical assistance throughout the world. |
| **Other Initiatives** | | | | |
| 20. Other Coral Reef Management Initiatives | DMWR: Commenced coral reef habitat monitoring program; improved quantitative monitoring of fish and invertebrates on coral reefs; conducted research on life hist of fish. | Coming under separate cover. | UOGML, DAWR, GEPA, and GCMP meet on regular basis on problems for reefs and ocean water issues. | DOH initiated two community-based watershed mgt projects aimed at controlling nutrient and/or pollution run off. |

## IV. CORAL REEF MANAGEMENT PROBLEMS IN EACH OF THE AMERICAN FLAG PACIFIC ISLANDS

**Despite the regulatory and enforcement, assessment and monitoring, and public education and awareness programs currently being administered in the American Flag Pacific Islands, coral reef management problems persist. Problems identified for each of the American Flag Pacific Islands and those agreed upon as common problems that should be addressed through a regional Coral Reef Initiative are presented here in summary form.**

| ***Consensus on Shared Problems*** | **American Samoa** | **Northern Marianas** | **Guam** | **Hawaii** |
|---|---|---|---|---|
| **Physical Problems with Coral Reef Ecosystems**<br><br>***Land-based Sources of Pollution*** | **Non-point source pollution (sedimentation, nutrient enrichment, contaminated stormwater, marine debris) affects water quality and reef health** | **Non-point source pollution from on island development, especially port and harbor development and leachates from Puerto Rico dump; point source pollution from sewer outfalls** | **Runoff and sedimentation are primary cause of reef mortality; sewage outfalls need to be reassessed and extended from existing discharge sites or upgraded to secondary treatment. Pesticides and fertilizer use on golf courses is a concern.** | **Siltation from various land uses, non-point sources of pollution other than siltation, and debris stress the reef ecosystems. Dredging, blasting, construction of piers harbors, maintenance work and construction of outfall systems are most visible marine activities that produce problems directly impacting coral reef systems.** |
| ***Marine-based Sources of Pollution*** | | | | |
| ***Population Growth*** | **Population growth causing stress from over fishing and non-point source pollution** | **Population growth and tourism development contributing to human activities on coral reefs and additional non-point source pollution.** | **Growth of tourism contributing to degradation of coral reefs.** | |
| | **Extensive damage to reefs from three major hurricanes and crown of thorns starfish** | | | |

| *Consensus on Shared Problems* | American Samoa | Northern Marianas | Guam | Hawaii |
|---|---|---|---|---|
| **Management Problems**<br>*Overharvesting/Overfishing* | Management of fisheries for sustainable yield-Inadequate enforcement of regulations and education against over fishing and harmful fishing techniques and data collection on fisheries dynamics. | Over harvesting of reef species; abnormal fishing practices (eg, use of explosives and bleach), poaching of coral. Inadequate funds for enforcement of regulations and for development of a plan for new marine protected area on Rota. | Education needed to support controls of destructive fishing practices. | Impact of human activities including fishing, boating, diving and other commercial and non-commercial activities often viewed as problems. |
| *Regulations and Enforcement* | | | Need for development of appropriate legislation and increased enforcement needed.<br>Marine reserves need to be established and monitored with results available to the public. | Lack of enforcement which contributes to disrespect of public policies. |
| *Assessment and Monitoring* | Require more knowledge about recovery processes from damage caused by crown of thorns, hurricanes, and massive coral bleaching episode. | Lack of monitoring equipment for reef ecosystems. | More data needed on effects of coastal pollutants; coral reef specific monitoring protocols and bioassays needed. Better understanding of coral reef recruitment processes needed. Long-term monitoring sites need to be established. | There are gaps in understanding of the relationships between natural processes and between human and natural processes. Scientific analysis and recommendations often limited in scope. Insufficient fiscal and human resources for monitoring health of coral reefs. |
| *Lack of Public Education and Awareness* | Lack of public awareness about sources of pollution and their impact on coral reef ecosystems. | General lack of public knowledge and understanding about reef ecosystems and sources of degradation. | More classroom and community education needed to support efforts at controlling in appropriate activities such as grassland burning, destructive fishing practices, and human impacts on reefs. | Lack of shared vision among agencies for coral reef management. Broader education about corals and their valuable role in economic enhancement, environmental protection, and cultural empowerment. |
| *Need for Greater Political Understanding* | | | Territorial Seashore Protection Plan needs to be completed and better controls on development instituted. Environmental process needs major overhaul to allow for quality control. | Government decisions based on narrow requirements of specific permits and insufficient attention to cumulative impacts. Land of resources for independent validations of representations of project proponents. Rely on EIS. |

## V. RECOMMENDED PROGRAM ELEMENTS FOR THE AMERICAN FLAG PACIFIC ISLANDS CORAL REEF INITIATIVE MANAGEMENT PROGRAM

Program elements agreed upon by planning meeting participants for recommendation to their governments and as potential elements of the US domestic Coral Reef Initiative are summarized here.

| ACTIVITY | HOW | WHEN | WHO |
|---|---|---|---|
| **1. Build Political Understanding** | | | |
| a. Provide Briefings at Regional Meetings<br>PBDC<br>Assoc of Pac. Is. Legislator<br>CSO (1/9-10/95)<br>Western Legislators Conference | Develop fact sheet on Domestic CRI<br>Get CRI on PBDC Agenda; Presentation<br>Identify active APIL members; provide brief.<br>Discuss at Exec. Comm Meeting through Islands and Oceans Committee Chairs. | January 1995<br>January 1995<br><br>January 1995 | Points of contact<br>PBDC<br><br>CSO Committee Chairs |
| b. Provide Briefings to Pacific Congressional Delegation--CSO; PBDC | Make at time of PBDC Winter Meeting--Use CRI planning meeting report. Work through CSO. | February 1995 | PBDC Staff<br>CSO |
| c. Target Leaders Who Are Already Knowledgeable | Identify local legislative & executive branch leaders; provide briefing; enlist support. | On-going | Local Working Groups |
| d. Hold Fund Raising Events | Work with NGOs. | On-going | Points of Contact;\NGOs |
| e. Develop Study of the Economic Value of Reefs | Develop proposal for funding. | | |
| f. Develop Briefing Papers on CRI with Local & Regional Perspective | Use CRI planning meeting report & develop briefing papers on local CRI from materials prepared for regional meeting. | February-June 1995 | Local Working Groups |
| g. Set up Snorkel & Dive Tours for Leaders | Initiate discussion with Atlantis Submarines | On-going | Hawaii Working Group\Points of Contact |
| h. Invite Leaders as Conference CRI Panelists | Annual CZM (5/95)& EPA meetings (6/95) | May and June 1995 | CRM\CNMI; |
| i. Invite Tim Wirth to Island CRI Event | Invite Wirth to meet with Governors on 2/1/95 | January 1995 | PBDC |
| j. Develop Program to Maximize Year of the Reef | Points of contact to meet in conjunction with other meetings as plans develop. | January (CSO) 1995; May (CZM) 1995 | Points of Contact\Local Working Groups |

| ACTIVITY | HOW | WHEN | WHO |
|---|---|---|---|
| 2. **Public Education/Awareness** | | | |
| a. Develop Materials with Pacific Focus & Content (Videos, PSAs, Brochures) | Video targeted at airlines<br>Use of CZM Funds; marine lab--regional perspective; chambers of commerce | On-going; Need specific time frame for video | All government and private groups |
| b. In Developing Local Materials Provide for Ability to Share (allow for dubbing, etc.) | Video: each island develop script; Kids for coral on Guam | ASAP: Need specific time frame | David Rainey and Bob Richmond and Mike Ham |
| c. Develop List of Existing Materials | Computerized Data Base; Contact SPREP | ASAP: Need specific time frame | Local Working Groups |
| d. Develop Program for Using Local & RegionalPrint Media | Make contact with local media; start with CRI regional meeting release; develop own release | ASAP: Need specific time frame | PBDC; Local Working Groups |
| e. Identify List of National Programs that Can be Used on Local TV (NOVA, J. Cousteau) | Contact local public TV; Seek assistance from Feds in contacting NOVA & CNN | On-going | Points of contact |
| f. Have Regional Workshop for Educators | Contact Pacific Regional Education Lab | Next 12 to 24 months | PBDC; Nick Strauss |
| g. Identify Methods of Changing Behavior (get TA on social marketing) | Develop TA project proposal; meanwhile, work through kids. | ASAP: Need specific time frame | PBDC w/ Research Institutions |
| h. Share Information Among AFPI<br>- Volunteer Monitoring Program<br>- Involvement of Elders & Church Leaders<br>- Community Based Management | Exchange of program and project reports; develop success story/case studies for presentation at regional meetings | January to June 1995 | Lelei Peau & Dave Rainey lead |
| i. Develop Standard Protocols for Assessment & Monitoring | Convene scientific panel | ASAP: Need specific time frame | Scientific Institutions |
| j. Seek Seagrant Funding & Assistance | defer to Guam CZM | ASAP | |

| ACTIVITY | HOW | WHEN | WHO |
| --- | --- | --- | --- |
| **3. Baseline Assessment, Data Gathering & Monitoring** | | | |
| a. Develop Regional Database on Existing Materials on Coral Reefs (UOG, UH)<br>- Database on Gray Literature for Use by Resource Managers-- | Produce annotated list of existing materials on AFPI & regional needs & resources including unpublished reports | ASAP | Local Agencies & other appropriate organizations; Points of contact to coordinate Regional synthesis by Pacific Science Association. |
| b. Develop Regional Technical Assistance Program<br>- Establish Local Priorities | Establish advisory panel composed of appropriate scientific and resource management personnel; | Year 1 | Local CRI Working Group |
| - Develop TA Roster & Guide Book<br>- Develop Curriculum | Develop directory of resource persons, facilities & organizations; | Year 1 | PBDC<br>(see education and public awareness) |
| - Use Shared Protocols<br>-Train\Empower Local Residents to Do Assessment, Data Gathering & Monitoring | Panel to identify appropriate guidelines for assessment (eg Maragos & Carpenter), monitoring (eg AIMS, Caroline Rodgers), and ecosystem classification (eg Holthus); include consideration of receiving water characteristics. | Year 1 | Consult Birkland, Maragos & Holthus<br>East-West Center<br>UOG Marine Lab<br>HIMB |
| -Hold Regional Workshops<br>- Establish Partnerships to Train for Assessment--Community Colleges, NGOs, Universities | Develop workshop program on assessment & monitoring. Develop partnerships on a local basis to feed into regional effort. | Year 1 | NGOs & Local Working Groups |
| c. Information Sharing Among AFPI | Through existing PEACESAT & e-mail Establish e-mail capacity in Samoa & CNMI | Year 1 | CRI Points of Contact and Local Working Groups |
| d. Development of Assessments of Economic Value | Identify appropriate expertise; Develop cooperative project among research institutions | Year 1 | Contact Ray Clark at NMFS |
| e. Establish program for continuity of funding | Examine feasibility of endowment program with NGOs; maximize value of year of the reef. | Year 1 | NGOs & private organizations and granting agencies. |
| e. Set up Program to Get Gray Lit into Journals | Scientific and managers advisory panel to consider the problem | Year 1 | Scientific advisory panel |

| ACTIVITY | HOW | WHEN | WHO |
|---|---|---|---|
| **4. Population** | | | |
| a. Work with SPREP & UNFPA Population People to Seek Information on the Impact of Population Growth on Resources (focus on coral reef habitats) | Write to SPREP & UNFPA on CRI; include briefing papers on Federal CRI and report of regional meeting; request information on impacts. | Need specific time frame | Suggestion by small group that Federal agencies be asked to do all of the tasks under this heading |
| b. Identify & Circulate Studies of the Impact of Population Growth on Resource Degradation--start with papers from Cairo<br>--include papers from other international conferences | Identify a contact point for the Pacific. Assemble reference list and incorporate into CRI Database | As database developed; Need specific time frame | |
| c. Educate Transient Population on Impact of People on Reefs | In appropriate languages, develop education for transients through brochures & videos. Work through airport authorities, visitor bureaus and hotels. | Need specific time frame | |
| d. Develop compatible format and develop and make presentation to policy makers at all levels of government on impacts of population growth on coastal resources | | Need specific time frame | |

| ACTIVITY | HOW | WHEN | WHO |
|---|---|---|---|
| **5. Land Based Impacts of Pollution** | | | |
| a. Information Sharing on<br>-Successes in Dealing with LBSP<br>- Lessons Learned on Assessment & Controlling | Presentations at regional meetings to document experiences; create network on land-based sources of pollution; provide more information to engineers & developers; publicize enforcement actions; identify what works and what does not work; address issues at the planning stage of projects. | On-going | Small group indicated that Federal agencies should handle all of this. Information sharing outlined in this section could be done by AFI CRI working group members. |
| b. Assessment of Best Management Practices in §6217 Guidance in Terms of AFPI | Identify problems with BMPs in guidance documents that are not appropriate and local management measures that are. Request technical assistance of engineers & biologists; Organize a workshop on local BMPs for sharing among AFPI governments(?)<br><br>Coordinate better with USGS and Natural Resources Conservation Service (formerly SCS) and fisheries programs.<br><br>Add grant conditions for environmental program grants from EPA, NOAA, and other Federal Programs and agencies; share information on experiences. | By July 1995 unless §6217 deadline changed | This will probably have to be initiated by AFI CRI working groups. |

| ACTIVITY | HOW | WHEN | WHO |
|---|---|---|---|
| 6. **Marine-Based Sources of Pollution & Degradation (Marine Debris, Oil Spills, Vessel Groundings)** | | | |
| a. Coordination & Sharing of Program Experience on Controlling MBSP | Presentations at regional meetings; exchange of program plans for controlling MBSP including use of volunteers and community based approach | Need specific time frame | Points of contact and local CRIworking grou[p] |
| b. Coordination with WESTPAC on Problems of Controlling MBSP | AFPI representatives on WESPAC to raise as agenda item | Need specific time frame | AFPI representatives to WESTPAC |
| c. Regional Effort Aimed at Educating about Impact of Gill Nets | Request information from NMFS and share info among AFPI agencies; contact NGOs for info | Need specific time frame | Points of contact\PBDC |
| d. Coordination with Oceania Regional Response Team on Oil Spill Preparedness & Response | Contact ORRT and ask for status report on regional and local plans | Need specific time frame | Points of contact\Local ORRT representative |
| e. Get & Disseminate Information from International Maritime Organization to solicit support on improving policies to prevent discharge & dumping | Contact IMO and distribute information | Need specific time frame | Federal government points of contact |
| f. Sharing or DevelopingInformation on Valuation of Reefs as Resources | (see public awareness & education and assessment and monitoring sections) Contact ORRT on procedures under OPA 90 rules | Need specific time frame | Scientific advisory panel (see sections above) |
| g. Develop Approach to Identifying Vessels as Source of MBSP--use alien species hook to get Coast Guard assistance | Request technical assistance from USCG through PBDC | Need specific time frame | Points of contact\PBDC |
| h. Regional Effort Aimed at Increasing Funding for Coast Guard in 14th District | Letters to USCG and include needs in briefings for Congressional staff (see building political understanding) | Need specific time frame | Points of Contact |
| i. Regional Support for National Ocean Policy with CRI | | | Points of Contact\CSO Committee Chairs |

| ACTIVITY | HOW | WHEN | WHO |
|---|---|---|---|
| 7. Over Harvesting & Over Fishing | | | |
| a. Develop Information on Regional Level for Legislators on Needs of Management & Enforcement Agencies | Each area will develop briefing papers to include catch per unit of effort, catch size, change in specie composition, etc., as a basis for a regional paper entitled Overview of the Health of Inshore Fishery in the American Flag Pacific Islands. | Due January 15 | Peter Craig |
| b. Information Sharing<br>-Sustainable Harvest<br>-Community-based Approaches | Apply to SPC for ??????<br><br>PEACESAT Conferences | ASAP: Need specific time frame | CRI Working Group in each AFPI<br><br>PBDC |
| c. Identify Expertise<br>-Sustainable Harvest | Contact SPC and NMFS | Need specific time frame. | Lou Eldredge |
| d. Work with WESTPAC to Develop Coral Reef Fisheries Management Plan | Investigage need and how to manage and conserve coral. | Draft due April 15, 1995 | Bob Schroeder |
| e. International Cooperation on Management of Species that Cross Boundaries (reef fish?) | On hold. | | |

| ACTIVITY | HOW | WHEN | WHO |
|---|---|---|---|
| 8. Regulations & Enforcement | | | |
| a. Develop Standardized Training for Compliance Review Officers | Develop basic enforcement officer training protocol. | By January 31, 1995 | Rufo Lujan |
| b. Identify Ways in Which Grant Funding Can be Restructured to Support Enforcement | Letter to Secretary of the Interior. | After PBDC Winter Meeting | PBDC |
| c. Adopt Regional Goal to Develop Better Regulations | On hold. | | |
| d. Information Sharing<br>-Existing Regulations<br>-Lessons Learned on Regulations & Enforcement<br>-Experience with Public Hotline<br>-Community-based Regulation & Enforcement<br>-Regional Workshop on Enforcement through CZM | Establish a clearing house on enforcement, regulations, and related matters. | ASAP: Need specific time frame. | PBDC |
| e. Develop Genetic Database to Fingerprint Illegal Takings | Develop an agreement with and set up sampling program with FWS Fisheries Lab. | No need??????????? | |
| f. Develop Regional Register on Violators | Need specific information on how. | Need specific time frame. | Who? |

## VI. POTENTIAL CONTRIBUTIONS OF THE AMERICAN FLAG PACIFIC ISLANDS TO THE INTERNATIONAL CORAL REEF INITIATIVE

The American Flag Pacific Islands have had considerable experience in developing scientific, regulatory and enforcement, and public education and awareness programs that are aimed at insuring the health of coral reef ecosystems. They have also learned many lessons about what has been effective and what has not be effective in protecting coral reef ecosystems.

Participants in the planning meeting identified expertise and experience in the AFPI that could contribute to the management, research and capacity building components of the international coral reef initiative. The include:

- The directory of resource people being compiled as part of the AFPI Coral Reef Initiative Management Program;
- Government and research institution expertise in coral reef ecosystem assessment and monitoring;
- University of Guam scientific resources in the area of coral breeding and sedimentation monitoring;
- Government experience in developing programs to control land-based sources of pollution;
- Government experience with the development community-based resource management and protection programs;
- Government and university expertise in the development of integrated coastal zone management programs;
- Lessons learned from coral reef management problems resulting from the rapid growth of tourism industries;
- Experience of AFPI-based non-governmental organizations in coral reef protection activities;
- Education and public awareness media productions including public service announcements developed in American Samoa and videos produced by the Government of Guam;
- Education and public awareness books, brochures, and pamphlets developed by the AFPI governments, educational institutions, and non-governmental organizations;
- Small boat mooring technology adapted to island environments in Hawaii and Guam;
- Experience with voluntary methods of assessment and monitoring of coral reef ecosystems;
- WESTPAC's experience in developing its coral reef management plan; and
- University of Hawaii and University of Guam expertise in coral transplantation.

## VII. POTENTIAL FUNDING SUPPORT OPTIONS FOR THE AMERICAN FLAG PACIFIC ISLANDS CORAL REEF INITIATIVE MANAGEMENT PROGRAM

American Flag Pacific Island governments are already contributing substantially to the management or coral reef ecosystems as evidenced by the activities outlined in Section III of this report. There are, however, coral reef management needs that cannot be met from existing resources (see Section IV), and AFPI governments would like to seek financial assistance from the Federal government to help meet those needs.

The enthusiasm AFPI governments have shown toward the Coral Reef Initiative has largely resulted from the "bottom up" nature of the CRI planning process. Island governments have greatly appreciated the opportunity to take a leadership role in framing the domestic coral reef initiative for the American Flag Pacific Islands. They have been grateful for the encouragement and support in their planning efforts from the Office of Territorial and International Affairs in the Department of the Interior, the Office of Ocean and Coastal Resource Management in NOAA, and the Office of Oceans, Science and Technology in the Department of State. They believe, however, that efforts to improve the management of coral reef ecosystems must be initiated at the local level, and the appropriate role for the Federal government is to provide technical and financial support.

In discussing the options for utilizing Federal funds made available through the Coral Reef Initiative, Island government officials believe that the "bottom up" approach that has been characteristic of the CRI planning process must be maintained. They do not feel that it would be appropriate for Federal agencies to independently plan and implement coral reef management initiative activities for the American Flag Pacific Islands. They believe that overall priorities for Coral Reef Initiative funding in the American Flag Pacific Islands need to be established by state, territorial, and commonwealth governments in cooperation with Federal agencies. They also believe that planning and implementation of projects and programs involving Federal agencies within the AFPI need to done cooperatively.

AFPI governments are aware of the fact that discussions of possible funding mechanisms for the CRI have already taken place among Federal government agencies. They understand that consideration has been given to funding: a CRI research program through the National Science Foundation; additional coral reef management activities through Sanctuaries and Reserves Division of the Office of Ocean and Coastal Resource Management; coral reef management activities through the National Marine Fisheries Service; and state, territorial, and Commonwealth programs through the Office of Ocean and Coastal Resource Management.

AFPI governments, in their discussions about the Coral Reef Initiative, clearly favor a funding mechanism that will allow the bottom up nature of the CRI to continue. They also favor a funding mechanism that will allow flexibility at the local level and minimize the administrative costs for grants management. Given the limited amount of funding that will be available for CRI activities, AFPI governments want to direct their efforts at improving the management of coral reefs rather than applying for and reporting on several small grants for individual activities. Therefore, AFPI governments would suggest that serious consideration be given to block grants for approved CRI management programs developed by state, territorial, and commonwealth governments in cooperation with the appropriate Federal agencies.

AFPI governments clearly recognize the need for scientific research to help solve many of the coral reef management problems they now face. Experience in the AFPI has shown, however, that scientific research aimed at addressing coral reef program in which the research problems are defined by resource managers inconsultation in consultation with scientists is a better investment than traditional academic funding programs that are planned with little or no consultation with resource managers. AFPI governments would, therefore, favor a CRI science program that provides funding to researchers that are willing to address problems identified by either the resource managers themselves or through a consultative process involving both resource managers and scientists.

AFPI governments recognize the value of sanctuaries and reserves in the management of resources of national significance. Indeed, American Samoa has a National Marine Sanctuary at Fagatele Bay and the Hawaii State Government has been involved in a cooperative effort with NOAA to develop a draft Environmental Impact Statement and Management Plan for the Hawaii Humpback Whale National Marine Sanctuary. However, aside from reefs within the Fagatele Bay National Marine Sanctuary, coral reefs in the American Flag Pacific Islands do not fall under the jurisdiction of the sanctuary and reserves system at the Federal level. Rather, coral reef management responsibility falls to state, territorial, and commonwealth governments. Therefore, AFPI governments favor a funding mechanism that would build coral reef management capacity within their governments rather than through the Sanctuaries and Reserves Division of OCRM as its program is now constituted.

## VIII.. NEXT STEPS IN THE DEVELOPMENT OF THE AFPI CORAL REEF INITIATIVE MANAGEMENT PROGRAM

Planning meeting participants agreed that they would continue to develop local coral reef initiatives in each of the four American Flag Pacific Islands. Each of these efforts would involve the coastal zone management, marine resource management, and water quality agencies as well as research institutions and non-governmental organizations.

Participants also agreed to maintain the existing regional communication structure with the points of contact working with PBDC and Federal officials to maintain an on-going dialogue on the development of the local Coral Reef Initiatives, the refinement of the regional plan recommendations developed at the December 5-7 planning meeting, and the Coral Reef Initiative at the Federal level.

Planning meeting participants agreed to provide feedback through the Office of Territorial and International Affairs on the draft agenda of the International Coral Reef Initiative Workshop including suggestions for speakers and panelists by January 20, 1995. The points of contact were asked to take responsibility for insuring that comments were gathered from members of their CRI working groups and forwarded through OTIA to the Department of State and NOAA.

PBDC staff agreed to work with the Office of Territorial and International Affairs on establishing electronic mail access for the AFPI governments to facilitate further planning and communication in the development of the Coral Reef Initiative. Access is currently available in Hawaii and Guam but not in American Samoa and the Commonwealth of the Northern Mariana Islands. PBDC staff agreed to explore the feasibility of INTERNET access through PEACESAT and the establishment of more direct access to the network.

Planning meeting participants agreed to review the draft of the planning meeting report prepared by PBDC and make suggested revisions by January 16. PBDC staff agreed to make revisions in the report for presentation to the AFPI Governors at the February 1, 1995 meeting of the PBDC Board and forward the report to the Office of Territorial and International Affairs, the Office of Ocean and Coastal Resource Management, and the Office of Oceans, Science and Technology.

Acronyms List

ACOE: US Army Corps of Engineers
AFPI: American Flag Pacific Islands
AG: Attorney General
ASCMP: American Samoa Coastal Management Program
BMPs: Best Management Practices
ASEPA: American Samoa Environmental Protection Agency
CRM: Coastal Resources Management--CNMI
CRI: Coral Reef Initiative
CSO: Coastal States Organization
CUC: Commonwealth Utilities Corporation--CNMI
CWA: Clean Water Act
CZM: Coastal Zone Management Program--Hawaii
DAR: Division of Aquatic Resources--DLNR, Hawaii
DAWR: Division of Aquatic and Wildlife Resources--DOA, Guam
DEQ: Division of Environmental Quality--CNMI
DLM: Department of Land Management--Guam
DLNR: Department of Land and Natural Resources--Hawaii
DLNRM: Department of Land and Natural Resource Management--CNMI
DMWR: Department of Marine and Wildlife Resources--American Samoa
DOA: Department of Agriculture--Guam
DOCARE: Division of Conservation and Resource Enforcement--DLNR, Hawaii
DOH: Deparment of Health--Hawaii
DOT: Department of Transportation, Hawaii
DPOor EDPO: Economic Development and Planning Office--American Samoa
DPS: Department of Public Safety--Hawaii
DPW: Department of Public Works--Guam, American Samoa, CNMI
EPA: Environmental Protection Agency--American Samoa
EWC: East West Center
FBNMS: Fagatele Bay National Marine Sanctuary--American Samoa
GCMP: Guam Coastal Management Program
GEPA: Guam Environmental Protection Agency
GIS: Geographic Information Systems
HIMB: Hawaii Institute of Marine Biology, University of Hawaii
HRS: Hawaii Revised Statutes
IMO: International Maritime Organization
MBSP: Marine-based Sources of Pollution
NGO: Non-Governmental Organization
NMFS: National Marine Fisheries Service
NOAA: National Oceanic and Atmospheric Administration
NPDES: National Pollution Discharge Elimination System
OCRM: Office of Ocean and Coastal Resources Management, NOAA
OTIA: Office of Territorial and International Affairs
OPA: Oil Pollution Act of 1990
ORRT: Oceania (Oil Spill) Regional Response Team
PEACESAT: Educational Satellite Network, University of Hawaii
PNRS: Project Review and Notification System--American Samoa
PBDC: Pacific Basin Development Council
SOEST: School of Ocean and Earths Sciences and Technology, University of Hawaii
SPC: South Pacific Commission
SPREP: South Pacific Regional Environment Programme
UNFPA: UN Fund for Population Activities
UOGML: University of Guam Marine Lab, University of Guam
UH: University of Hawaii
WESTPAC: Western Pacific Regional Fishery Management Council

**YEAR OF THE CORAL REEF**

**ACTIVITIES ON GUAM**

YEAR OF THE CORAL REEF AD HOC COMMITTEE/ PACIFIC YEAR OF THE CORAL REEF COMMITTEE MEETINGS:

30 JANUARY
20 FEBRUARY
6 MARCH
13 MARCH
3 APRIL
(Two April meetings postponed for typhoon & earthquake)
12 MAY
16 MAY_
24 JUNE

GUAM GOVERNOR'S PROCLAMATION AND KICKOFF OF 1997 AS THE YEAR OF THE CORAL REEF

4 FEBRUARY

U.S. KICKOFF FOR THE YEAR OF THE CORAL REEF, ATTENDED BY GUAM'S LIEUTENANT GOVERNOR IN WASHINGTON D.C.

11 FEBRUARY

WEEKLY PUBLICATION OF 'DID YOU KNOW' NOTES ABOUT CORAL REEFS IN THE PACIFIC DAILY NEWS PAGE 2, ILLUSTRATED IN COLOR

BEGAN MARCH

JEAN-MICHAEL COUSTEAU VISIT AND MEETINGS ON GUAM AND INTERNATIONAL CORAL REEFS

APRIL

EARTHWEEK PUBLIC DISPLAYS WITH LIVE CORALS, CORAL REEF VIDEOS AND INFORMATION

20 TO 26 APRIL

GOVERNOR'S EXECUTIVE ORDER ESTABLISHING GUAM'S CORAL REEF INITIATIVE

12 MAY

MAN , LAND AND SEA NEWSLETTER VOL.IX, #3, ENTIRE ISSUE DEVOTED TO GUAM'S YEAR OF THE CORAL REEF

MAY/JUNE

UOG MARINE LAB COURSE ON CORAL TAXONOMY
JANUARY TO JULY

GUAM'S FIRST ANNUAL CORAL SURVEY-"REEF CHECK 97"
TRAINING 7, 10, 15 AND 17 MAY
SURVEY 14 JUNE
REVIEW 28 JUNE

25TH ANNIVERSARY OF WORLD ENVIRONMENT DAY
5 JUNE

CORAL MASS SPAWNING OBSERVATIONS
28 JUNE TO 4 JULY
27 JULY TO 2 AUGUST

"CORAL REEFS-THEIR HEALTH, OUR WEALTH" VIDEO COPIES RECEIVED AND DISTRIBUTED
JUNE/JULY

PACIFIC SCIENCE ASSOCIATION MEETING, SUVA, FIJI
JULY

MICRONESIAN REGION CENTER FOR INTERNATIONAL CORAL REEF DATA SYSTEM TO BE ESTABLISHED ON GUAM FOR INTERIM OPERATIONS PRIOR TO SET UP IN PALAU
AUGUST

TUMON BAY PUBLIC VOLUNTEERS' CLEANUP
2 AUGUST

CORAL REEF LEGISLATION REVIEW AND DEVELOPMENT
ON-GOING ALL YEAR

CORAL SPAWNING, CULTURE, TRANSPLANTING AND USE FOR ON SITE ENVIRONMENTAL MONITORING
ON-GOING ALL YEAR

MAN, LAND AND SEA TELEVISION SERIES
ON-GOING ALL YEAR

# OPINION

## Standards necessary to preserve our reefs

The Fish Eye Marine Park in Piti, sitting on top of Tepungan Bay's largest "bombhole," opened last month to mixed reaction from visitors, divers and environmentalists.

Visitors to the underwater observatory have enjoyed watching a colorful array of fish, attracted by bags of food set out by the park. Some divers, familiar with the area before the observatory was started, have complained that there is debris strewn around the area as a result of the construction. And environmentalists aren't convinced that the so-called environmental attraction is all that environmentally friendly.

The observatory fought a decade-long battle to get the required permits. During that time the company was threatened with lawsuits and constant objections from environmentalists.

Pedro Leon Guerrero Jr., of Pacific Underwater Observatories, Inc., says "We're pretty proud of this project. We want to showcase the environment ... it's not in our best interest to destroy it. I think if people see this, it'll be good. If they learn a little about the environment — maybe they won't throw their trash on the beach anymore."

Frankly, most of us — including residents, businesses and government — have a lot to learn about the environment.

Marine biologist Bob Richmond, from Guam's Marine Lab, is critical of the project. "Guam has a limited number of resources. To use them in this way is a burden on future generations," he said. The problems associated with the observatory won't end with the construction, Richmond added, because the structure itself has changed the environment. He pointed out that while a lot of the coral that was moved to make way for the 1,000 foot structure, has survived, it did so because of the professional environmentalists on island — and at taxpayer expense.

It will take a while to see how things settle down after the construction, and will take years to measure the full impact on the underwater environment. However, the observatory may prove to be just what it claims to be.

But ecological "experiments" like this need clear standards in place before investors start plans for similar or even more ambitious projects. We shouldn't proceed by trial and error and risk damaging the environment along the way.

Island residents and investors must know the "bottom line." People need to understand what affect such projects will have on the ocean ecosystem, so they can make informed choices.

And investors will shake their heads and walk away, if truly unjustified 10-year hassles are going to be typical.

## SCORE aids businesses

A local non-profit business assistance organization, the Service Corps of Retired Executives has struggled to stay afloat following loss of funds from the Small Business Administration. But local businessmen and organizations came to their rescue, raising more than $5,000 since last November.

Made up of both retired and active business executives, who volunteer their time to help fledgling and established businesses, SCORE gives much more back than it receives.

Joan Marder, director of the Guam SCORE chapter, says this money and the support received from various island organizations involved in promoting business ventures, are the foundation of their program. SCORE conducts monthly workshops on such topics as: how to open a small business, financing a small business, writing a business plan, managing a small business and record keeping.

The organization also provides free counseling services from their corps of volunteer executives, who have the expertise many inexperienced entrepreneurs need to be successful.

This concept is a valuable resource not only for the "little guy" who is struggling to make a go of it, but for potential business operators who are weighing their chances. Many of the successful executives who dedicate their time and experience to this program may very well have availed themselves of SCORE's services on their way to the top.

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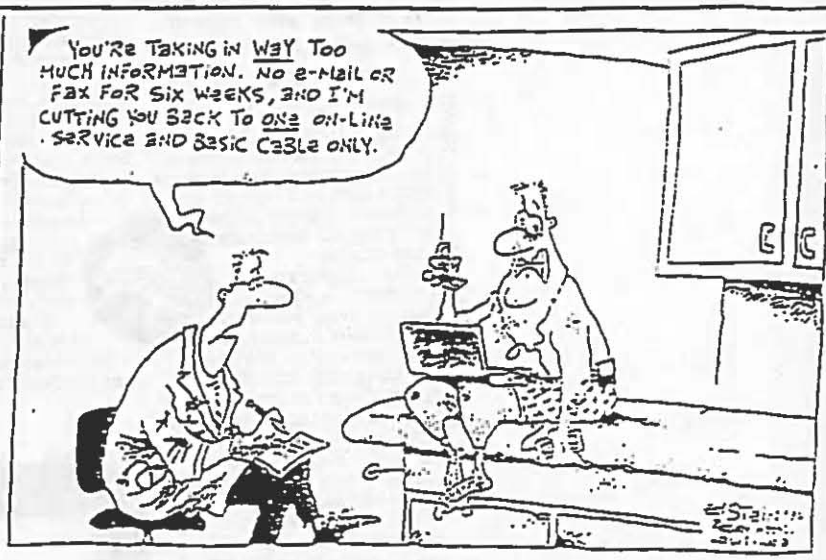



## The Freemen remind us that lawlessness has to be stopped

NORMAN LOCKMAN

Americans of all kinds have long had a romantic attraction to pirates and outlaws, so it is not surprising that there are plenty of people quietly rooting for the "Freemen" of Jordan, Mont., who, by Monday, were in their second week of a stand-off against the FBI.

In the American West, and in parts of Appalachia, Australia and South Africa, there is a long tradition of anti-government militancy that is bound together by race, religion and jingoism. In South Africa it was the Boers against the English. In Australia, the Outbackers against the Commonwealth. In Appalachia, the bootlegger against the revenuer. In the West the manifestation has been outlaw against government.

Make no mistake about it, the Freemen are outlaws. Their religious and political veneers are thin, indeed. Their main agenda was trying to run the same kind of swindle that helped make Robert Vesco one of the richest fugitives ever. They were kiting checks, worth millions, against the value of property they had filed liens upon, using their own "courts." Vesco floated bogus paper on the ephemeral Bank of Sark, located on an islet in the English Channel. The Freemen floated worthless paper on the Norwest Bank of Butte, Mont., where their accounts have been shut down since the FBI uncovered their scam in 1992.

Their "ideology," is actually a criminal credo: that all forms of government (except the "Freemen's" own) are illegal, that taxes and all forms of licensing are illegal, that foreclosures are illegal, that their own "township" government can issue arrest warrants and hold trials and executions of encroaching government officials. And finally that their own "central bank" is the only legal financial institution, allowing it to legally defraud other financial institutions, the government and businesses.

It is banditry, just as surely as holding up a bank — or waylaying an armored car, which is the method used by some of the Freemen's less squeamish far-right compatriots.

So, why is there such hand wringing on the part of the federal bureaucrats whose job it is to stop this sort of thing? And why do the self-styled "militias" threaten to march to the defense of outlaws holed up on Justus Township, really a rundown farm in Montana where the rebels can't even spell justice. It's because there is a layer of disenchanted people out here who fantasise about escaping the obligations of American citizenship, including obeying courts, honoring debts, paying taxes and refraining from racial, religious and ethnic discrimination.

In the Old West, when bands of outlaws defied law and order and tried to take over a town, they sent federal marshals, and sometimes troops. Sometimes there were shootouts. Nervous townspeople were glad to have them, as, we are told, are the townspeople of Jordan, Mont.

its cameras to the other side and we began to explore the "anti-heroes," bad guys with a hankering to smash bad authority. They are imbued with some kind of vague nobility, the "Braveheart" syndrome. Rebels over tyranny, just like in the movies.

It's baloney, but we in the media do love it. We get caught up in the drama of Big Bad Government against yokel rebels. It's not so much that we are rooting for the rebels, it's our fascination with armed confrontation and the possibility of sudden death. The fascination with the raw violence, like the shootout at Ruby Ridge, Idaho, and the armored attack in Waco, Texas, overwhelms the details of what was — and is — at stake.

What is at stake in Montana is preservation of law and order, the same as it is in urban ghettos overwhelmed by criminals.

Lawlessness needs to be stopped. Period. That's what the FBI and other federal law enforcement agencies are for. Let's not tie their hands too much.

*Norman A. Lockman is associate editor of The Wilmington News Journal.*

PACIFIC DAILY NEWS, Friday, January 31, 19

# Florida acts to save its endangered reefs

**■ Fishing and diving:** Rules prohibit fishing in many areas, require moorings at dive sites

TALLAHASSEE, Fla. (AP) — After six years of wrangling, Florida has finally agreed to protect the fragile coral reefs in the Florida Keys by limiting fishing and diving and keeping big ships miles away.

For generations, freighters hugging the coast to avoid powerful Gulf Stream currents had run aground on the reefs, crunching coral that takes thousands of years to form. Smaller boats bringing tourists in for closer looks have also slammed into the coral and chewed up the only living reef near the shores of the lower 48 states.

"We need the benefits of comprehensive management," Karen Lee, co-owner of an Islamorada mortgage company, told Florida Gov. Lawton Chiles and his cabinet before they approved the management plan on Tuesday.

"Population explosion in this state ... threatens to destroy the very beauty that has attracted millions of people to visit and live here," Ms. Lee said.

## 1.5 million visitors a year

The Florida Keys National Marine Sanctuary was created in 1990, but because two-thirds of the sanctuary lies in state-controlled waters, the final management plan needed state approval.

And that has meant appeasing residents wary of a federal role in the Keys, where the fishing, diving and tourism businesses that attract 1.5 million visitors a year are depended on an increasingly endangered marine environment.

The plan approved Tuesday includes using mooring buoys to let boats tie up for diving without causing anchor damage, and channel markers to keep boats away from the coral and fragile seagrass.

It also bars any fishing in 19 critical areas, less than one percent of the 2,800-square nautical mile sanctuary. That represents a compromise; the federal plan had called for a no-fishing area of more than 5 percent.

The ban applies to all anglers, not only charter businesses, and some residents weren't happy with the deal.

## 'A big Trojan horse'

"I have read the documents. I have attended the hearings. This is a big Trojan horse," said John Clark of Ramrod Key, an amateur angler who said the waters are still teeming with life.

To ease residents' fears, the National Oceanographic and Atmospheric Administration, the federal partner in running the sanctuary, agreed to let the Florida Marine Fisheries Commission review 19 proposed no-fishing zones between now and July 1, when the plan is to take effect.

Limited protections in place since the sanctuary was created in 1990 have kept freighters, oil tankers and other ships longer than 155 feet at least two miles from the reef. Those protections weren't changed before Tuesday's vote.

NOAA deputy administrator

new protections have the backing of President Clinton as part of the effort to restore South Florida's environment, including the Everglades and Florida Bay.

Congress has 44 days to review the plan, although congressional action is not required to enact it.

"We want our children to be able to see beautiful coral reefs," said Jennifer Murray, 17, of Tavernier, speaking for a group of Coral Shores High School students at Tuesday's cabinet meeting.

Without the agreement, Miss Murray said, "We may find ourselves referring to present conditions as the good old days."

and Japan to Indonesia/Philippines.
- Pacific Island states.
- Caribbean and Intra-Americas, including countries with reefs bordering the Atlantic Ocean.

Regions will be divided by the participant countries into smaller sub-nodes, each of which will employ a team of trainers and database operators to assist a small group of countries Funding for each of these sub -nodes will be requested from country, development bank and agency donors, with the responsibility of funding monitoring to devolve to the countries, after about five years. Donors are invited to assist in developing the networks and funding proposals in regions where their interests are paramount.

Thus, the GCRMN will emphasise the involvement of local communities. Wherever possible, the GCRMN will use existing organisations and networks, integrate existing monitoring programmes, and maintain flexibility to incorporate different methods of monitoring, other than the standard methodology.

## GCRMN OBJECTIVES

The GCRMN aims to improve management and sustainable conservation of coral reefs for people by assessing the status and trends in the reefs and how people use and value the resources. It will do this by providing many people with the capacity to assess their own resources, within a global network, and to spread the word on reef status and trends.

In summary, the core objectives are:
- To link existing organisations and people to monitor biophysical and social, cultural and economic aspects of coral reefs within interacting regional networks.

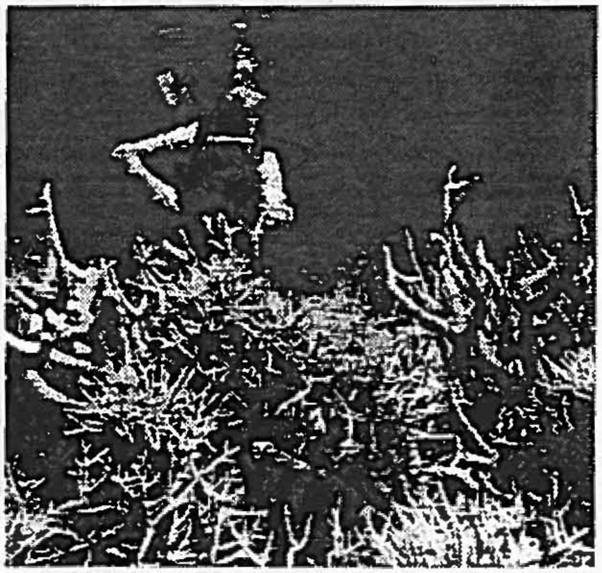
- To strengthen the existing capacity to examine reefs by providing a consistent monitoring

program, that will identify trends in coral reefs and discriminate between natural, anthropogenic, and climatic changes.

- To disseminate results at local, regional, and global scales by providing annual reports on coral reef status and trends to assist environmental management agencies implement sustainable use and conservation of reefs. Data will also aid preparation of predictive global climate change models for the GOOS Coastal Zone Module.

## HOW DOES THE GCRMN WORK?

The strategy to establish the global network is to employ a team of monitoring trainers in each GCRMN sub-node and use this team to train similar trainers in participating countries. The training will continue throughout the region with the focus on monitoring by local communities.



Monitoring will continue over time at key national sites, to gather data and develop skills. Experienced marine institutes will assist in training, establishing of databases and problem resolution.

A range of reef types will be monitored along line transects, assessing easily recognisable lifeforms and total fish counts, with specific counts of 'target' fish of commercial or recreational value. As people gain more experience, monitoring will be upgraded using the same methods, but to species level. Local communities will be questioned on their use and knowledge of reef resources and how management may be improved. The Network will be responsive to reef users and provide information back in an understandable format. Much of the monitoring will be in current or planned Marine Protected Areas and adjacent unprotected areas. This will be coordinated with the World Bank, IUCN/CNPPA, and GBRMPA Global Representative System of Marine Protected Areas project.

Monitoring data will be accumulated in each sub-node for distribution within the region and to *ReefBase* (ICLARM, Manila). These will be combined, by the GCRMN Coordinator, into annual global reef status summaries and disseminated to international forums, organisations and the media.

Two special monitoring projects will be supported by the GCRMN: a pilot programme undertaken simultaneously by research institutes around the world to give a snapshot of reef status; and the development of a tourist monitoring programme coordinated through tourist operators.

## How can you assist?

- Ensure that your organisation or country is informed of the GCRMN and its objectives.
- Inform the GCRMN Coordinator about organisations and individuals who wish to be part of the International Coral Reef Initiative and the GCRMN.
- Recommend the possibility of funding by donors to assist a sub-node or country, or through the direct funding of training workshops or publications.
- Assist us to provide training or equipment to countries to monitor and operate their own databases.

## Contact information

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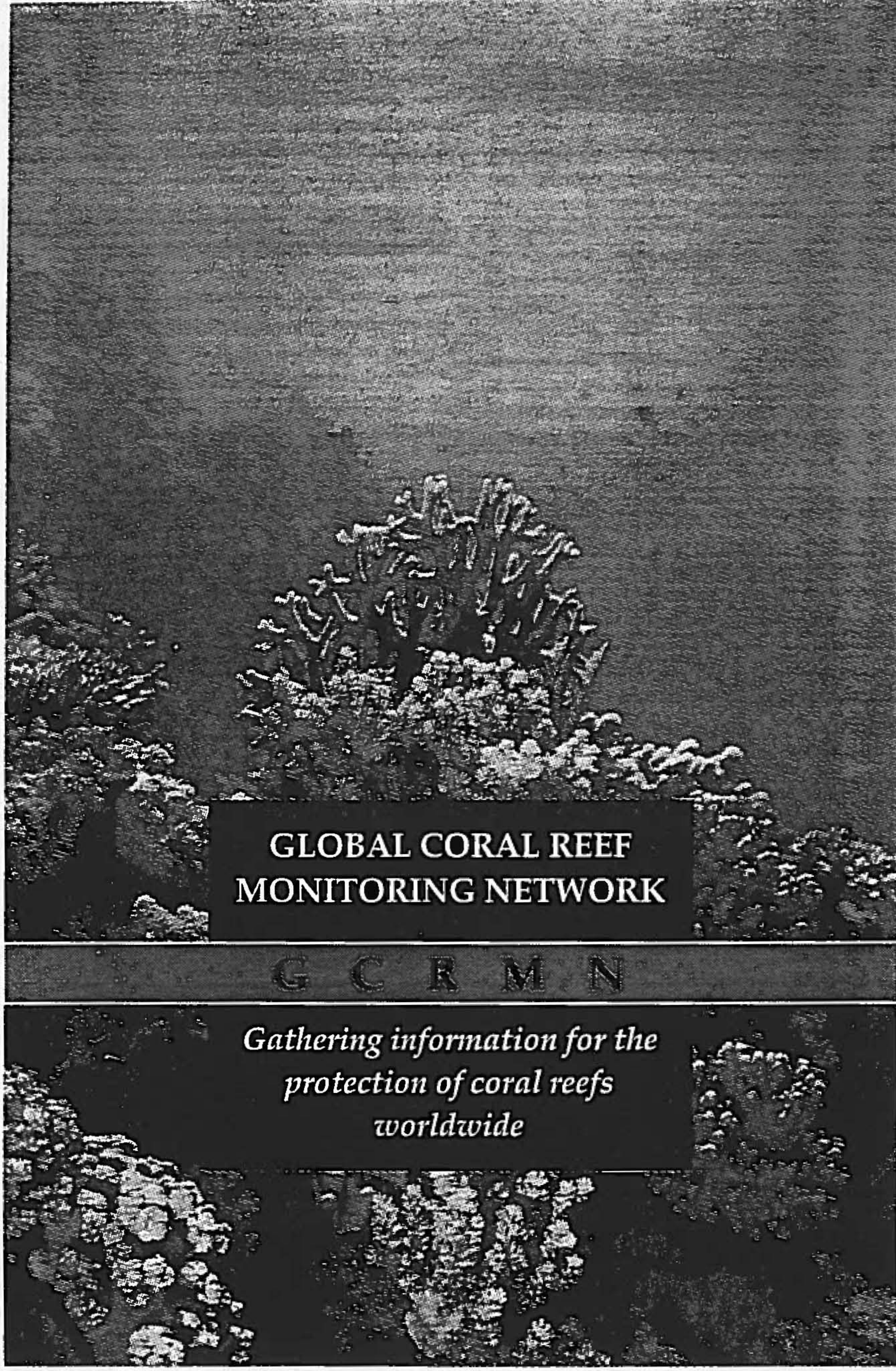


# GLOBAL CORAL REEF MONITORING NETWORK

GCRMN

*Gathering information for the protection of coral reefs worldwide*

## INTRODUCTION

Coral reefs around the world are being damaged and destroyed at an increasing rate. But we cannot be precise about how much and where, because of the special difficulties of monitoring underwater. Thus, there is a need to assess how, where and why damage is occurring and determine the best methods for prevention.

By harnessing the interest and skills of all users in reef assessment and management, the Global Coral Reef Monitoring Network (GCRMN) has been established to tackle these problems and to provide valid management data.

The GCRMN's major product will be the facilitation of networks of people trained to look closely at coral reefs and to monitor their progress over time. This will also provide knowledge and data on reef status and trends.

Essentially, the GCRMN is a bottom-up network which aims to tap into the current knowledge about coral reefs in order to advance reef management.

## BACKGROUND

Global reef monitoring has been discussed seriously for some time. When the International Coral Reef Initiative (ICRI) was launched at the United Nations Global Conference on Sustainable Development of Small Islands Developing States in Barbados in 1994, there was renewed emphasis on monitoring coral reefs. In 1995 ICRI called on many nations to commit themselves towards increasing research and monitoring of reefs to provide the data for effective management.

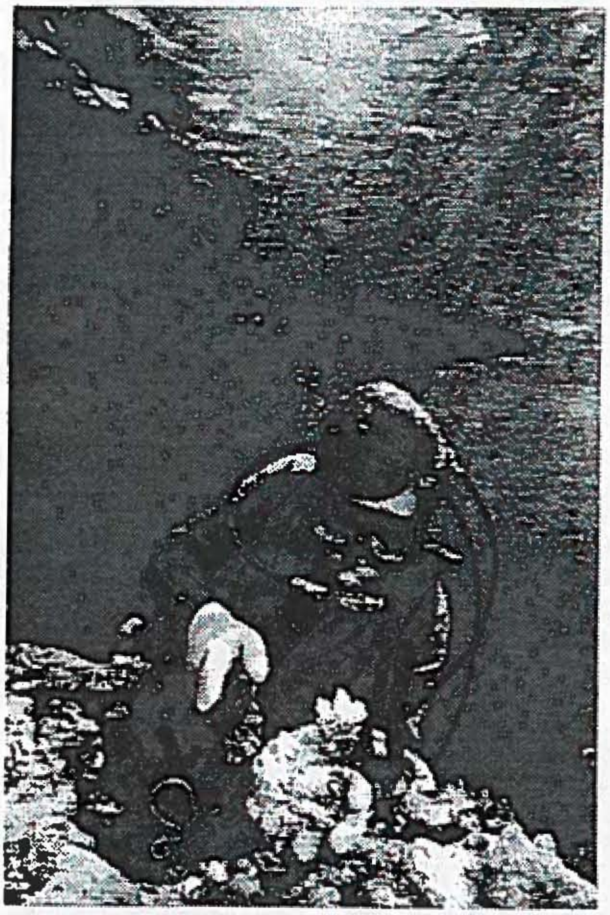
IOC, UNEP, and IUCN have joined forces to co-sponsor the GCRMN, which is hosted jointly by AIMS (Australian Institute of Marine Science) and ICLARM (International Center for Living Aquatic Resources Management). These bodies, along with the ICRI Secretariat, form the GCRMN Management Group. Advice is provided by a widely representative Scientific and Technical Advisory Committee (GCRMN-STAC).

## WHERE IS GCRMN LOCATED?

The GCRMN will function through fifteen independent networks, or sub-nodes, in six regions around the world. These networks will contain many different groups of people, all collaborating to monitor coral reefs and share data.

The regions are:

- Western Indian Ocean islands and East African States.
- Middle East Gulfs (those countries bordering the Red Sea around to the Persian/Arabian Gulf.
- South Asia (India, Sri Lanka and Maldives).
- East Asian Seas (from Burma/Myanmar



# Parking at Hanauma Bay costs at least $1

HONOLULU (AP) — Visitors to Hanauma Bay, get your dollar bill ready.

As of Thursday you'll have to use it to park there. And tourists will have to pay an additional $3 to use the park.

The City Council approved the fees Wednesday. Officials estimate they will collect about $2.6 million annually under the new policy.

Councilman Mufi Hannemann said most complaints about the fees disappear when visitors find out that much of the money will go toward the park.

About half of money collected each year will be used to expand the bay's educational program and to study how many people should visit the bay each day, Hannemann said.

The rest of the money goes in the city's operating budget, he said.



# OPINION

## Saving the reefs will take entire community

The poor condition of Guam's reefs — which environmentalists have been telling us about for some time — is starting to become obvious to other members of our community as well.

Divers, fishermen and beachgoers can see the stark evidence in sections of our reef that have turned into skeleton or are covered in algae. Along with that, the fish population that depends on the reefs for its food and habitat is becoming scarce.

> If we don't do something to halt the destruction of our reefs, then the tourists, who come here to enjoy this natural beauty, will recognize the blight and find better places to go.

This problem is caused by uncontrolled toxic runoff into our bays and damage to the reefs from boats and souvenir hunters. When their habitat is destroyed, the fish don't reproduce. And overfishing eventually decimates the population.

If we don't do something to halt the destruction of our reefs, then the tourists, who come here to enjoy this natural beauty, will recognize the blight and find better places to go.

Obviously, this is a communitywide problem that goes beyond just the concerns and efforts of environmentalists.

There are several actions the entire community has to embrace if we are going to restore our reefs:

- Businesses which depend on healthy reefs, such as dive shops, fishermen and those in the tourist industry, must band together to start a campaign that shows the community the results of careless action and what that will cost us.
- Voters must contact members of the Legislature to show support for Bill 49 that sets aside several small stretches of the reef to allow them to revive and recover.
- Lawmakers must enter legislation that prohibits indiscriminate reef fishing using bang sticks and spearfishing using scuba equipment. In addition, we need laws that require developers to design holding ponds and other diversion methods to contain runoff from commercial development projects.
- Members of the community are also responsible to ensure that toxic substances aren't dumped into the ocean and that trash and litter are not allowed to wash up onto the reefs, so the coral has a chance to rejuvenate.

The motivation to save our reefs is more than protecting these living organisms — it is critical to our economic survival.

## Rehabilitation survey results

PACIFIC DAILY NEWS, Friday, November 22, 1996

# Scientists sound alarm for world's coral reefs

By KEN MILLER
Gannett News Service

WASHINGTON — The world's coral reefs, known as the rain forests of the ocean for their rich biological stores, must be saved for their obvious environmental importance and because they are key to the survival of dozens of countries, scientists said Wednesday.

The task is formidable, experts told a coral reef forum as they prepared for the International Year of the Reef next year: 10 percent of Earth's coral reefs are dead or mortally wounded; another 30 percent could die in two decades without dramatic action.

"Reefs are in trouble around the world, in trouble from a lot of sources," said Charles Wahle of the National Oceanic and Atmospheric Administration's Office of Ocean and Coastal Resource Management.

"Is there a crisis?" said Stephen Colwell, executive director of the Coral Reef Alliance. "Yes. Simple and straightforward. If you're talking about a resource that is one of the oldest ecosystems in the world, an ecosystem that's been around 50 million years, and you see a change in a couple decades, that's a crisis."

☐ See REEFS, Page 25

PACIFIC DAILY NEWS, Friday, November 22, 1996

## brings high-profile events

☐ Continued from Page 24

Scientists long have urged attention to the planet's ailing reefs, but they are counting on a year's worth of high-profile events in the Year of the Reef to drive their message home.

"It's not enough to talk about the environmental importance of reefs in order to capture (public) attention," Colwell said. "You need to talk about the economic value of reefs."

Among the least understood of all known life forms on Earth, coral reefs harbor a quarter of all marine species and supply 12 percent of the seafood. More than 100 nations have economies that depend in part on reefs for tourism or to feed their people; and Colwell said reefs remain "an almost untapped source of chemical compounds" for medicines and other uses.

Yet they are collapsing for so many different reasons that these scientists warned a unified international response is needed to reverse the trend. The threats:

- Poor water quality — "the most pervasive threat to reef ecosystems," said Mark Chiappone, a marine biologist at The Nature Conservancy in Florida and one of the nation's leading reef experts. Reefs require clear and relatively nutrient-free water, but coastal development and agricultural runoff are destroying near-shore water quality.
- Increasing temperatures. Reefs, actually a menagerie of plants and animals orbiting animals known as corals, live on the thermal edge. They are extremely sensitive to temperature swings, which are more common as water quality declines.
- Overfishing. It ranges from Filipino fishermen using cyanide and dynamite to stun and capture fish for the aquarium trade to excessive taking of reef fish for food and overharvesting of other life forms.
- Bleaching. It's caused when corals, which are translucent, lose their pigmented, one-cell algae that live in them. It is a "worldwide phenomenon," said Gary Ostrander, associate dean for research at the Johns Hopkins University's School of Arts and Sciences. "Ninety-seven percent of the Galapagos corals are gone because of bleaching."

Coral bleaching usually is fatal, because suffocatingly thick algae normally replaces the simpler forms that corals need to survive. Marine species then flee the barren corals, dooming them.

"We're beginning, for the first time, to understand just how complex these ecosystems are," Wahle said, adding that many reef systems have sustained heavy damage and "we're beginning to see crashes."

For Americans, understanding the threats to reefs and their impacts requires looking no further than Florida, where the only continental U.S. reef system is under siege from pollution, overfishing, and ship groundings.

The Florida Keys saw their first "bleaching event" in 1980, he said, but four more broke out from 1980-90 and each seems to be getting worse.

Jack Sobel, director of habitat conservation at the Center for Marine Conservation, said creation of the Florida Keys sanctuary, and the touchy issue of creating "no-take" zones where fishing and marine life collecting is prohibited, was what is needed to protect the keys from further destruction.

"The general public cares a lot about coral reefs, but only a small portion understands the issues," Sobel said. He said only half of 1 percent of the Florida sanctuary would be off limits to fishing, but even that will be "critically important to the health of the reef" and can help restore declining fish

TERRITORY OF GUAM
OFFICE OF THE GOVERNOR
AGAÑA, GUAM 96910
U.S.A.

PROCLAMATION NO. 97-010

"YEAR OF THE CORAL REEF -
TAKING RESPONSIBILITY FOR OUR ENVIRONMENT AND FUTURE"

WHEREAS, our Administration recognizes the significant ecological and cultural values of Guam's coral reefs and the importance of protecting them from over exploitation; and

WHEREAS, our coral reefs, including associated mangroves and seagrass beds, provide shelter from typhoons and tsunamis, shelter for our shallow bays and lagoons which offer recreation and sustenance, nourishment for Guam's beaches which support our economy, and habitat for the bio-diversity which defines the soul of our community; and

WHEREAS, divers and marine biologists in Guam are under the impression that our island's coral reefs are being degraded, slowly dying by attrition, i.e., corals die from natural and man-made causes; and

WHEREAS, degradation of Guam's reefs and near-shore waters have resulted in toxification of seaweeds and fishes which has led to human fatalities; and

WHEREAS, urgent and immediate action must be taken if we are to prevent the loss of most of Earth's coral reef ecosystems during our children's lifetimes; and

WHEREAS, innovative partnerships are needed at local, national and international levels to encourage and support efforts by governments, resource managers, scientists, educators, non-governmental organizations and the private sector to conserve and sustain these biologically diverse and economically important resources;

NOW, THEREFORE, I, MADELEINE Z. BORDALLO, Acting Governor of the Territory of Guam, by virtue of the authority vested in me by the Organic Act of Guam, as amended, do hereby proclaim 1997 as "YEAR OF THE CORAL REEF" "TAKING RESPONSIBILITY FOR OUR ENVIRONMENT AND FUTURE." In so doing, I urge our community to acknowledge the importance of preserving the coral reef that surrounds Guam and to "think globally - but - act locally."

FURTHER, on behalf of Acting Lieutenant Governor Antonio R. Unpingco and the people of Guam, I extend congratulations to the Guam Coral Reef Coordinating Committee, and the Guam Coral Reef Initiative Policy Advisory Committee for their participation and coordination in developing specific proposals to strengthen coral reef management efforts at local, regional, national and international levels.

IN WITNESS WHEREOF, I hereunto set my hand and cause the Great Seal of the Territory of Guam to be affixed in the City of Agana, this 4th day of February in the Year of Our Lord, Nineteen Hundred and Ninety-Seven.

MADELEINE Z. BORDALLO
Acting Governor of Guam

COUNTERSIGNED:

ANTONIO R. UNPINGCO
Acting Lieutenant Governor of Guam

SEA GRANT HAWAII

University of Hawai'i Sea Grant College Program
School of Ocean and Earth Science and Technology

Makai Toward the Sea

Vol. 18, No. 11 November1996

# Maui's coral reefs: underwater tropical rainforests

by Kelly Shimabukuro

Coral reef ecosystems are home to a variety of marine organisms, providing both food and shelter to various fish and invertebrates. Found in warm and temperate waters around the world, these "underwater tropical rainforests," as coral reefs are often called, take hundreds of years to develop.

In recent years, coral reefs have become increasingly threatened by naturally occurring disturbances and dangers caused by human negligence.

In response to these environmental and man-made pressures, the Coral Reef Research Study was established in 1989 with the purpose of studying threatened reefs along the West Maui coastline. Administered by the Pacific Whale Foundation and funded by Earthwatch, it is the longest running continuous study of Maui's coral reefs.

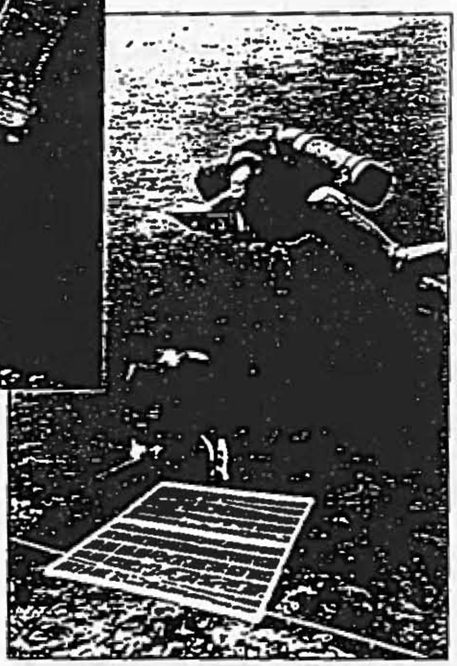
The study, led by coral reef biologist and Ph.D. candidate Eric Brown, was initiated when Brown realized the need for a comprehensive study to monitor coral reef ecosystems. Now in its seventh year, Brown and a team of more than 40 volunteers, work from June through early October gathering data on coral and fish populations at research sites located at the West Maui beaches of Honolua Bay, Olowalu, Puamana and Kahekili Park.

"Originally we began doing the project to characterize Hawaiian reef systems on Maui," Brown said. "We were primarily focusing on coral

(Continued on page 3)

*A diver, conducting visual transects at Honolua Bay, measures fish density and diversity using an underwater slate. By employing the transect method, divers collect data with minimum disruption to the ecosystem.*

*—photo courtesy Pacific Whale Foundation*



*Measurements of coral diversity and percent coverage are collected by divers at Olowalu Beach using the quadrat method. This method, also used at the other two longterm monitoring sites, utilizes meter-by-meter grids from which underwater visual measurements of coral are taken.*

*—photo courtesy Pacific Whale Foundation*

## 1997: International Year of the Reef

In recognition of the International Year of the Reef, the Sea Grant College Program at the Univerity of Hawai'i has joined hands with the Pacific Science Association (PSA) to produce a volume on the status and health of coral reefs in the Pacific. The PSA study is an activity of its Scientific Committee on Coral Reefs which has received support for the project from the U.S. State Department's International Coral Reef Initiative.

The joint effort between ICRI, IYOR, PSA and Sea Grant/SOEST will produce a series of 10 country reports on the health of the reefs in 10 regions of the Pacific. Each month a summary of one country report will appear as an extension of the UH Sea Grant web page at http://www.soest.hawaii.edu/SEAGRANT/coral reef.html. The full report will be published by next July to coincide with the 8th PSA Inter Congress to be held July 13-19, 1997, in Suva, Fiji. Interested parties should address inquiries to the UH Sea Grant Communications at (808) 956-7410.

# QUEST Pohnpei aims at reef conservation

The UH Marine Option Program (MOP) offered a modified version of its Quantitative Underwater Ecological Surveying Techniques (QUEST) course in Pohnpei, Federated States of Micronesia, in August. Designed to suit the needs of its participants, primarily regional resource managers, QUEST Pohnpei uses regional counterparts to each instructional staff person from UH. The approach provides training and experience necessary for the counterparts to continue the course without the direct assistance of UH staff.

Funded by the U.S. Department of the Interior, Office of Territorial and International Affairs, the Quest Pohnpei grant is administered by the UH Sea Grant College Program. Sherwood Maynard and Steve Russell coordinate all MOP activities.

A similar, modified version of QUEST is in the planning stages for Palau in 1997 and America Samoa in 1998. Representatives from the dive tour industry, community college and high school teachers, faculty from the University of Guam, government agency and NGO resource managers, and community college students will be able to participate. A modified QUEST training workshop is also under consideration for volunteer reef surveyors of the Hawai'i Coral Reef Initiative.

# What is a reef?

Coral reefs are one of the most diverse and biologically productive ecosystems on earth. Their high productivity is the result of efficient biological recycling and a high retention of nutrients in an otherwise nutrient-poor environment. Coral reefs are tropical, shallow-water ecosystems restricted to latitudes 25° to 30° north and south and year-round surface water temperatures of 25° to 30° C. Hermatypic corals (i.e., reef-building or stony corals) are multicellular animals which collectively secrete the hard external skeleton of calcium carbonate that form reef structures. These reefs provide habitats for a wide variety of marine organisms, such as fish, sea turtles, marine mammals, crustaceans and invertebrates. A critical aspect of reef-building corals is their symbiotic relationship with the unicellular algae, zooxanthellae. The algae live, conduct photsynthesis, and process the coral's waste products all within the cells of their host. The entire biological productivity of the coral reef ecosystem rests on this symbiotic relationship.

Corals have very specific requirements for light, temperature, water clarity, salinity and oxygen. Coral growth is relatively slow, especially in areas where sediments are regularly disturbed because silted substrates prevent larval settlement. If light penetration is decreased these is a reduction in photosynthesis by the zooxanthellae algae. Most corals, therefore, are restricted to depths of less than 30 meters. Their lack of mobility makes them vulnerable to environmental disturbances, such as oil spills, through smothering and oxygen depletion.

Coral reefs in Hawaii are fairly well developed but display low species diversity because of Hawaii's extreme isolation and more northerly latitude. The best developed reefs in Hawaii are found on leeward(south and southwestern) coasts or in bays which are sheltered from wave action. Examples include the Kona Coast of Hawaii, the south coast of west Maui, the north coast of Lanai and Kauai, Kaneohe Bay, Hanauma Bay and Barber's Point, Oahu, and the lagoons of the Northwestern Hawaiian Islands.

—*Oil Spills at Sea: Potential Impacts on Hawaii*, 1992

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SEA GRANT HAWAII

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# Hawai'i Coral Card Available Free

To help celebrate the International Year of the Reef, staff at the Hawaiian Islands Humpback Whale National Marine Sanctuary on Maui created the Hawai'i Coral Card. The waterproof card features the most commonly encountered coral species in Hawaiian waters, as well as tips on coral conservation.

The Hawai'i Coral Card is available free at the Hawaiian Islands Humpback Whale National Marine Sanctuary:

O'ahu: P.O. Box 50186, Honolulu, HI 96850, phone (808) 541-3184, interisland (800) 831-4888.

Maui: Main office, 726 South Kihei Road, Kihei, HI 96753, phone (808) 879-2818.

Kaua'i: P.O. Box 3390, Lihue, HI 96766, phone (808) 335-0555.

# Maui's coral reefs (Continued from page 1)

populations and fish populations and not only how they were different between sites, but how they changed over time. Since then, we've expanded our efforts to look at other areas or other aspects of the environment, such as water motion, sedimentation, and factors influencing water quality, which might help us explain some of the observed patterns we were seeing with coral and fish." In addition to studying the changes in fish and coral population, researchers are also studying the effects of fish feeding at Kahekili Park, a popular tourist area.

Coral and fish populations can be affected by pressures from the environment and from humans. According to findings from past years, natural factors such as hurricanes can influence reef structure over a short term period with regards to the density of coral and fish. In contrast, human-use factors seem to take longer to manifest their impacts upon fish and coral density and diversity.

According to Brown, coral reefs on Maui are being threatened by shoreline development and human pressure. Brown feels that anchoring, pollution from boats and water users, and fishing pressure are all issues affecting coral reef ecosystems which need to be addressed.

Fish feeding poses another threat to coral reefs. Results of the research done at Kahekili Park indicate that fish feeding has a negative effect on the coral reef fish community structure. According to the study, fish feeding causes a decrease in species diversity, with an overall increase in fish density. This indicates that the more aggressive species may be displacing the less dominant fish species.

Paul Jokiel, Sea Grant researcher and Brown's doctorate advisor, has assisted Brown with his field methodology and experimental design for the study. "Brown has the best longterm monitoring data set of anyone in the state right now," said Jokiel. "At the sites, the data is extremely good because he has had very good quality control."

Data regarding coral and fish populations for the longterm monitoring sites of Honolua Bay, Olowalu and Puamana are gathered using SCUBA equipment and the quadrat and transect methods. The quadrat method utilizes a point-intercept method in which a meter-by-meter grid is placed on the ocean floor. From this method, coral coverage and diversity are measured. Similarly, the modified Brock transect method is used to measure fish density and diversity.

*"One of the neat things is that now we're getting the chance to see very gradually how a reef will recover, and at what rate it will recover."*

Both methods employ divers who conduct underwater visual counts to obtain fish and coral measurements.

Fish feeding research at Kahekili Park is conducted by dividing the park into three equivalent regions based on biological habitat and human use patterns. A treatment site, controlled treatment site, and control site are organized at the three regions to monitor changes in fish density and species composition.

Research for the study is gathered by teams comprised mainly of volunteers who are trained in the necessary research techniques used to assemble data. Each team surveys the different sites so every research location is studied several times by different groups of volunteers. This technique is used to reproduce results and give the study statistical reliability.

Brown has found that the longterm monitoring sites of Puamana, Olowalu and Honolua Bay have experienced varying degrees of changes between sites over the years.

At Olowalu, there have been few changes observed over the course of the study. The stability of Olowalu's reef community may be attributed to shelter from physical and biological factors.

In the case of Puamana, coral coverage was severely affected by Hurricane Iniki, where coral coverage was measured at 12.6% before Iniki and subsequently measured to be 0.9% the following year. This major reduction, caused by Puamana's exposure to Iniki's southwesterly waves, is not without its benefits. "One of the neat things is that now we're getting the chance to see very gradually how a reef will recover, and at what rate it will recover," said Brown.

At Honolua Bay, results indicate two very different trends occurring within the bay itself. "Part of the bay has been pretty much stable over the past six or seven years," Brown explained. "But the other part of the bay has been experiencing a severe decline, and we don't know what it is yet."

The preliminary results seen in this year's study correspond to trends seen in the past two years, so Brown believes that some of the reef areas may be beginning to stabilize. But he also believes that these trends may be more of a seasonal occurrence and intends to sample through the wintertime when the big northerly swells come.

The Coral Reef Research Study will be entering a new phase of research, with the emphasis on finding the cause-and-effect relationships between trends observed and the biological and physical factors present. Findings to date have allowed the Pacific Whale Foundation to work with both state and county agencies in order to preserve coral reef ecosystems by increasing the level of understanding on coral reef community dynamics.

Brown presented his findings, with the focus on trends seen at Honolua Bay, at the Maui Summit held in late August.

# Marine Miscellany

## Is Hawaii Ready?

*Hawaii's Readiness to Prevent and Respond to Oil Spills* is a follow-up to the 1992 report, *Oil Spills at Sea: Potential Impacts on Hawaii*. UH Sea Grant's latest report focuses on the state's responsibilities for improving its oil spill prevention and response capabilities.

Sea Grant conducted the year-long study to assist the state in determining how to prevent and respond to oil spills. In preparing the summary, the authors reviewed, evaluated and synthesized information, recommendations and rationales presented in the appendices.

P. Rappa and J.N. Miller, 1996. *Hawaii's Readiness to Prevent and Respond to Oil Spills*. UNIHI-SEAGRANT (CR-96-02); 36 pp.; no charge.

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do not distinguish between the different forms of organic production, even though the fates of the production and the consumer communities may differ markedly in their composition and usefulness to top predators like humans. It follows that simple carbon metabolism assays of trophic status cannot be used alone as reliable metrics of coral-reef condition or "health."

More complete measurement regimes, involving other nutrients besides carbon in inorganic and organic forms, are required to qualify metrics of anthropogenic change in the trophic status of reef communities. Such ecoindicators may prove to be more sensitive (thereby providing earlier warning) than the characteristic changes in community structure that follow anthropogenic impacts, but there are too few data to judge at this time.

### 7.5.2. *Harvestable Yields from Reefs*

The net community (excess) productivity of entire reef systems sets the upper limit on sustainable yields of organic material from reefs at about 2–3% of gross productivity. This would be a huge mass (ca. $350 \times 10^6$ Mt. Fresh Wt $yr^{-1}$) on a global basis, but of course only a small fraction is actually available for harvest by humans. First-order estimates suggest that 75% of the excess production is exported from reefs in unusable form (e.g., dissolved organics, detritus) and 15% accumulates in reef structures, leaving only about 10% (ca. $35 \times 10^6$ Mt. $yr^{-1}$ globally) to be fished (Crossland et al., 1991). This number is equivalent to well under 1% of the gross production by reefs, a proportion in accord with independent trophodynamic analyses (Fig. 7–8). The errors inherent in attempting to estimate reef-specific (much less species-specific) fishery yields from measures of reef metabolism and production should be apparent from this huge discrepancy between gross production and harvestable secondary production.

Current catches from coral-reef fisheries are but a few percent of this estimated sustainable yield (Marshall, 1985; Russ, 1991), suggesting that considerable potential exists for increasing the harvest from reefs. Yet there are already many examples of overfishing (Russ, 1991; Roberts and Polunin, 1993). High yields are generally obtained when the fisheries are nonselective (most species of large vertebrate and invertebrate consumer are harvested) and their long-term sustainability has yet to be demonstrated (Ludwig et al., 1993). It appears that the great diversity of reef food webs acts to limit both the harvest efficiency of multispecies fisheries and the ecological efficiency of energy transfer. The result is anomalously low fishery yields from reefs compared to other marine ecosystems having similar rates of primary production (Fig. 18–1). Given the profound effects that overfishing has already had on the structure and function of reef communities, it would be imprudent to attempt to achieve the theoretical maximum sustainable yields from them. They will cease to be coral reefs long before that point is reached.

# 8

# Reproduction and Recruitment in Corals: Critical Links in the Persistence of Reefs

*Robert H. Richmond*

Each chapter in this book deals with factors that can shift the balance from processes supporting coral-reef growth and development to those that result in reef degradation. Reproduction and recruitment are among the critical processes upon which the persistence of coral reefs depends. Reproduction is the process by which new individuals are formed. Recruitment is the process by which newly formed individuals become a part of the reef community. This distinction is important, as it is possible to have successful reproduction, with healthy larvae, tissue fragments, or other types of seed material being produced, but eventual death of a coral-reef community if these new individuals are unable to find appropriate substrata for settlement, or if conditions prevent growth, maturation, and survival.

This chapter will describe the methods by which corals reproduce, how coral larvae are formed and develop, the factors that affect site selection, settlement, and metamorphosis in coral larvae, and how particular problems can affect the success of both reproduction and recruitment. By studying the biology of coral reproduction and recruitment, we gain an understanding of how it is possible to slowly degrade a reef, through the interruption of the critical processes that replenish populations of these important organisms. This understanding is of central importance to coral-reef management and preservation. Whether a reef is killed quickly by sedimentation or slowly through reproductive or recruitment failure, the result is the same: the loss of the beauty, economic and cultural value, and benefits that coral reefs provide.

Research supported by NSF grant 8813350 and NIH grant S06 GM 44796-06. This is contribution number 380 of the University of Guam Marine Laboratory, and is dedicated to Keana Avery Richmond, who recruited July 27, 1996, between the two annual coral spawning events. I hope that the information in this chapter and book will help in the protection of coral reefs for her children, as well as all future generations, to enjoy.

## 8.1. Coral Reproduction

Corals reproduce both asexually and sexually. Asexual reproduction in corals includes several processes by which one coral colony forms additional colonies through the separation of tissue-covered fragments, or through the shedding of tissue alone. Sexual reproduction is more complex, and requires the fusion of two gametes, egg and sperm, to form embryos that develop into free-swimming planula larvae. Asexual and sexual processes are not mutually exclusive; species and/or individuals may produce "offspring" both ways within the same time period. The products of the two types of reproduction can differ both physically and ecologically.

### *8.1.1. Asexual Reproduction*

In discussing asexual reproduction in corals, it is helpful to separate colony growth from the formation of new colonies. Most reef-building stony corals are true colonies, made up of hundreds to thousands of interconnected polyps. Colonies grow through the asexual process of budding, during which new polyps form. Additional polyps can form when one polyp divides into two (intratentacular budding), or sometimes a new mouth with tentacles can simply form in the space between two adjacent polyps (extratentacular budding). If the polyps and tissue formed by these asexual processes remain attached to the parent colony, the result is considered growth and is seen as an increase in colony size. If polyps or buds become detached from the parent colony and give rise to new colonies, we consider this to be asexual reproduction, that is, the direct formation of new individuals from prior stock.

New coral colonies can be formed asexually in several ways. Fragmentation is common among finely branched or relatively thin plating corals (Highsmith, 1982). Coral fragments, including the underlying skeleton, may become detached from parent colonies as a result of wave action, storm surge, fish predation on associated animals, or other sources of physical impact. If a fragment lands on a solid bottom, it may fuse to the surface and continue to grow through budding. Many fragments generated by storms roll around, eventually losing their thin covering of coral tissue, and do not succeed in becoming new colonies, that is, they do not recruit (Knowlton et al., 1981).

Pieces of living tissue may leave the underlying coral skeleton, and through the use of cilia that cover the outer surface, swim and drift in the water column until coming into contact with an appropriate surface for settlement and attachment. This process has been referred to as polyp bailout (Sammarco, 1982b), as polyps appear to actively leave their skeletons. In a similar process, balls of coral tissue may remain on an otherwise dead skeleton, or may ooze out of the coral calices and later differentiate into coral polyps and begin secreting a calcareous skeleton (Rosen and Taylor, 1969; Highsmith, 1982; Krupp et al., 1993). Sections taken through coral colonies, particularly massive forms, often reveal periods of growth, diebacks, and regrowth over a previous skeletal base. For this reason, colony diameter may not always be a reliable measure of age (Hughes and Jackson, 1980).



It is also possible that coral larvae may arise from unfertilized eggs, through a process known as parthenogenesis (Stoddart, 1983). While eggs are produced, they are not fertilized by sperm, but develop directly. This asexual mechanism for production of embryos has been observed in plants and many clonal organisms.

Asexual reproduction results in the production of offspring that are genetically identical to the parent. As long as conditions remain the same, the offspring will enjoy the same level of success that the parent colonies had. In reality, the physical and biological aspects of coral-reef communities vary. Seawater temperatures may change because of El Niño events, predators may evolve new feeding habits, a new disease may appear, or a new competitor may immigrate to the reef. A population with no genetic variability is vulnerable to changes in the physical or biological components of the environment. Another disadvantage of asexual reproduction in corals is that fragments, residual tissues, and some shedded tissues have limited dispersal abilities. The distribution of offspring is important to the success of coral populations and coral reefs.

### *8.1.2. Sexual Reproduction*

Unlike asexual reproduction, which produces exact copies of the parent, sexual reproduction offers two opportunities for new genetic combinations to occur: (1) crossing over during meiosis in the formation of eggs and sperm, and (2) the genetic contribution of two different parents when an egg is fertilized by a sperm. These serve to add genetic variation to populations, which may lead to enhanced survival of a species. In corals, the resulting embryo develops into a ciliated planula larva. Planulae are particularly well adapted for dispersal and can seed the reef of origin, nearby reefs, or reefs hundreds of kilometers away (Richmond, 1987, 1990).

### *8.1.3. Gonochorism Versus Hermaphroditism*

If a species has separate males producing sperm and females producing eggs, it is said to be gonochoric. The term *dioecious* is also used, but it is more appropriate for plants. If, however, a single individual of a species is capable of producing both eggs and sperm, it is said to be hermaphroditic. This term originates from Greek mythology, in which Hermes was the male messenger god, and Aphrodite was the goddess of beauty. The joining of these two names is used to describe organisms that have both male and female function within the same individual.

Approximately 25% of the coral species studied to date (e.g., species of *Porites* and *Galaxea*) are gonochoric (Harrison and Wallace, 1990). The identification of separate sexes in corals is sometimes confused by the fact that it takes eggs longer to develop than sperm; hence a study early in the gametogenic cycle may lead to the conclusion that a coral is female, since no sperm would be seen until later in the year. Additionally, individual colonies of some species are distinctly male or female, while other colonies of the same species may be hermaphroditic (Chornesky and Peters, 1987; Harrison and Wallace, 1990). These cases may represent reproductive plasticity, or in some cases, differences at the species level.

If an organism has both ovaries for producing eggs and testes for producing sperm at the same time, it is called a simultaneous hermaphrodite. If, on the other hand, an individual is a functional male first, then develops into a female later (protandry), or is initially female, eventually changing into a male (protogyny), it is a sequential hermaphrodite. Corals display the full range of sexual characteristics, with the majority of species studied so far identified as simultaneous hermaphrodites (e.g., most acroporids, faviids, and some pocilloporids). A few species have been found to be sequential hermaphrodites (e.g. *Stylophora pistillata* and *Goniastrea favulus*; Rinkevich and Loya, 1979b; Kojis and Quinn, 1981), while others are gonochoric.

Hermaphroditism is particularly favorable in small populations, as it ensures sexual partners will be present if there are more than two individuals. If self-fertilization is possible, a single simultaneous hermaphrodite is capable of sexual reproduction and at least taking advantage of the genetic variation introduced during the crossing-over phase of meiosis.

### 8.1.4. Brooding Versus Spawning

Corals display two distinct modes of reproduction that differ in the way the gametes come into contact with each other. In brooding species, eggs are fertilized internally, with the embryo developing to the planula stage inside the coral polyp. Alternatively, spawning species release eggs and sperm into the water column, where subsequent external fertilization and development take place. The differences between the two modes of reproduction influence many aspects of coral ecology, including the transfer of symbiotic algae to the larvae, larval competency (the period during which larvae possess the ability to successfully settle and metamorphose), dispersal of larvae, biogeographic distribution patterns, genetic variability, and even rates of speciation and evolution (Richmond, 1990). Also, spawned gametes that float to the surface may be more vulnerable to the effects of pollutants often found in the surface layer in coastal waters.

Planula larvae released from brooding corals are immediately competent, that is, capable of settlement and metamorphosis. Brooded larvae are generally larger than spawned larvae, and in hermatypic (reef-building) corals, contain a full complement of symbiotic zooxanthellae from the parent colony (Fig. 8–1). It has been demonstrated that zooxanthellae contribute metabolites to the larvae, giving them additional energy sources to promote long-distance dispersal



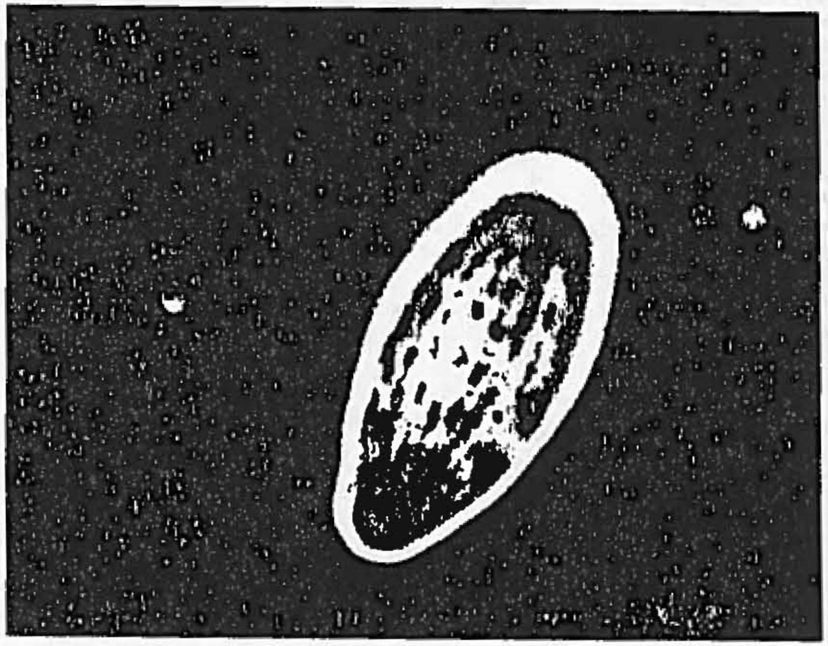

*Figure 8–1.* Planula larva of *Pocillopora damicornis* with bands of symbiotic zooxanthellae.

(Richmond, 1987, 1988). Nevertheless, the ability to immediately settle results in some brooded planulae attaching to the substrata within centimeters of the parent colony.

Brooders, sometimes referred to as planulators, represent only a small portion of the corals studied, perhaps 15%. The pan-Pacific coral *Pocillopora damicornis* releases brooded planulae on a lunar cycle monthly, throughout the year, on the reefs of Micronesia and Hawaii (Richmond and Jokiel, 1984; Jokiel, 1985). This same species releases larvae only a few months per year in Okinawa and in western Australia (Stoddart and Black, 1985; Richmond and Hunter, 1990). *Pocillopora damicornis* has also been reported to spawn in the eastern Pacific and western Australia, raising questions about the taxonomy of corals that look alike but demonstrate differences in reproductive characteristics (Glynn et al., 1991; Ward, 1992).

For over 250 species of corals already studied, the majority (perhaps 85%) are spawners (Table 8–1), many of which participate in multispecies mass-spawning events during limited periods each year (Fadlallah, 1983; Harrison et al., 1984; Harrison and Wallace, 1990; Richmond and Hunter, 1990). In Okinawa, most spawning species release their gametes over a 5–8-day period commencing

*Table 8-1. Reproductive Characteristics of Corals from the Caribbean Sea, Hawaii, Central Pacific, Eastern Pacific, Indo-West Pacific, Great Barrier Reef, and Red Sea*

| Caribbean<br>Coral | Sex | Mode | Season | Source |
|---|---|---|---|---|
| *Acropora cervicornis* | H(pg) | S | sr | 1,6,29 |
| *Acropora palmata* | H(pg) | S | sr | 6,29 |
| *Agaricia agaricites* | H | B | sp-yr | 1,10 |
| *Agaricia fragilis* | x | B | sr | 13 |
| *Agaricia crassa* | x | B | sp | 13 |
| *Dendrogyra cylindris* | G(pg) | S | sr | 6,29 |
| *Diploria strigosa* | H(pg) | S | sr | 6,7 |
| *Favia fragum* | H | B | sp-yr | 1,6,10 |
| *Isophyllia* sp. | G? | B | sp | 1 |
| *Manicina areolata* | H | B | sp | 1 |
| *Meandrina* sp. | x | B | sp | 1 |
| *Montastrea annularis* | H(pg) | S | sr | 6,29 |
| *Montastrea cavernosa* | G(pg) | S | sr | 6,29 |
| *Mycetophyllia ferox* | H(pg) | B | w-sp | 6,29 |
| *Porites astreoides* | H(s) | B | sp-yr | 1,6,10 |
| *Porites porites* | G? | B | w-sp | 1 |
| *Siderastrea radians* | G | B | yr | 1,6,10 |
| *Siderastrea siderea* | G | S | sr | 6 |
| | 6G:9H:3? | 11B:7S | | |

| Pacific Corals<br>Hawaii | | | | |
|---|---|---|---|---|
| *Acropora cytherea* | H | • | • | 12 |
| *Acropora humilis* | H | • | • | 12 |
| *Acropora valida* | H | • | • | 12 |
| *Cyphastrea ocellina* | x | B | yr | 13 |
| *Dendrophyllia manni* | x | B | sr-f | 1 |
| *Fungia scutaria* | G | S | sr | 15 |
| *Montipora verrucosa* | H | S | sr | 10 |
| *Pocillopora damicornis* | H | B | yr | 16,17 |
| *Porites lutea* | G | S | sr | 10 |
| *Tubastrea aurea* | x | B | sr-f | 1,10 |
| | 2G:5H:3? | 4B:3S | | |

| Central Pacific (Guam, Marshall Islands, Palau) | | | | |
|---|---|---|---|---|
| *Acrhelia horrescens* | x | B | yr | 20 |
| *Acropora bruggemanni* | x | B | x | 18 |
| *Acropora cerealis* | H | x | sr | 14 |
| *Acropora corymbosa* | x | B | sr | 13 |
| *Acropora humilis* | x | B | sr | 13 |
| *Acropora hystrix* | H | x | sr | 14 |
| *Acropora irregularis* | H | S | sr | 10 |
| *Acropora nasuta* | H | S | sr | 10 |
| *Acropora palawensis* | x | B | x | 19 |
| *Acropora smithi* | H | x | sr | 14 |
| *Acropora* sp. | H | S | sr | 10 |
| *Acropora striata* | x | B | w | 13 |
| *Acropora tenuis* | H | S | sr | 10 |
| *Acropora valida* | H | x | sr | 14 |

*Continued*



*Table 8-1. Continued*

| Cental Pacific (Guam, Marshall Islands, Palau) *Continued* | Sex | Mode | Season | Source |
|---|---|---|---|---|
| *Euphyllia glabrescens* | x | B | x | 20 |
| *Favia mathaii* | H | x | sr | 14 |
| *Favites abdita* | H | x | sr | 14 |
| *Favites flexuosa* | H | x | sr | 14 |
| *Fungia actiniformis* | H? | B | yr | 21 |
| *Fungia fungites* | G | x | sr | 14 |
| *Galaxea apera* | x | B | yr | 23 |
| *Goniastrea aspera* | x | B | f | 21 |
| *Goniastrea edwardsi* | H | x | sr | 14 |
| *Gonioporaqueenslandiae* | G | B | sr | 1 |
| *Leptoria phrygia* | H | x | sr | 14 |
| *Platygyra pini* | H | x | sr | 14 |
| *Pocillopora damicornis* | H | B | yr | 13,17 |
| *Pocilloporaelegans* | x | B | sr | 13 |
| *Pocillopora verrucosa* | x | B | yr | 13 |
| *Porites lutea* | G | x | sr | 14 |
| *Seriatopora hystrix* | x | B | yr | 13 |
| *Stylophora pistillata* | x | B | yr | 13,22 |
| | 16H:3G:13? | 16B :4S:12? | | |

| Philippines | | | | |
|---|---|---|---|---|
| *Acanthastrea hillae* | x | x | sp | 30 |
| *Acropora austera* | x | x | sp | 30 |
| *Acropora cytherea* | x | x | sp-sr | 30 |
| *Acropora florida* | x | x | sp | 30 |
| *Acropora humilis* | x | x | sp | 30 |
| *Acropora hyacinthus* | x | x | sp | 30 |
| *Acropora loripes* | x | x | sp | 30 |
| *Acropora pulchra* | x | x | sp | 30 |
| *Acropora selago* | x | x | sp | 30 |
| *Acropora tenuis* | x | x | sp | 30 |
| *Acropora valida* | x | x | sp | 30 |
| *Astreopora myriophthalma* | x | x | sp | 30 |
| *Echinophyllia aspera* | x | x | sp | 30 |
| *Echinopora gemmacea* | x | x | sr | 30 |
| *Favia pallida* | x | x | sp | 30 |
| *Favia helianthoides* | x | x | sp | 30 |
| *Galaxea fasicularis* | x | x | sp | 30 |
| *Goniastrea edwardsi* | x | x | sp | 30 |
| *Goniastrea favulus* | x | x | sp | 30 |
| *Montipora* sp. | x | x | sp | 30 |
| *Oulophyllia bennettae* | x | x | sp | 30 |
| *Pectinia lactuca* | x | x | sp | 30 |
| *Platygyra daedalea* | x | x | sp | 30 |
| *Platygyra sinensis* | x | x | sp | 30 |

*Note:* While it may be assumed that coral species identified as spawners elsewhere also spawn in the Philippines, this table lists sex and mode as unknown unless an actual observation was recorded. The corals listed as tentatively spawning in the spring were observed to contain ripe gonads in April and May. The data summarized here are based on preliminary observations reported in Bermas et al. 1993.



*Continued*

*Table 8-1. Continued*

| Taiwan | Sex | Mode | Season N | Season S | Source |
|---|---|---|---|---|---|
| *Acanthastrea echinata* | x | x | | May | 31 |
| *Acropora austera* | x | x | | May | 31 |
| *Acropora cerealis* | x | x | Jun | Apr, May | 31 |
| *Acropora cytherea* | x | x | | May | 31 |
| *Acropora danai* | x | x | | May | 31 |
| *Acropora digitifera* | x | S | | Apr, May | 31 |
| *Acropora divaricata* | x | x | | Jun | 31 |
| *Acropora formosa* | x | S | | Jun | 31 |
| *Acropora humilis* | x | S | | Apr, May | 31 |
| *Acropora hyacinthus* | x | x | | May | 31 |
| *Acropora monticulosa* | x | S | | May | 31 |
| *Acropora nana* | x | x | | Apr, Jun | 31 |
| *Acropora nasuta* | x | x | | Jun | 31 |
| *Acropora nobilis* | x | S | | May | 31 |
| *Acropora palmerae* | x | S | | May | 31 |
| *Acropora spicifera* | x | S | | Jun | 31 |
| *Acropora valida* | x | x | Jun | | 31 |
| *Acropora spp.* | x | x | | Apr, May | 31 |
| *Astreopora gracilis* | x | x | | May | 31 |
| *Astreopora listeri* | x | S | | May | 31 |
| *Cyphastrea chalcidicum* | x | x | Jul | Apr, May | 31 |
| *Cyphastrea microphthalma* | x | x | | May | 31 |
| *Cyphastrea serailia* | x | x | Jul | May | 31 |
| *Echinophyllia aspera* | x | x | Jul | May | 31 |
| *Echinopora lamellosa* | x | x | Jul | Sep | 31 |
| *Euphyllia ancora* | x | S | | Apr, May | 31 |
| *Favia laxa* | x | x | Jul | May | 31 |
| *Favia pallida* | x | x | Jul | May | 31 |
| *Favia sp.* | x | S | | Apr | 31 |
| *Favia speciosa* | x | S | Jun | Apr, May | 31 |
| *Favites abdita* | x | x | | Apr, May | 31 |
| *Favites chinensis* | x | x | Jul | Apr | 31 |
| *Favites complanata* | x | x | Jun | May | 31 |
| *Favites russelli* | x | x | Jul | | 31 |
| *Galaxea astreata* | x | S | | Apr, May | 31 |
| *Galaxea fascicularis* | x | S | | Apr, May, Jun | 31 |
| *Goniastrea aspera* | x | S | | Apr, May | 31 |
| *Goniastrea edwardsi* | x | S | Jul | May | 31 |
| *Goniastrea retiformis* | x | S | Jul | Apr, May | 31 |
| *Leptoria phrygia* | x | x | | Apr, May | 31 |
| *Merulina ampliata* | x | x | | Sep | 31 |
| *Montastrea curta* | x | x | Jul | | 31 |
| *Montastrea valenciennesi* | x | x | Jun | Jun | 31 |
| *Montipora aequituberculata* | x | S | | Jun | 31 |
| *Montipora digitata* | x | S | | Apr, May | 31 |
| *Montipora efflorescens* | x | S | | Apr, May | 31 |
| *Montipora foliosa* | x | S | | Jun | 31 |

*Continued*

*Table 8-1. Continued*

| Taiwan–Continued | Sex | Mode | Season N | Season S | Source |
|---|---|---|---|---|---|
| *Montipora informis* | x | S | | Apr, May | 31 |
| *Montipora spp.* | x | S | | Apr, May | 31 |
| *Montipora tuberculosa* | x | S | | Apr, May | 31 |
| *Montipora venosa* | x | S | | Apr, May | 31 |
| *Mycedium elephantotus* | x | x | Jul | May | 31 |
| *Pachyseris rugosa* | x | x | | May | 31 |
| *Pachyseris speciosa* | x | x | | May | 31 |
| *Platygyra daedalea* | x | x | | Apr, May | 31 |
| *Platygyra lamellina* | x | S | | Apr, May | 31 |
| *Platygyra pini* | x | x | Jul | Apr, May | 31 |
| *Platygyra sinensis* | x | S | Jul | Apr, May | 31 |
| *Plesiastrea versipora* | x | S | | Apr | 31 |
| *Pocillopora damicornis* | x | B | | Nov–Mar | 31 |
| *Porites annae* | x | x | | May | 31 |
| *Porites lobata* | x | x | Jul | | 31 |
| *Seriatopora hystrix* | x | B | | yr | 31 |
| *Stylophora pistillata* | x | B | | yr | 31 |

N = North Taiwan, S = South Taiwan

| Eastern Pacific | Sex | Mode | Season | Source |
|---|---|---|---|---|
| *Pocillopora damicornis* | H(s) | S(?) | sr | 32 |
| *Pocillopora elegans* | H(s) | S(?) | sr | 32 |
| *Tubastrea aurea* | x | B | Jun–Nov | 33 |

| Great Barrier Reef | Sex | Mode | Season | Source |
|---|---|---|---|---|
| *Acropora aspera* | H(s) | S | seasonal | 4 |
| *Acropora cuneata* | H(s) | B | x | 4 |
| *Acropora digitifera* | H(s) | S | sp-sr | 4 |
| *Acropora formosa* | H | S | sp-sr | 5 |
| *Acropora humilis* | H(s) | S | sp-sr | 4 |
| *Acropora hyacinthus* | H(s) | S | sp-sr | 4 |
| *Acropora millepora* | H(s) | S | sp-sr | 4 |
| *Acropora palifera* | H(s) | B | x | 4 |
| *Acropora pulchra* | H(s) | S | sp-sr | 4 |
| *Acropora robusta* | H(s) | S | sp-sr | 4 |
| *Acropora variablis* | H(s) | S | sp-sr | 4 |
| *Favia abdita* | H(s) | S | sp-sr | 3 |
| *Favia favus* | H(s) | S | sr | 5 |
| *Favia pallida* | H(s) | S | sp-sr | 1 |
| *Goniastrea aspera* | H(pg) | S | x | 9,11 |
| *Goniastrea australensis* | H(pa) | S | sp-sr | 2,9 |
| *Leptoria phrygia* | H(s) | S | sp-sr | 3 |
| *Lobophyllia corymbosa* | H(s) | S | sr | 1,5 |
| *Montipora ramosa* | H | S | x | 5 |
| *Pavona cactus* | G | S | x | 25 |
| *Platygyra sinensis* | x | S | x | 9 |

*Continued*

*Table 8-1. Continued*

| Great Barrier Reef–*Continued* | Sex | Mode | Season | Source |
|---|---|---|---|---|
| *Pocillopora damicornis* | H | B | yr | 1,25 |
| *Porites andrewsi* | G | S | sp-sr | 24 |
| *Porites australiensis* | G | S | sp-sr-f | 5 |
| *Porites haddoni* | x | B | sr-f | 25 |
| *Porites lobata* | G | S | sp-sr | 24 |
| *Porites lutea* | G | S | sp-sr | 5,24 |
| *Porites murrayensis* | G | B | sp-sr-f | 24 |
| *Seriatopora hystrix* | x | B | sp-sr | 26 |
| *Symphyllia recta* | H | S | sp-sr | 25 |
| 6G:21H:3? | 6B:24S | | | |

*Note:* A total of 133 species out of 356 have been observed to mass spawn during the week following the full moon in October (see Willis et al., 1985, for details).

| Red Sea | Sex | Mode | Season | Source |
|---|---|---|---|---|
| *Acropora eurystoma* | H(pg) | S | sp | 27 |
| *Acropora hemprichii* | H | x | x | 28 |
| *Acropora humilis* | H(pg) | S | sp | 27 |
| *Acropora hyacinthus* | H(pg) | S | sr | 27 |
| *Acropora scandens* | H(pg) | S | sr | 27 |
| *Alveopora daedalea* | H(pg) | B | f-w | 27 |
| *Astreopora myriophthalma* | H(pg) | S | sr | 27 |
| *Favia favus* | H(pg) | S | sr | 27 |
| *Galaxea fascicularis* | H(pg) | S | sr | 27 |
| *Goniastrea retiformis* | H(pg) | S | sr | 27 |
| *Platygyra lamellina* | H(pg) | S | sr | 27,28 |
| *Pocillopora verrucosa* | H(pg) | S | sr | 27 |
| *Seriatopora caliendrum* | H(pg) | B | sp-sr-f | 27,28 |
| *Stylophora pistillata* | H(pg) | B | w-sp-wr | 27,28 |
| 0G:14H | 3B:10S:1? | | | |

*Sources:* 1. Fadlallah, 1983; 2. Kojis and Quinn, 1981a; 3. Kojis and Quinn, 1982; 4. Bothwell, 1982; 5. Harriot, 1983a; 6. Szmant-Froelich, 1984; 7. Wyers, 1985; 8. Van Moorsel, 1983; 9. Babcock, 1984; 10. Richmond, pers. obs.; 11. Babcock, 1984; 12. Grigg et al., 1981; 13. Stimson, 1978; 14. Heyward, 1989; 15. Krupp, 1983; 16. Harrigan, 1972; 17. Richmond and Jokiel, 1984; 18. Atoda, 1951a; 19. Kawaguti, 1940; 20. Kawaguti, 1941; 21. Abe, 1937; 22. Atoda, 1947b; 23. Atoda, 1951b; 24. Kojis and Quinn, 1982a; 25. Marshall and Stephenson, 1933; 26. Sammarco, 1982b; 27. Shlesinger and Loya, 1985; 28. Rinkevich and Loya, 1979b; 29. Szmant, 1986; 30. Bermas et al., 1993; 31. Dai et al., 1993; 32. Glynn et al., 1991; 33. Richmond, pers. obs. *Sex:* H = hermaphroditic; G = gonochoric; pg = protogynous; pa = protandrous; s = simultaneous; x = unknown. *Mode:* S = spawner; B = brooder. *Season:* w = winter; sp = spring; sr = summer; f = fall; yr = year-round; x = unknown. Abbreviations for months are used when available and appropriate. (Updated from Richmond and Hunter, 1990.)



around the night of the May and June full moons each summer (Hayashibara et al., 1993). In Guam, Micronesia, peak spawning occurs 7–10 days after the July full moon (Richmond and Hunter, 1990). In the nearby islands of Palau, coral spawning appears to occur several months per year, including March, April, and May (Kenyon, 1995). In Australia, mass spawning events occur during November (Harrison et al., 1984).

Why are there differences in timing of coral spawning among sites, and yet so many species have a high degree of synchronization at a particular location? A critical aspect of spawning is synchronization among members of a species in the production and release of sperm and eggs. If eggs are ripe while the sperm are not, reproduction will be unsuccessful.

Corals have the ability to respond to several environmental factors. Water temperature is one signal that determines the time of year when spawning will occur (Shlesinger and Loya, 1985; Oliver et al., 1988). Many invertebrates in polar, temperate, subtropical, and tropical habitats reproduce during the times of maximum water temperatures. The "fine-tuning" seems to be in response to lunar phase. Since tides are affected by the moon, these may also affect timing, but studies have shown that nocturnal illumination plays a key role in reproductive timing in corals (Jokiel, 1985; Jokiel et al., 1985).

Corals are sensitive to chemical compounds that may also facilitate synchronized reproduction on a particular reef (Coll et al., 1989, 1990; Atkinson and Atkinson, 1992). In simultaneous comparisons among reefs in Japan separated by distances of over 50 km, different species were found to spawn on different nights during the period following the June full moon; but by the end of the week, all of the same species had released their gametes. Contagious spawning events occur as the gametes from one coral colony stimulate other colonies of the same species downcurrent to release their eggs and sperm upon contact with the gamete cloud. These observations support the notion that chemical signals are a likely cause of synchronized spawning within a reef.

Spawning species that are simultaneous hermaphrodites typically release combined egg-sperm packets (Fig. 8–2), with egg size and number of eggs per cluster varying among species. Gamete bundles may consist of between 9 and 180 eggs surrounding or embedded within a mass of sperm. Sections taken through a coral polyp prior to gamete release reveal the eggs lined up vertically or in clusters along mesenteries (Fig. 8–3). Sperm-filled packets have also been observed within the same polyp, but attached to different mesenteries (Harrison and Wallace, 1990). On the night of spawning, sperm packages are moved up from within the colony to a position near the mouth of the polyp and are rotated as eggs are either attached to the outer surface (many acroporids) or embedded within the sperm packet (e.g., *Favites*). The exact sequence of events may differ among species. In some, the transparent expanded polyps appear white as the sperm packets are moved up toward the mouth, but later become orange, pink, or red, as the colored eggs are attached (Fig. 8–4). Eventually the mouth of the polyp

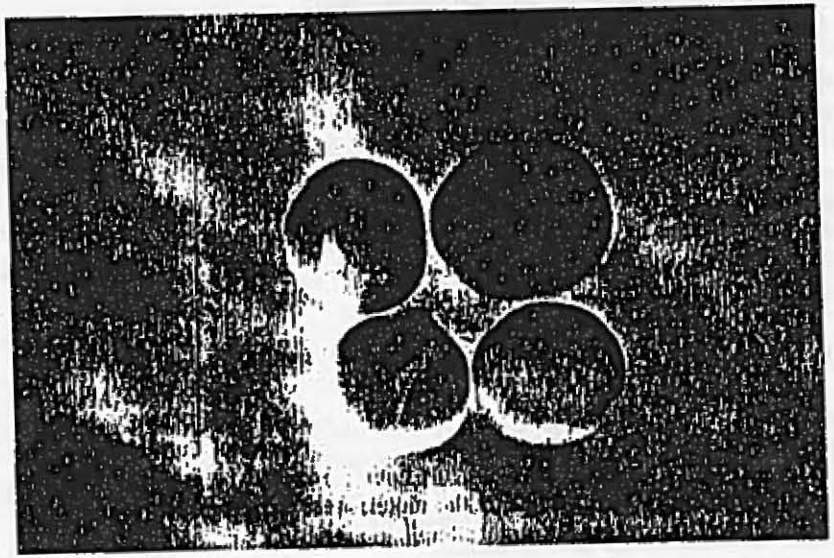

*Figure 8–2.* Egg-sperm clusters of *Acropora* sp. Each cluster contains 9–16 eggs surrounding a central sperm packet. Each cluster is approximately 1 mm in diameter.

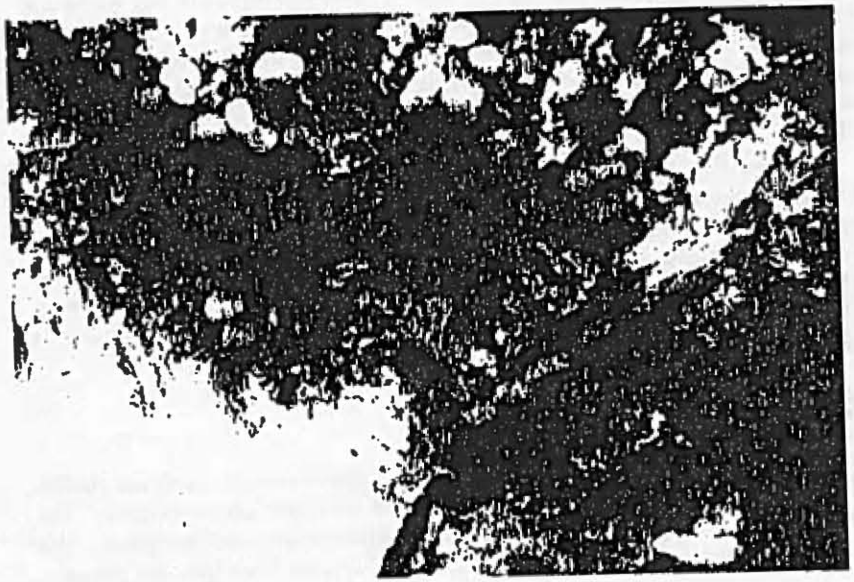

*Figure 8–3.* A cross-section of a branch of an *Acropora* containing pigmented eggs and white sperm packets.



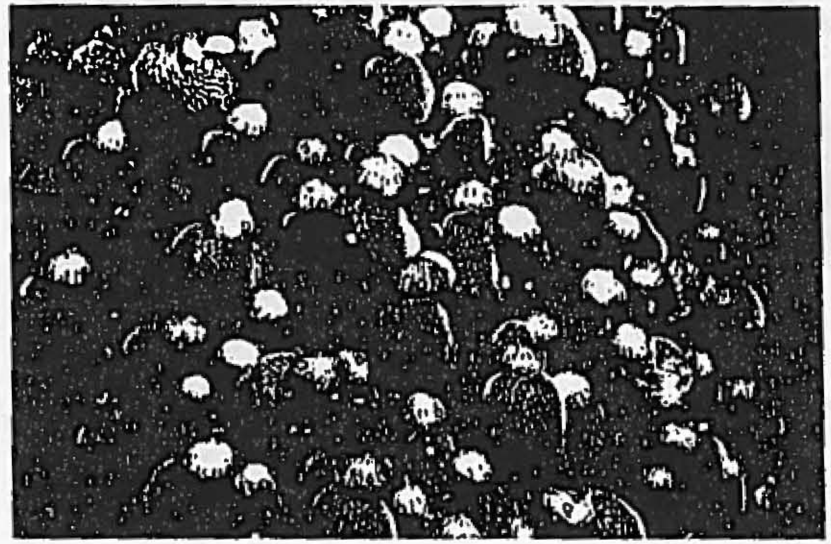

*Figure 8–4.* *Acropora* colony ready to release egg-sperm clusters.

expands and the gamete clusters are released (Fig. 8–5). In the field, these events are visible to the naked eye as the outer surface of the coral colony takes on color and as the colored gamete clusters are released.

The high lipid content of eggs makes the clusters positively buoyant. Sperm are neutrally buoyant and would otherwise have to swim to the surface in order to fertilize the eggs. Combining the eggs and sperm as a cohesive unit guarantees the sperm will reach the ocean's surface within moments of their release at no energetic cost, and will be in the proximity of appropriate eggs if conspecifics are nearby.

Once the combined egg-sperm packets reach the surface, there is a delay of approximately 10–40 minutes before they break apart and fertilization can take place (Fig. 8–6). Experiments have shown that eggs will not become fertilized until after this breakup occurs. Whatever the mechanism, the time delay reduces the chance of self-fertilization among eggs and sperm from the same colony, and increases the chances of fertilization among gametes from different individuals (outcrossing). However, this observed characteristic also increases the period during which gametes will be exposed to pollutants, like oil and contaminants carried in freshwater runoff, that are found at highest concentrations at the ocean surface.

### *8.1.5. Self-Fertilization Versus Outcrossing*

A number of interesting questions arise from the observations of multispecies mass-spawning events. Does self-fertilization occur, and if so, at what frequency

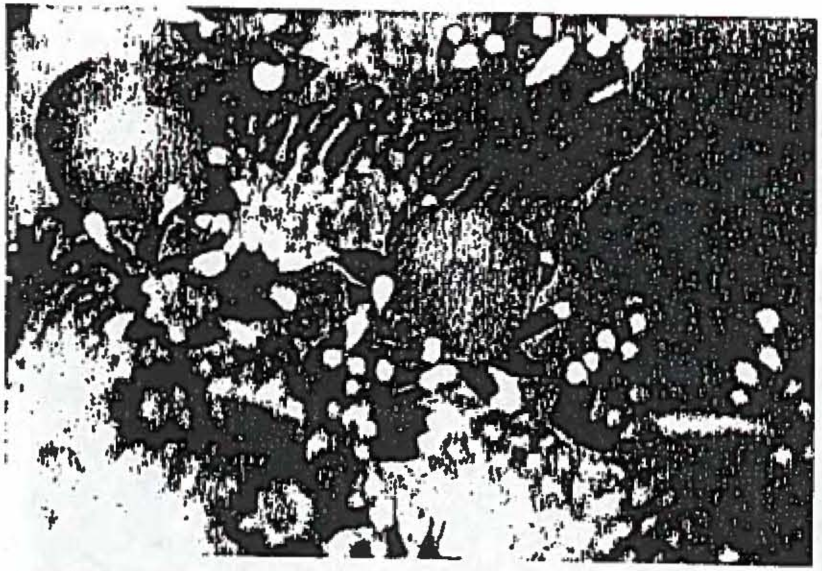

*Figure 8–5.* *Acropora* polyps releasing egg-sperm clusters.

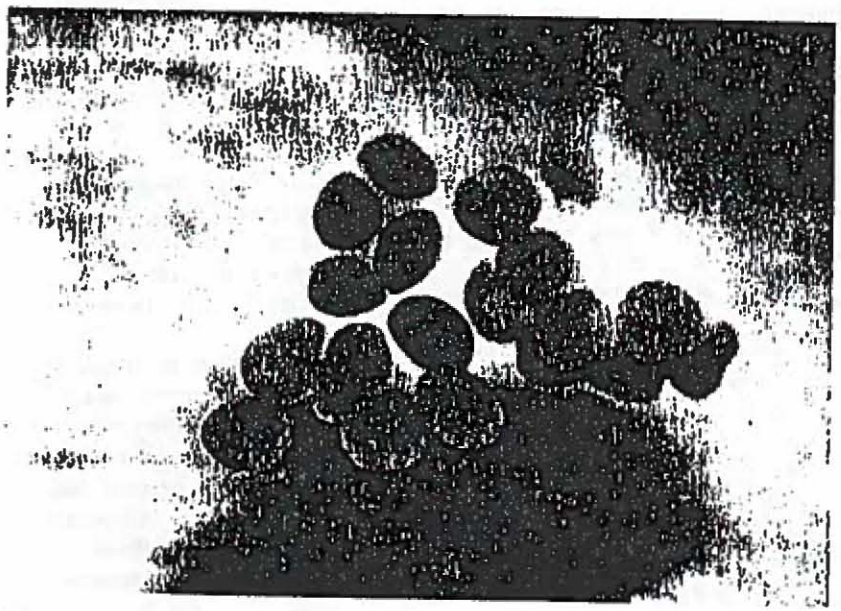

*Figure 8–6.* Egg-sperm clusters breaking apart approximately 20 minutes after release. The eggs are now ready to be fertilized by sperm from different colonies.



compared to outcrossing? Does hybridization occur among closely related species? Why does multispecies synchronization occur?

Barriers to self-fertilization do exist in corals that promote outcrossing, but these barriers may be time dependent and break down after several hours (Heyward and Babcock, 1986; Richmond, 1993a). In some experiments, it has been shown that sperm do not fertilize eggs from the same colony until 6 hours after release, and even then, observed rates of self-fertilization are less than 10%. The same eggs treated with sperm from another colony of the same species demonstrated fertilization rates of 70–100% within 2 hours of gamete release. This warns us that fertilization rates and reproductive success of corals may be reduced by pollution with chemical contaminants that can interfere with chemical recognition between gametes.

### *8.1.6. Hybridization*

During a multispecies mass-spawning event, sizable slicks of coral eggs and sperm can be observed above reefs, extending hundreds to thousands of meters in some cases (Oliver and Willis, 1987). With so many eggs and sperm from a wide variety of species intermingling, the question arises, Can eggs of one species become fertilized by sperm from another?

Laboratory experiments have demonstrated that hybridization does occur among corals. This has been observed not only among closely related species within the same genus, but across genera (Richmond, 1993a, 1995; Willis et al., 1993; Kenyon, 1993). In one case, crosses of *Acropora digitifera* and *Acropora gemmifera* were unidirectional, meaning eggs of *A. digitifera* were fertilized by sperm from *A. gemmifera*, but eggs of *A. gemmifera* were not fertilized by *A. digitifera* sperm (Richmond, 1995). This type of unidirectional hybridization has been observed in echinoderms and fruit flies (Kaneshiro, 1987; Uehara et al., 1990).

Hybridization among species spawning on the same evening may be deterred by differences in the timing of gamete release. Some species usually release their eggs and sperm around 8 P.M. (e.g., *Acropora tenuis* on Guam), whereas others consistently release gametes at 10 P.M. (*Acropora humilis* on Guam), 11 P.M. (*Acropora valida* on Guam), and 11:45 P.M. (*Acropora irregularis* on Guam). Corals may also spawn during the day, as demonstrated by certain pocilloporids (Kinzie, 1993).

### *8.1.7. Larval Development*

The planula larvae that develop from brooding and spawning corals are similar in some aspects. Both are ciliated, rich in lipid, and have chemoreceptors used for detecting the appropriate substrata for settlement and metamorphosis. But brooded larvae tend to be larger than larvae that develop from spawned gametes, possess zooxanthellae, and are capable of settling immediately upon release from the parent colony. The smaller larvae that develop from spawning corals require time to reach a stage capable of settlement and metamorphosis. Smaller eggs of the spawning coral genera *Leptoria*, *Goniastrea*, and *Montastrea*, averaging 350–400 µm in diameter, require 18 hours before they become ciliated and capable of settlement, whereas the larger eggs of many spawning *Acropora* species take nearly 72 hours to reach the same stage of development.

Most planula larvae that develop from spawned gametes do not contain symbiotic zooxanthellae, and do not appear to obtain them until after settlement and metamorphosis. Calculated competency periods indicate such larvae retain their ability to recruit for only 3–4 weeks (Richmond, 1988). After that, they may remain alive but lack the energy reserves needed to make the transformation to a benthic calcified coral. Corals in the genus *Montipora* are an exception, as the spawned eggs contain zooxanthellae. All brooded planulae studied to date possess zooxanthellae, and in the case of *Pocillopora damicornis*, the competency period has been found to exceed 100 days, attributable in part to the contribution of the symbiotic algae to the nutritional needs of the larva (Richmond, 1987a, 1988).

The biogeographic distribution patterns of specific groups of corals suggest that possession of zooxanthellae during the larval stage enhances dispersal ability. Widely distributed species have a decreased risk of extinction from local events. Some corals endemic to Japan may be threatened with extinction due to anthropogenic (human-induced) disturbance (Chapter 14; Veron, 1992).

## 8.2. Larval Recruitment

Successful reproduction is only the first step in the replenishment of corals on the reef. In order for coral populations to be maintained, dead corals must be replaced, either from larvae or asexually produced products. Recruitment depends on the ability of larvae to identify an appropriate site for settlement and metamorphosis. These two distinct and critical processes are often dependent on specific chemical signals for marine invertebrates (Pawlik and Hadfield, 1990).

### *8.2.1. Settlement*

Settlement of coral larvae is a change from a planktonic existence to a benthic lifestyle, and usually includes attachment to the reef. In order for settled larvae to survive and develop into young corals, they must settle on an appropriate site. The criteria for appropriate sites include substratum type, water motion, salinity (generally above 32‰), adequate sunlight for zooxanthellae, limited sediment deposition, and sometimes specific algal species or biological films of diatoms and bacteria.

Site selection by coral planulae may be made on the basis of chemical signals that are affecting receptors located on the outer surface of the larvae. Coral



planulae react to biological films, and in the case of species of *Agaricia*, species-specific chemical signals from particular types of crustose coralline algae (Morse and Morse, 1993).

In the laboratory, competent planula larvae can be observed to swim downward until they contact a surface. If the substratum has the proper texture and biochemical coating, the planula forms an attachment with the aboral surface, begins to contract, and lays down an organic matrix layer, followed by the deposition of the stony carbonate skeleton (Vandermeulen, 1974).

Substratum type as well as orientation can affect recruitment, growth, and survival rates. In most laboratory settlement experiments, planulae would not settle on loose sediment, especially if solid substrata were available. When settlement did occur on sediment, coral planulae had poor survival rates. In field experiments, Birkeland (1977) found recruits had faster growth rates on upper surfaces of artificial substrata, but survivorship was greater for those larvae settling on vertical surfaces. The same study reported faster growth rates of recruits at shallower depths, but higher survivorship with intermediate depth and at lower nutrient levels. Survival of young corals depends not only on the attributes of the settlement surface, but on competition with other organisms including algae and encrusting invertebrates such as sponges.

### *8.2.2. Metamorphosis*

Metamorphosis is a developmental process during which a larva undergoes a series of morphological and biochemical changes while completing the transformation to the benthic juvenile stage. A planula larva is quite different from a coral polyp in that it does not have tentacles for feeding, the mouth has not yet opened to the gastrovascular cavity, digestive enzymes have not yet been produced for heterotrophic feeding, and no calcification has taken place.

During metamorphosis, a commitment is made to the settlement site. A calcified basal plate is secreted along with the first skeletal cup, and tentacles complete with stinging cells known as nematocysts form surrounding the mouth. A new coral colony will develop from this first or primary polyp through growth, budding, and continued calcification. Larvae that develop from spawned eggs, and that did not acquire zooxanthellae from the parent colony, will incorporate these algal symbionts from external sources. Observations made on a variety of *Acropora* species found that these corals obtain their zooxanthellae only after settlement and metamorphosis, and that recruits that did not pick up their algal symbionts within 2 weeks were often overgrown by crustose coralline or other red algae.

Larvae that settle in unfavorable sites may get a second chance. If a newly metamorphosed coral is stressed within days of settlement and development, it may be able to retract its tissue from the freshly secreted skeleton and return to the plankton until another suitable site is encountered (Richmond, 1985). This has been observed in *Pocillopora damicornis*, but only from the single-polyp stage and within 3 days of initial settlement and metamorphosis.

The process of settlement does not guarantee metamorphosis will follow. For many types of invertebrate larvae, metamorphosis is a complex chain of reactions that commences only in the presence of a chemical inducer (Hadfield and Pennington, 1990). The inducer of metamorphosis can be highly specific as seen in coral planulae that will only settle on a single species of coralline algae, or more general in nature, as with short-chain peptides or general biological/diatomaceous films (Pawlik and Hadfield, 1990; Morse and Morse, 1991). Observed differences in species distribution patterns are more likely the result of larval selection than colony survivorship (Morse and Morse, 1991; Morse et al., 1994).

An important consideration in studies of recruitment is that coral larvae may be sensitive to chemical signals at levels below the detectable limits of human technology. Bioassays, biological tests using sensitive organisms, are the appropriate tools to determine if environmental contamination is at levels that can interfere with critical biological processes like reproduction and recruitment (Connell and Miller, 1984).

However, the choice of bioassays is also important (Cairns et al., 1978). Accepted standardized protocols, such as a 96-hour $LC_{50}$ (the concentration at which 50% of the test organisms die within 96 hours of exposure), are not useful to the reef manager, as sublethal effects to organisms can be as damaging to a reef over time as lethal effects. For example, an environmental toxin at a level that allows 100% survival of larvae over 96 hours, but prevents them from detecting the appropriate settlement cue and hence prevents recruitment, has the same overall effect on the reef as causing 100% mortality of the larvae. Recent experiments demonstrated that the pesticide Chlorpyrifos, a chemical often used on golf courses, can be taken up by crustose coralline algae and that coral larvae had statistically lower recruitment rates on substrata exposed to the chemical (5 parts per billion) than on untreated controls.

By understanding the biology of coral reproduction and recruitment, it is easy to see how environmental quality can affect these two processes that are responsible for the persistence of reefs. While corals may not represent the greatest biomass on the reef, they do serve as primary framework builders and as an initial link in reef food chains as the host for symbiotic zooxanthellae.

## 8.3. Reproductive and Recruitment Failure of Corals

Coral reefs are diverse and productive ecosystems with complex interactions at the cellular, organismal, and community levels. Many interactions, including those between adjacent corals, between their gametes, and between larvae and their settlement substrata, are chemically mediated (Coll et al., 1990; Atkinson and Atkinson, 1992; Richmond, 1993a, b; Morse et al., 1994). Changes in water



quality that affect transmission of these chemical signals can have negative effects on reproductive timing, synchronization, egg-sperm interactions, settlement, metamorphosis, and the incorporation of zooxanthellae. Jokiel (1985) observed that changes in salinity, water temperature, and light availability affected planula production in the coral *Pocillopora damicornis*. Kojis and Quinn (1984) found a negative correlation between fecundity and depth, turbidity, and sedimentation for the coral *Acropora palifera*. They also found that allocation of energy to tissue repair in *Goniastrea favulus* resulted in a decrease in reproductive ability (Kojis and Quinn, 1985).

Colony size has been found to be a determinant of fecundity. Among small-polyped coral colonies of the same size, age can also affect overall reproductive output, with older corals being more fecund (Kojis and Quinn, 1985). For large-polyped forms, such as *Lobophyllia corymbosa*, polyp size was found to be more important than colony size for both maturity and fecundity (Harriott, 1983). For branching corals, including representatives from the genera *Pocillopora* and *Acropora*, it appears to take at least 2–3 years to attain reproductive maturity and produce the first gametes and/or larvae. Massive corals (e.g., species of *Porites*) may require a longer period of growth and development, ranging from 4 to 7 years (Rinkevich and Loya, 1979a; Szmant-Froelich, 1985; Szmant, 1986; Babcock, 1988a). For species that exhibit a direct relationship between colony size and reproduction (both onset of sexual maturity and reproductive output), reduced growth from "stress" (Brown and Howard, 1985) will also lead to a depression of reproductive potential.

Normal seawater salinity for thriving coral reefs is near 35‰. Coral colonies can survive higher and lower salinities for periods of time, and if exposed by an extremely low tide, can secrete a layer of mucus to act as a barrier against desiccation. Coral gametes, however, are more sensitive to conditions of altered salinity than adult colonies. Since peak coral spawning occurs during the rainy season in Micronesia and Okinawa, gametes released may end up in a surface layer of reduced salinity. Field samples have found surface salinities over reefs adjacent to streams and storm drains may be decreased by more than 25% to 26‰ or lower. Bioassays designed to test the effects of salinity on fertilization and larval development in corals found a 20% drop in salinity from 35‰ to 28‰ caused a corresponding 86% decrease in fertilization rate (Richmond, 1993b, 1994; Fig. 8–7). If red clay soil is included in the runoff, the same drop in fertilization was observed to accompany a smaller decrease in salinity (to 33‰), demonstrating synergistic effects. Additionally, larvae formed in uncontaminated waters showed decreased settlement rates in areas of lowered salinity.

### 8.3.1. Terrestrial Runoff and Water Clarity

Water clarity is an important factor affecting coral growth, and has also been observed to affect reproduction and recruitment (Jokiel, 1985; Tomascik and

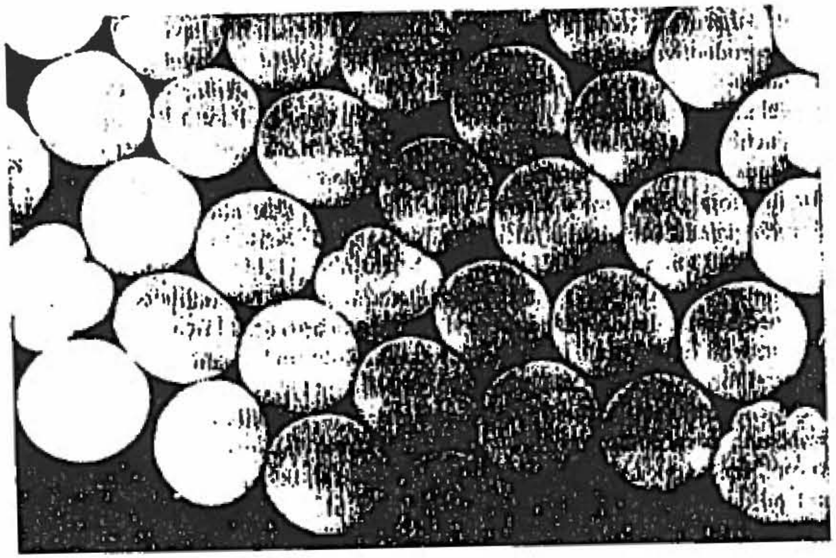

*Figure 8–7.* Coral eggs from a reduced salinity (28‰) fertilization bioassay showing only 4 of 35 eggs fertilized. The control (34‰) displayed an 88% fertilization rate versus 25% for the experimental treatment.

Sander, 1987b). The symbiotic association between corals and zooxanthellae (Chapter 5) allows reefs to flourish in nutrient-poor waters and also helps fulfill the energetic demands of coral reproduction. Photosynthetic products of zooxanthellae contribute to the production of eggs and larvae (Rinkevich, 1989). Since coral reefs are predominantly coastal, shallow-water features, they are vulnerable to the influence of land-based activities that result in runoff and increased turbidity (Chapter 15).

Sedimentation continues to be the most persistent problem affecting coastal reefs and those surrounding high islands (Johannes, 1975; Rogers, 1990; Richmond, 1993b). Sediments may exact an energetic cost to the coral that must cleanse its surface. The results are lower growth rates and less energy available for reproduction (Tomascik and Sander, 1987b). Sediment can also be a barrier preventing coral larvae from detecting the chemical signals from preferred settlement substrata like coralline algae.

Nutrient enrichment or eutrophication can be a problem affecting reproduction and recruitment of corals (Tomascik, 1991) and can originate from several sources including agricultural runoff and sewage outfalls. Eutrophication can lead to reduced light levels by increasing turbidity. Furthermore, elevated nutrient levels give fast-growing organisms like algae, sponges, tunicates, and bryozoans a competitive advantage over slower-growing corals (Birkeland, 1977, 1988a).



Such competitors can overgrow corals and dominate available substrata, preventing coral larvae from settling, and may lead to alternate stable states (Hatcher, 1984; Tomascik, 1991; Done, 1992; Hughes, 1994).

### 8.3.2. Water Pollution

A general consideration for islands and coastal communities is that substances used on land today often end up in the coastal zone tomorrow. The distance between sources of chemical contamination and coral reefs may be small. Common toxins in street runoff, including oil and petroleum products, cadmium from automobile tire wear, and miscellaneous heavy metals, enter the coastal zone every time it rains. If industrial wastes and toxins are released into residential drainage and sewer systems, they too can reach the reef. These problems all point to the need for sound watershed management and serve as examples of how land-based activities must be regulated to protect the marine environment.

Substances adhering to soil particles and contained in runoff water can be toxic and/or interfere with chemical signals (Ingersoll, 1995). Pesticides and other chemicals may bind to soil particles on land, but due to the difference in the pH of seawater, they can be released when these particles reach the ocean (Connell and Miller, 1984). The pesticide Chlorpyrifos was found to decrease levels of larval settlement and metamorphosis on settlement substrata that had been incubated in the presence of the chemical at the level of 5 parts per billion. The behavior of pesticides and toxic substances can change over time and space. Breakdown products may be more toxic to cells than the original chemical form, and processes including photoisomerization and methylation may increase stability, toxicity, and biological activity (Connell and Miller, 1984).

Corals in an area affected by an oil spill showed decreased gonad size compared to colonies from unaffected reefs years after the spill occurred (Guzman and Holst, 1993). Oil pollution was found to abort the formation of viable larvae in a brooding species of coral (Loya and Rinkevich, 1979). The presence of contaminants in coral-reef waters can also interfere with chemical signals that allow reproductive synchrony among coral colonies as well as interactions between egg and sperm (Richmond, 1994).

### 8.3.3. Population Depletion

Coral planula competency and recruitment patterns suggest some reefs may depend on distant coral communities for their supply of planulae larvae (Richmond, 1987; Babcock, 1988). If source reefs are disturbed, the effects may also be felt on downcurrent reefs. This issue is important, as it points to the need for interisland and regional cooperation if reefs are to be protected. This also has implications for planning coral-reef reserves, which should include consideration of dispersal patterns (Williams, et al., 1984).

Even if reproduction is successful, replenishment of reef populations is not guaranteed until larvae and asexual products successfully recruit. Planulae produced from corals living on healthy reefs will not recruit onto reefs where substrata or water quality are unacceptable. For example sedimentation and runoff may be sublethal to adult corals, yet can prevent larvae from settling (Richmond, 1993b). Living coral cover alone (abundance and diversity) does not reliably reflect the health of a reef. Such values only describe the state of the reef at that moment in time. Recruitment patterns are important in predicting what the future of a reef may be. Adult corals can survive in areas where reproduction is failing and larvae are unable to settle.

Commercially valuable sea cucumbers in Micronesia have provided an example of how populations of reef organisms may be affected by reproductive and recruitment failure. In the late 1930s, prior to World War II, large numbers of edible sea cucumbers were exported from Chuuk (Truk) to Japan, with records reflecting quantities in the hundreds to thousands of tons. Surveys performed in 1988 found only two individuals of the valuable species *Holothuria nobilis* from over eight sites in Chuuk Lagoon. Based on interviews with local residents and fishermen, it appears that populations of several species of sea cucumbers have not recovered from the severe exploitation levels prior to and during the Second World War. It is reasonable that for spawning species, once populations are reduced below a certain level, chances of successful reproductive events are low because of gamete dilution (Allee effect; Levitan et al., 1992). If an island is beyond the dispersal range of larvae from other source areas, immigration is not going to occur, and populations will not rebound. The effect of population reductions on future numbers is clear when considering the decrease in reproductive success.

### *8.3.4. Prevention and Mitigation*

Corals can die as a result of both natural occurrences and human activities. If these corals are not replaced through the processes of reproduction and recruitment, the reef will eventually degenerate. Corals provide a primary link in the food chain as the sites of photosynthetic fixation of light energy through their zooxanthellae. They also provide a habitat for numerous associated fish and invertebrates. If the coral populations on the reef go into decline, so will the rest of the community. Whether a reef is killed quickly by catastrophe or slowly by attrition (no population replenishment), the result is the same: the loss of the reef and all it has to offer.

Our present knowledge of factors affecting reproduction and recruitment enables us to better understand how to manage activities that affect reefs, and also allows us to examine methods for applying this knowledge to reseeding and rehabilitating damaged reefs once suitable conditions return. Experiments on the cultivation of coral larvae for reseeding have proven successful. Larvae raised from mass-spawning events have been introduced onto suitable substrata in three



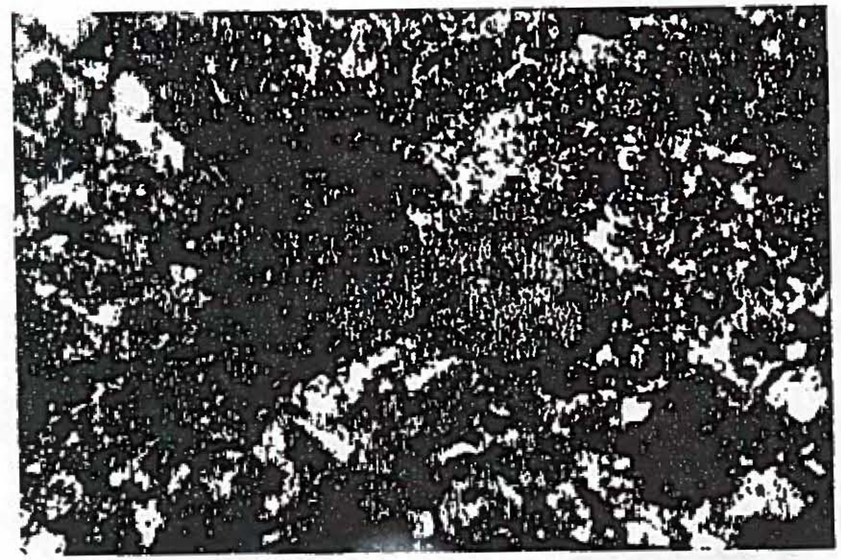

*Figure 8–8.* *Acropora* recruits, approximately 24 hours after settlement and metamorphosis.

areas damaged by crown-of-thorns starfish predation and by sediment. Numerous recruits were found in the seeded areas (Fig. 8–8), while no recruits of the species used were found in adjacent reference sites. These results indicate that if the environment is appropriate for recovery, reseeding can enhance recruitment rates above natural levels. Unfortunately, a 50-year-old coral cannot be replaced by reseeding in less than the 50 years it took to grow to a particular size. Prevention of human-induced damage and protection of water and substratum quality are the most effective means of supporting successful reproduction and recruitment of corals, and hence, the persistence of coral reefs.

environment book review

*Books, videos, slides and other materials from SPREP and other environmental organisations in the Pacific islands*

# The International Coral Reef Initiative (ICRI) Pacific Regional Strategy

The ICRI Pacific Regional Strategy was developed and agreed to by participants of the ICRI Regional Workshop held in Suva, Fiji from 27 November to 1 December 1995. This Strategy is built upon aims to assist in the implementation of the ICRI call for action, with emphasis on:

- The global problem of serious decline of coral reefs, especially those near shallow shelves and dense populations.
- The threats to coastal ecosystems by human activity as the primary agent of coral reef degradation.
- The significance of coral reef ecosystems in sustaining innumerable coastal communities worldwide. As competition among multiple users of reef resources increases, so too will their significance to human populations that depend on them.
- Reducing the threats from human-related impacts through improved and sustained management practices; increasing national and local capacities for coral reef ecosystem management; increasing political support for managing coral reef ecosystems; and sharing of existing important new information related to maintaining these ecosystems.
- Integrating coastal management into local, national and regional coastal development plans and projects; and supporting their long-term implementation and developing coral reef initiatives to encourage local participation.
- Capacity building, in terms of establishing regional networks to share information, develop and support educational and information programmes aimed at reducing the adverse impacts of human activities.
- Developing research and monitoring networks to achieve better coordination using regional networks among national research programmes; promoting linkages between global research and monitoring programmes, projects and activities identified as essential to managing reef ecosystems for the benefit of humankind; and promoting the development and maintenance of a global coral reef monitoring network.
- Periodically reviewing the extent and success of the implementation of actions identified in the initiative.

The strategy in this report has been developed for the specific issues and priorities of the Pacific region for conservation, management and sustainable development of coral reefs and ecosystems. Detailed actions to address many relevant issues are identified in a range of other sources including a number of regional and international treaties and agreements. However, this report is not intended to reproduce such high-level detail but rather to highlight the strategy that will be implemented in light of these instruments and in using other relevant tools. The objectives and actions in this report broadly identify how this strategy should be carried out in a manner which is appropriate to the Pacific region.

*International Coral Reef Initiative Pacific Regional Strategy, paper prepared for ICRI Workshop held in Suva, Fiji, 27 November to 1 December 1995.* Apia: SPREP, 1996. vi+30pp. ISBN: 982-04-0141-0. Copies of this report are available from SPREP.


*International Coral Reef Initiative (ICRI) Pacific Regional Strategy* (ISBN: 982-04-0141-0)

*Pacific Regional Report on the Issues and Activities Associated with Coral Reefs and Related Ecosystems* (ISBN: 982-04-0146-1)

*International Coral Reef Initiative (ICRI) Pacific Regional Workshop* (ISBN: 982-04-0147-X)

*Environmental Impact Assessment Guidelines for Mine Development and Tailings Disposal at Tropical Coastal Mines* (ISBN: 982-04-0150-X)

*Development of Boat Harbours at Anibare and Gabab, Nauru*

*Coral Reef Survey, Vava'u, Kingdom of Tonga* (ISBN: 982-04-0151-8)

*Neiafu Master Plan, Vava'u, Kingdom of Tonga* (ISBN: 982-04-0157-7)

*SPREP Training Course on Coral Reef Survey and Monitoring Techniques* (ISBN: 982-04-0160-7)

# Pacific Year of the Coral Reef: Why?

*Major concerns about increasing threats to coral reefs have prompted Pacific Island governments to declare 1997 as the Paci Year of the Coral Reef.*

This decision is based on a recommendation by the International Coral Reef Initiative (ICRI) Pacific Regional Strategy. Research reveals that 10 per cent of the world's coral reefs are degraded beyond recovery while an even greater percentage is threatened. If this trend continues, most of the earth's reef resources will be lost in the next century. This trend affects the Pacific region more than any other, given the Pacific Island people's high dependence on the sea for their daily subsistence requirements.

The Planning Meeting for the Pacific Year of the Coral Reef Campaign, held from 2 to 8 July 1996 in Nadi, Fiji, produced a regional campaign plan and national campaign plans (to be finalised in-country). Some of the key outputs from the meeting were: a slogan (Coral Reefs: Their Health, Our Future!); key messages (such as Dynamiting kills coral reefs and blows up our families' future!); and key audiences (for example, resource users and owners).

Also the participants were briefed on how to interact and work with the media.

According to the regional coordinator of the campaign, SPREP's Wetlands and

Mangroves Officer Mrs Lucille Apis-Overhoff, "The Pacific Year of the Coral Reef Campaign aims to increase understanding, appreciation, support and immediate action for coral reef conservation and wise use through the use a range of communication tools".

The campaign will be launched simu taneously across the Pacific region i February 1997, focusing on ho communities can become involve in the protection of the reefs.

Mrs Apis-Overhoff als mentioned the collaboratin assistance from the Great Barrie Reef Marine Park Authorit (GBRMPA), through Mr Davi Lloyd, which produced draf awareness and resource material for the campaign as well as a training workshop on media skills.

"The campaign dynamics have been mobilised and momentum is gathering daily from the reports we have had from the countries. These include events such as artwork, music, poetry, storytelling etc., using the coral reef themes and key messages. Also, the winner of the regional artwork competition currently in progress, will be announced early in December," said Mrs Apis-Overhoff. "I am confident the campaign will be a success based on the enthusiastic support received from the countries through our focal points, the experience gained from the successful Year of the Sea Turtle Campaign through Ms Sue Miller, together with support from SPREP, its member countries and other organisations such as GBRMPA. I hope that as the campaign kicks off, the media and other organisations will reinforce the good work that has already begun."

**The Pacific Year of the Coral Reef Campaign aims to increase understanding, appreciation, support and immediate action for coral reef conservation and wise use through the use of a range of communication tools**

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*Annual Review*

# ECOTOXICOLOGY OF TROPICAL MARINE ECOSYSTEMS

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**Abstract**—The negative effects of chemical contaminants on tropical marine ecosystems are of increasing concern as human populations expand adjacent to these communities. Watershed streams and ground water carry a variety of chemicals from agricultural, industrial, and domestic activities, while winds and currents transport pollutants from atmospheric and oceanic sources to these coastal ecosystems. The implications of the limited information available on impacts of chemical stressors on mangrove forests, seagrass meadows, and coral reefs are discussed in the context of ecosystem management and ecological risk assessment. Three classes of pollutants have received attention: heavy metals, petroleum, and synthetic organics such as herbicides and pesticides. Heavy metals have been detected in all three ecosystems, causing physiological stress, reduced reproductive success, and outright mortality in associated invertebrates and fishes. Oil spills have been responsible for the destruction of entire coastal shallow-water communities, with recovery requiring years. Herbicides are particularly detrimental to mangroves and seagrasses and adversely affect the animal–algal symbioses in corals. Pesticides interfere with chemical cues responsible for key biological processes, including reproduction and recruitment of a variety of organisms. Information is lacking with regard to long-term recovery, indicator species, and biomarkers for tropical communities. Critical areas that are beginning to be addressed include the development of appropriate benchmarks for risk assessment, baseline monitoring criteria, and effective management strategies to protect tropical marine ecosystems in the face of mounting anthropogenic disturbance.

Keywords—Ecotoxicology    Coral reefs    Mangroves    Seagrasses    Chemical contaminants

## INTRODUCTION

Islands and coastal waters of the tropics and subtropics possess unique, speciose, and highly productive ecosystems, including mangrove forests, seagrass meadows, and coral reefs. These economically and culturally valuable ecosystems had long been considered to be pristine and safe from the degradation of human activities. However, in the late 1960s and early 1970s, as natural resource exploitation spread from temperate regions to the tropics, environmental concerns led to numerous reports documenting the decline of these ecosystems [1]. Scientists now agree that shallow-water tropical marine ecosystems in many areas are degraded, if not destroyed, as a result of exposure to sedimentation, nutrient loading, and chemical contaminants as well as physical habitat destruction associated with human harvesting of wood, and food, mining of coral block and limestone, and dredging and filling for construction [2–6]. Destruction of these important ecosystems, which form and protect land masses from the open ocean, has serious consequences in areas where tropical storms, hurricanes, or typhoons occur. Disruption of ecological processes in these ecosystems affects not only the resident organisms but also the humans who depend on them for food and recreation.

At the interface between land and sea, wave action is dissipated by salt-tolerant mangrove forests. The roots of these trees trap and stabilize sediment as peat (a combination of silt, sand, and decomposing forest detritus), which prevents fine particles in coastal rivers from reaching offshore seagrass beds and coral reefs. The roots provide a substratum for encrusting algae, sponges, and molluscs, attracting crustaceans and fishes that feed on these resources and providing shelter for these organisms, many of which are juveniles of species found in seagrasses and on coral reefs as adults [7]. The leaf detritus and associated microbes form the basis of the mangrove community food web and are also a food source when transported to adjacent deeper waters [8].

Seagrasses inhabit mud or sand bottoms to a depth of 30 m or more throughout tropical and subtropical areas. Principal tropical seagrasses include the flat-bladed genera *Thalassia*, *Halodule*, and *Halophila* and round-bladed *Syringodium* [9]. The blades of the grasses can extend approx. 40 to 60 cm above the substratum and are anchored by an extensive system of rhizomes. Seagrasses grow rapidly and have high organic productivity, serving as food for herbivorous urchins, molluscs, fishes, and sea turtles, as well as producing large quantities of detrital material, which serves as another food source when exported to adjacent ecosystems. The dense leaves and roots also buffer the coastline, trapping sediment and reducing erosion while providing attachment for epiphytes and shelter for a variety of organisms [9,10].

Coral reefs are biogenic fringing, bank, barrier, or atoll structures that are the seaward component of much of the tropical shoreline, buffering it from wave action. Coral reefs are formed primarily by the calcification processes of coralline algae and scleractinian corals, producing structural habitat for filamentous and fleshy algae, invertebrates, and fishes. The unique symbiosis of the reef-building scleractinia with single-celled

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Contribution 363 of the University of Guam Marine Laboratory.

dinoflagellates, also known as zooxanthellae, enables these organisms to live in clear, oligotrophic waters with low nutrient levels [11,12]. Corals are very susceptible to changes in environmental conditions including light levels, nutrients, and temperature, outside the range that they normally experience. Such changes affect the coral–algal symbiosis and, ultimately, calcification and the entire reef community. The death of key organisms on the reef or the shift from an autotrophic to a heterotrophic (suspension/detritus-feeding) community changes the dominant ecological process from calcium carbonate deposition to erosion [13]. Many organisms (e.g., urchins, sponges, fishes) assist in the destruction of the reef and the formation of sand.

Like coral reef ecosystems, seagrass meadows and mangrove forests are also adversely affected by changes in water quality (increased or decreased temperature, salinity, oxygen; increased turbidity; presence of chemical contaminants) or substratum quality (alterations in grain size, composition, porosity), which can cause direct mortality or physiological alterations [see reviews in 1–4,14]. Sublethal effects of environmental changes are reflected in impaired reproduction and recruitment of key species, eventually resulting in a cascade of losses within the ecosystem [13].

Because concerns about the demise of coral reefs and adjacent ecosystems have increased, there have been numerous international efforts to conserve and protect them, primarily by designating marine parks (e.g., Great Barrier Reef Marine Park, Queensland, Australia; Florida Keys National Marine Sanctuary, Florida, USA). Efforts are also under way to educate people and change attitudes and practices that are adversely affecting the ecosystems, including those associated with fishing and land management. Managers of tropical marine ecosystems need to be able to synthesize information on stressors and develop methods to assess and predict risks to these ecosystems. To determine risks, however, there must be knowledge of the magnitude of stressors at which effects become apparent. Although much research has been conducted on factors affecting tropical marine ecosystems, particularly coral reefs, efforts to direct research to address management goals and decisions have been limited until recently.

The "Framework for Ecological Risk Assessment" [15] provides guidance to evaluate what is known about an ecological resource and its susceptibility to physical, chemical, or biological stressors with the intent of developing one or more estimates of risk involved from past or potential exposure to these stressors [16,17]. Statements of ecological consequences [17] help provide managers with options to more effectively protect resources at greatest risk while balancing costs and benefits to society. Although most ecological risk assessments have been site- or stressor-specific, efforts are under way to develop assessments on larger temporal and spatial scales. This is particularly important for ecosystems, watersheds, or landscapes with numerous ecological components involved in complex interactions and exposed to multiple and different types of stressors. Such an approach might also be appropriate for coral reefs and adjacent tropical marine ecosystems.

A recent review of pollution in tropical marine ecosystems discussed a variety of stressors and effects and proposed some preliminary tolerance levels for corals on the Great Barrier Reef [4]. This article focuses on the current status of knowledge on chemical contamination in tropical coastal ecosystems, how this information might be used in the context of ecological risk assessment, and the need for further ecotoxicology research. The valued ecological resources for these ecosystems are primary producers, those organisms that provide physical structure and food for the major communities on which other organisms, including humans, depend. The following resources, which might serve as index species or the focus of assessment endpoints in assessing ecological risk, are targeted: for mangrove forests, *Rhizophora* and *Avicennia* spp.; for seagrass beds, the turtle grass *Thalassia testudinum*; and for coral reefs, scleractinian corals. The three ecosystems differ in their structural basis (tree, macrophyte, and colonial invertebrate containing symbiotic algae, respectively) as well as in longevity (decades for mangroves, 1 year for seagrasses, centuries for corals). Tropical fishes are also discussed, although there is limited research on the effects of pollutants on these organisms. Many fishes migrate from the reef to seagrass beds and mangroves or spend part of their lives in the adjacent ecosystems, potentially transferring pollutants from one ecosystem to another. Fishes are important components of marine food webs and can pass bioaccumulative chemicals acquired from these primary producers and/or invertebrate prey to fishes at higher trophic levels and to coastal birds and mammals that prey on fishes.

Here we review the current data and make recommendations for further research that can benefit managers and users in protecting these important ecosystems [18]. In tropical marine communities, waterborne chemical threats can come from far as well as near, from both point and nonpoint sources. Through a better understanding of the tropical marine ecosystems and their responses to chemical stressors, managers will be able to more effectively address the goals of reducing negative effects and improving mitigation measures by designing appropriate policies and regulations.

## STATUS OF KNOWLEDGE ABOUT CHEMICAL STRESSORS IN TROPICAL MARINE ECOSYSTEMS

The sources of chemical contamination in tropical marine environments are similar to those in temperate marine ecosystems (Fig. 1). Terrestrial runoff from rivers and streams, urban areas, and agricultural areas is probably the most important. In addition, some urban areas have sewage outfalls near coral reefs [19,20] or can contribute to the contaminant load through desalination plants [21]. Landfills can leach directly or indirectly into shallow water tables, streams, and the coastal zone, a particular problem on porous limestone islands. Many reefs are located near population centers and are the focus of tourism, which makes them vulnerable to chemical inputs from recreational uses and industries related to recreation (e.g., boat manufacturing, boating, fueling at marinas). Reefs are economically and socially important for their fishery resources, and chemical-based fishing methods (e.g., using bleach or cyanide) are not uncommon in developing regions.

Some shallow coastal zones are near shipping lanes where ships pump out contaminated bilge water or spill their cargo. Dredging of channels to allow ship traffic can increase chemical concentrations through resuspension of buried organics or heavy metals. Ocean disposal of waste chemicals or incidental chemical spills are also contributing factors. Industrial inputs from coastal mining and smelting operations [22] are sources of heavy metals; offshore oil and gas activities and coastal petroleum refineries contribute metals, phenols, and oil [20] from tanker loading, spills, well blowouts, and pipeline ruptures.

Because the transport of most point and nonpoint source

Fig. 1. View from the reef off Guayanilla and Tallaboa Bays, a heavily industrialized area on the southern coast of Puerto Rico. Similarly developed coastal areas occur in the vicinity of mangrove forests, seagrass meadows, and coral reefs around the world.

toxicants is primarily from inland to offshore, the ecosystem sections in this document are arranged accordingly, i.e., from inshore (mangroves) to offshore (coral reefs). The fate and transport of chemical pollutants, factors influencing bioavailability and toxicity, and ecosystem effects are discussed under the categories of metals, oil and dispersed oil, and pesticides and other organics. One general factor affecting the bioavailability of contaminants is that the organic carbon content of sediments decreases from mangroves to seagrass beds to coral reefs. An overview of the ecological significance of these contaminants and reports of trends in contaminant loading in these ecosystems are also included in the following discussion.

*Mangrove forests*

Mangrove forests are an important buffer for adjacent marine ecosystems, trapping sediments and nutrients, as well as many anthropogenic chemical contaminants. Different species of mangrove trees have different types of sediment-trapping root systems adapted for combatting the low-oxygen conditions in the peat, including the pores or lenticels on the branching prop roots of the red mangroves (*Rhizophora* spp.) or on the cylindrical pneumatophores of black mangroves (*Avicennia* spp.), which project above the water level. Species in these genera are the most salt-tolerant mangroves, and they form extensive forest communities criss-crossed by tide-draining channels along tropical and subtropical coasts. Physical destruction of this ecosystem for building materials, fuel, and land reclamation has increased greatly during this century, largely because of population pressures.

*Heavy metals.* Impacts of heavy metal exposures on mangrove trees are apparently minor or nonexistent. Mangrove sediments, composed of fine particles with a high organic content and low pH, are particularly effective in sequestering potentially toxic heavy metals, which are immobilized as sulfides in the usually anaerobic sediments [23–26]. However, metals can be reintroduced to nearshore waters when they are taken up by mangrove trees and concentrated in exported leaf detritus. Storms and human activities such as dredging or clearing of mangrove forests also remobilize metals and facilitate transport from mangrove forests to coastal waters.

Whether metals are available for uptake by mangrove trees and to what extent metals are transported out of mangrove forests to coastal waters are debatable. Silva et al. [27] found that sediments were the main reservoir of the total metal content in a mangrove forest dominated by *Rhizophora mangle* and concluded that the major portion of metals is probably unavailable for mangrove uptake. However, *Rhizophora* species appear to take up metals in a different manner and to a lesser extent than other mangroves species [28–31]. In other studies, metal concentrations were higher in leaves than in water or sediment [28,29,31]. Tam et al. [32] did not detect lead, chromium, or cadmium in leaf samples from the mangroves *Kandelia candel* and *Aegiceras corniculatum* in the Futian National Nature Reserve, China; these metals occurred in sediments at high concentrations at some sites but were not bioavailable. Metals were also concentrated in perennial tissues such as the trunk and limbs [27].

Lacerda et al. [33] argued that plant litter is very poor in trace metals, leading to very low export. Even if the material is poor in trace metals, substantial quantities of mangrove detritus are exported from the forests and used as a food source [34,35]. This serves as an avenue by which metals could be transported from mangrove forests to surrounding communities. Mercury, a bioaccumulative metal, was detected in red mangroves, mangrove oysters, and a variety of fishes, including great barracuda, from Puerto Rico and the U.S. Virgin Islands [36]. Mangrove leaf detritus is enriched in metals as it ages [30], possibly as a result of the loss of organic material, and metals are enriched in suspended matter [24,37]. DeLaune et al. [38] calculated that 3% of the annual accumulation of copper and 5% of the annual accumulation of zinc in a mangrove ecosystem were exported through detritus and that cadmium, lead, and manganese were also exported via detritus. Nye [39] estimated that 3,499 kg of iron, 9,130 kg of manganese, 1,063 kg of copper, and 412 kg of zinc are exported annually from mangrove forests in southeast Florida. Tidal deposition might also influence the distribution of metals in mangrove sediments [40]. Table 1 summarizes ranges of metal contaminants measured in mangrove forests.

*Oil and dispersed oil.* Mangroves are very sensitive to oil. The low wave action and small tidal amplitude characteristic of mangrove swamps make them excellent traps for oil slicks [41,42]. At very low concentrations, oil stimulates growth. This phenomenon, hormesis, might be due to the hormone-

Table 1. Metal concentrations in mangrove ecosystems[a]

| Component | Fe | Zn | Cu | Mn | Cd | Pb |
|---|---|---|---|---|---|---|
| Sediments (μg/g dry weight) | 100–33,492 | 0.28–379 | 0.3–75 | 1.23–640 | 0.1–2.39 | 1–650 |
| Suspended material (μg/L) | 195–2,808 | 18–595 | 62–76 | 466–788 | 2.85–3.2 | 21–139 |
| *Rhizophora* spp. (μg/g dry weight) | 0.16–166 | 0.03–32 | 0.12–11 | 0.42–497 | 0.04–0.24 | 0.43–27 |
| Inverterates (μg/g dry weight) | 124–886 | 30–1,800 | 2.6–20 | 4.8–31 | 0.4–10 | 0.9–5.06 |

[a] Compiled from [24,27,29–33,39,40,349–361].

like action of some aromatic hydrocarbons or to selective action against a parasite [43–47]. However, because mangroves span the air/water boundary, they come into direct contact with spilled oil, and the physiological adaptations that mangroves have evolved to survive anaerobic soils make them particularly vulnerable to smothering by oil slicks. The specialized gas-exchange pneumatophores are susceptible to clogging, and when they are blocked the roots die from lack of oxygen [48,49].

Oxygen concentrations are lower in warmer waters [50], whereas respiratory rates are higher, and aerobic tropical organisms must live at oxygen levels closer to their lethal limits than do the biota of cooler waters [1,3]. Spilled oil has a large biological oxygen demand (BOD), which can further exacerbate the oxygen shortage. In addition, oil contains toxic compounds that can disrupt the metabolic activity of sensitive organisms [23]. In experiments with oiled pneumatophores, both light and heavy oils effectively blocked gas exchange through the lenticels, even when most of the oil was washed away [51]. Damage to pneumatophores can take a year or more to become noticeable [43,52,53]. When aerial roots regrow, they are often deformed or abnormal [49,53,54–57].

The anaerobic conditions and low redox potential values found in mangrove sediments are known to be unfavorable for the biodegradation of hydrocarbons [58], and substantial concentrations of hydrocarbons remain in mangrove sediments 10 to 30 years after spills [59,60]. Three years after the *Zoe Colocotronis* spill in Puerto Rico, soil samples from the mangrove community had up to 80,000 ppm extractable hydrocarbons [61]. Mangroves can translocate aromatic hydrocarbons into their tissues [46], and the toxic components of retained oil continue to cause sublethal effects, including reduced productivity, lower rates of litter production, and lower seedling survival [62]. In this state of chronic stress, mangroves are highly susceptible to any additional perturbation or stress [62]. Dodge et al. [60] noted in an experimental field exposure that Prudhoe Bay crude oil killed 17% of mangrove trees after 2 years and 46% after 10 years, with degraded oil still present. Gundlach and Hayes [63] concluded that mangroves are the coastal marine environment most vulnerable to oil spill impacts [see also 64]. Oil spills from tankers have caused massive die-offs of mangroves and their associated organisms [42,48,62,65–71, reviewed in 55].

Once a mangrove forest has been damaged by oil, recovery is often slow. Some areas of Bahia Sucia, Puerto Rico, that were destroyed by a large spill in 1973 were still devoid of mangrove growth 20 years later [72]. Subsequent erosion prevented recovery, and it takes at least 3 years for debris from the former mangrove community to decay [73]. Lugo et al. [52] reported mangrove seedlings to be more resistant to oil; however, seedlings that colonize an area before debris has decomposed can be scoured away by the tidal movement of debris. When recovery occurs, it takes a minimum of about 20 years [74–78], and trees might not reach their full height for 80 years. The rate of recolonization often depends on the size of the patch affected, with large patches relying on recruitment of planktonic propagules [79]. Infaunal populations might recover rapidly, but some epibiont invertebrate populations, including shrimp, polychaetes, cerethid snails, and sipunculids [69], can be affected for several years [80–82]. Klekowski et al. [72] reported that the biota of oil-polluted mangrove habitats might experience increased mutation rates.

Because mangroves are very sensitive to oil spills and slow to recover, it has been suggested that every effort should be made to keep spilled oil from reaching mangroves [48]. In some cases, treating oil with dispersants mitigated damage [43,46,47,48,60,83,84], but in other cases, addition of a dispersant increased toxicity [43,46–48,83]. The toxicity of an added dispersant can be affected by the type of dispersant used and the concentration in water, the type of oil spilled, and the age and species of the mangroves treated. The toxicity of the dispersant to adjacent marine communities should also be taken into consideration. Seagrasses and corals are very sensitive to Corexit 9527, but Elastosol, Cold Clean, and Finasol are much less toxic to these organisms and have been recommended for tropical estuarine spills when mechanical procedures are inadequate to contain the spill [85].

*Pesticides and herbicides.* Mangroves are also susceptible to herbicides [83–88]. During the Second Indochina War, 18.9 million gallons of herbicides was sprayed on forested and agricultural areas of Vietnam. Of all the habitat types in South Vietnam, the coastal mangrove forests were the most vulnerable to wartime herbicide operations [89–91]. In the Rung Sat area, 73% of mangrove cover was destroyed [89]. It is estimated that 41% (124,000 ha) of the total mangrove forest area of Vietnam experienced significant mortality during the Second Indochina War [90–92].

The reason for this sensitivity is poorly understood but could be related to the physiological stress of living in a saline environment [77]. Species of *Avicennia* have been shown to be more resistant to 2,4-dichlorophenoxyacetic acid (2,4-D) [86,93], but *Rhizophora*, the most economically and ecologically important genus of trees in South Vietnam, was especially sensitive to hormone-mimicking pesticides [90,91]. In an experimental exposure of mangrove species in Florida, USA, to 2,4-D, the buttonwood *Laguncularia racemosa* was the most sensitive species tested, *Avicennia germinans* was the most resistant, and *R. mangle* was intermediate [93]. Seedlings were also much more sensitive than adults. *Rhizophora mangle* has been shown to take up and translocate 2,4-D and picloram to various plant parts [93–95], and 2,4-D induced the breakdown of cell walls in both roots and leaves [94,95]. Death of mangroves exposed to 2,4-D is believed to be due to the loss of meristematic tissues [96].

Some herbicide residues remained in the environment 5 to 10 years after intensive spraying, but they were far below levels that would inhibit seedling establishment [89]. Laboratory analyses of residual herbicides and breakdown products in aquatic or marine sediments are limited but indicate that most do not persist at high concentrations [97]. However, Snedaker [90] warned that the absence of data should not be interpreted to mean that no problems exist.

In the Rung Sat area of South Vietnam, numerous differences have been noted in biota inhabiting defoliated versus undisturbed areas, but it is not known to what degree these differences were caused by herbicide exposure or habitat destruction. The abundance and species richness of planktonic organisms and large fish were lower in sprayed areas, while fish eggs and larvae were more numerous in denuded regions [89], possibly as a result of an absence of predators. Orians and Pfeiffer [98] reported an enormous reduction in numbers of birds. Marine fishery stocks declined, and certain species disappeared [99,100].

Although the devastation of mangrove forests by herbicides is uncontested, the rate of recovery of sprayed forests, like mangroves destroyed by oil spills, is uncertain, with estimates varying from 20 years [76,90] to more than 100 years [89]. Reestablishment might occur only along the edges of the river channels and backwaters [78,98]. Natural regeneration of mangroves has been minimal in coastal South Vietnam [91,101]. Important factors impeding recovery are the almost complete elimination of mature seed- or propagule-bearing trees in sprayed areas [89,90,102], lack of vegetative cover [89], debris [102–104], and increased erosion [91,102]. However, erosion might actually accelerate revegetation by exposing reduced sediments, lowering land elevation relative to surface water elevation, promoting beneficial surface water recirculation and flushing, and removing persistent herbicides from the system. In certain deforested areas, weed species now dominate the habitat to the exclusion of various mangrove species and will probably remain dominant for some time [90].

Very little information is available on the possible effects of other pesticides on mangrove forests. Mosquito larvicides such as temephos are regularly sprayed on mangrove communities in the Florida Keys and elsewhere. Concentrations of temephos decline rapidly after application [105–107]. Temephos persists on mangrove leaves for up to 72 h and in oysters for up to 48 h [107]. At normal application rates, concentrations of temephos in water reach levels that are toxic to mysids [107] and can cause sublethal effects in fish [105,108]. Temephos has also been shown to have a significant effect on fiddler crab populations at normal application rates [109–111].

*Seagrass meadows*

Seven of the 12 genera of seagrasses occupy tropical climates (*Halodule, Cymodocea, Syringodium, Thallassodendrum, Enhalus, Thalassia, Halophila*). A few species of the remaining five genera are occasionally found in subtropical and tropical waters [112]. The majority of the work on the impact of anthropogenic inputs has been performed on temperate grasses such as *Zostera* and *Posidonia*. A decline in the health of seagrass beds has been reported recently in many areas of the world, including the United States [113–115] and Australia [116], and shifts in dominant species have been found to correlate with pollutant exposure [117,118]. Seagrass die-offs resulting from chemical contaminants, as well as physical damage and disease, reduce habitat availability and sediment-trapping ability, leading to increased transport of contaminated sediment particles to coral reefs. In addition, decreased decomposition of detritus alters carbon cycling and transport of contaminants.

*Heavy metals.* In temperate species, metals can be incorporated into seagrass leaf tissues directly from water and sediment [119], and in uncontaminated areas, seagrass leaves constitute the major transport pathway for the cycling of copper, iron, manganese, and zinc between these media [120]. Trace metals in *Halodule wrightii* are positively correlated with concentrations in sediment [121]. Metal concentrations tend to be higher in leaves than in shoots for Indonesian tropical seagrasses [122] and *H. wrightii* [121]. These results reflect the bioavailability and translocation of contaminants to biomass above the sediment. Biotic transport of trace metals from seagrass detritus may occur through the food chain [22].

Field studies of seagrasses have shown that several species are capable of accumulating a range of trace metals [e.g., 121–124]. Baseline data for nickel, copper, lead, and zinc have been collected for Indonesian seagrasses [122]. *Halodule ovalis* had higher levels of zinc than other congeners [122,124] and therefore might be a zinc accumulator. In *Thalassia* microcosm studies, seagrass communities were shown to rapidly take up and process tributyltin [125], increasing the potential exposure of associated fauna.

Several studies using microcosms demonstrated a similar potential for ecosystem-wide effects in tropical seagrass beds from toxic chemicals such as tributyltin [130], as have been found in metal exposures of temperate seagrass species [22,126]. At 22 μg/L of tributyltin, carbon turnover decreased, with reduced detrital decomposition and above-sediment plant biomass, in *T. testudinum* [127]. Benthic invertebrates decreased in abundance [128]. *Cymadusa* and *Crepidula* were identified as indicators of impending invertebrate mortality. Exposure to drilling muds containing ferrochrome lignosulfonate (FCLS) and other metals such as barium affected the abundance and species richness of the invertebrate community in a *Thalassia* microcosm [129,130]. Associated epiphytes had decreased photosynthetic potential and biomass when treated with drilling mud [129,131]. The concentration of chlorophyll *a* per gram dry weight of leaf tissue and the rate of leaf decomposition were reduced [129,130]. Productivity, measured as growth rate and carbon uptake, was reduced, with an observed seasonal variability [131].

*Oil and dispersed oil.* Damage to seagrass communities from oil exposure includes acute mortality resulting from physical impacts (i.e., smothering, fouling, asphyxiation) and chemical toxicity; indirect mortality as the result of light loss, death of food sources, or the destruction or removal of habitat; destruction of sensitive juvenile fishes and invertebrates; and accumulation of potentially carcinogenic or mutagenic substances in the food chain [132]. The 1986 spill at Bahia Las Minas, Panama, demonstrated several of these effects. Oil and possibly oil plus dispersant caused mortality of intertidal *Thalassia* beds [133], as well as damage to shoreward margins of the beds, which receded [118]. *Thalassia* subsurface biomass increased at oiled sites, whereas *Syringodium* biomass continued to decline [118]. These findings agree with results of Thorhaug et al. [134], who exposed both species to oil. In an experimental spill, hormesis, evident as increased biomass of seagrass, was observed, with minor or no overall effects on seagrasses resulting from oil or chemically-dispersed oil up to 10 years afterward [47,60].

Fauna and flora associated with seagrasses are also affected

Table 2. Metal concentrations in coral reef ecosystems[a,b]

| Component | Fe | Zn | Cu | Pb | Ni |
|---|---|---|---|---|---|
| Water column (mg/L) | 1.0–5.93 | 0.02–1.5 | 0.01–1.8 | 0.18 | |
| Sediment (μg/g) | 237–11,445 | 7.6–40 | 2.2–17 | 18–45 | 74–122.6 |
| Coral skeleton (μg/g) | ND–560 | 0.08–25 | 0.24–18 | 0.04–39 | ND–126 |
| Coral tissue (μg/g dry weight) | ND | ND–126 | 7.5–18 | | |

[a] Compiled from [196,198,362].
[b] ND = not detected.

by oil. Fleshy and calcareous algae did not recolonize oil-damaged areas at Bahia Las Minas. Infauna, nearly completely killed by oil exposure, gradually returned to abundances above prespill levels [118]. However, only species with high reproductive potential or planktonic stages recovered quickly. The effects of oil on tropical fish have not been extensively studied. Sublethal doses of No. 2 fuel oil, at concentrations greater than 1.0 ppm water-soluble fraction, caused decreased growth and slow avoidance responses in the estuarine spotted seatrout, *Cynoscion nebulosus* [135]. Metabolic rates were affected by petrochemical effluents in the warm-water pinfish (*Lagodon rhomboides*); sublethal effects were aggravated by salinity changes and differed with size class [136].

Oil in direct contact with seagrasses causes decreasing growth rates, smothering of leaves, leaf yellowing and browning, loosening of leaves, and decreasing percent cover [137]. Laboratory experiments have demonstrated reduced photosynthetic ability depending on oil type, exposure time concentration, and species tested [134,138,139]. However, the WSF of Kuwait crude oil had no effect on the photosynthetic parameters or respiration in seagrasses indigenous to the Persian Gulf [140]. Field observations of species composition, distribution, abundance, productivity, and morphology for three species of seagrass in the Arabian Gulf indicated that the Gulf War oil spill had little or no impact on the seagrasses [141].

Of the Caribbean seagrasses exposed experimentally to dispersed oil, *T. testudinum* had a higher LC50 than *H. wrightii* and *S. filliforme* [134]. Dispersant type and length of exposure influence response. The latter two species were more sensitive to dispersant alone than *T. testudinum*, which showed no effect after 100 h of exposure [134]. *Thalassia* was most affected by exposure to dispersant over longer time periods and exposure to greater concentrations of dispersant mixed with oil [142].

*Pesticides and other organics.* Seagrass beds located near agricultural regions likely receive runoff containing pesticides. Chemicals such as atrazine and pentachlorophenol (at concentrations of 1 ppm) depressed the rate of oxygen evolution (photosynthesis) and oxygen uptake (respiration) of leaves of *T. testudinum* [143]. Atrazine (30 ppm) caused a significant reduction in survival, production of new ramets, above-sediment biomass (greater than 50%), and growth of *H. wrightii* [144]. Cropping and variation in light and salinity did not influence the biological response to atrazine. *Halodule wrightii* appears to be more tolerant to pollution than other species [117,144]. At 50 ppb, organophosphorus, carbamate, and organochlorine pesticides, especially dichlorodiphenyltrichloroethane (DDT) and lindane, caused decreased net photosynthesis and increased dark respiration in *Halophila* and *Halodule* spp., but to a lesser degree than observed in the macroalgae tested [145].

*Coral reefs*

Although coral reefs are composed of diverse organisms, the major structural components of reefs are the scleractinian corals, with more than 600 species in tropical and subtropical climates. The reef-building, hermatypic coral species can form branching, foliose, and mound-, or boulder-shaped colonies occupying tens of cubic meters. These corals contain symbiotic algae (also known as zooxanthellae) within their gastrodermal tissue. This animal–algal symbiosis is maintained through chemical communication between the partners via the translocation of metabolites [11,146,147]. Branching species might be more susceptible to some chemical contaminants than are massive corals [148]. Scott [149] found that small-polyped species were more adversely affected by increased concentrations of heavy metals than are large-polyped species. Larger-polyped species appear to be better adapted to carnivory [150] and might be less dependent on high light levels required for successful algal photosynthesis. Coral species and individuals also differ in their ability to remove sediment particles falling on their surfaces, depending on their orientation, growth form, and mucus production [151]. Coral colonies are particularly susceptible to contaminants dissolved in seawater or adsorbed to particles because the layer of tissue covering the coral skeleton is thin (only approx. 100 μm) and rich in lipids, facilitating the direct uptake of lipophilic chemicals.

In addition, chemical communication plays an important role in mediating processes central to the existence and persistence of reefs. Reproduction and recruitment of many reef organisms are known to be chemically mediated. Changes in water quality, most notably caused by coastal pollution, can interfere with critical interactions among reef organisms and reef productivity and hence result in the eventual death of the coral reef [13,152]. Brooded planula larvae of some coral species might be afforded some protection from toxics; however, larvae of many broadcast spawners pass through sensitive early stages of development at the sea surface, where they can be exposed to contaminants in surface slicks. Reef communities can harbor an estimated standing crop of fishes 20 to 30 times greater than those found in temperate waters [153], but our understanding of the effects of chemicals on these fish communities, and on associated reef invertebrates and algae, is very limited.

*Heavy metals.* Elevated concentrations of metals have been found in the tissues of some reef invertebrates from contaminated sites (Table 2). Giant clams of the genus *Tridacna* collected from a populated atoll had significantly higher concentrations of iron, manganese, copper, zinc, and lead than clams from an unpopulated atoll [154]. Similar relationships have been seen in corals [155,156], and some corals might be better indicators of metal exposure than others [155,157,158].

Metals might occur in coral skeletons as the result of structural incorporation of metals into aragonite [159–162], inclusion of particulate materials in skeletal cavities [163], surface adsorption onto exposed skeleton [162,164,165], and chelation with the organic matrix of the skeleton [162,166,167]. Howard and Brown [155,158] found that metal concentrations were higher in the tissues than in the skeletons of corals near a tin smelter and suggested that coral skeletons were not a good indicator of environmental metal concentrations. However, several other studies reported greater concordance of data on metals concentrations in coral skeletons than in tissues at metal-contaminated sites [149,168–170].

Metals can enter coral tissues or skeleton by several pathways, and there is some evidence that corals might be able to regulate the concentrations of metals in their tissues [171–176]. Retraction of coral tissue in response to environmental stress exposes skeletal spines, which can directly take up metals from the surrounding seawater [169]. Another common response to physical and chemical stressors, particularly metals, is the production of copious amounts of mucus [177–184], which can effectively bind heavy metals [185–189] and may be involved in metals regulation [177,190]. Harland and Nganro [190] found that the rate of copper uptake in an anemone increased after mucus production ceased.

Organisms in low-nutrient tropical waters might be particularly sensitive to pollutants that can be metabolically substituted for essential elements such as manganese [191,192]. The symbiotic algae or zooxanthellae of corals can influence the skeletal concentrations of metals through enhancement of calcification rates [160,193], and they might be involved in the uptake of metals in cases where potentially toxic metals are metabolically substituted. Harland and Nganro [190] found that *Actinia equina*, an anemone lacking algal symbionts, exhibited lower uptake rates of zinc and cadmium than did *Anemonia viridis*, an anemone with algal symbionts. Benson and Summons [194] proposed that oceanic arsenate was assimilated by the symbiotic algae of giant clams. Symbiotic algae have been shown to accumulate higher concentrations of metals than do host tissues in corals [156,190,193] and in clams [194]. Sequestering metals in symbiotic algae might diminish possible toxic effects to the host [190]. The expulsion of symbiotic algae has been reported as a stress response to heavy metals [156,184,195] and has been proposed as a mechanism for the excretion of metals [176,190].

Tin was highly concentrated in reef sediments in the vicinity of a tin smelter in Thailand, and copper and zinc were slightly elevated [196]. Although there were no significant differences in coral cover, diversity, or growth rate in the study, the colony size of massive species such as *Porites* tended to be smaller in areas exposed to copper, zinc, and tin [196]. Later evidence indicated that the smelter effluent reduced the growth rate of branching corals [155], and when branching corals were transplanted to a contaminated site from a relatively pristine site 1 km distant, linear extension and calcium carbonate accretion were significantly reduced. Corals in a polluted estuary in Hong Kong also showed clear signs of stress resulting from increasing exposure to heavy metals, pesticides, nutrients, sewage, and turbidity [149]. Growth rates, species abundance, diversity, and cover declined between 1980 and 1986 during a period of decreasing water quality. Corals were replaced by ascidians, mussels, and holothurians, and corals from the more polluted site were slower growing and more heavily bioeroded [149]. Although the effects of heavy metals were not isolated from the possible effects of other stressors, the concentrations of heavy metals reported were as high as or higher than those reported by other investigators and increased with time [149]. Harland and Brown [197] noted that laboratory exposure of *Porites lutea* to elevated iron resulted in loss of symbiotic algae. The response was most noticeable in corals obtained from pristine areas, but response was less in corals that had been exposed to daily runoff from an enriched iron effluent, suggesting that the corals could develop a tolerance to the metal [156].

Metals have also been detected in reef fishes, and some effects on fish populations have been documented. Tissue metal concentrations of zinc, copper, cadmium, and mercury from 50 species of fish from the Great Barrier Reef were greater in liver than in muscle; however, all levels were very low. Of these four metals, mercury was positively correlated with size and trophic level [198]. Comparison of mercury levels in Hawaiian (USA) fish at different trophic levels showed that mercury tissue concentration increased from herbivore (0.022–0.036 ppm) to omnivore (0.058–0.070 ppm) to carnivore (0.75–0.80 ppm) and that levels are higher in the trophic food chains for fish feeding above the sediment/water interface than for those in direct contact with the sediment [199, see also 36]. Zinc concentrations in the liver of blue-striped grunt *Haemulon sciurus* from Bermuda were two to three times higher in grunts from clean sites (20–30 μg/g liver) than in grunts from sites with five times the levels of heavy metals (60–70 μg/g liver) [200]. Behavioral modifications, including erratic swimming, increased gill ventilation, and disrupted schooling ability, were noted in tropical fish exposed to heavy metals [201]. Increased mucus production, fin erosion, and change in color were also observed.

The drilling of oil wells near coral reefs has been a concern. Howard and Brown [157] noted that concentrations of up to 6 mg/L FCLS might occur within 100 m of a discharge. Six months of exposure to FCLS (concentrations not reported) decreased growth rates in the coral *Montastraea annularis* [202]. Linear growth and extension of calices (skeleton supporting the polyps) decreased in response to laboratory exposure to 100 mg/L drilling mud, and the lower calical relief might impair sediment-shedding capability [183]. Field assessment of a reef several years after drilling indicated a 70 to 90% reduction in abundance of foliose, branching, and platelike corals within 85 to 115 m of a drilling site, although massive corals appeared relatively unaffected [203]. These findings agree well with predictions based on laboratory and field experiments, indicating that detrimental effects on corals seem probable within a minimum distance of 100 m from a drilling site [179,181–183,204–206].

*Oil and dispersed oil.* The potential threat of oil to reefs is high given their proximity to shipping lanes and offloading sites in shallow coastal environments. Studies indicate that small, frequent spills might be a greater threat to reefs than single-spill events [207–210]. Acute exposure of mangrove, seagrass, and reef ecosystems to spilled oil can occur from land runoff, as in the Gulf War or Panama spills, or from accidental discharges from ships at sea, as has occurred off Puerto Rico and in the Red Sea. Eighty-three of the more than 150 major oil spills in the tropics caused by shipping from 1974 to 1990 occurred near coral reefs, seagrass beds, reefs flats, sand beaches, and mangrove forests [208].

Petroleum reaching the reef might float above the reef and never directly contact it, although buoyant eggs and developing coral larvae could be affected. Reef flats are more vulnerable to direct coating by oil. Petroleum hydrocarbons, in the form of naturally and chemically dispersed oil or water-soluble components, are available for uptake by corals, and oil globules can adhere to the coral surface [133,211,212]. Petroleum hydrocarbons were found in oiled corals (25–50 mg hydrocarbon/g lipid) in Panama 5 months after the original spill [213]. Gas chromatographic patterns indicated uptake primarily from the water column and not from the sediment (19–715 μg oil/g reef sediment). Within 2 years, hydrocarbon residues were substantially reduced in sediments and coral tissues at high-energy reef sites [214]. Uptake and incorporation of petroleum hydrocarbons into coral tissues has also been demonstrated in experiments [212,215]. The relatively high lipid content of corals contributes to rapid uptake of aromatic hydrocarbons, while detoxification and depuration can be slow [212,216,217].

A combination of dispersants and oil has been shown to be more toxic than oil or dispersant alone [47,60,66,209,218–221]. Comparisons among studies are difficult because of interlaboratory variation in experimental methods, concentrations, oil fractions, durations of exposure, and species tested. No effects were observed for short exposures followed by short recovery times [222] and for short-term, low-level dosing with long recovery times [223,224]. However, even when no gross effects are seen, histological changes can occur from oil exposure [215].

Effects of oil on individual coral colonies range from tissue death to impaired reproduction to loss of the symbiotic algae (bleaching) [221]. Stress, defined by a decline in tentacular expansion, occurred at greater than 20 ppm of oil and dispersed oil, but recovery was observed within 1 week of exposure [220]. Photosynthetic rates decreased in some, but not all, laboratory-exposed corals [218,225]. Burns and Knap [213] noted a trend toward increasing protein/lipid ratios in corals exposed in the field for 5 months, suggesting that lipid reserves are reduced in oil-stressed animals. These reserves might be used to support proliferation of mucus secretory cells [215] and increased mucus production caused by exposure [133]. In the field, oiling can lead to the increased incidence of mortality and continued partial mortality of coral colonies [133]. During 5 years of monitoring on the reefs oiled by the refinery spill at Bahia Las Minas, the percentage of injured corals was correlated with sediment concentrations of oil [226,227].

In contrast to some laboratory studies that showed no change in coral growth rates with oil exposure [224], growth rates were reduced during longer-term field exposures [47,226]. In a field experiment in Panama, the dispersed-oil site had decreased percent cover of corals, which did not return to preexposure levels after 1 year. Growth rates of the corals *Montastraea annularis* and *Acropora cervicornis* were not affected by dosing with oil or dispersed oil, but the growth rates of *P. porites* and *Agaricia tenuifolia* decreased at the dispersed-oil site. These data suggest that dispersion of oil has a greater impact on reef organisms than oil alone. However, 10 years later coral coverage at the dispersed-oil site was the same as or greater than at the untreated site [60]. Newly developed dispersants might be less toxic to corals [228].

Oiling affects not only coral growth and tissue maintenance but also reproduction. Histological evidence confirmed impaired gonadal development [215,229] in both brooding and broadcasting species. In field exposures, increased injury and associated reduction of colony size led to decreased egg size, a sensitive indicator of coral reproductive viability, and decreased fecundity in colonies of *Siderastrea siderea* 5 years after the Bahia Las Minas oil spill in Panama [229]. Damaged reefs depend on recruits from unoiled reefs. Premature expulsion of planulae from brooding cnidarians following oil exposure was demonstrated by Loya and Rinkevich [230] and Ormond and Caldwell [231]. Spills occurring near or at peak reproductive season (e.g., late August in the Caribbean and Gulf of Mexico, April in the Great Barrier Reef area) could effectively eliminate an entire year of reproductive effort while continuing to reduce fecundity through partial mortality and impairment of gonadal development. In addition, successful recruitment and recruit survival can be compromised by oil exposure [209,226,232].

Short-term laboratory studies do not accurately predict long-term community effects, which vary greatly by region, species, and type of oil. Long-term studies are more likely to reflect impacts at sites with chronic petroleum pollution or at sites subjected to large oil spills. While Bak [207] stated that oil spills are unique events and chronic pollution is a greater threat to reefs, the results of his study of the effects of chronic refinery petroleum pollution on a reef do not differ greatly from those found at the refinery spill in Panama [226]. Both studies found decreased coral cover and diversity in Caribbean reefs due to petroleum exposure and decreased local recruitment [207,226]. *Acropora palmata* was identified as a sensitive indicator species, whereas *Diploria strigosa*, the subject of many of the Bermuda studies [233], might be hardier than other Caribbean species [207,226]. In the Gulf War spills, no long-term impacts on coral reefs of the region were identified [234]. Unlike the other field studies discussed, no dispersants were used on these spills, and significant weathering of oil may have occurred before it reached the reefs. Partial mortality of colonies, identified by Guzmán et al. [226] as a sensitive measure of impact, was observed on Kuwaiti reefs surveyed in the Gulf but was not thought to be caused by the spill [234].

*Pesticides.* The literature on concentrations of pesticides occurring in reef environments and reef organisms is patchy but does suggest that pesticides occasionally reach reef ecosystems, sometimes in high concentrations. In a baseline study of organochlorine pesticides on the Great Barrier Reef, lindane was the only compound that was consistently detected, with concentrations of 0.05 to 0.39 ng/g wet weight in coral reef organisms [235]. McCloskey and Chesher [236] found DDT at 3 to 12 ng/g wet weight and dieldrin at 0.260 to 0.320 ng/g weight wet in coral tissues off Florida. Pesticides were also found in 96.6% of the scleractinian corals and 100% of the gorgonian corals sampled off the northern Florida Keys, with concentrations up to 7.6 μg/g wet weight [237]. Chlordane was the most frequently encountered and highly concentrated pesticide. Samples of corals, lobsters, sponges, and fishes from sites further south on the Florida reef tract had lower concentrations of pesticides. A more recent study of sediment and biota samples in Pennekamp Coral Reef State Park and Key Largo National Marine Sanctuary, Florida, USA, also detected low concentrations of organochlorine pesticides in sediments and tissues of sponges, corals, crustaceans, and fishes [238]. No obvious effects on organisms or reef community damage were observed in these studies.

## ECOTOXICOLOGY AND ECOLOGICAL RISK ASSESSMENT OF CHEMICAL STRESSORS IN TROPICAL MARINE ECOSYSTEMS

Research during the last 20 years has confirmed that chemical contaminants are present in the water, sediment, and biota of tropical marine ecosystems and that exposure concentrations, frequency, and duration are not unlike those found in temperate marine ecosystems. Although the potential for impacts from toxicants appears greatest for the nearshore mangrove and seagrass ecosystems, offshore shallow and even deeper coral reefs can be directly and indirectly affected by chemical exposures. What is less certain is whether fate and transport processes in this environment occur in the same manner, or at the same rates, as in temperate regions and to what extent tropical species react to equivalent exposures in the same way as temperate species. Gaps in our knowledge of these topics are greater than for temperate ecosystems. In the following sections, we identify several broad but key issues and information needs to focus further research in tropical marine ecosystems to close critical information gaps and to improve the use of assessment tools for examining and predicting potential impacts from chemical and other stressors.

*What managers need to know*

Protection of coastal marine ecosystems is becoming recognized as critical in many tropical and subtropical areas. Regulatory agencies are instituting new policies and regulations reflecting public concerns to reduce or restrict environmental impacts to these habitats, ranging from conservation to improving effluent quality. For chemical contaminants, the identification of point and nonpoint watershed or oceanic sources of pollutants might not be easy, and such contaminants do not recognize political boundaries. Restricting the movement of chemicals to the mangroves, seagrass meadows, and coral reefs might be impossible. Furthermore, persistent and bioaccumulative contaminants can remain in sediments and biota for years, causing long-term impacts and limiting ecosystem recovery.

*Management issues.* An assessment of risks to an ecosystem can be prospective, meaning it will attempt to predict problems that might occur in the future given a particular scenario (e.g., clearing a mangrove forest that has trapped contaminated sediments), or retrospective, meaning it will attempt to assess risk posed by stresses that have occurred in the past (e.g., effluent from a desalination plant released near a reef). Managers need to understand that chemical stressors might pose significant risks to tropical marine ecosystems. Existing statutes, laws, and regulations can be used to reduce impacts. For example, many human communities are diverting sewage discharges that contain potentially toxic chemicals to deep water, away from reefs. Pesticide runoff from golf courses or other areas might be controlled by requiring vegetation buffers or holding ponds near shore. Toxicants in ground water could reach reefs through the porous limestone substratum, which could require pumping and treatment strategies. Oil tankers could be restricted to offshore shipping lanes and well-marked harbor approaches to reduce the possibility of groundings and spills. Sediment loading from land clearing can cause problems not only by physically smothering sedentary organisms but also through chemical toxicity. Land management practices could be modified to minimize such effects. Dredged material management is a key issue in tropical marine ecosystems as well as in temperate ecosystems in regard to removal and disposal of contaminated sediments. In addition, the timing of critical events, like reproductive periods, could be incorporated into management plans to reduce interference with chemical cues used for synchronization and to reduce effects on particularly sensitive life-history stages.

At any particular site, managers need to examine the types of stressors that could affect the ecosystems and to identify management options or alternatives for consideration that could help them meet clearly defined goals to protect resources [as evaluated in 47]. They need to work with local citizens and governments, as well as with scientists, to understand the nature of the ecosystems and the best way to minimize environmental impacts while minimizing societal (e.g., economic) impacts [239]. This information is needed to develop a sound decision framework and to identify the basis for decisions and scientific data needs [3,240,241]. Ecological risk assessment is a tool that provides a framework for decision-making by using screening-level to sophisticated analyses to successively evaluate risks to the ecosystem over a long period of time. An example of the development of such a framework to support decisions on loss and recoverability of reefs of the Great Barrier Reef has been described by Done [242].

*Conceptual models.* As part of the problem formulation phase of an ecological risk assessment [15, see also 243], a conceptual model is developed to help focus the risk assessment process. The conceptual model illustrates, in words, pictures, or diagrams, how the ecosystem under consideration works and how the stressors are affecting or might affect the components of the natural environment. Ecological components or features of valued resources that are considered important, also known as "assessment endpoints" [15,16], are selected on a site-specific basis. These include scientific, cultural, and policy considerations. The interactions of the biotic and abiotic components and the energy requirements and flows that occur in the ecosystem must also be considered because any change that occurs to even a single component can alter established relationships and, hence, the ecosystem. Measurement endpoints are measurable responses to a stressor, such as concentrations of chemicals, that are related to the valued characteristics selected as the assessment endpoint, for example, fish population size and condition, areal coverage of mangroves or seagrasses, or coral reef community composition. These endpoints must be pertinent to the decisions that might be made to protect the environment. The preliminary, qualitative analysis of the ecosystem, the stressor characteristics and potential or actual ecological effects within the ecosystem, are used to identify possible exposure scenarios for the assessment.

Figure 2 presents a generic conceptual model of actual or potential effects of chemical stressors on tropical marine ecosystems, including the principal ecological components and biotic and abiotic processes. For any particular site, or particular group of chemical stressors such as metals, different aspects of this conceptual model would require modification or emphasis. Site-specific exposure scenarios need to be developed, including consideration of direct and indirect exposures for plants, invertebrates, and vertebrates, as well as factors that could modify the amount and toxicity of the chemicals, including adsorption, photolysis or photoactivation, temperature, and microbial alteration.

For example, the uptake of heavy metals by fishes, primarily through gill and intestine, depends on food choice, metabolic rate, and bioavailability of the metals [243]. In mangrove forests, metals and highly hydrophobic organics might adsorb onto sediment particles and not be bioavailable and directly toxic to fishes, but they could be ingested by worms living in the sediment, which might then be ingested by fishes or birds. In seagrass meadows, exposure of fishes to pollutants can occur

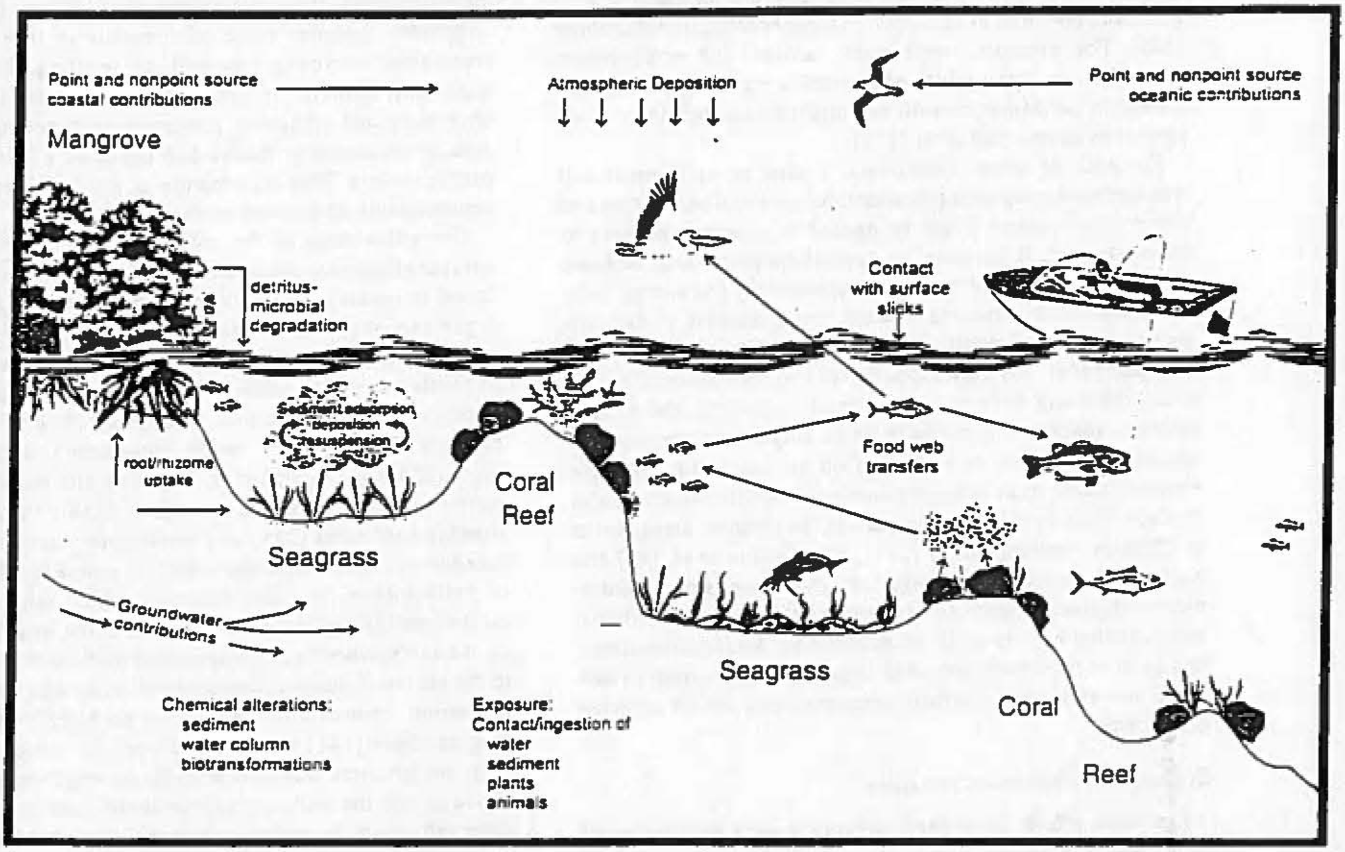


Fig. 2. Simple conceptual model of sources of chemical contaminants and potential exposure pathways in tropical marine ecosystems. Fate and transport varies with different chemicals and should be examined on a site-specific basis.

through passage across the gills, by uptake during seawater ingestion, through the food chain, or by exposure through contact with contaminated sediments. Uptake of polycyclic aromatic hydrocarbons from the water column by the warm-water benthic toadfish *Opsanus beta* is concentration-dependent and temperature-sensitive, with greater uptake occurring at higher temperatures or during acute increases in ambient temperature due to changes in respiratory rate [244]. In seagrass meadows and reefs, where sand has low organic carbon content and highly hydrophobic chemicals are readily absorbed by coral tissue and not greatly metabolized [212,215,216], these chemicals can be transferred to grazing herbivorous fishes and sea urchins or other organisms. Suspected direct and indirect contacts with chemical stressors could then be targeted to evaluate ecological effects of the chemical stressors, using literature values, laboratory and field toxicity tests, histopathological examinations, and species abundance surveys (measurement endpoints).

Linkages between assessment and measurement endpoints and policy goals need to be clearly identified for each exposure scenario. The value of organizing this information in one or more conceptual models lies in developing and refining a series of testable hypotheses about how a particular stressor might affect ecological components of concern so that analyses conducted during the assessment can establish, to the extent possible, a cause-and-effect relationship [15]. One example of such a statement is "Pesticide *X* causes 30% or greater reduction in coral cover." The approach used and the types of data and analytical tools that are needed to analyze impacts and risks are based on information contained in the conceptual model. The problem formulation phase of the assessment is critical to its success and must be conducted carefully; the abundance of species, complexities of these ecosystems, and limited funding resources could quickly lead the assessment astray, leaving managers in confusion instead of helping them evaluate management options.

*Selection of appropriate assessment and measurement endpoints.* The valued ecological resources or assessment endpoints should be susceptible to the stressor in question and should also reflect policy goals and societal values. In our review we identified the major structural components of each of these ecosystems (mangrove trees, seagrasses, scleractinian corals) and fishes as potential assessment endpoints [15,16]. However, other biotic components need to be considered in assessments of these ecosystems, such as those encrusting mangrove roots (algae, sponges, bivalve molluscs), soft-bottom fauna (polychaetes, bivalves, burrowing crustaceans, holothurians), and hard-bottom species, such as coralline algae, sponges, or sea urchins, that could be very sensitive to chemical stressors and might be easier to study than the structural biota. In addition, sea turtles, marine mammals and seabirds, and endangered or threatened species (e.g., osprey, manatee) are important assessment endpoints. Keystone species are those known to control the abundance and distribution of many other species in the community; the basic ecology of the tropical ecosystem should be considered at the conceptual model stage. Thus, although scleractinian corals have economic and aesthetic value, species less valued by humans but crucial for the survival and health of reefs [6], such as herbivorous fishes or long-spined sea urchins, might be useful indicator species. Effects can occur at every level of biological organization, so a variety of indicator species and appropriate biomarkers might give advance warning of the bioavailability of the contaminants and potential effects prior to the loss of significant habitat [245]. For example, amphipods, tanaids, and echinoderms (holothurians, ophiuroids, echinoids) were most affected by the Bahia Las Minas oil spill and might be appropriate sentinel species to assess pollution [118].

For each of these ecosystems, a suite of assessment and measurement endpoints that addresses potential population and community impacts might be needed to estimate the risks to the ecosystem. If possible, ecological endpoints that measure the characteristics of ecosystem sustainability and energy flow, such as physical structure of coral reefs, seagrass or fish productivity, and alterations in trophic structure, should also be included [246]. Different species vary in their susceptibilities to stressors, and different life stages of organisms also exhibit different susceptibilities. Because no single measurement can describe the effects of a stressor on an ecosystem, multiple endpoints need to be evaluated and must be selected on a case-by-case basis to develop successful, integrative assessments of chemical contamination [247]. Both Ballou et al. [47] and Keller and Jackson [248] assessed several types of measurement endpoints for each assessment endpoint to examine lethal and sublethal effects of oil on mangroves, seagrass meadows, and coral reefs, which provided important information to link cause and effect and estimate recovery rates for the affected ecosystems.

### *Evaluation of chemical stressors*

Extensive efforts have been directed toward monitoring of coral reefs and adjacent marine ecosystems, but most monitoring programs quantify ecological responses and have only limited quantification of stressors. Rapid ecological assessments, such as that conducted at Palau [249], or comprehensive monitoring programs, such as that conducted for Jamaican coral reefs [6], provide a basis for quantifying trends in coral cover and diversity, as well as identifying possible stressors and evaluating the role of rare events such as hurricanes. However, few programs collect data on chemical contaminants in addition to assessing such biological parameters as cover, species diversity and evenness, and recruitment. A thorough examination of the uncertainties and limitations associated with these methodologies is also required to help improve assessments of chemical exposure and effects. Numerous issues still remain for developing appropriate guidance to evaluate ecosystem responses to stressors in the well-studied temperate regions of the world [reviewed in 16,23,246,250,251], and the literature should be consulted for the latest methodological details. This section highlights only a few of the many specific needs to collect data for assessing the condition of and risks to tropical marine ecosystems.

*Exposure analyses.* These analyses focus on determining the sources, pathways of exposure, fates, and concentrations of potentially toxic chemicals in an ecosystem, as well as identifying the populations of organisms most likely to be adversely affected by exposure to a particular concentration. Measured or estimated concentrations of chemical stressors in water and sediment [16] and the duration and frequency of exposure observed in the ecosystem are the primary data on which the assessment is based. Levels measured in biota provide important information on the form of the chemical (soluble or adsorbed onto particles), whether, and to what extent, the contaminant can be taken up by living organisms (its bioavailability), and the ability of the organism to bioconcentrate or biomagnify the contaminant. In addition, metals and hydrophobic organics can bioaccumulate in tissues and can be transferred to young (via yolk or seedling reserves) and to organisms at higher trophic levels in the ecosystem food web, so metals and lipophilic contaminant concentrations should also be measured or modeled in organisms from two or more trophic levels. This information is used to identify potential contaminants of concern in the ecosystem.

Our knowledge of the concentrations at which particular adverse effects are observed in the field is limited. Most studies failed to measure contaminant levels in water, sediment, and organisms at the same time and from the same locations [but see 252]. For example, pesticides and metals were measured in corals but not in water or sediments [237]; pesticides were measured in sediment and organisms [238]; *n*-alkanes were measured in sediments, fishes, crustaceans, corals, and molluscs [253]; hydrocarbons in dissolved and particulate phases were measured in a mangrove lagoon [254]; metals were measured in sediments [255]; and metals and pesticides were measured in oysters [256]. Johannes [219] noted that determination of pollutants in the water column coupled with observations on the plankton at Kanehoe Bay missed the impacts occurring on the reefs, where pollutants settled to the bottom and sorbed to the sediment and the impact of pollution was more profound in bottom communities. Media on reefs [207,209,257] and seagrass beds [141] were not analyzed for oil contamination, even though there was evidence that oil might be a significant, although not the only, stressor at these sites and that effects observed might be concentration-dependent. Notable exceptions to this were the studies conducted by Ballou et al. [47], Getter et al. [55], and Keller and Jackson [248], in which ecological effects of measured concentrations of petroleum hydrocarbons and dispersants were studied following application in experimental enclosures and accidental spills, respectively. Water samples, mangrove leaves, seagrasses, and oysters were analyzed for up to 20 months after the spill in one study [47]; water, sediment, and oiled producers and consumers were analyzed in another [55]; and petroleum hydrocarbons in surface sediments, coral tissues, and bivalve molluscs were measured in the third study [248]. The feasibility of measuring metal loads in samples of sediment and coral tissue [258,259] and echinoderms [260] and of measuring organochlorines in coral eggs [261] has been investigated.

The types and number of contaminants examined have also been limited compared to studies conducted in temperate regions. Polychlorinated biphenyls were detected in mangrove organisms in the Caribbean in the early 1970s [36,262] but have not been measured more recently, except in oysters in Hawaii [256], and dioxins have not been examined at all, even though atmospheric contributions might be significant in some areas [263]. Standardization of chemical analytical methodologies lags behind that for studies conducted in temperate freshwater and marine ecosystems. The high costs of chemical analyses and lack of analytical facilities are often cited as the reasons that they are not performed. Computer models have been developed to provide estimates of environmental concentrations of chemicals in temperate ecosystems. However, unless appropriate chemical analyses are performed for water, sediment, and tissues of organisms, it will be impossible to develop concentration–response relationships for tropical marine organisms or to examine differences in fate and transport, biodegradation rates, biotransformations, or bioaccumulation [23]. Invertebrates and fishes feeding on contaminated coral tissue can accumulate these compounds, but we have no idea how rapidly they might be metabolized, how easily they might be passed on to larger fishes and marine birds, and what toxicological impacts might occur.

In the 1980s extensive research was focused on developing reliable biomarkers of exposure [264] that could be used to identify populations and communities exposed to various contaminants, and several studies examined the utility of these biomarkers for tropical marine organisms (Table 3). Hogstrand and Haux [200] demonstrated that the concentration of hepatic metallothionien (MT), a protein that binds strongly to heavy metals, shows a dose–response curve following intraperitoneal injection of cadmium chloride. The concentration of MT has been shown to increase with environmental exposure in two reef species, substantiating its usefulness as an indicator of heavy metal exposure [200]. However, there can be variability in MT concentrations between species and among individuals within species; handling stress, salinity changes, and reproductive status significantly increased the amount of zinc associated with MT in estuarine teleosts [265]. Therefore, care must be taken in the interpretation of elevated MT levels.

The cytochrome P450 mixed function oxidases located in the endoplasmic reticulum of the liver and other tissues are responsible for the metabolism of lipophilic xenobiotics and endogenous compounds such as steroids and prostaglandins. Exposure to pollutants induces increased activity of these enzymes and might allow some species to detoxify pollutants. The P450 response to organics has been described for only a few warm-water species [217,266–271]. Enzymatic induction of cytochrome P450 in fish increased with greater proximity to the areas most affected by the 1991 oil spill in the Arabian Gulf during the Gulf War [272], demonstrating that mixed function oxidase activity can be used in tropical systems as an indicator of hydrocarbon exposure. Conversely, in some tropical fish, elevated enzyme levels might be indicative of allelochemical, not contaminant, exposure [271]. Temperature or seasonal changes in temperature are also important factors to consider when using xenobiotic-metabolizing enzymes as indicators of pollution exposure, even in the tropics. The Caribbean coral *Favia fragum* had very little cytochrome P450 [216], supporting observations that the rate of xenobiotic detoxification or elimination in corals might be slow [213,217,237,264,273,274]. In some corals, the activity of glutathione-*S*-transferase (GST), an enzyme that conjugates endogenous molecules to substrates to increase hydrophilicity, exceeded that found in most marine invertebrates [216,275–277] and some fish species [278,279] but was not as high as in some species of crabs and mussels [280]. Additional work will be needed to determine the most appropriate techniques for use and interpretation of these biomarkers and others, such as stress protein synthesis, in tropical marine organisms [281].

For reef corals a suite of behavioral effects has been used as an indicator of exposure to contaminants (e.g., polyp expansion, mesenterial filament extrusion, mucus production), as well as tissue color change related to loss of symbiotic algae, but there is often great variability between and within species. Furthermore, these parameters, as well as mortality in adult corals, cannot be as easily quantified for corals in laboratory toxicity tests as for other organisms [148]. Once the symbiont association breaks down and "bleaching" occurs (the white exoskeleton of the coral shows through the translucent tissue when the symbiotic algae are expelled or the algal pigments are destroyed), some corals die, while others show signs of stress until algal populations are recovered (reviewed in special coral bleaching issue of *Coral Reefs*, B.E. Brown, ed., vol. 9, no. 3, 1990). Large-scale bleaching events have been attributed to temperature-induced stress and increased exposure to ultraviolet radiation related to El Niño warming events and other sea surface temperature anomalies [282,283]. Pollutants appear to be responsible for more localized bleaching events; elevated levels of iron resulted in the loss of zooxanthellae in *P. lutea* [156]. The pesticide atrazine is stable enough in seawater to permit exposure of susceptible marine life, and the chemical's role as a photosynthetic inhibitor could affect the coral–algal symbiosis [284]. Few studies have been performed to determine what levels of environmental contamination are sufficient to cause localized bleaching events. Such studies are needed to address the effects of herbicides, in particular when used in agriculture and on golf courses adjacent to coral reefs.

Toxicological endpoints that indicate impaired function of the coral–algal symbiosis, such as photosynthesis and loss of symbiotic algae or algal pigments, are needed. Lang et al. [285] have quantified digitized photographic images of the reef corals *P. astreoides* and *Montastraea* spp. to create color indices, although they noted that there is considerable individual variability as well as variability in color brightness values at different seasons of the year. In situ measurements of photosynthesis and coral growth rates have also been attempted, but techniques used thus far involve handling coral colonies, which can introduce additional stress [224,286]. Other research is under way to develop more accurate noninvasive measurements of photosynthesis that are based on natural fluorescence of chlorophyll, spectral fluorescence, and spectral reflectance, which could also be linked to coral growth [287,288]. The data need to be quantitative to be converted to chronic criteria or to be used in simulation models for predicting ecosystem risks.

Temporal scales in the detection of exposure and resulting impacts can vary widely: changes in seagrass productivity could be measured in a few hours, whereas induction of mutations by polycyclic aromatic hydrocarbons (PAH) resulting in visibly manifested chlorophyll deficiencies in mangroves [72] might require more than 10 years to detect. Fate-and-transport models are increasingly being applied in coastal marine studies to determine potential inputs from chemical and physical stressors and, with modifications, might prove useful for tropical coastal ecosystems. A few attempts have been made to develop population food web, and other simulation models in tropical marine ecosystems. Several studies have examined the ECOPATH model for coral reefs, a top-down (top carnivores to primary producers) food chain model that can provide estimates of mean annual biomass, annual biomass production, and annual biomass consumption for each species group (species having common habitat and similar diet and life-history characteristics) and can be tested by providing an independent measure of primary productivity [289,290]. Appropriate models could be applied to describe and test site-specific patterns of exposure and bioaccumulation by sensitive species or life stages to chemical or other stressors occurring in these ecosystems. The models could examine differences in pharmacokinetics between tropical and temperate organisms and the potential for toxic effects at higher trophic levels, as well as changes in biomass and trophic flows resulting from impacts at lower trophic levels.

Developing residue–effect relationships can link information from fate-and-transport models to food chain accumulation and

Table 3. Biomarkers in tropical marine organisms[a]

| Biomarker | Species | Results | Considerations | Reference |
|---|---|---|---|---|
| Metallothionein | Squirrelfish *Holocentrus rufus*, blue-striped grunt *Haemulon sciurus* | Correlated dose-response to intraperitoneal injections of $CdCl$; MT increased with environmental exposure to metals | Squirrelfish had MT values 2 orders of magnitude above those of grunts; Concns. of Cd, Zn, and Cu in squirrelfish (1.0, 2,630, and 231 μg/g liver, respectively) were 10 times greater than those in grunts at unpolluted sites; Zn concns. in grunt were 20–30 μg/g liver at clean sites and 60–70 μg/g liver at sites with 5 times the level of heavy metals | [200,268] |
| Cytochrome P450 | Blue-striped grunt *Haemulon sciurus* | Peak induction of mixed function oxidase system seen 3 d after injection with >1 mg/kg PAHs; returned to control level in 10 d | Dose–response relationship to amount of PAHs injected | [269] |
| | Squirrelfish *Holocentrus rufus* | Little induction observed following injection with PAHs | Possibly more susceptible to pollution | [269] |
| | Gulf toadfish *Opsanus beta* | Enzyme induction greater during summer months in field-collected fish | Enzyme activity increases with temperature | (N.J. Gassman et al., unpublished data) |
| | Warm-water fishes | Activity of enzymes and formation of DNA adducts increased when exposed to xenobiotics at higher temperatures | Enzyme activity increases with temperature | [270,363] |
| | Coral *Favia fragum* | Little P450 detected | Corals may not be capable of metabolizing PAHs | [216] |
| | Star coral *Montastrea annularis* | Cytochrome P450 and EROD activity not detected after intermittent exposure to 15 μg/L chlordane for 90 d | | [364] |
| Glutathione-*S*-transferase | Star coral *Montastrea annularis* | GST activity significantly increased by a factor of 2.6 after intermittent exposure to 15 μg/L chlordane for 90 d | Greater GST activity induction than reported for freshwater mussels [365], not as great as that seen in crabs and shrimp [366] | [364] |
| Bleaching in corals | Star coral *Montastrea annularis* | 3-month exposure to 1 to 15 μg/L chlordane caused rapid and significant depressions of respiration, photosynthesis, density of the algal symbionts, and chlorophyll; corals exposed to 1 μg/L chlordane attained normal rates of photosynthesis after 2 weeks in clean seawater; respiration rates returned to normal levels, but chlorophyll concns. were still significantly depressed after 5 weeks of recovery | Laboratory exposures to pesticides can have devastating effects on corals at very low concns. | [315] |
| Mucus production | Coral *Pocillopora damicornis* | At lowest concns. of 2,4-D and 2,4,5-T administered (100 μg/L), specimens produced copious amounts of mucus and died within 24 h | Lamberts [367] found no evidence of injury in corals exposed to concns. of 10 μg/L to 2 mg/L of 2,4-D for 24 h | [368] |

[a] EROD = ethoxyresorufin-*O*-deethylase; GST = glutathione-*S*-transferase; MT = metallothionein; PAH = polycyclic aromatic hydrocarbon; 2,4-D = 2,4-dichlorophenoxyacetic acid; 2,4,5-T = trichlorophenoxyacetic acid.

acute and chronic effects determined from toxicity tests and bioassays, potentially allowing predictive modeling of population impacts [23, 250,291–294]. Models have limitations in the number of contaminants and routes of exposure that can be examined, but they could be useful in identifying important routes of exposure and potential impacts when coupled with appropriate chemical analyses of water, sediment, and biota. Rogers et al. [295] provide methods to collect data on basic water quality and on current speed and direction, which are also needed to analyze exposure in tropical marine ecosystems.

*Ecological response analyses.* Monitoring of ecological effects in tropical marine ecosystems and what methods are most appropriate for particular habitats or biota (e.g., forereef vs. backreef, mangrove mud or seagrass meadow vs. rubble field) have been intensely debated at numerous meetings and in the literature. Ecological effects should be examined at several levels, from individual to population to community, within any ecosystem [23,246]. Ecological effects must also be examined on appropriate spatial and temporal scales and with respect to the ability of the ecosystem to recover from observed damage. Seasonal variability occurs in the tropics as well as in temperate regions; changes in temperature, rainfall, storms, tidal ranges, current patterns, and insolation are observed, and these natural disturbances and their impacts on the ecosystems need to be analyzed. Again, biological and physical data need to be collected at the same time as data on chemical or other stressors to determine the correlation between exposure and effects.

At the individual level, effects of chemicals on physiology, biochemistry, reproduction, and pathology have been documented [see reviews in 23,296,297, this paper] and will be reflected in responses at the population and community levels. In Biscayne Bay, Florida, USA, a subtropical estuarine ecosystem, abnormalities and increased incidence of diseases have been documented in several fish species over the last 20 years and have been associated with exposure to sewage, petroleum products, heavy metals, and industrial chemicals [298–300]. Although pathological responses can be difficult to interpret as indicators of ecological effects, there is increasing evidence that cytochrome P450 (CYP1A1) induction is associated with liver neoplasms and exposure to PAHs; the distribution of abnormalities in Biscayne Bay has been correlated with sediment hydrocarbon concentrations [300]. Few studies of tropical ecosystems have examined the toxicological pathology of fishes and other organisms in mangrove forests, seagrass beds, or coral reefs, but this area of research provides important tools for linking biomarkers of exposure to ultimate effects within an organism, population, or community, as well as for comparing responses in the field with laboratory exposures to chemicals using appropriate condition indices.

The collection of information on populations and communities using quantitative techniques is important for evaluating stressor impacts [23,301]. Metrics include species composition, presence or absence of sensitive and rare or endangered species, species richness and evenness or diversity, relative abundances, dominance, resemblance indices, population biomass and age, community trophic structure, and productivity. Ballou et al. [47] examined several parameters of survival, growth, and reproduction in mangroves, seagrass beds, and corals that were experimentally oiled and exposed to dispersant. A variety of methods have been used. For sedentary soft- and hard-bottom organisms, chain or line transect and random or belt quadrat methods all have proponents and opponents, and ease of data collection must be weighed against information obtained and amount of time spent under water. In addition, the patchy distribution of fauna, comparability of sites, and hypotheses to be examined must be considered. More recently, photography and videography have been adapted for use in coastal areas, including digitizing aerial photographs and incorporating these into geographic information system (GIS) analyses and conducting high-resolution photography and videotaping along transects of coral reefs [285,302–305]. Biological monitoring methods for reefs in the tropical western Atlantic and Caribbean are described by Rogers et al. [295].

Despite numerous attempts, however, no specific criteria have been established as to what constitutes optimum conditions in tropical marine ecosystems, and baseline data are often not available. As in other ecosystems, risk assessors need to look for relative changes at a particular site over time, or differences between similar habitats in which a gradient of exposure to chemical stressors is apparent. Furthermore, several different metrics should be combined to more appropriately describe communities (species presence or absence, diversity, abundance, competition, trophic structure), but little work has been done on combining metrics for tropical marine ecosystems.

It is also important to describe and quantify the fish communities that might be affected by chemical contaminants, and more work needs to be done to determine appropriate methods for conducting fish censuses. For example, even in the extensive long-term study of the Bahia las Minas spill, the slow recovery of fish communities from oiled seagrass beds was described only by density of fish caught by push net, not species composition of the total community [118]. Shifts in community structure of herbivores favoring damselfish were documented on oiled versus unoiled reefs [226], potentially identifying a reef species tolerant of oil exposure or one that can rapidly colonize and exploit resources abandoned by other species during the early stages of oiling. Following the Gulf War, reef fish populations on oiled reefs appeared to be healthy. Comparison of long-term data revealed both increases and decreases in species composition and densities following oiling [306]. Could some of these fish species have developed PAH-induced neoplasms that are now affecting the population and community structure? A broader view is needed to understand and quantify impacts on and recovery of fish communities exposed to oil and other chemicals.

Another important analytical tool for evaluating the potential for chemical impacts is the bioassay, particularly because the toxicity or hazard potential of chemicals can vary with environmental conditions. The phrase "below detectable limits" is commonly used to report levels of environmental pollutants, yet this finding can often result from technological limitations or use of inappropriate protocols to identify and quantify compounds rather than the presence of levels below those that affect tropical marine organisms. Bioassays that take advantage of organisms' responses to detect toxics are clearly needed. Testing procedures for acute and chronic toxicity of water and sediment samples using temperate marine indicator species have been developed and standardized by the U.S. Environmental Protection Agency, the American Society for Testing and Materials, and others [e.g., 23,307–309]. However, we have little knowledge of how well the sensitivities of these species compare to those of tropical marine species or how well they might test under tropical conditions. Most chemicals, including pesticides and inorganics, elicit an increase or decrease in LC50 in exposed temperate species by a factor of 2 to 4 per 10°C change, conforming to the $Q_{10}$ concept [310]. Tropical and subtropical fauna appear to be at least as sensitive to the effects of toxic chemicals as are temperate-and cold-water species [133], but these species could be living at their upper limit of temperature, which might affect their responses to toxics [1].

Work is needed to determine suitable tropical test species (amphipods, bivalve larvae, echinoderm embryos, coral em-

Table 4. Summary of toxicity tests using coral embryos and larvae

| Species, life stage | Type of test | Results | Considerations | Reference |
|---|---|---|---|---|
| *Goniastrea aspera, Favites chinensis, Platygyra ryukuensis*, eggs and sperm | Static, fertilization | Zn at 1.0 mg/L reduced fertilization to 6.3%; threshold for fertilization inhibition, 0.01–0.1 mg/L | | [369] |
| *Diploria strigosa*, newly fertilized embryos | 96-h static acute toxicity | Larval survival and inhibition of development affected by exposure to sodium dodecyl sulfate | Sensitivity comparable to the sea urchin fertilization and embryological development acute toxicity tests; coral larvae may be very sensitive to chemical contaminants | [370] |
| *Pocillopora damicornis*, planula larvae | 96-h static acute toxicity | LC50 for Cu, 0.067 mg/L | At 0.01–0.1 mg/L Cu, symbiotic algae were expelled, and mucus was produced | [184] |
| *Pocillopora damicornis*, planula larvae | Static acute toxicity | 12-h LC50 for nickel, 9 mg/L | Larval settlement reduced after exposure to 1 mg/L nickel for 12 h | [371] |
| *Pocillopora damicornis*, planula larvae | Static acute toxicity | Effects of pesticides (carbaryl, 1-naphthol, chlorpyrifos), metals, and petroleum products (benzene, gasoline/oil mixture) were examined; neither LC50s nor EC50s were calculated | Preliminary tests, used different procedures, exposure periods, and endpoints | [372,373] |

bryos or larvae, symbiotic algae) that are or relate to potential impacts on keystone species as well as appropriate test conditions [311–313]. For example, the scleractinian coral species *M. annularis* and *D. strigosa* have been used most frequently in laboratory tests of stressors; they are among the major reef framework builders in the Caribbean, but they may not be the most sensitive species, depending on the chemical contaminant to which they are exposed. *Acropora* spp. are very susceptible to adverse changes in water quality and should be more sensitive to potentially toxic chemicals, but they require strong currents and rapid water exchange and are difficult to maintain in aquaria, as are many other coral species [148,313]. Specially prepared, uniformly sized "nubbins" and explants or cores of scleractinian corals provide more suitable material for field and laboratory studies than large, irregularly shaped whole colonies or portions [313–315].

The use of surrogate species for those actually found in the ecosystem assumes that chemical exposure in the laboratory can be related to species found in nature and that surrogate organisms are representative of the ecosystem. A factor can be added to allow a margin of safety when these results are extrapolated to the organisms in the ecosystem under investigation [148]. Nganro [316] observed that the zooxanthellate anemone *A. viridis* was as sensitive to copper exposure as corals, coral gametes, and larvae and that it might serve as a useful surrogate test species. However, this approach will not work well in complex ecosystems or with chemicals that cause persistent ecological effects at low levels [17].

Bioassays should also be designed to study the effects of pollutants on processes that are chemically mediated at the community level and not just the organismal level. Studies of the effects of chemical contaminants on embryos and larvae of fish (again, mostly freshwater and/or temperate) indicate that most are more sensitive than adults, and further decreases in populations over natural mortality, not only as a result of chemically mediated mortalities but also teratogenic effects and adverse effects on hatching and growth, can be highly detrimental [317]. Sublethal effects can occur in corals and other reef organisms exposed to minute chemical concentrations that affect chemical signals between obligate algal symbionts and coral hosts, can interfere with chemical cues used to synchronize reproductive activity among individuals within a population, and can disrupt settlement cues and metamorphic inducers, affecting recruitment processes and ultimately affecting key species and communities [9,318,319].

Coral gametes and larvae provide suitable tools for studying coral reef ecotoxicology since our present knowledge of reproductive timing and subsequent recruitment processes in corals is substantial. In addition, the numbers of gametes and larvae that can be produced and used in bioassays is large enough to allow good statistical analyses, a problem that often arises when trying to observe both lethal and sublethal effects in colonial organisms. Many of the coral species studied in the Indo-West Pacific and tropical Western Atlantic spawn once a year [320,321], often during the rainy season, when coastal contaminant concentrations, particularly in the 50-$\mu$m-thick sea surface microlayer, would be expected to peak. Considering that most coral eggs are buoyant, floating in the surface water layer for up to several hours before fertilization occurs, terrigenous runoff and coastal pollution have the potential to produce reproductive failure of spawning reef species. Gametes of *S. siderea* were released at the Bahia Las Minas oil spill site during the rainy season, when oil slicks were common [248]. Examples of toxicity tests conducted with coral gametes, embryos, and larvae are presented in Table 4.

With respect to recruitment processes, many species of benthic marine invertebrates have larvae that respond to specific metamorphic inducers [322,323]. Morse and Morse [324] found several species of corals were highly selective in choosing settling substrata, reacting only to certain species of crustose coralline algae. Metamorphic inducers can be small molecules and might be effective in concentrations below $10^{-10}$ M [323]. Pollutants in the water column at levels below those lethal to adult organisms, below detectable limits by high-performance liquid chromatography, or bound up in substrata where they are not identified by routine monitoring protocols,

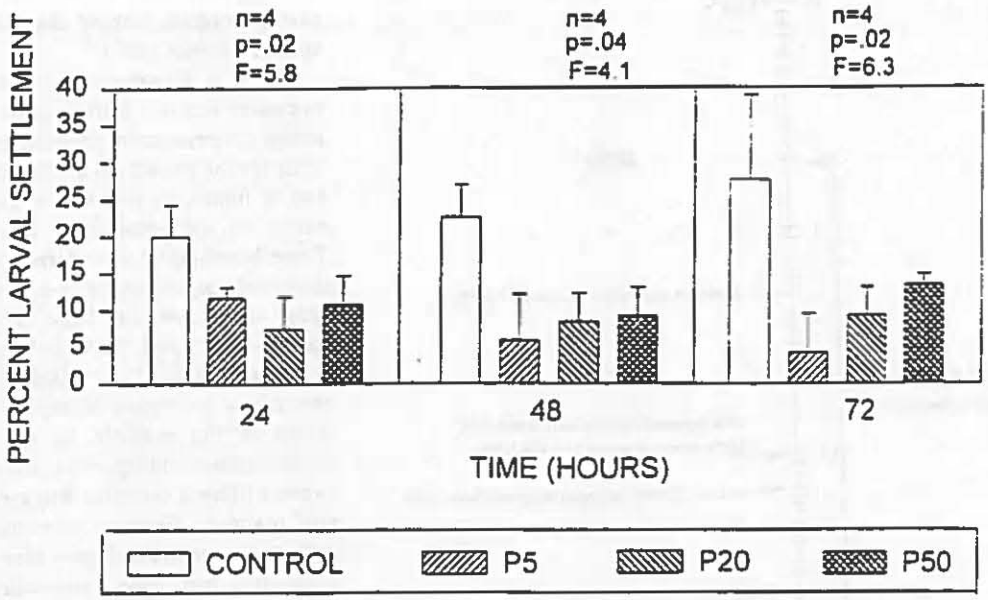


Fig. 3. Effects of chlorpyrifos on coral larval settlement. Percent of coral planula larvae that settled on coralline algae substratum incubated for 12 h in filtered seawater containing 0, 5, 20, and 50 ppb chlorpyrifos, after 24, 48, and 72 h (cumulative settlement percentages). Algal substrata were rinsed with filtered seawater, then placed in 200 ml of untreated filtered seawater for the settlement trials. Two replicates (40 larvae per replicate) were conducted for each of the four treatments.

can have a negative effect on recruitment processes. However, this type of sublethal effect can be more difficult to discern since the time frame is longer (i.e., months to detect settled, growing colonies). Coral larvae exposed to chemically treated substrata rather than directly to chlorpyrifos [325] exhibited significantly lower levels of settlement and metamorphosis than the controls for each of the 3 days of exposure (Fig. 3) (R. Richmond, D. Crosby, S. Leota, and H. Wood, manuscript in preparation). Chlorpyrifos was recovered from coralline algal substrata extracted after initial treatment in the chlorpyrifos solutions. These results were consistent with a previous study that demonstrated that the pesticide *p*-nitroanisole was taken up by the crustose coralline alga *Porolithon* sp. [326]. Many pesticides are hydrophobic, and seawater analyses might not detect these substances even though they are present in the reef environment in other media. The fate of chemical contaminants, including half-lives, breakdown rates, and breakdown products, is important to our understanding of the effects of pollutants on coral reefs.

In addition to concerns about bioassay test conditions, such as water quality and feeding, exposure to ultraviolet light can increase the toxicity of PAHs to benthic invertebrates placed in contaminated sediments [312,327] and planktonic fishes, crustaceans, and algal species exposed to PAHs in the water column [328]. Because organisms in tropical marine ecosystems could be exposed to ultraviolet irradiation [329], PAHs accumulated and not metabolized by these organisms could become more toxic through photoactivation. Bioassays need to be designed to account for a variety of factors that could affect the toxicity of chemical contaminants under field conditions.

Multiple-species tests and microcosm and mesocosm studies composed of several species of marine plants and animals should prove useful to examine effects of toxicants on ecosystem processes such as food chain and food web bioaccumulation and impacts, primary and secondary productivity and decomposition rates, nutrient cycling, and pollutant degradation, among other factors [127–129,330,331]. Controlled experimental manipulations of whole ecosystems, such as those performed by Ballou et al. [47] to study the effects of petroleum hydrocarbons on tropical marine ecosystems under field conditions, can provide a more realistic view and provide direction for extrapolation from laboratory tests to ecosystems, detecting, for example, which fishes might avoid contaminants, how metal methylation by microbes in situ increases toxicity, or which coral species are most susceptible. However, another important tool used in temperate toxicity evaluations is in situ (cage) testing using several benthic and epibenthic species and/or water column species that represent different trophic levels at the study site [297]. Cage studies could be used in mangrove channels or over seagrass beds; for reefs, small colonies of adult corals, such as those developed for physiology studies, could be cemented to inert frames and placed on the reef for observation [148,219,286].

In any case, it will be important to translate bioassay water or sediment concentrations to reflect toxicokinetics and toxicodynamics (uptake and toxic response) in the effects measured in the bioassay. Measurements of whole-body residues to determine concentrations of chemicals taken up by biota in site-specific bioassays (critical body residue method) can provide additional information on bioaccumulation and potential food web effects [294].

### *Risk characterization for tropical marine ecosystems*

To characterize risks to an ecosystem, correlations must be developed between observed adverse ecological effects and the stressor. Comparisons might be made between adverse effects observed in the exposed ecosystem and the condition of a reference site, between toxicity test results and observed adverse ecological effects, or between expected environmental concentrations and criteria and standards. Thus, we need to develop stressor–response profiles based on measured or modeled chemical concentrations plotted against observed adverse effects in potentially exposed sites and reference sites to es-

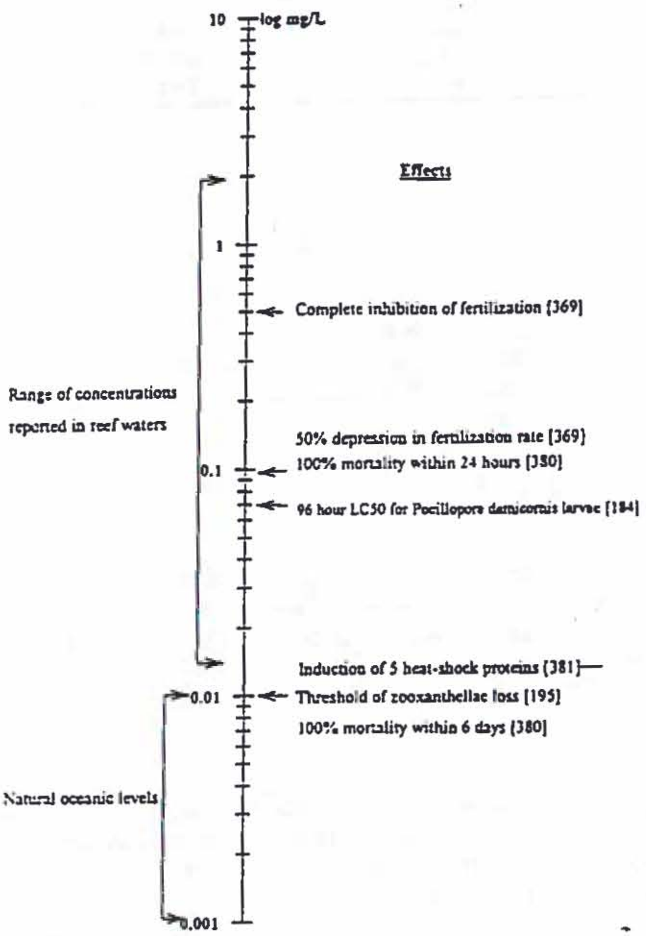


Fig. 4. Effects of copper on corals. References from which this information was compiled are cited in brackets.

timate risk to an ecosystem and for comparisons with stressor–response profiles in which toxicity has previously been documented. Examples of exposure–response profiles are presented in Figures 4 and 5, but few studies have provided these types of correlations [e.g., 72,259,316]. Keller and Jackson [248] noted concentration–response correlations of amount of oiling with coral tissue injury and growth rate, mangrove leaf longevity and biomass, and proportions of dead mangrove roots.

The risk assessment process initially relies on comparisons of measured or modeled concentrations of contaminants in water, sediment, and biota to pertinent qualitative and quantitative threshold values or benchmarks; contaminant concentrations below the benchmark should, with some degree of confidence, not result in adverse effects [16]. Benchmark comparisons are used as a screening tool to identify contaminants of potential concern and to assist in characterization of risks following the analysis of exposure and effects data. Such benchmarks are usually developed from the results of carefully controlled laboratory chemical analyses and toxicity tests to provide a standard for estimating the magnitude and probability of potential dangers. However, benchmarks cannot account for synergistic or interactive effects of multiple chemical stressors and are most useful for prioritizing contaminants for further evaluation. In the final stages of the risk assessment process, benchmarks that evaluate risks to particular assessment toxicological endpoints can be derived from statistical evaluations of site-specific bioassays and mathematical simulation models, linking observed exposures with stressor–response profiles [291].

The U.S. Environmental Protection Agency has developed saltwater ambient water quality criteria (acute, maximum criterion concentration; chronic, criterion continuous concentration) for the protection of aquatic life for approx. 30 chemicals and is finalizing sediment quality criteria for five chemicals based on the equilibrium partitioning approach [332,333]. These benchmarks were derived from toxicity test results using temperate organisms, as were the "Apparent Effects Thresholds" developed for Puget Sound [334] and the "Effects Range–Low" and "Effects Range–Median" values reported by Long et al. [335] for sediment contaminants. We are unsure about how protective of tropical marine species these criteria might be. For example, the toxicity of organics such as carbophenothion, chlorpyrifos, and fenvalerate varies widely between different estuarine fish species. The subtropical benthic gulf toadfish, *Opsanus beta*, has a 96-h LC50 one to three orders of magnitude higher than that of *Menidia* spp. [336], suggesting that some warm-water estuarine species might be relatively tolerant of chemicals in their environment. Ninety-six-hour LC50s for two tropical Australian fish exposed to different metals were influenced by exposure, salinity, and life stage, but not temperature [201]. For the mangrove-sediment-dwelling fish *Rivulus marmoratus*, the 96-h LC50 for cadmium at 14 ppt salinity was similar to LC50s found for zinc and copper using *Fundulus heteroclitus* [337].

Clearly, much work is needed in this area. Development of toxicity tests for tropical species is under way at a number of locations around the world. Scientists at the University of Miami have been testing tropical species of sea urchins and oysters and mangrove propagules (D. Rumbold, S. Snedaker, personal communication). Under the action plan for conservation of nature in the Association of Southeast Asian Nations (ASEAN), the 7-year (1991–1998) ASEAN–Canada Cooperative Programme on Marine Science [338], Phase II (CPMS-II), focuses on establishing environmental criteria for development and management of living marine resources. To support this objective, one of the main activities is toxicity testing of approx. 10 chemicals using tropical marine algae, invertebrates, and fishes. Acute, sublethal, and chronic toxicity test protocols are being developed for organisms indigenous to the ASEAN area. More than 11 toxicity testing laboratories from the ASEAN region are involved in CPMS-II, and the data generated will be used to support formulation of tropical environmental quality criteria. In the ASEAN region, toxicity testing is becoming more common in environmental assessment. For example, the oil and gas industry conducts biological testing to evaluate the impacts of its activities, such as the use of oil dispersants, drilling muds, and other products.

Worldwide environmental quality criteria, guidelines, and standards, with a focus on tropical criteria, where possible, were compiled in a database [339]. This project reviewed the methods used to formulate environmental quality criteria and to summarize the values obtained for various jurisdictions. The review, which was reasonably extensive but not exhaustive, indicated that few tropical marine jurisdictions have published environmental quality criteria. In Table 5, environmental quality values (i.e., criteria, guidelines, standards) for tropical regions are presented for a few representative parameters. However, the ability of these criteria to adequately protect mangrove forests, seagrass meadows, and coral reefs has not been thoroughly investigated.

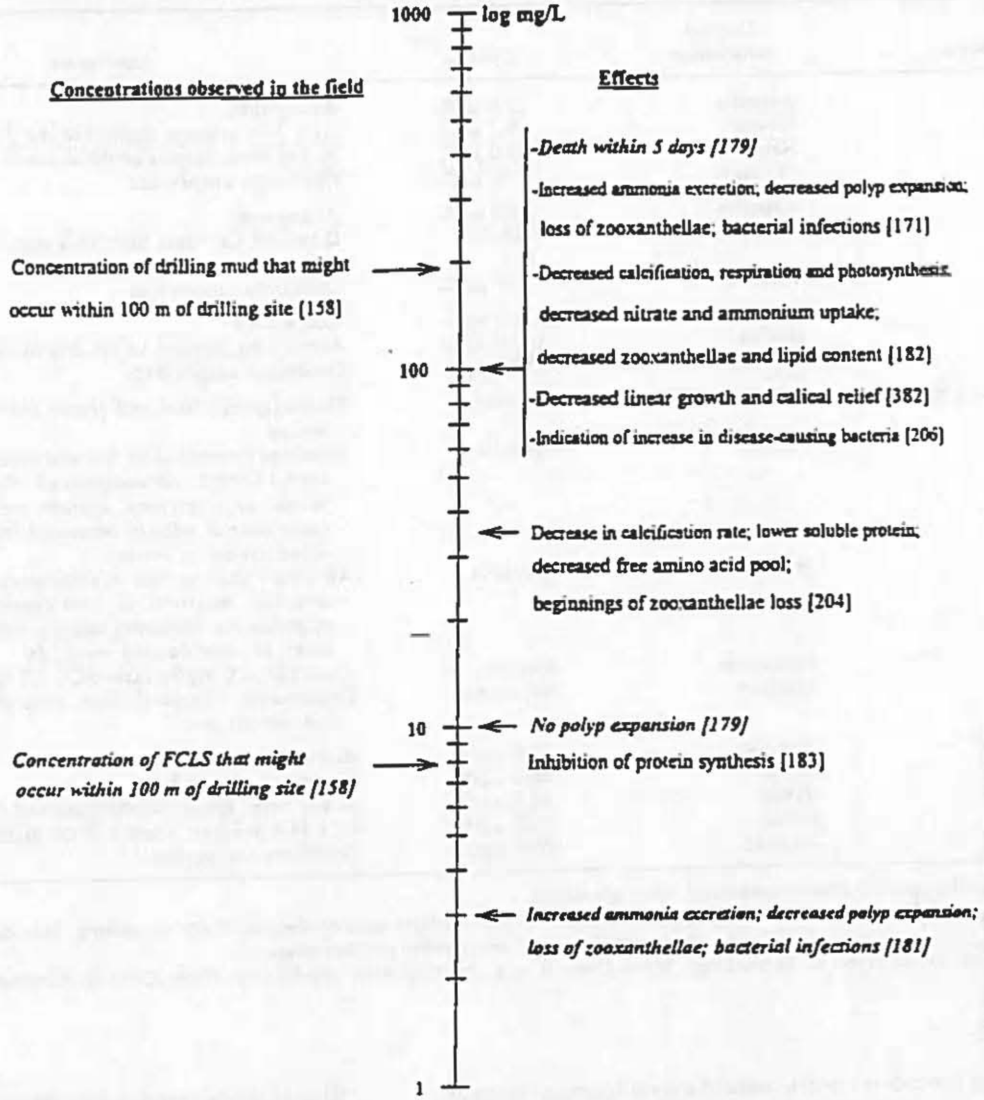


Fig. 5. Effects of ferrochrome lignosulfate (FCLS) and drilling muds on corals. References from which this information was compiled are cited in brackets.

Because of the variability in the species found in different tropical marine ecosystems of the world and perhaps their relative sensitivities to chemical stressors, toxicity tests following strict protocols should probably be developed for a suite of species in each ecoregion, such as the tropical western Atlantic, Great Barrier Reef, Hawaii, Red Sea, and southeast Asia. Simultaneous multiple-species toxicity tests [331] could provide a more rapid approach to obtaining minimum data to develop toxicity criteria [340]. Comparative toxicity tests, for example, simultaneous testing of several species of tropical amphipods from each region, could assist in determining the ability of the tests to predict toxicity for criteria development on a global basis.

Procedures for both acute and chronic toxicity tests are needed, and appropriate sublethal endpoints (growth, reproduction, immune responses, development, carcinogenesis, neurotoxicity) must be evaluated for organisms from tropical coastal ecosystems. Although it is difficult to bring massive corals, mangrove trees, and seagrasses into the laboratory, procedures for testing temperate sea urchin embryos, bivalve larvae, and seed germination can be adapted for tropical sea urchin species, coral larvae, and mangrove propagules. Perhaps simultaneous multiple-species acute and chronic tests could be conducted using mangrove propagules, fish and coral larvae, seagrass, and sea urchin embryos with appropriate endpoints (e.g., germination, mortality, productivity) to determine criteria. Gorrie et al. [341] reported that symbiotic algae from corals (*Symbiodinium kawagutii*) could be used in toxicity testing. If simultaneous tests were conducted with the intact coral–algal association to determine the responses, then the algae alone might be used as a standard test species on which to base criteria and conduct bioassays at potentially contaminated sites. The species included and endpoints examined should be linked to different assessment endpoints identified for each tropical marine ecosystem. Appropriate concentration–response distributions should be developed. Care must be taken in extrapolating results to less well-studied species [5]. Based on our review, we conclude that the effects of chemicals on reproduction and recruitment of corals and other key tropical marine organisms merit more emphasis in research programs. Efforts to coordinate species and test selection could prove fruitful and eliminate redundancy in the development of chemical criteria and benchmarks.

Risk characterization also involves the use of appropriate

Table 5. Summary of criteria values for tropical jurisdictions for several common environmental parameters[a]

| Parameter | Tropical jurisdiction | Criteria | Comments | Reference |
|---|---|---|---|---|
| Cd | Australia | 2.0 μg/L | At any time | [374] |
| | Hawaii | 9.3 μg/L | As a 24-h average; applies to the dissolved fraction | [375] |
| | Hawaii | 43.0 μg/L | At any time; applies to the dissolved fraction | [375] |
| | Thailand | 5.0 μg/L | Conditions unspecified | [376] |
| Cu | Australia | 5.0 μg/L | At any time | [374] |
| | Philippines | Narrative | Dissolved Cu; class SB[b]: 20.0 μg/L; class SC[c], 50.0 μg/L | [377] |
| | Thailand | 50.0 μg/L | Conditions unspecified | [376] |
| Pb | Australia | 5.0 μg/L | At any time | [374] |
| | Hawaii | 140.0 μg/L | At any time; applies to the dissolved fraction | [375] |
| | Thailand | 50.0 μg/L | Conditions unspecified | [376] |
| Oil and grease | California/Ocean | Narrative | Floating particulates and grease and oil shall not be visible | [378] |
| | Florida | Narrative | Dissolved or emulsified oils and greases shall not exceed 5.0 mg/L; no undissolved oil, or visible oil defined as iridescence, shall be present so as to cause taste or odor or otherwise interfere with the beneficial use of waters | [379] |
| | Hawaii | Narrative | All waters shall be free of substances attributable to domestic, industrial, or other controllable sources of pollutants, including floating debris, oil, grease, scum, or other floating materials | [375] |
| | Philippines | Narrative | Class SB[b], 2.0 mg/L; class SC[c], 3.0 mg/L | [377] |
| | Thailand | Not visible | Conservation of natural areas; aquaculture and shellfish, not visible | [376] |
| Zn | Australia | 50.0 μg/L | At any time | [374] |
| | Florida | 86.0 μg/L | Conditions unspecified | [379] |
| | Hawaii | 95.0 μg/L | At any time; applies to the dissolved fraction | [374] |
| | Hawaii | 86.0 μg/L | As a 24-h average; applies to the dissolved fraction | [374] |
| | Thailand | 100.0 μg/L | Conditions unspecified | [376] |

[a] Refer to the specific criteria documents for more details.
[b] SB classification refers to Recreational Water Class I (Areas regularly used by the public for swimming, skin diving, etc.) and Fishery Water Class I (Spawning areas for *Chanos chanos* or "bangus" and similar species) usage.
[c] SC classification refers to Recreational Water Class II (e.g., boating, etc.) and Fishery Water Class II (Commercial and sustenance fishing) usage.

statistical procedures to determine the significance of observed or predicted effects, and there have been many recent developments in this field that could be applied to tropical marine ecosystems. For example, Logan and Wilson [342] outlined a methodology for estimating ecological risks in situations in which populations are exposed to mixtures of chemical contaminants. Multivariate techniques, such as nonmetric clustering and association analysis [343], can combine different types of scales or metrics in multivariate analyses and could be used to combine large data sets into distinct measures to be used as a measure of risk and a test of the prediction of risk. These procedures could also improve the selection and interpretation of assessment and measurement endpoints because multivariate data can be used to identify natural and toxicant-induced patterns. New technologies such as GIS can provide overlays of spatial and temporal scaling of stresses with spatial and temporal aspects of species and life stages at risk [246,305] to improve the interpretation of data collected in support of chemical contaminant assessments. Risk assessment methodologies should be applied in tropical marine ecosystems as appropriate benchmarks and toxicity tests are developed and refined to investigate site-specific risks to specified assessment endpoints and to further validate and refine the methodologies for general use with populations and communities of the tropics, as well as to identify the uncertainties and limitations that will be associated with these methods.

Risk characterizations for tropical marine ecosystems need to be as rigorous as possible and should include the spectrum of factors known to affect organisms and their habitats and evaluations at several levels of organization to allow interpretation of the ecological significance of exposure to stressors (i.e., potential for ecosystem recovery from observed or predicted impacts). Multiple stressors (e.g., sedimentation, overfishing) should be factored into site-specific ecological risk assessments, and ranking of stressors (exposure and effects) must be conducted [242].

Even for the well-studied temperate ecosystems and biota, however, uncertainties abound in ecological risk assessment because few ecological risks can be measured with precision, resulting in wide confidence intervals for ecological predictions [17]. Careful discussion of uncertainties and use of "best professional judgment" in assessing ecological risk will always be important. Ecological risk assessments should provide information that can help managers evaluate their options and direct further data collection to refine the assessment if necessary. The weight-of-evidence approach, involving interpretation of qualitative and quantitative data and consideration of risks from all stressors identified to different ecological components at different levels of organization, is recommended [15]. Throughout the process, there must be sufficient knowledge and documentation of uncertainties, assumptions, and limitations that might affect the evaluation of risks.

## SUMMARY AND CONCLUSIONS

Mangrove forests are sinks for heavy metals because the physical and chemical properties of mangrove sediments allow them to sequester large quantities of metals. For this reason mangroves tolerate high metal fluxes and serve as a buffer protecting adjacent marine communities. However, mangroves are extremely sensitive to oiling and herbicide exposure. When mangroves are destroyed, metals and organic compounds that might be bound in the sediments can be mobilized by erosion and oxidation of the sediments. Destruction of mangroves also exposes seagrass and coral reef communities to a pulse of nutrients and increased sedimentation. Seagrass meadows and coral reefs exposed to chemical contaminants from point and nonpoint sources from land and ocean also experience adverse effects on productivity, reproduction, and recruitment of component organisms, leading to eventual replacement of the communities with fewer, more tolerant species, as in temperate ecosystems [301].

These retrospective insights suggest that tropical marine ecosystems can be evaluated and that risks from chemical contaminants can be assessed and used to assess the need for remediation or prevention of adverse ecological effects. Further work with tropical species will be required, however. The primary producers discussed in this review are sensitive to changes in water quality, and their abundance can be visually assessed with relative ease, but they can be difficult to maintain and test in the laboratory. Other species might be used more successfully in toxicity tests to develop benchmarks for estimating risks.

One final question on ecotoxicology of coral reefs and adjacent ecosystems: Is this a moot point? Tropical marine ecosystems are vulnerable to other environmental stressors, particularly habitat destruction, sedimentation, and nutrient loading [2,3,4,12]. At some sites these stressors can be overwhelmingly more important than chemical contaminants. For example, eutrophication might pose a greater threat to seagrass communities than do organic pollutants and heavy metal contamination [116,344–346]. Yet, despite much research, our knowledge of the tolerance ranges and critical levels of nutrients for seagrass meadows and coral reefs is also minimal. Elevated nutrient levels can be considered "toxic" to corals in that they alter the animal–algal symbiotic association [12]. The photosynthetic efficiency of corals is reduced in the presence of added nutrients because of the accelerated growth of zooxanthellae (to the point of becoming self-shading) [347]. Shifting competitive interactions among coral reef species to favor faster-growing forms and fleshy algae increases the risk of bacterial infections in corals and reduces the amount of light available to the zooxanthellae by supporting phytoplankton growth. No studies on the role that chemical contaminants in sewage discharges might play in the "toxic" response have been conducted.

Chemical contaminants have sublethal chronic, as well as acute, direct and indirect impacts on mangrove, seagrass, and coral reef organisms. However, little is known about the interactions of these contaminants with calcareous sediments and bioavailability, the influence of high light and temperature, microbial degradation in the tropics, and food web bioaccumulation. The ecological effects of contaminants are often not distinguishable from anthropogenic or natural sedimentation, nutrient loading, and habitat destruction. Metals, petroleum hydrocarbons, and some pesticides often persist in the environment in sediments and organisms long after sources are removed. Changes in water quality or movement of sediments can increase their bioavailability and toxicity.

Therefore, considerations of chemical contamination can be important in evaluating the status of a tropical marine ecosystem and in predicting the likelihood of its demise or recovery under different management scenarios [242]. Research must be relevant to managers and must include quantification of diverse effects and interactions, including physical and biological stressors and overfishing [5,242,348]. Further research on the quantities and roles of anthropogenic chemical contaminants and the development of appropriate risk criteria are needed by managers now, and managers need to interact with scientists and assessors to focus research efforts [15]. As more guidance on tolerance levels becomes available, the ecological risk assessment process can assist in sorting out the relative risks at particular sites to strengthen management. Prevention through early detection and appropriate action should be the goal of scientists and managers concerned with protection of these vulnerable ecosystems. With a better understanding of how tropical marine ecosystems work, management practices that both reduce and mitigate for the negative effects of controllable human activities on these biological communities can be developed.

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# MAN, LAND AND SEA

News of Guam And Her Ocean Environment

COMPLIMENTARY COPY

Bureau of Planning/Guam Coastal Management Program

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## SPECIAL EDITION

# *Guam's Year of the Coral Reef*

***EDITORS NOTE:***

In celebration of the Year of the Coral Reef, this edition of **MAN, LAND AND SEA** will devote the entire issue to the topic of coral reefs and their importance to our community.

On May 12, 1997 Governor Carl T. C. Gutierrez signed Bill 49 into law (P.L. 24-21), thereby creating 5 marine preserves on Guam. Governor Gutierrez also signed Executive Order 97-10 adopting the Guam Coral Reef Initiative.

### *WHO NEEDS MARINE PRESERVES? WE DO!*

Something must be done! Over the last 15 years, we have lost 50% of our coral cover, are now harvesting 77% less fish, routinely have to announce poor water quality conditions for swimmers and have reefs which are dying or being overtaken with algae. Bill 49 was introduced and as of this writing was passed by the Guam Legislature. Among other things, it will establish marine preserves. This proposal stems largely from the dwindling health of reef fish populations. A healthy coral reef community is a delicate balance of the interactions of all the animals and high water quality. This balance has been broken and is going to take commitment from all factions of the community to restore.

To understand how marine preserves will help address current problems, the problems need to be better understood. Declining fish harvests or fish populations result from several factors which are accelerating the rate of loss. Fish, like most other coral reef animals, are dependent on a healthy habitat. Normally, coral reef slopes, the area just outside where the waves break, are rich in live coral, having 60% coral cover or higher. Today, live coral cover on Guam's reef slopes has been reduced to 20% or less in many areas. This is the result of poor water quality affecting corals in two ways; Smothering through sedimentation, and; Reduced fertilization.

Guam's rapid economic growth and poor land management practices

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***OF INTEREST IN THIS ISSUE:***

# Preservation...(cont. from page 1)

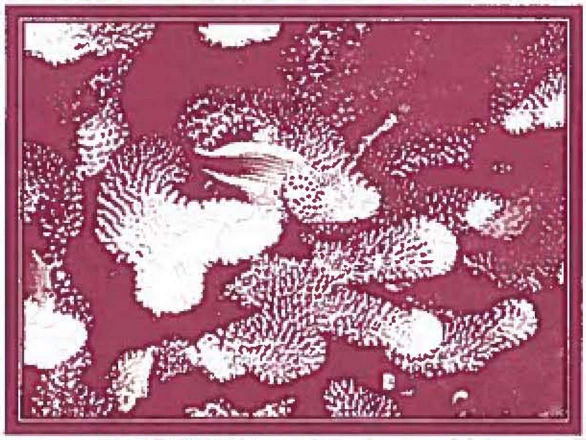

Photo provided by DAWR

have introduced many potential environmental hazards to the surrounding ocean. Land clearing for development, frequent wildland fires, and the inability to revegetate exposed soil have resulted in extensive sedimentation.

Initially, this does not seem like a coral reef issue, but what we do on land is eventually going to affect the surrounding coastal waters. Rain erodes exposed soil and carries the silt laden water into rivers, which empty into the ocean. Corals need light to survive. Sediment in the water obstructs light and can actually smother coral. Many reefs in southern Guam have been smothered to death. Corals grow only ½ to 6 inches a year. Some corals on Guam can grow larger than a school bus; these corals are hundreds of years old. These corals can be lost in a matter of weeks by pollution and sedimentation, and cannot be replaced in less than the hundreds of years they originally took to grow.

Second, research at the UOG Marine Laboratory has shown that suspended solids (silt in the water) and chemical pollution can prevent coral eggs from being fertilized by sperm. Since corals usually spawn only once a year, poor water quality during the single spawning time can cause corals to lose an entire year's production. One of the main sources of such pollution is oil contaminants from vehicle exhausts, which are washed into storm drains and dumped into the ocean. Many reefs around Guam have not had any juvenile corals produced in the last 5 years, or so. In all living populations, if the population is healthy, the number of animals dying is equaled or exceeded by the number of new individuals recruiting. This is not happening on Guam. Corals die of natural causes, like all other living things, but many are also dying from man-caused events. There are few or no new corals being formed and, therefore, the reefs are dying.

This is further complicated by another aspect of the water quality. The sediment-rich waters also are nutrient rich. These conditions support the rapid growth of algae. As coral is slow growing, algae has overtaken the coral. The coral provides shelter or food for almost all the life on a reef. Naturally, with dwindling coral populations everything else declines also.

Finally, the balance has been further disturbed by the absence of large schools of herbivorous fish normally present, that graze on the algae to keep it under control. Because of poor water quality and increased fishing pressure, these large schools of grazing fish are gone. This has allowed the algae to grow out of control.

This does not suggest development should be stopped or fishing prohibited, but rather that development needs to be better managed and water quality better protected. Likewise, if fishery management is done wisely, fish populations should increase and offer more fishing opportunities. Preventing reef loss and destruction should always be easier than recovery and this needs to be the focus.

Fortunately, reefs can be restored if suitable conditions are provided. The logical approach to restoring balance on the reef is through improved water quality, re-establishment of reproductive pools and prevention of further damage. The establishment of preserves will not fix all these problems, but is the first step in addressing some of them.

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## Preservation.... (cont. from page 2)

Restoring healthy natural conditions is much preferred over reseeding or restocking because these are typically only temporary fixes and are usually in response to specific short-term disasters or needs.

Since it is important to restore all marine life forms, the proposed preserves were selected to ensure a wide range of habitat types and cover large areas to serve as reproductive pools for many species.

With respect to fishing, the preserves serve the public well. Preserves do not target a specific type of fisherman. They exclude everyone equally. There is the issue of NIMBY or "Not in my backyard." This simply means most people may support establishing preserves until the area selected is their favorite place to fish. It is impossible to avoid this, but the proposed preserves were scattered around Guam to minimize this effect. This also has merit because the ocean current circulation continuously changes around the island, so scattered preserves ensure better egg and larval distribution. An alternate management approach often suggested by the public is implementation of fish size restrictions. This approach creates the problem of having several hundred different size requirements due to the many types of fish on coral reefs, and becomes an enforcement nightmare because every infraction requires inspection and measurement. A biological problem of this approach is that reef fish reproduction is very dependent on the largest fish within a population surviving, and size regulation allows the very largest animals to be harvested; a few very large fish can produce many more eggs than hundreds of small fish. If these regulations are passed, in several years more fish should be available to be caught in non-preserve areas than are available islandwide prior to the preserves. In many other places in the world, fishermen opposed preserves but later became staunch advocates because of increased catches.

Photo provided by DAWR

Economically, Guam depends heavily on tourism. Marine preserves fit well with this concept because each preserve is an attraction in and of itself. They will serve as public attractions, augment SCUBA diving, snorkeling, etc. The number one reason people come to Guam is for tropical weather and beautiful ocean. We have lost some of the beautiful ocean and need to ensure our future by protecting and restoring this vital resource.

These proposed regulations are the first step in recovering our depleted marine resources, but this will not work without a healthy environment and the support of the public. Given the facts, we need to act now! (Written by Gerry Davis, Dept. Of Agriculture, Division of Aquatic and Wildlife Resources)

## The Future of Guam's Coral Reefs

Guam and the other islands of Micronesia possess natural resources of great economic and cultural value, as well as unparalleled beauty: Coral Reefs. Coral reefs are structures built by a variety of plants and animals, including corals and algae, that protect our shorelines during typhoons, provide the white sand for our beaches, recreational opportunities for

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# Guam's Coral....(cont. from page 3)

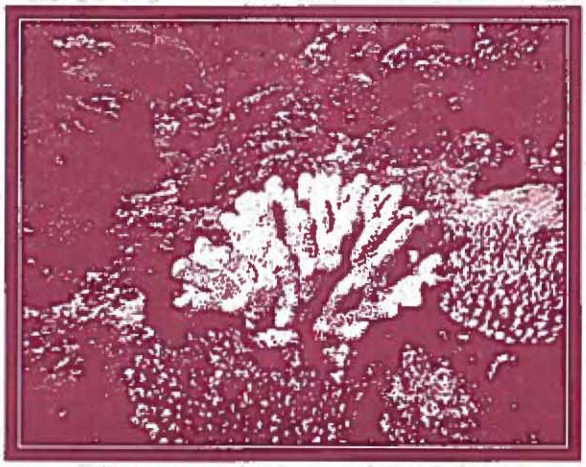

Photo provided by DAWR

residents and visitors alike, a habitat for fish, lobster, octopus and other edible creatures, and an attraction for tourism. Guam's reefs are among the richest in the world in terms of diversity, that is, the variety of species present. Much of Guam is built from pre-existing coral reefs, as seen in the limestone outcrops from the central portions of the island through the northern cliff lines.

To understand how coral reefs function, it is important to look at some of the key animals and plants that build these unique structures. Corals are animals that produce a hard skeleton made up of calcium carbonate. This white, stony substance is what most people think of as coral. The living portion of the coral is a thin layer that overlies the skeleton. With the aid of a microscope, it is possible to see most corals are true colonies, made up of hundreds to thousands of interconnected flower-like units called polyps. Each polyp has a central mouth surrounded by tentacles, and can share food with neighboring polyps when it feeds. Most of the corals on Guam's reefs possess algae that live inside of the coral cells. These plants use sunlight, and through photosynthesis, provide energy to their coral host.

Coral reefs throughout the world are showing signs of degradation and loss as a result of both natural and human-induced disturbances. Guam is no exception. During the past decade, Guam's reefs have lost considerable coral cover, and the trend is continuing. Sedimentation is a serious problem, as it not only kills corals through burial, but prevents new corals from replacing those lost from both natural and human-induced causes. The poor quality of our coastal waters is also having a negative effect on coastal reefs, as pollutants and nutrients continue to interfere with critical reefs processes, from spawning and fertilization of coral eggs, to the development and settlement of the coral seed or larvae. Areas that used to be suitable for coral growth are now covered by sediment and algae, making recovery difficult to impossible.

Considering the value of coral reefs to Guam, it is surprising how little is being done to protect these resources. Both federal and local legislation is lacking, and what laws do exist are weak, hard to enforce, and don't really address the critical issues. We presently know more about how coral reefs work than ever before, and it is essential that this information be applied to protecting our coral reefs. Without immediate action, future generations will not be able to enjoy the benefits coral reefs provide.

An effort is presently underway to provide much needed guidelines for coral reef preservation. These include guidelines for improving land-use practices, controlling the level of sedimentation and runoff, reducing the levels of coastal pollution, and establishing marine reserves which are essential to maintaining the production of corals, fish and other key coral reef inhabitants.

While laws are necessary, enforcement is always difficult if people are unwilling to comply. Education is a key component of any efforts at coral reef preservation, and programs are being implemented this year, the International Year of the Reef, to raise public awareness. An education video on coral reefs has been

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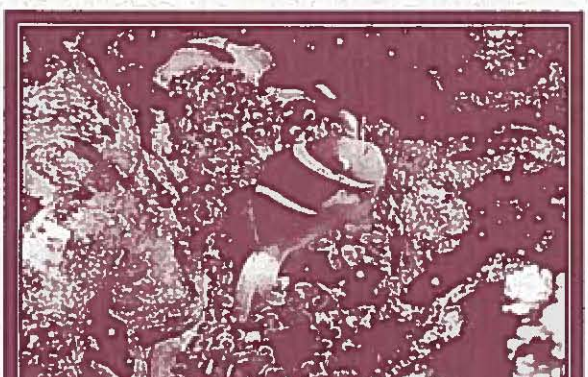
## Guam's Coral.... (cont. from page 4)

produced by the University of Guam Marine Laboratory and the Guam Department of Agriculture's Division of Aquatic and Wildlife Resources. Copies can be obtained by contacting either of these agencies. Several community-based coral reef surveys will take place this summer, with future opportunities for public involvement in reef protection. The hope is that better public knowledge and awareness will eventually lead to a stronger "political will" among island leaders to support the protection of Guam's most valuable natural resources.

The positive news is that coral reefs are robust creatures that can recover if given a chance. If care is taken to control erosion and sedimentation, wave action can cleanse the reef surfaces, supporting recruitment of young corals. Repairing Guam's sewage systems and extending the outfalls will reduce the amount of nutrients being released onto the reef, and also support recovery. The establishment of marine preserves will enable fish populations to recover, and assist corals through the fish grazing down the algae dominating the reef surface. Mooring buoys will reduce anchor damage in popular dive sites. Through understanding, community cooperation, compliance with rational guidelines, and appropriate care, we can ensure that Guam's coral reefs will survive to support the needs of future generations.

(Written by Robert H. Richmond, Ph.D. Professor of Marine Biology)



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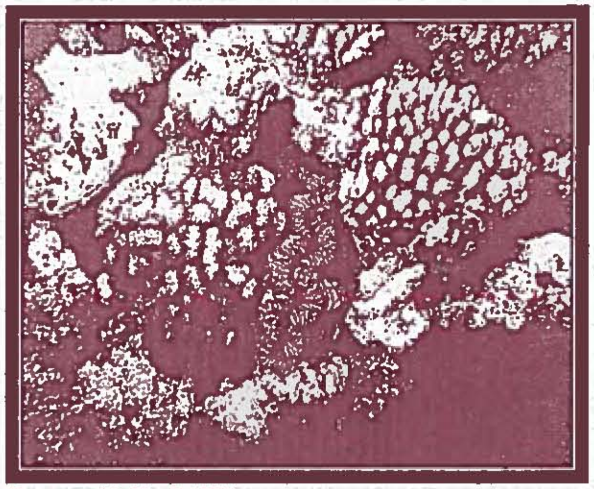


Photo provided by DAWR

## Wetlands are Mother Nature's system of flood Control.......

Wetlands are like sponges. They absorb surging storm and flood waters and release them slowly. This process saves hundreds of thousands of dollars in flood damage to agricultural, urban, and shoreline areas. Often, existing wetlands can provide better, and more cost-effective flood control than any man-made or constructed flood control facility can achieve.

As an added benefit, Guam's wetlands function as protectors of our coral reefs. Storm water run-off is one of the major threats to the health and survival of our reefs. Wetlands catch polluted run-off from agricultural or urban areas and remove or reduce the sediment, silt, excess nutrients, and other harmful substances that, when carried to the ocean, will smother or poison our delicate live coral.

# Coral Reef in Your Medicine Cabinet:

## The Biomedical Applications of Marine Organisms.

Photo provided by DAWR

What do didemnin B, diazonomide A, dolastatin 10, and discodermolide all have in common? They are all potential cancer fighting compounds, and they are all derived from marine organisms which live within coral reef ecosystems. Bryostatin 1, another promising anti-cancer agent, is produced by a particular population of the plant-like bryozoan Bugula neritina. The pseudopterosins produced by the Caribbean sea whip Pseudopterogorgia elisabethae, are anti-inflammatories. The compounds from this soft coral accentuate the healing process of human skin and are now used in some skin care products. Curacin A is produced by the blue-green algae Lyngbya majuscula, and functions as an anti-proliferative. It inhibits cell division, the mechanism by which cancer grows and spreads. In addition to anti-tumor and anti-inflammatory compounds, marine organisms also produce chemical compounds with anti-viral, anti-bacterial, and anti-fungal properties.

Coral reefs, the rain forests of the sea, offer a rich array of both biological diversity and chemical diversity. Over 6,000 unique chemical compounds have been isolated from marine organisms. Hundreds of these compounds have provided "drug leads", while a few, including those described above, are "drug candidates" in various stages of testing. It is likely that these compounds represent only a fraction of the useful chemicals produced by marine organisms. According to William Fenical, a natural products chemist at the Scripps Institution of Oceanography, "marine sources could be the major source of new drugs for the next decade." Unfortunately, many of the undiscovered compounds might remain undiscovered as marine biodiversity is diminished due to the destruction and degradation of coral reefs around the world.

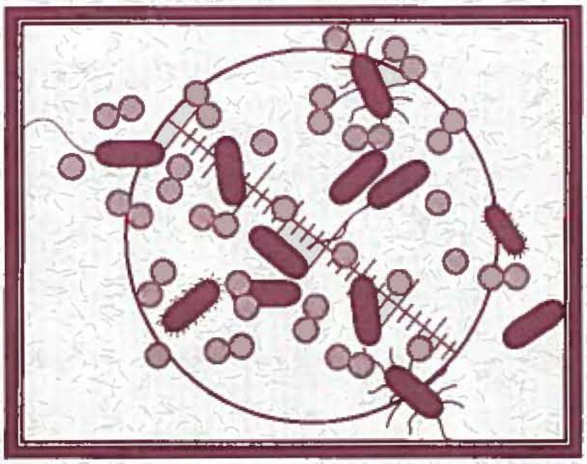
Not only will the resulting loss of marine chemical diversity and potentially useful compounds have long-term negative effects on the quality of human life, it will also have quantifiable economic impacts. For example, the royalties received by the University of California for patented pseudopterosins have reached $1.2 million. This number does not include the revenues earned by the major cosmetics firm which uses pseudopterosins in its products. Without the Caribbean sea whip Pseudopterogorgia elisabethae, these revenues and royalties would not have been generated.

In addition to potentially life-saving chemical compounds, coral reefs supply the structural components necessary to repair human bone. Interpore International manufactures bone graft material by converting the calcium carbonate endoskeleton of coral into calcium phosphate, or coral line hydroxyapatite, which closely resembles the physical and chemical structure of human bone. Other companies manufacture pieces of coral for the same purpose without changing their chemical composition. Unlike allograft bone, obtained from a cadaver, grafts manufactured from coral do not carry the risk of implant rejection or transmission of infectious agents such as hepatitis and HIV.

The United States government supports research on the biomedical uses of organisms associated with coral reefs through

(continued on page 7)

## Medicine Cabinet..(cont. from page 6)



the National Oceanic and Atmospheric Administration/National and State Sea Grant College Programs, the National Science Foundation, and the National Institutes of Health/National Cancer Institute.

## Protecting Our Coral Reefs

One way to protect Guam's coral reefs is to protect the Territorial Seashore Reserve. The Seashore Reserve includes not only the shorelands, but also the water extending seaward to the ten fathom contour including all islands within the Government's jurisdiction, with the exception of Cabras Island.

Any proposed development within the seashore reserve is subject to review and clearance by the Territorial Seashore Protection Commission (TSPC). Applicants requesting for a TSPC permit must demonstrate that the development will not have any substantial adverse environmental effect; is consistent with the objectives of the Territorial Seashore Protection Act; and that some of the following conditions are met: public recreation areas and wildlife preserves are reserved, the potential dangers of flooding, landslides, erosion and siltation are minimized or eliminated and access to beaches and recreation areas is increased through dedication.

For further information or assistance in obtaining a TSPC permit application, contact the Department of Land Management.

## Did You Know???

1. That rainfall acts as nature's shower. Contaminates are washed from the surface of the land into the island's rivers which carry these contaminates to the sea. These contaminates are called "no-point source pollutants" and the process is called "non-point source pollution".

2. That the average surface runoff from streams into the sea is 250 million gallons per day.

3. That wetlands provide habitat for aquatic animals and act as natural water treatment systems by trapping or consuming such pollutants as sediments and nutrients.

4. That it is illegal to operate motor vehicles on Guam's beaches except when loading or recovering a vessel from the ocean.

5. Miles of coastal reefs that took hundreds of years to grow have been killed on Guam in less than a month by erosion and sedimentation.

6. That shore access fishing on Guam has dropped 50 percent and catches have dropped by 75 percent over the last 10 years.

(continued on page 8)

## Did You Know?.. (cont. from page 7)

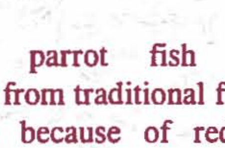
7. Fertilizers washed into Guam rivers are discharged onto the reef flat where they feed algae and disrupt the natural balance between algae and coral.

8. That corals have stopped recruiting on many Southern reefs because of poor water quality.

9. That parrot fish (lagua) are disappearing from traditional fishing method catches and because of reduced stocks, fishermen are having to go deeper with SCUBA gear to find them.

10. Coral reefs have little to no protection under Guam or Federal law. It is easier to **build** on a coral reef than in wetland.

11. Guam currently does not have an Environmental Impact Assessment statute (law) to require comprehensive evaluations and mitigation for land development activities.




### *MAN, LAND AND SEA*

This newsletter is funded by the U.S. Dept. Of Commerce, Office of Ocean and Coastal Resource Management, and the Guam Coastal Management Program, Bureau of Planning.

For more information or comments write: Administrator, GCMP, P.O. Box 2950 Agana Guam 96932. Or call (671) 472-4201/3; fax (671) 477-1812.

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## Earth Week Essay Contest Winners

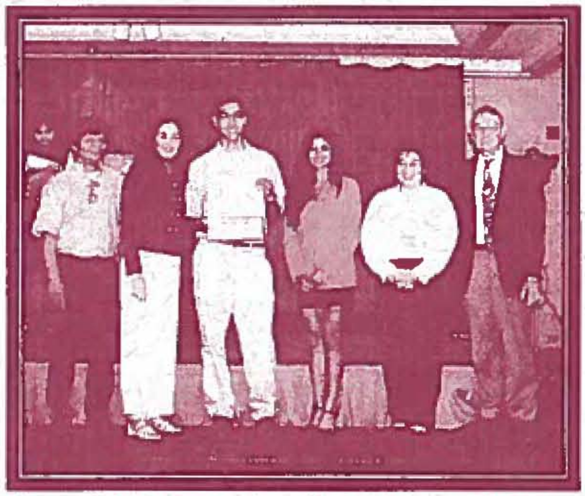

Photo provided by GEPA, pictured in front left to right Francis P. Damian/GEPA, Jacquie Quitugua Ronan/Soroptomist President, Christian Basa/First place winner, Charlotte Dimarucut/Pres. Elect, Nancy Tan/Soroptomist member, and Tom Churan/AAFB.

Andersen Air Force Base, the Soroptimist International of the Marianas, and the Guam Environmental Protection Agency are proud to announce the winners of the 1997 Islandwide High School Essay Contest held in conjunction with Earth Week activities. Essay topics dealt with the protection of the island's coral reefs.

The first place winner is Christian Basa of John F. Kennedy High School. He will receive \$200.00 plus a \$50.00 school contribution to be used by the school to purchase aluminum recycling bins. Second place winner is Simon Libao also of John F. Kennedy High School. Libao garners the second place \$150.00 prize money. Third place winner is Patricia Camacho of George Washington High School who will receive \$100.00 in prize money.