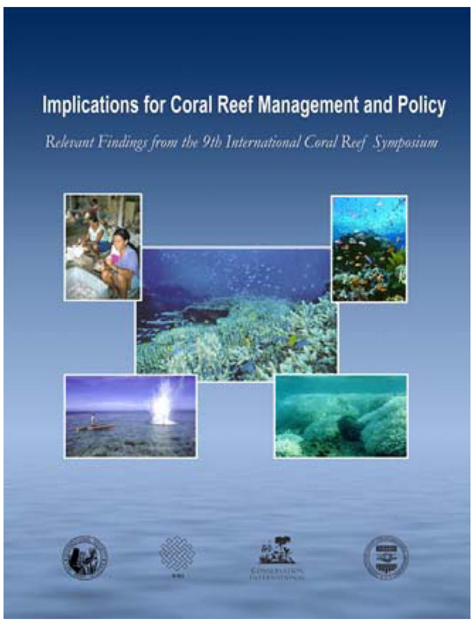
IMPLICATIONS FOR CORAL REEF MANAGEMENT AND POLICY:

Relevant Findings from the 9th International Coral Reef Symposium
[Bali, Indonesia - October 2000]



Coral reefs constitute one of the earth's most complex, beautiful and biologically diverse ecosystems. Unfortunately, many coral reefs around the world are seriously threatened by overexploitation, destructive fishing practices, coastal development, pollution, and global climate change. In response to these threats, over 1,500 scientists, managers, resource users, government officials, journalists and others interested in coral reef studies and management gathered in Bali, Indonesia in October of 2000 for the 9th International Coral Reef Symposium (ICRS). This report synthesizes some of the best scientific and management information presented at ICRS and is intended for use by those in positions to conserve, protect, and rehabilitate coral reefs — policy-makers, managers and the public-at-large. We must now utilize this information in conjunction with a precautionary approach to management. We must also develop policy and management actions that reflect the multiple dimensions of coral reef ecosystems — human, biological and ecological.

WEB LINKS

Web Links Photo Source: International Coral Reef Information Network Photobank

Implications for Coral Reef Management and Policy

Relevant Findings from the 9th International Coral Reef Symposium

INTERNATIONAL SOCIETY FOR REEF STUDIES

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Implications for Coral Reef Management and Policy:

Relevant Findings from the 9th International Coral Reef Symposium

Edited by

Barbara A. Best, Robert S. Pomeroy, and Cristina M. Balboa

A publication of the U.S. Agency for International Development, in collaboration with, the World Resources Institute, Conservation International, and the International Society for Reef Studies

Cover Photos (clockwise):

Cleaning ornamental shells in Cebu, Philippines – Barbara Best
Great Barrier Reef, Australia – Great Barrier Reef Marine Park Authority
Great Barrier Reef, Australia – Great Barrier Reef Marine Park Authority
Bleaching Reef at Reunion Island, April 2001 – M. Rard/ECOMAR
Dynamite blast-fishing – Reef Check

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Conservation International

Conservation International (CI) is an international, non-profit organization based in Washington, D.C. CI acts on the belief that the Earth's natural heritage must be maintained if future generations are to thrive spiritually, culturally, and economically. Its mission is to conserve biological diversity and the ecological processes that support life on earth and to demonstrate that human societies are able to live harmoniously with nature. For more information, please visit: www.conservation.org.

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The U.S. Agency for International Development (USAID) is the U.S. Government agency responsible for worldwide humanitarian and development assistance. USAID's programs foster sustainable development, provide economic assistance, build human capacity and democratic governance, and provide foreign disaster assistance. Environment programs are committed to improving conservation of significant ecosystems and promoting sustainable natural resource management. For more information, please visit: www.usaid.gov. This publication was made possible through support provided by the USAID Environment Office.

World Resources Institute

The World Resources Institute is an environmental think tank that goes beyond research to create practical ways to protect the Earth and improve people's lives. Our mission is to move human society to live in ways that protect Earth's environment for current and future generations.

Our program meets global challenges by using knowledge to catalyze public and private action:

- To reverse damage to ecosystems. We protect the capacity of ecosystems to sustain life and prosperity.
- To expand participation in environmental decisions. We collaborate with partners worldwide to increase people's access to information and influence over decisions about natural resources.
- To avert dangerous climate change. We promote public and private action to ensure a safe climate and sound world economy.
- To increase prosperity while improving the environment. We challenge the private sector to grow by improving environmental and community well-being.

In all of its policy research and work with institutions, WRI tries to build bridges between ideas and action, meshing the insights of scientific research, economic and institutional analyses, and practical experience with the need for open and participatory decision-making. For more information, please visit: www.wri.org.

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Contents

Preface

Call for Actions to Protect and Conserve Coral Reef Ecosystems

CORAL reefs constitute one of the earth's most complex, beautiful and biologically diverse ecosystems. These unique ecosystems benefit people directly by supplying a vast array of goods and services such as food, medicine, recreation, and coastal protection, as well as aesthetic and cultural benefits. Coral reefs occur in over 100 countries. According to one estimate, coral reefs provide over US $375 billion worth of goods and ecosystem services to humans. The economies of many countries, especially small island nations, are highly dependent on the goods and services that coral reefs provide. In addition, coral reefs are intimately associated with mangrove forests and seagrass meadows and form a broader tropical coastal ecosystem upon which more than a billion people depend.

Photo: Roger Steene

Coral reef with rocky island in Calamianes Islands, Philippines

Unfortunately, many coral reefs around the world are in serious decline. According to the recent report *Status of Coral Reefs of the World: 2000* by the Global Coral Reef Monitoring Network, one quarter of the world's reefs have already been lost and another one-third may disappear within the next 30 years. Coral reefs are threatened both directly and indirectly from a variety of human activities. These threats include coastal development, overexploitation and destructive fishing practices, diseases, land-based pollution and erosion, marine-based pollution, and global climate change. In addition, the recent global impacts of catastrophic events, such as widespread coral bleaching and mortality and increased storm intensity, compound the more localized human impacts that place reefs at risk. There is an urgent need to respond to these threats facing coral reefs at local, national, regional, and global levels in order to address biodiversity loss, food insecurity, loss of economic livelihood, and loss of development potential.

In response to these threats facing coral reefs, the organizers of the 9th International Coral Reef Symposium (ICRS) incorporated strong management and human or socio-economic dimensions into the symposium, expanding their usual biological and ecological emphasis. Over 1500 scientists, managers, resource users, government officials, journalists and others interested in coral reef studies and management gathered in Bali, Indonesia in October of 2000. The overall theme of the meeting was the *World Coral Reefs in the New Millennium: Bridging Research and Management for Sustainable Development.* To intervene effectively, we need to view and understand coral reefs in multiple dimensions – human, socio-economic, biological, and ecological.

The 9th ICRS continues a process begun in 1969 at the first ICRS – bringing together those interested in coral reef studies and management to share, debate and learn from each other, and to set a course of action to conserve and sustain the coral reefs. Organized into five broad themes: "State of Knowledge;" "Resource Management;" "Socio-economic Values;" "Assessment, Monitoring, and Rehabilitation;" and "The Future of Coral Reefs," over 1400 papers were presented orally in 58 mini-symposia, and more papers were presented in poster sessions.

The purpose of this report is to synthesize some of the best scientific and management information presented at ICRS for use by those in positions to conserve, protect and rehabilitate coral reefs – policy-makers, managers and the public-at-large. Session convenors, collaborators and colleagues were asked to prepare short syntheses of relevant sessions and/or topics for coral reef management and policy. Each topic area is meant to be a stand-alone piece that can be used separately from the whole report. Some topics relate directly to one or more sessions, while other topics were dispersed throughout many sessions. We extend our sincere thanks and gratitude to Dr. Anugerah

Nontji and his Indonesian colleagues for hosting a wonderful Symposium, and to those session convenors and colleagues who responded to our requests for contributions to this report. The success of this project is due to their dedication and assistance.

Although efforts must be made by all parties on all issues, some of the more important recommendations from the 9th ICRS are the following:

For Policymakers

- reduce greenhouse gases and address climate change
- address threats from invasive species and coral diseases
- strengthen law enforcement
- reduce land-based sources of marine pollution
- expand and strengthen marine protected areas
- enhance communication of scientific information to the general public

For Researchers

- encourage research targeted to management needs
- conduct valuation studies of coral reefs
- increase monitoring studies for more informed management

For Managers

- implement co-management approaches
- implement ecosystem level management
- make more use of socioeconomic information in management
- promote stakeholder participation and participatory decision-making in management
- exercise vigilance and precautionary approaches in all coral reef fisheries
- prohibit destructive fishing practices – such as explosives, cyanide and other poisons, dredging, and trawling

We must now utilize the information available to us to conserve and protect the world's coral reefs, in conjunction with a precautionary approach to management. We must also develop policy and management actions that reflect the multiple dimensions of coral reef ecosystems – human, biological and ecological.

TERENCE J. DONE
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Vice-President, World Resources Institute

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FRANKLIN C. MOORE
Acting Deputy Assistant Administrator and Acting Director, Environment Office, U.S. Agency for International Development

The 9th International Coral Reef Symposium in Bali, Indonesia

THE Ninth International Coral Reef Symposium (9th ICRS) was organized by the International Society for Reef Studies (ISRS), an organization with a membership of approximately 1000-1100 members from more than 50-60 countries that is devoted to the scientific understanding and conservation of the world's coral reefs. The Indonesian State Ministry for the Environment hosted the Symposium in Bali, Indonesia, October 23-27, 2000. Approximately 1500 participants shared information and ideas regarding the science, conservation, management, and future of the world's coral reefs.

The meeting had major regional and global impact at a critical time in the policy efforts of coral reef countries. Through personal commitment and the generous support of numerous sponsors, there was wide representation of participants – particularly students, scientists, conservationists, and managers – from developing countries. Ten excellent plenary speakers drawn from science, policy, conservation, and management inspired the audience to build bridges across different scientific disciplines, as well as outside the scientific community. ISRS fundraising efforts also facilitated integration of a large contingent of journalists and media into the program, ensuring that the ideas and science relevant to conservation were communicated to a large audience including the press, decision-makers, and the public.

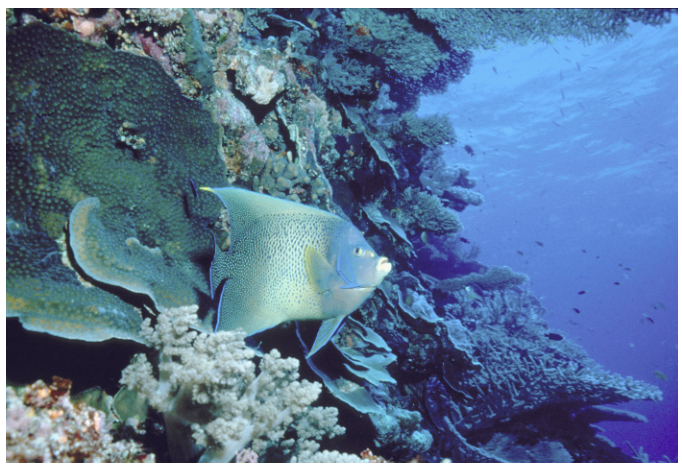

Photo: Great Barrier Reef Marine Park Authority

View from the Great Barrier Reef, Australia

The ICRS has been held every four years since 1969 and has steadily grown to become the premier forum for discussions of the science, conservation, and management of global coral reefs. The proceedings of these 8 symposia are key references to the development of coral reef science, management, and conservation and to the dynamism and trends of global coral reefs over the past 30 years. The ICRS is also a critical global venue to initiate actions to support coral reefs and the human societies that depend upon them.

The theme of the 9th ICRS was *World Coral Reefs in the New Millennium: Bridging Research and Management for Sustainable Development*, and discussions were arranged under five broad themes:

1. State of Knowledge: What coral reefs are; how they have developed; what inhabits them; and how they function in natural and stressed environments.
2. Resource Management: Approaches to sustainable utilization of coral reef resources while achieving conservation goals; managing risk and uncertainty; performance indicators.
3. Socio-economic Values: What are they and are we using them wisely? What are the best incentives for good environmental practice; public awareness.
4. Assessment, Monitoring and Rehabilitation: The what, where, how, and how much of assessment, monitoring, and rehabilitation; ecological goals and performance indicators.
5. The Future of Coral Reefs: International Coral Reef Initiative's (ICRI) Framework for Action and its implementation; global climate change and adaptation in coral reefs; implications for people.

In addition to the formal sessions, many strong lessons were exchanged and alliances forged. The shared passion for the understanding and preservation of coral reefs was greatly strengthened, important new actions identified, and existing actions progressed, notably through the International Coral Reef Initiative (ICRI). ICRI was established in 1995 at a major international meeting in Dumaguete, Philippines and led successively by secretariats in the United States, Australia, France, and currently, The Philippines, in partnership with Sweden.

Further information about the 9th ICRS can be found at: www.nova.edu/ocean/9icrs/, including a detailed listing of speakers and presentation titles under "Program Schedule."

Organizers of the 9th International Coral Reef Symposium

The International Society for Reef Studies (ISRS)

The International Society for Reef Studies—composed of scientists, managers, and conservationists—was formed in 1980 and currently has a membership of approximately 1000-1100 members from more than 50-60 countries. According to its constitution, the principle objective of the Society is: "promoting the production and dissemination of scientific knowledge and understanding of coral reefs, both living and fossil." To achieve its objective, the Society holds regular meetings and co-sponsors other gatherings, publishes in cooperation with Springer-Verlag (Berlin) the quarterly international scientific journal, *Coral Reefs,* and internally publishes a biannual newsletter, *Reef Encounter*. In recent years, with the rising concern about the fate of coral reefs, the membership of the ISRS has grown to include many resource managers and conservationists.

The ISRS is entirely a voluntary organization governed by a constitution, a 12-member council, and five officers. At the time of the Symposium, officers and their affiliations were: Dr. Terence J. Done, President, Australian Institute of Marine Science, Australia; Professor Barbara Brown, Vice President, University of Newcastle, United Kingdom; Dr. Daphne Fautin, Treasurer, Kansas Geological Survey, USA; Dr. Richard Aronson, Corresponding Secretary, Dauphin Island Sea Lab, Alabama, USA; Dr. Steven Miller, Recording Secretary, University of North Carolina, Wilmington, USA. Further details may be found on the Society Web site: (www.uncwil.edu/ISRS).

State Ministry for the Environment of the Republic of Indonesia

The State Ministry for the Environment, as lead agency for the Government of Indonesia, was represented by Mr. Sudarsono on the local organizing committee as an 'in kind' contribution to the symposium. Mr. Sudarsono is Executive Secretary for the State Ministry of Environment.

Research and Development Agency for Oceanology: Indonesian Institute of Sciences

The Institute is the premier scientific body in Indonesia and has central responsibility for studies and activities related to management of the coral reefs of the Indonesian archipelago. Its Deputy Director, Dr. Anugerah Nontji, was Chair of the local organizing committee. The Institute was also represented on the local organizing committee by Dr. Suharsono, who is also on the Council and Scientific Program Committee of ISRS, and Professor Kasim Moosa, who is Editor-in-Chief for the Symposium Proceedings.

The International Coral Reef Initiative

AT the Small Island Developing States conference in 1994, the Governments of the United States, Australia, France, Jamaica, Japan, The Philippines, Sweden, and the United Kingdom, along with international organizations such as the World Bank and the United Nations Environment Program, initiated a global partnership to stop and reverse the global degradation of coral reefs. The International Coral Reef Initiative (ICRI) is a unique environmental partnership among nations and organizations seeking to implement Chapter 17 of Agenda 21, and other international Conventions for the benefit of coral reefs and related ecosystems. ICRI is an informal mechanism that allows representatives of developing countries with coral reefs to sit in equal partnership with major donor countries and development banks, international environmental and development agencies, scientific associations, the private sector and non-governmental organizations (NGOs) to promote the best strategies to conserve the world's coral reef resources. ICRI does not develop and fund proposals, but ensures that the needs of the developing world concerning their coral reefs are conveyed to operational and funding organizations.

Thus, ICRI is unique and its strength lies in the fact that it is a voluntary body with basic operational objectives. There are no plans to form a permanent structure with permanent staff, and funds spent on meetings are kept to a minimum. The agenda for ICRI has been set by over 80 countries and states with coral reefs expressed at 2 ICRI International Workshops (1995 and 1998) and 7 ICRI Regional Workshops.

ICRI voluntary partnership of developing countries, donor countries, development banks, international environmental and development agencies, scientific associations, the private sector and NGOs are linked by a global Secretariat, run and funded by the Government of one country for two years, but often with assistance of others.

The Global Secretariat is deliberately kept small and temporary. To date, coordination staff have performed the ICRI tasks in addition to their other responsibilities in Government. The ICRI Secretariat is advised by the Coordination and Planning Committee (CPC), which meets once or twice per year, often opportunistically to coincide with other international meetings. In turn, CPC members are requested to facilitate the objectives and projects of ICRI.

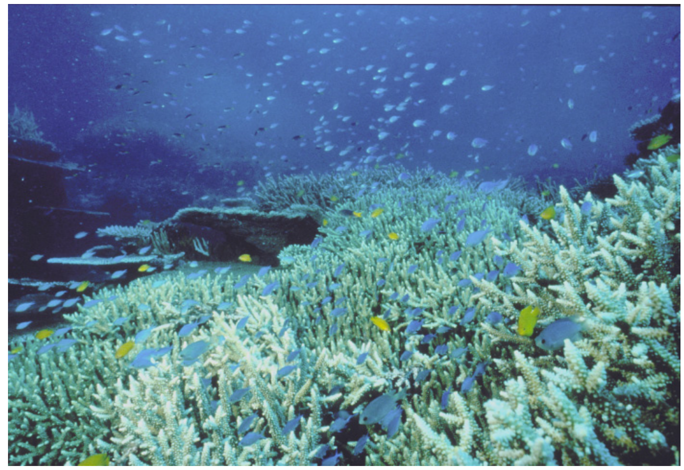

Photo: Great Barrier Reef Marine Park Authority

Fish and Coral on the Great Barrier Reef, Australia

The first Secretariat was hosted by the U.S. Department of State of the U.S. Government (1994 to September 1996). The second Secretariat was hosted by the Great Barrier Reef Marine Park Authority of the Australian Government (September 1996 to December 1998). The third Secretariat was hosted by the Ministry of the Environment of the Government of France (January 1999 until December 2000). It is now co-chaired by the Philippines and Sweden, and is based in the Department of Natural Resources in Manila.

ICRI Program of Actions

The ICRI Action Agenda is based on the *Call to Action* and *Framework for Action,* which listed achievable objectives for Governments, donors and funding agencies, development organizations, NGOs, the research community, and the private sector to work together for sustainable development of coral reef resources.

In November 1998, the International Tropical Marine Ecosystems Management Symposium formulated a *Renewed Call to Action* that added a series of urgent tasks to ICRI and the ICRI Secretariat. Thus, ICRI will continue to focus the world's attention on the need for action to protect and manage coral reefs. This must be done at local, national and international levels. The success of the Initiative will be measured in the ability to turn this

Photo: Roger Steene

***Tridacna* clam on the reef in Raja Ampat, Indonesia**

international momentum into concrete action at all levels and in all regions.

During 1998-2000, ICRI made progress on the following key objectives:

- Mobilize the international community at the highest levels on the declining status of the world's coral reefs and promote actions that must be implemented immediately to reverse this decline
- Establish operational ICRI networks at international and regional scales to coordinate the key objectives of implementing integrated coastal management, building capacity, conducting effective research and monitoring, promoting awareness amongst all stakeholders, and involving the private sector – especially the tourism industry
- Catalyze funding of programs and projects through these networks that will allow partners of ICRI to cooperate in the conservation and sustainable development of coral reefs and related ecosystems; a data bank of funded projects has been set up

The Philippines-Sweden Joint Secretariat

In January 2001, the ICRI Secretariat was assumed by The Philippines in partnership with Sweden. As part of their work agenda, ICRI will be holding a series of regional workshops in East Asia, East Africa, and the Caribbean, as well as the Second International Tropical Marine Ecosystem Management Symposium (ITMEMS2) in 2002. Details on all these events can be found on the ICRI Web site at: www.icriforum.org.

The ICRI Forum Web site

In conjunction with the World Bank, ICRI has established a Web site on coral reef ecosystem issues that is intended to serve as a major link to any organization that is an ICRI partner. The Web site will also host ICRI discussion groups on selected topics. Organizations and ICRI partners are invited to participate in the Forum and establish a kiosk to represent their partnership within ICRI on the Web site at: www.icriforum.org.

ICRI Organizational Structure

ICRI is composed of the following organizational units:

- ICRI Secretariat
- The Coordination and Planning Committee (CPC)
- The Global Coral Reef Monitoring Network (GCRMN)
- The International Coral Reef Information Network (ICRIN)
- The International Coral Reef Action Network (ICRAN)

A Primer on Coral Reefs

CORAL reefs are among the earth's most biologically diverse ecosystems and are an integral part of the tropical coastal systems—that include mangrove forests, seagrass meadows, and beaches—upon which people depend for livelihood, recreation, medicine, and other valuable goods and services. Coral reefs directly benefit people from extractive uses, such as fisheries for food, or from nonextractive uses, such as tourism. The indirect benefits from coral reefs include protection of shorelines from storms and the provision of natural breakwaters, which create harbors for many coastal communities.


Photo: Gerald R. Allen

Mangroves and corals in Raja Ampat, Indonesia

Coral reefs are generally grouped into three types: atolls, barrier reefs, and fringing reefs. Fringing and barrier reefs are natural, self-repairing breakwaters that protect low-lying coastal areas from erosion and other destructive action by the sea. Fringing reefs are composed of a number of living communities. Most shores are sandy beaches, mangrove forests, and rocky cliffs or intertidal areas. Sloping gently away from this shore is a shelf-like, reef flat of variable width and depth. It usually consists of a combination of sand, mud, rocks, sea grass, algae, and scattered corals. At the outer edge of the reef flat is the reef crest, which is often the most diverse and productive zone being exposed to waves, currents, and clear and shallow water. Proper coral reef management depends on maintaining the reef and its associated ecosystems within tolerable ranges and in balance.

The primary productivity of coral reefs is quite high, and one reef may support as many as 3000 species. The high productivity of coral ecosystems results principally from water flowing over the reef, and the efficient biological recycling and high retention of nutrients. Although coral reefs may contain high species numbers, most reefs are characterized by many species with relatively low population numbers and many rare species. The low population numbers, tight nutrient recycling and complex food webs, make reefs especially vulnerable to overexploitation. Even though reefs are often referred to as "productive" ecosystems, experience has shown that coral reefs can be easily overexploited by the transport of organisms out of the system and must be carefully managed and monitored.

Coral reef communities are not closed systems but are complex systems that depend on many internal and external factors: nutrient flow, recycling, symbiosis, predator-prey relations, and specific environmental conditions. For example, coral reef communities may obtain their supplies of fixed or usable nitrogen, which is essential to phytoplankton and algae for photosynthesis, from algae on adjacent reef flats, and bacteria in reef sediments, sea grass beds and mangroves. Transport of mass and nutrients between seagrass meadows, mangrove forests and coral reefs often depend upon the active movement of animals, rather than transport by water flow, since tropical waters are relatively clear and nutrient poor. Thus, the destruction or alteration of other marine ecosystems can have a direct impact on the coral reef.

Reef building through the accumulation of calcium carbonate is a very slow process. Most existing reefs are the result of growth over the past 5000 years of relative sea

Photo: Coastal Resources Center, URI

Mangrove conservation project, Pat Nimat, Indonesia,

level stability. Unlike other marine systems, coral reefs are built up entirely by biological activity. Reefs are composed of large deposits of calcium carbonate that have been produced by corals (*phylum Cnidaria, order Scleractinia*) with major additions from calcareous algae and other organisms that secrete calcium carbonate. Reef growth also depends on a symbiotic relationship between the coral polyps and the algae that live in their tissues.

Reefs survive under relatively narrow ecological limits: water temperature usually stays between 18 and 30 degrees Celsius, with a few exceptions; salinity should be fairly constant at 30 to 36 parts per thousand; sedimentation must be low so that the water is clear; and there must be sufficient circulation of nutrient-limited and pollution-free water. Changes to these conditions will quickly damage or kill the coral animals and other organisms that live in the reef habitat. Thus, there are limits to the amount of human activity and impacts that coral reefs can stand before they are altered or destroyed.

The physical complexity of a reef contributes to its diversity and productivity. The great number of holes and crevices in a reef, primarily by the corals, provide abundant shelters for fish and invertebrates, and are important fish nurseries. The reef provides a solid bottom for many organisms to settle and grow. A number of highly specialized species have become dependent for their survival on the reef. Physical damage to the reef must be avoided in order to ensure the health of the ecosystem.

Coral reefs are threatened by both natural and human-made causes. Natural causes include storm or monsoon damage, changes in weather patterns such as "El Nino," and predation on corals. Human-made causes include mining of coral products, destructive fishing practices, sedimentation due to poor land-use practices, overexploitation of reef resources, pollution, dumping of waste, tourism, and shorefront construction, among others.

The demand for coral reef resources is increasing, for both extractive and non-extractive uses, and it is becoming more difficult to address the causes of coral reef degradation and destruction. Unless appropriate and timely management is implemented, these valuable resources may be lost.

Useful Reference

White, A. T. 1987. "Coral reefs: Valuable resources of Southeast Asia." *ICLARM Education Series 1*. International Center for Living Aquatic Resources Management, Manila, Philippines.

Global Coral Reef Monitoring Network – Status of Coral Reefs of the World: 2000

Clive Wilkinson [1]

THE Global Coral Reef Monitoring Network (GCRMN) is the monitoring arm of the International Coral Reef Initiative. At the 9th ICRS, the GCRMN released its second status report on the coral reefs of the world. Below is a summary of that report.

Photo: GCRMN

A diver assessing coral cover on a reef along a transect line placed at a constant depth along the contour of a reef. The diver notes the position of all items under the tape to estimate percent cover of live and dead coral as well as other organisms

The Crisis With Coral Reefs

The coral reef science and management community has been noting a continual decline in coral reef status since the awareness of the fragility of these systems to human activities developed in the early '80s. The first attempt to document reef status was by Susan Wells and colleagues in the three part series *Coral Reefs of the World* published by UNEP and IUCN in 1988. An attempt to quantify the status was made by Clive Wilkinson at the 7th International Coral Reef Symposium in 1992, suggesting that 10 percent of the world's reefs were effectively lost and estimating that 30 percent were under immediate threat (severe degradation in 10 to 20 years) and a further 30 percent were under longer term threat (20 to 40 years). In 1998, the *Reefs at Risk* analysis by the World Resources Institute, found that 27 percent of the world's reefs are under high risk of damage from human activities and a further 31 percent were under medium level risk.

The latest assessments from the GCRMN in late 2000 are that 27 percent of the world's reefs have been effectively lost, with the largest single cause being the massive climate-related coral bleaching event of 1998. This destroyed about 16 percent of the coral reefs of the world in 9 months during the largest "El Nino" and "La Nina" climate changes ever recorded. While there are signs that many of the 16 percent of damaged reefs will recover slowly, probably half of these reefs will not adequately recover within the next 50 years. These will add to the 11 percent of the world's reefs already lost due to human impacts of sediment and nutrient pollution, over-exploitation, and destructive fishing, mining of sand and rock, and development on and 'reclamation' of coral reefs.

These new assessments show that the problems are most severe in:

- Middle East – 35 percent lost mostly in the Arabian/Persian Gulf, with low chances for short-term recovery
- Wider Indian Ocean – 59 percent lost with reasonable chances of recovery for the remote reefs not affected by human pressures
- Southeast and East Asia – 34 percent lost with reasonable chances for slow recovery on the remote reefs, and dire predictions for the future of the remaining reefs
- Caribbean/Atlantic Region – 22 percent lost due mostly to previous human stresses, hurricanes, bleaching and coral diseases.

[1] Global Coordinator, Global Coral Reef Monitoring Network, c/o AIMS PMB#3, Townsville 4810, Australia; E-mail: C.wilkinson@aims.gov.au

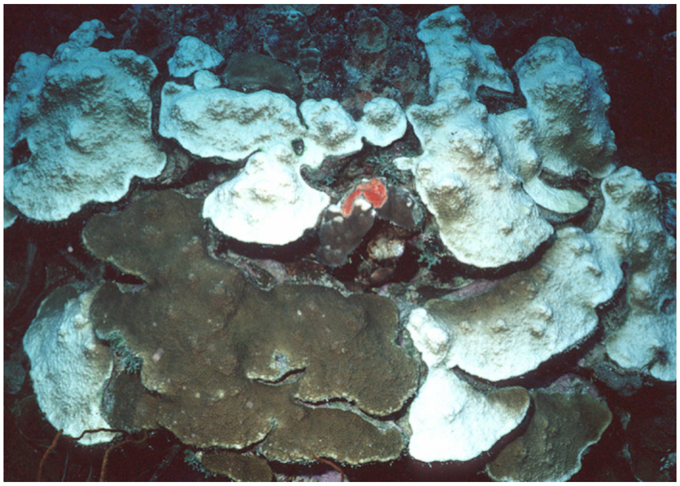

Photo: Andy Bruckner

Montastraea faveolata bleaching, Caribbean

In contrast, the extensive reefs in the Pacific and off Australia are in reasonably good health with a positive outlook, unless global climate change events like those of 1998 strike these areas. Indications are that bleaching may recur with severe, localized bleaching mortality near Fiji and the Solomon Islands in early 2000 and again in 2001.

Coral Bleaching and Mortality in 1998

The massive coral bleaching and mortality event of 1998 devastated large parts of the Indian Ocean, Southeast Asia, and the far western Pacific. The most affected reefs were in the Arabian/Persian Gulf; Kenya, Tanzania, the Seychelles; Maldives, Chagos Banks, Sri Lanka, and India in the wider Indian Ocean; parts of Southeast Asia, especially Vietnam, the Philippines, Taiwan, southern Japan, and Palau. Many areas reported coral losses of 60-95 percent over large areas and often down to 30 meters or more. In the wider Caribbean and parts of the Great Barrier Reef, there was minimal mortality after extensive bleaching, and many severely bleached reefs recovered almost fully. There was no bleaching over vast areas of the Pacific. The bleaching was caused by the combination of extremely calm conditions during the 1997-98 "El Nino-La Nina" events, coupled with a steadily rising baseline of sea surface temperatures in the tropics (increasingly attributed to greenhouse warming). These drove temperatures in parts of the tropics above records for the past 150 years, and bleaching was indiscriminate; impacts were equally severe on relatively pristine, remote reefs as on reefs already under major human stresses.

It may be several decades before we can state that reefs will recover, or whether there will be local losses of species, including some rare endemic species. Reef recovery will depend on few or no repeats of the extreme events of 1997-98, and even then, it will take 20 to 50 years before reefs recover to ecological structures resembling those before the bleaching. Recovery will often depend on reducing human pressures through sound management.

Coral reef experts from around the world compiled these losses and predictions of potential losses under a 'business-as-usual' scenario with little effective conservation. They stressed that many reefs lost in 1998 should recover, with some clear evidence of slow recovery.

Regions of the World	Percentage of Reef destroyed pre 1998	Percentage of Reef destroyed in 1998	Percentage of Reef in critical stage, possible loss in 2-10 yrs	Percentage of Reef threatened, possible loss in 10-30 yrs
Arabian Region	2	33	6	6
Wider Indian Ocean	13	46	12	11
Australia and PNG	1	3	3	6
Southeast & East Asia	16	18	24	30
Wider Pacific Ocean	4	5	9	14
Caribbean Atlantic	21	1	11	22
Status 2000 Global *	**11**	**16**	**14**	**18**

** Mean values adjusted for the proportional area in each region of the global total of coral reefs; PNG – Papua New Guinea.*

Two Parallel Agendas to Conserve Coral Reefs

The events of 1998 indicate that there are two necessary actions to conserve coral reefs:

- direct management to reduce human stresses of land-based pollution, shoreline and reef modification, and over-exploitation, including damaging practices like blast and cyanide fishing. The best mechanisms are through integrated coastal management combining policy, legal and economic mechanisms and the establishment of more effective Marine Protected Areas
- global action to study the impacts of global climate change on coral reefs and reduce emissions of greenhouse gases.

Coral reefs are ideal models for management and conservation as they are often discrete with water barriers separating them from the sources of land-based pollution and exploitation. Reefs have high 'charismatic appeal' and the public demand their conservation. There are no large economic or political lobbies

Photo: Mark Erdmann

A coral rubble field – a result of blast-fishing

opposing conservation, and the massive reef-based tourism and transport industries support conservation. Reefs are strategically important for about 20 members of the United Nations, which have few natural resources other than reefs; and another 70 countries or states have coral reefs, which expand their economies and Exclusive Economic Zones. Coral reefs are frequently major discussion topics at meetings of the Conventions on Sustainable Development, Biological Diversity, and the Asia Pacific Economic Co-operation.

International efforts to monitor, research, manage, and conserve coral reefs have expanded recently with the formation of the International Coral Reef Initiative (ICRI) in 1994 and the Global Coral Reef Monitoring Network (GCRMN) in 1996. ICRI has compiled the coral reef problems and needs of almost 90 countries during global and regional meetings from mid-1995 to early 2000. The Call to Action and Framework for Action were produced in 1995 and the Renewed Call to Action in 1998, along with many regional recommendations for action to conserve coral reefs (http://www.icriforum.org). Major Government and agency donors participate in ICRI with the running of the global Secretariat being undertaken by the United States from 1995-96, Australia from 1997-98, France from 1999-2000 and by a partnership of Philippines and Sweden for 2001-02. There are two new ICRI networks to conserve reefs: the International Coral Reef Information Network (ICRIN), established in 1999 to raise awareness about coral reefs, particularly targeting senior decision-makers; and the International Coral Reef Action Network (ICRAN) with funding from the UN Foundation to establish demonstration sites around the world showcasing successful MPA conservation projects and serving as major training facilities. The U.S. Coral Reef Task Force was formed in response to President Clinton's Executive Order 13089 in June 1998 to conserve the coral reefs under U.S. jurisdiction and assist in international activities.

Calls for Assistance from Coral Reef Countries

Many countries asked for the following assistance:

- Coral reef monitoring should be expanded with more training and employment of staff and funding for logistics, monitoring and databases. Monitoring should be encouraged in communities and volunteers to foster ownership.
- Greater coordination of existing monitoring is needed to ensure that data and information are delivered in a timely manner to the world. The GCRMN will assist with such coordination.
- Small marine protected areas are often successful, but surrounded by devastation. These need to be networked to include multiple users and communities, to address catchment area and trans-boundary problems and to accommodate industrial and tourism development along with traditional uses.
- Coral reefs are generally self-repairing systems, however, practical and low-cost rehabilitation methods may be warranted where recovery is not proceeding normally. Such methods must be effective at the scale of the damage, and not logistically expensive gimmicks that operate only at small scales.
- Where traditional rights and management practices exist, they should be recognized and incorporated into state laws to allow for co-management of coastal areas. Many effective traditional, conservation practices are being eroded under state and international law and 'western' influences.
- Many countries requested legal assistance to balance conservation and development. Many laws from colonial times focused on sectoral rather than integrated management; for example, optimized fish or forest harvesting. Countries need to redraft statutes to remove multi-sectoral overlaps in jurisdiction over coastal resources and promote sustainable use, including establishing MPAs.
- Many countries are concerned that global climate change may destroy their coral reefs, and they requested assistance in assessing future climate change impacts and alternative energy programs. Coral reef countries strongly urged developed countries to curb greenhouse gas emissions, to save their coral reefs and countries.

Future Predictions for Coral Reefs


Photo: Steve Turek

A pair of black, white, and yellow Bannerfish against a background of hard coral, Malaysia

We suggest that 40 percent of the world's coral reefs will be lost by 2010, and another 20 percent in the 20 years following unless urgent management action is implemented. While these figures are alarming, recent events show that they may be conservative. The continuation of severe anthropogenic stresses from growing populations and economies and the shock that came with the 1998 mass bleaching event all indicate that urgent action is essential to conserve coral reefs.

The major human threats to coral reefs can be managed by providing alternative livelihoods and educating people about the stresses that degrade coral reefs. If increases in greenhouse gas emissions are confirmed as the trigger for global climate change, then events like the "El Nino-La Nina" of 1997-98 will recur with increased severity and frequency, and reverse any coral reef recovery. We cannot predict where or when the next bleaching event will occur, but we know that coral bleaching can obliterate pristine, remote reefs as well as reefs under human stresses. Poor management of human activities on reefs will slow any recovery; for example, over-fished reefs are overgrown with large fleshy algae that prevent coral recruitment.

Already 11 percent of the world's coral reefs have been lost and a further 16 percent are severely damaged. Some should recover; others will not and the worse is yet to come with probable significant reductions in coral cover and biodiversity. However, large areas of Pacific and Australian coral reefs, are under no immediate threat, except for climate change.

Useful References and Resources

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Wilkinson, C. 2000. *Status of Coral Reefs of the World: 2000.* Global Coral Reef Monitoring Network and Australian Institute of Marine Science, Townsville, 363 pp.

ReefBase is the official database for the Global Coral Reef Monitoring Network, and is maintained by ICLARM - The World Fish Center. ReefBase provides online access or links to the to the published "Status of Coral Reefs of the World:2000" reports, regional and country reports, and to several unpublished reports which were used as the source material for the publication. In the future, users will be able to query interactively the GCRMN data to create custom tables and reports for a region or issue of interest. The Web site can be found at: www.reefbase.org/

The GCRMN is also supported on the NOAA coral reef home page at: http://coral.aoml.noaa.gov/gcrmn/

Details of monitoring methods are available from the AIMS Web site www.aims.gov.au

Reef Check is a global volunteer monitoring program and is a component of the GCRMN. Survey results from 1997 and 1998 are available for query at: www.reefcheck.org.

Reef Check – Status of Reef Health Indicators

Gregor Hodgson [1] and Jennifer Liebeler [2]

THE Reef Check program was established in 1997 to provide volunteer divers and local communities around the world with the tools needed to monitor the health of coral reefs. Now in its fifth year of operation, the volunteer program is active in over 60 countries and territories, and regularly offers regional training courses in the Caribbean and Pacific. In 1998, Reef Check became an official partner of the Global Coral Reef Monitoring Network, and was a major contributor of information for the *Status of the Coral Reefs of the World: 2000*.

Reef Check defined coral reef health based on a set of carefully chosen indicator organisms (please visit: http://www.ReefCheck.org). The organisms were chosen to be eco-holistic, representing a broad spectrum of key reef organisms sensitive to anthropogenic impacts. Indicators include spiny lobster, grouper, humphead wrasse, bumphead parrotfish, sea cucumbers, banded coral shrimp, algae and giant clams. Many of these organisms are destined for export and international trade. In 1997, the results of the first global survey of coral reefs provided the first scientific evidence of the global extent of the coral reef crisis. Subsequent Reef Check surveys of hundreds of reefs by thousands of divers each year have documented a dramatic decline in coral reef health. These results have been reported through standard scientific publications as well as via international and national press conferences.

Worldwide Reduction in High-Value Reef Organisms

During the 1997 survey, approximately 100 volunteer scientists trained and led over 750 volunteer divers in surveys of more than 300 reefs in 31 countries. The results revealed a dramatic worldwide reduction in high-value reef organisms due to overfishing and the use of damaging fishing methods. Most organisms selected as reef health indicators were completely absent from a high proportion of surveyed reefs.

Surveys have continued annually since 1997. The analysis of the data collected during 1998 and 1999 show similar patterns in abundance of key indicator organisms on reefs.

Photo: Reef Check

Volunteer conducting Reef Check survey

The results presented below were collected by over 300 marine scientists who trained and led more than 8,000 volunteer divers in surveys of over 1,000 coral reefs from 1997 to 1999. There is clear evidence of widespread damage to reefs due to overfishing, pollution, and coral bleaching linked to global warming.

Missing in Action – Reef Health Indicators

Lobsters

Lobsters were not found on 72 percent of the reefs surveyed from 1997-1999. Popular among commercial and recreational fisherman, lobsters were once ubiquitous on most reefs. Although lobsters are nocturnal, it is unlikely that many lobsters were missed, as the survey protocol requires searching crevices and lobster's long antennae typically extend outside the crevices and are easily identified.

Large Groupers

Large groupers (that is, larger than 30 centimeters) were missing from over 50 percent of the reefs surveyed. Large groupers are heavily fished throughout the tropics. Grouper were most common in the Red Sea, specifically at sites where no poison or dynamite fishing (common methods for fishing grouper) has occurred. Nassau grouper, the highly prized and previously abundant fish, was only found at 15 percent of the sites surveyed in the Caribbean.

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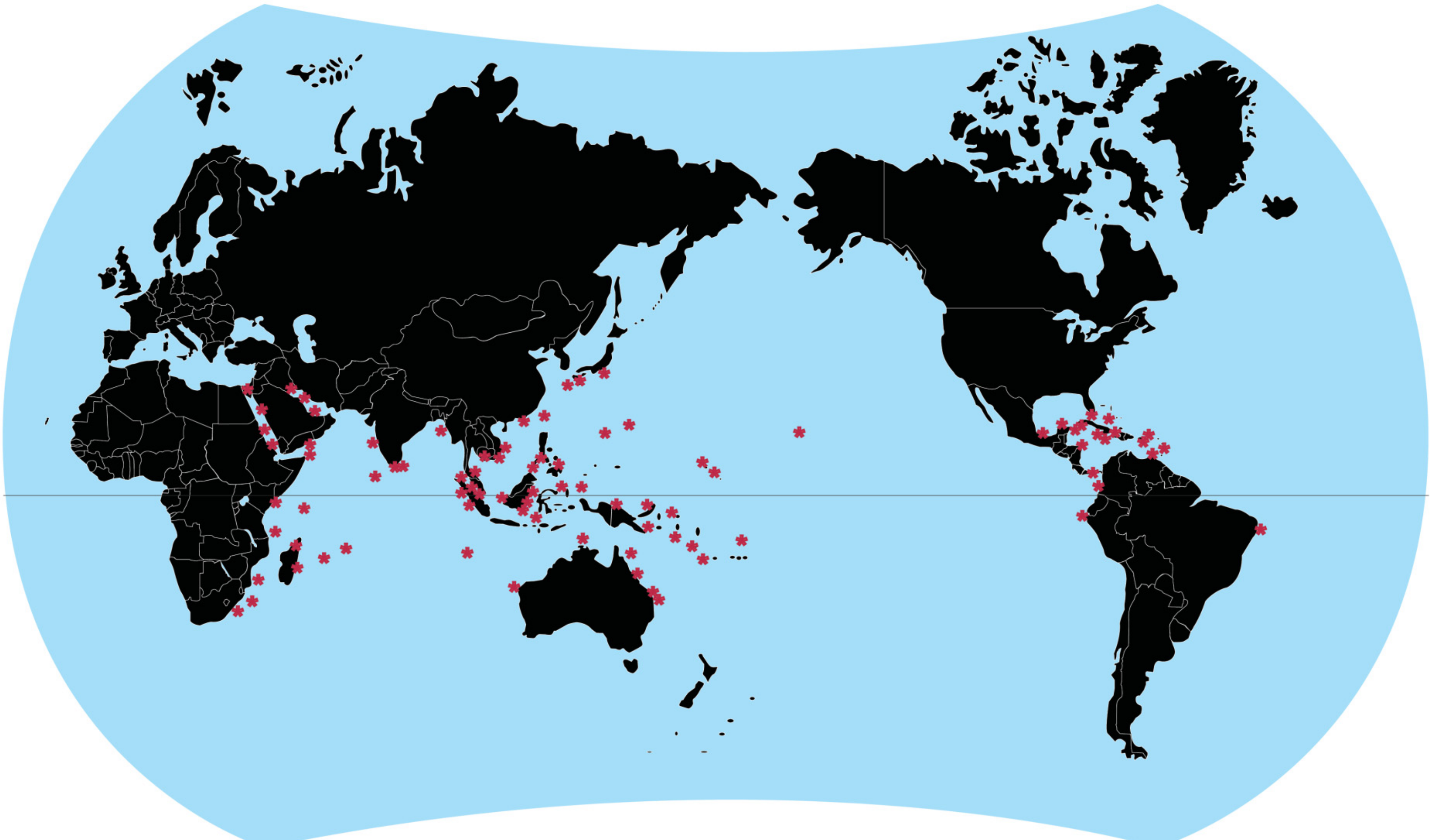
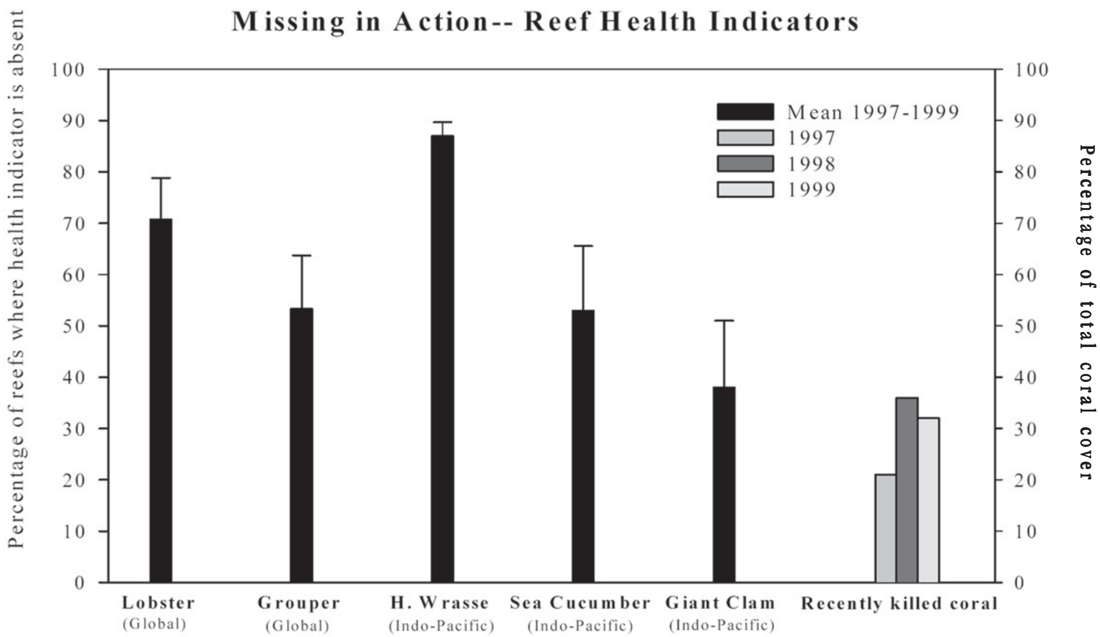
Reef Check Sites



1500 Reefs, 62 Countries and territories



Sweetlips fish
The Indo-pacific and Red Sea results for sweetlips (family Haemulidae) revealed similar abundance patterns, with a mean of less than 1 fish per survey site. There were more Haemulidae found in the Caribbean, with a mean of 2-10 fish per reef reported from almost half of the Caribbean sites. Biological differences among the different genera, as well as different levels of fishing pressure, may be responsible for the greater abundance of Haemulidae in the Caribbean than in the other regions.

Butterfly fish
Butterfly fish (family Chaetodontidae) also showed clear differences in abundance based on site. There was a higher percentage of sites with a low butterfly fish abundance in the Caribbean when compared to the Indo-Pacific or the Red Sea. Of all sites in the Caribbean, 48 percent had less than two butterfly fish per site, as compared to 13 percent in the Indo-Pacific and 3 percent in the Red Sea. However, the number of species of butterfly fish in the Caribbean and the Red Sea are five to ten times lower than in the Indo-pacific. More than 25 species of butterflyfish are collected for the marine aquarium trade; in some areas, overfishing is a major problem. A longer time series may help clarify these results.

Humphead wrasse
Over the three-year period, Humphead wrasse (*Cheilinus undulatus*) were only found at 14 percent of all reefs surveyed in the Indo-pacific. This may be a direct consequence of the high demand for these fish for international live fish trade – a full-grown Humphead wrasse can sell for up to US $10,000 in SE Asia.

Giant clams
On average, giant clams (*Tridacna* spp.) were completely absent from 40 percent of reefs surveyed in the Indo-pacific region over the three-year period. However, this indicator showed major differences between years — with no giant clams found at 23 percent of reefs in 1997, 53 percent in 1998, and 30 percent in 1999. Taken together, these results clearly indicate that another previously common reef dweller is now quite rare – especially large specimens which can only now be seen in museums.

Living Coral Cover
One component of reef health is the percentage of substrate covered by live coral. During 1997-1999 surveys, the mean percentage of living coral cover on reefs at the global scale has been relatively constant, at 33 percent (± 5 percent), over the three years. There were major regional differences. The Caribbean, which has been subjected to a high incidence of overfishing, the death of the long spined black sea urchin and subsequent algal overgrowth, has consistently recorded significantly lower living coral cover (21 percent ±15 percent) than the other two regions (Indo-pacific – 35 percent ± 17 percent; Red Sea – 31 percent ±13 percent, $p < 0.001$). Taken by itself, however, live coral cover can vary due to a variety of local factors such as percentage of sandy bottom found between coral patches. Therefore, a more meaningful component of reef health is the ratio of living coral cover to coral that has

recently died. The Red Sea has continued to have a higher ratio of live to dead coral (6:1) than the Caribbean (2.8:1) or the Indo-Pacific (3.5:1), showing that these coral reefs are among the healthiest in the world.

Recently Killed Coral

The percentage of coral that has died in the past year (recently killed coral/total coral cover) increased from 1997 (14.6 percent ± 24.6 percent) to 1998 (31.3 percent ± 39.9 percent). This was a result of the 1998 coral bleaching and mortality event that devastated reefs throughout all tropical oceans. That year, bleaching was reported at 30 percent of survey sites, with high mortality (up to 90 percent) in the Indian Ocean and parts of Asia. The severity of the event was illustrated by the death of 1000-year old corals in Vietnam and on the Great Barrier Reef. At the time, it was estimated that approximately 15 percent of the world's reefs died due to this one event in 1998. Using satellite tracking of temperature measurements provided by U.S. NOAA, Reef Check was able to follow global changes during and after this event using the standard Reef Check method throughout the world. Follow up surveys conducted in 1999 revealed that 30 percent of the corals that were reported dead in 1998 following the bleaching event had in fact recovered.

One of the more disturbing findings was that remote reefs, far from any city, are in just as bad shape as reefs near cities due to long distance fishing. For example, Pratas Reef (Dongsha) lagoon, (South China Sea) was a relatively healthy reef until it was decimated in 1998 by a fleet of several hundred blast and poison fishing boats from China and Hong Kong.

Although there is much natural inter- and intra- reef variation in the abundance of reef organisms, especially fish, the low numbers of organisms counted during three years of surveys at hundreds of the worlds "best" reefs confirm that overfishing and exploitation of reef organisms are problems on a global scale.

Over the next five years, the global network of enthusiastic volunteer divers and scientists will begin to disseminate information on how to manage the reef problems that have been identified. This type of community-level monitoring and management supported by Government efforts, may be the only realistic hope of saving the world's reefs from a downward spiral of overexploitation and damage.

Useful References and Resources

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Land-based Sources of Pollution and Impacts on Coral Reefs

Annadel S. Cabanban,[1] Christopher Reich,[2] and Lauretta Burke [3]

Statement of Issue

POLLUTION and sediment from land-based sources is causing widespread degradation of coral reefs. Increased nutrients in coastal waters from agricultural fertilizers and sewage discharge increase algal growth and decrease water clarity. This impedes coral growth and, in some cases causes algae to overgrow corals previously present. In addition, increased sedimentation from changes in land-use (often far upstream) and from coastal development activities can adversely impact coral reefs through smothering of coral, screening out sunlight needed for photosynthesis, scouring of the coral by sand and other transported sediment, and decreasing the survival of juvenile coral due to lack of suitable substrata for colonization.


Photo: Great Barrier Reef Marine Park Authority

Flood plume sediments threaten the survival of coral reefs

Land-based Sources of Pollution and the 9th ICRS
Several mini-symposia at the 9th ICRS included papers on land-based sources of pollution. The presentations on land-based sources of pollution covered a wide spectrum of topics and were global in context. The most popular themes of discussion were the pathways, delivery, and the impacts of pollutants to coral reefs. The presentations were based on research in the coral reefs of East Africa, Caribbean, Southeast Asia, and South Pacific.

State of Knowledge

Potential Pollutants, Sources and Pathways to Coral Reefs
Several pollutants and their sources were identified in the mini-symposium including, sediment to coastal waters from rivers, construction and alteration of land cover nearer the coastline, discharge of human sewage, application of agricultural fertilizers, and heavy metals from mines and industries.

The three major pathways for land-based sources of pollution to coral reefs are ground water, rivers, and sewage out-falls. The mechanisms for groundwater delivery to the reef are (1) tidal pumping, which drives ground water across the rock-water interface as a result of oceanic tidal variations, (2) spring discharge, and (3) diffuse seepage to bays and lagoons. Rivers are the most important pathway for land-based sources of pollution to coral reef environments. Rivers carry a vast amount of sediment, nutrients, and heavy metals. Mangroves and seagrasses filter pollutants and trap sediments. Loss of mangroves and seagrasses from coastal environments

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results in increased delivery of sediments and pollution to coastal environments, including coral reefs. Sewage outfalls deliver either raw or primary-treated wastewater to offshore environments. Table 1 presents a summary of potential impacts from these land-based sources.

Impacts of Land-based Sources of Pollution on Coral Reefs
The impact of land-based sources of pollution on coral reefs depends upon the nature of the pollutant and the location of the reef. Sediment typically has greater impact on fringing reefs than on reefs distant from shore. Sediments tend to settle near the source, though some sediment plumes extend beyond 100 kilometers. Nutrients and other chemical compounds are dispersed farther than sediments.

Sediment reaching a coral reef blocks sunlight, which is required by the zooxanthalae for photosynthesis, thereby affecting the growth of the coral. In severe cases, sedimentation can kill corals outright through smothering. However, an experiment in the Solomon Islands on the impacts of logging in cachments did not conform to predictions: more corals grew near logged catchments versus those further from logged catchments. This suggest that factors other than the proximity to disturbed catchments influence the survival of corals. Furthermore, sediment supply to reefs is a cause for concern as it is a transport mechanism for nutrients and heavy metals as well as other contaminants.

Eutrophication, resulting from domestic and agricultural inputs of dissolved nitrogen, phosphorus, and potassium, have impacts on the coral reef ecosystem. Eutrophication can reduce sunlight and increase growth of algae, in competition with coral. These physical changes can cause changes in the composition and abundance of corals (in terms of coral cover). The species composition and coverage of coral reefs change from branching corals (*Acropora* spp.) to massive corals (*Porites* spp.) on high sewage outfalls, where eutrophication is high. Inputs of nitrogen, phosphorus, and potassium from ground water can result in massive growth of green algae (*Ulva* spp. and *Chaetomorpha* spp.) in a lagoon.

Sea urchin diversity can increase in high nutrient areas. Indeed, the high density of sea urchins in Negril Marine Park in Jamaica was positively correlated with high nitrogen in macroalgae (*Chaetomorpha* spp.) but not coral cover.

Table I. Summary of the impacts of land-based sources of pollution

Pollutant	Impact
Sediments	- settle quickly on nearshore reefs - can smother and kill coral - reduce sunlight for photosynthesis - scour coral, reducing growth - reduce substrata for recruitment of juveniles
Chronic sewage	- localised eutrophication - poor water quality – high bacterial and viral content - Infection of coral mucus - Algal overgrowth
Sewage (at out-fall)	- Decrease in coral cover of *Acropora* spp. (50 percent down to 0 percent) - Change in dominant coral from branching (*Acropora* spp.) to massive (*Porites* spp.)
Dissolved Nitrogen (N) and Phosphorus (P)	- Increase in macroalgae (e.g., *Ulva* spp., *Chaetomorpha* spp.) - Increase (>60 percent) cover of green algae - Decrease in coral cover - Increase in sea urchin density Some other observations (not impacts): - Tall, branching algae use dissolved N, P - Mat-forming algae require high rates of advective current to reduce N, P concentration - Rhizophytic algae have higher N, P than those offshore
Mine spill	- Heavy metals (Cu, Zn) disperse as far as 5 km away, and incorperate in coral skeletons

Bacteria and viruses also have indirect impacts on coral reefs. High concentration of bacteria and viruses have been detected in the water column and in the mucus that corals produce. The pathogenic effect of these organisms on corals and on those feeding on mucus of corals is not well understood.

Chemical pollutants, especially persistent organic pollutants (POPS) can be dispersed far from shore. Heavy metals (zinc, lead, and mercury) can be incorporated in the coral skeleton. These metals have an indelible mark on the skeleton that is visible under ultraviolet light in the laboratory. It is not known at present how this is incorporated into the hard matrix of the coral and whether this affects the growth of corals.

An analysis of threats to coral reefs from human activities concluded that over 35 percent of the coral reefs of Southeast Asia are threatened by pollution and sediment related to land-based activities.

Relevant Actions Being Taken to Address the Issue

Land-based sources of pollution are considered a major threat to the alteration or destruction of coral reefs around the world. The United Nations Environment Programme has developed a Global Plan of Action to address this concern. In the East Asian Seas (including Australia, Brunei, Cambodia, China, Indonesia, Malaysia, Philippines, Singapore, South Korea, Thailand), a review of these impacts was conducted under two activities (Impacts of Watershed Activities on Coastal and Nearshore Ecosystems; Transboundary Diagnostic Study in the South China Sea). The Regional Coordinating Unit for East Asian Seas initiates and coordinates projects to ameliorate, restore, and manage the marine environment in this Region.


Photo: Coastal Resources Center, URI

Polluted water after the prawn harvest, Lampung, Indonesia

In addition, the Land Ocean Interaction in the Coastal Zone (LOICZ) Project estimated wide-spread species impacts from poor land-use practices within the coastal zone. The South East Asian-Basin Project of the SEA-START is developing a model for the movement of water from the watershed to the coastal zone. The Reefs at Risk project of the World Resources Institute modeled the threat of sedimentation (among other threats) on coral reefs in Southeast Asia and is starting a similar risk assessment of the wider Caribbean.

Management and Policy Implications

Overall, it can be stated that as countries increase their populations and development keeps pace, the resultant disturbances to the land will have deleterious effects on coral reef ecosystems. But, in addition to the rates of growth and development, the nature of development implementation can have profound implications for coral reefs. For example, the nature of coastal development (whether mangroves are retained or converted; whether a development is set back sufficiently from the shoreline; whether adequate sewage treatment is installed for a new development) will effect the ultimate impact on coral reef health.

Specific Recommendations for Action

- Good planning and integrated coastal zone management are the most important tools for limiting the impacts to coral reefs associated with coastal development. Sewage and industrial waste disposal practices and land-use practices must be monitored.
- Watershed-based (catchment-based) management for reducing upstream impacts is vital. Information tools for establishing these linkages between upland activities and stresses to coral reefs are important.
- Regional initiatives, such as those of the East Asian Seas Regional Coordinating Unit (of the United Nations Environment Programme), and research on the tolerance level of coral reefs to specific land-based sources of pollution, complemented by the concept of integrated coastal zone management, can help avert the destruction of coral reefs in the world.

Useful References and Resources

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Infectious Diseases Continue to Degrade Coral Reefs

Laurie L. Richardson [1] and Richard B. Aronson [2]

Statement of Issue

THE past three decades have revealed an increasingly serious threat to coral reefs worldwide – lethal coral diseases caused by an assortment of pathogenic micro-organisms. Coral diseases are detrimentally impacting individual coral species, coral populations, and entire reef ecosystems. The current status of knowledge of diseases of corals (and other marine invertebrates), including both knowledge of individual diseases and the effects of diseases on reefs, was explored by researchers representing laboratories in eight countries in a mini-symposium held in conjunction with the 9th ICRS.

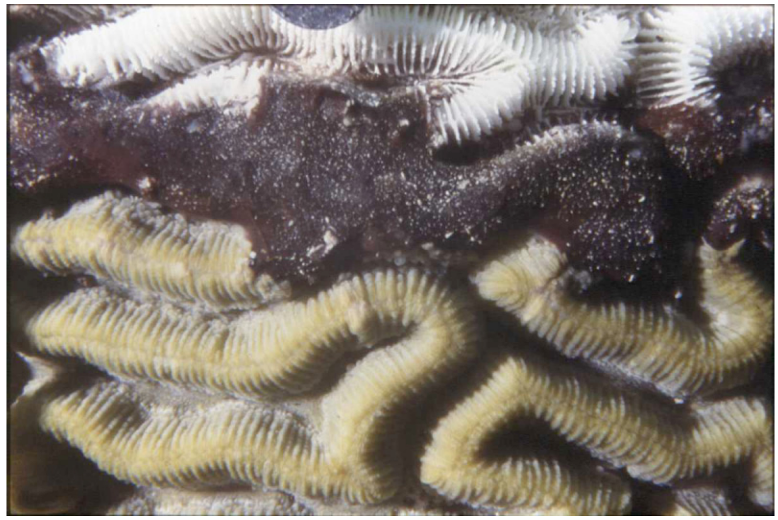

Photo: G. McFall

Black band disease on *Diploria strigosa*. This disease consists of a microbial consortium of bacteria, which together kill coral tissue by producing a toxic, sulfide rich environment. It is wide-spread throughout the Caribbean and has recently emerged on the Great Barrier Reef

State of Knowledge

Alarming Trends:
Several alarming trends have become apparent. It is now a documented fact that coral diseases have spread to affect reefs in all areas of the world. While the Caribbean continues to be the most severely impacted in terms of the largest number of specific diseases, and the Caribbean region also hosts the most extensive disease outbreaks, for the first time there are reports of severe outbreaks in the Great Barrier Reef, the Philippines, and Hawaii. Up to 3.6 percent of coral colonies (representing 24 species) of the Great Barrier Reef were reported to have black band disease, a potentially lethal coral disease widespread throughout the Caribbean that is caused by pathogenic bacteria. New reports confirm the continued presence of disease on reefs throughout the Indo-Pacific, including the Red Sea. At the time of the 9th ICRS, the first observations of white band disease on acroporid corals around Bali and Komodo were made by delegates to the symposium. This observation is of particular concern since this disease has completely restructured many coral reefs in the Caribbean and is believed to have killed over 90 percent of Caribbean acroporid colonies.

Results of the first, quantitative, large-scale disease-monitoring program, being conducted throughout the Caribbean were presented. This program, unique in that the same monitoring and disease identification protocols are being used at all sites, revealed the presence of coral diseases at all reefs surveyed. The area studied encompassed six geographical throughout the greater Caribbean region. A total of 38 coral species were observed to be affected by at least one disease, and several coral species were susceptible to as many as five specific diseases. Other, smaller-scale monitoring projects are also being conducted, each one of which reported increasing incidence of disease.

Global Database on Coral Disease:
The World Conservation Monitoring Centre (WCMC) has compiled observational data of coral diseases from 150 sites worldwide. This program has a Web site (http://www.unep-wcmc.org/marine/coraldis/) that presents the global distribution of all reported coral diseases. The site incorporates links allowing access to regional coral disease data bases, and to a literature data base that cites each report that formed the basis for the global data set. The latter separates peer-reviewed papers and non-peer reviewed (including anecdotal) reports. While this data set includes information about diseases that have not been

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fully characterized (see below) and, unlike the Caribbean-wide survey cited above, does not involve use of uniform sampling and disease identification procedures, the literature link allows one to assess the status of knowledge and scientific rigor of disease observation for each site.

Relationship Between Coral Disease and Global Warming:
One important theme that arose from the session was a possible relationship between disease and global warming. Several findings were reported which together support such a hypothesis. The study that documented the new geographic expansion of black band disease to the Great Barrier Reef included physical measurements that revealed that both black band disease and white band disease emerged on these reefs after a period of historically unprecedented, sustained, high sea water temperature. While it has been known for years that black band (and other) disease outbreaks occur in the warmest months of the year in the wider Caribbean, its sudden appearance on the Great Barrier Reef at the same time as a marked elevation of water temperature represents the first suggestion of a possible link between climatic trends and the emergence of coral disease in new locations. Similarly, while it has been known for some time that elevated temperatures can induce coral bleaching *in situ*, new laboratory-based results document that bacterial bleaching of coral can be directly triggered by high temperature. Additional laboratory studies of microbial pathogens of corals which have been isolated and are being characterized have revealed a common characteristic of growth optima at and above 30 degrees Centigrade, the temperature at which corals begin to exhibit physiological stress. Determination of a link between elevated temperature and increased bacterial pathogenesis of corals *in situ* was identified as a suggested future focus for research on coral health.

Effect of Coral Disease on the Reef Ecosystem:
Another critical theme explored in the symposium was the ecological effect of coral disease on the reef ecosystem. It is clear that disease is an under-appreciated source of mortality in corals and other reef organisms. This is true despite the fact that there is quantitative evidence of a long-term restructuring of Caribbean reefs on a regional scale as a result of disease outbreaks on individual reefs. In the Caribbean, white band disease was the primary reason for the decline of *Acropora palmata* and *A. cervicornis*, two species that formerly dominated reef-crest and fore-reef habitats, respectively. Paleontological evidence suggests that the decimation of *Acropora* populations in the Caribbean over the past three decades was unprecedented on a time scale of millennia.

Identification and Characterization of Microbial Pathogens:
One area of research that continues to be active is the identification and characterization of microbial pathogens of corals. To date, the pathogens of only five coral diseases (which includes bacterial bleaching) are known, although up to 29 diseases have been proposed. The range of characterized pathogens is dramatic in terms of both type of microorganism and disease process. The microbial pathogens associated with the following diseases have been characterized to the greatest extent:

- Black band disease – caused by a microbial consortium that functions synergistically to produce a community toxic to coral. The community includes a photosynthetic bacterium, sulfide-oxidizing and sulfate-reducing bacteria, and associated heterotrophic bacteria that form a highly structured microbial mat community
- White band disease (type II) – associated with a non-structured population of gram negative bacteria
- Aspergillosis of seafans and seawhips – caused by a fungus (*Aspergillus sydowii)* of terrestrial origin
- Plague types II and III – caused by a gram negative bacterium that may be a new genus;
- Bacterial bleaching – caused by the gram negative bacterium *Vibrio shiloii.*

The status of knowledge of microbial pathogens of corals is summarized in greater detail elsewhere (Richardson and Aronson, in press).

Research presented from both field and microbiological studies of coral diseases strongly supported the caveat that extreme caution is necessary when interpreting coral pathologies in the field as potential diseases. One case study was reported which documented a detailed investigation into the cause of widespread lesions and structural damage of Caribbean corals, first reported and highly publicized as a highly contagious "rapid wasting disease." The study documented that such degradation was, in fact, the result of bite marks of the stoplight parrotfish, *Sparisoma viride.*

There was general agreement that the results of both microbiological and ecological studies must be integrated and used directly to support and interpret the results of disease surveys and coral health monitoring programs.

Implications for Management and Policy and Specific Recommendations for Action

In summary, the session on coral diseases led to the following important points that should be considered by reef managers:

- Diseases continue to increase and are now found on reefs throughout the world, including the most pristine and geographically isolated coral reefs.
- Disease outbreaks can result in the complete restructuring of reef communities.
- Results from studies that focus on coral diseases at the most basic levels (isolation and characterization of pathogens) are available to support coral disease monitoring and prevention programs.
- New monitoring programs should be modeled after current quantitative monitoring programs that incorporate well-developed methodologies in order to facilitate direct comparison between different areas.

Conclusions

Research into the microbiological and ecological aspects of coral (and other invertebrate) diseases continues to be an active area. We are slowly beginning to understand the causes and effects of diseases on reefs, and are hopeful that this knowledge will eventually be instrumental in designing management programs to counteract continued reef degradation.

Useful References and Resources:

This paper is based on presentations made at the 9th ICRS, Mini-Symposium E7, *Coral Diseases: Pathogens, Etiology and Effect on Coral Reefs*. The following papers, presented at the symposia, were especially useful in preparing this synopsis:

Banin E, Ben-Haim Y, Fine M, Israely T, Rosenberg E (in press) *Virulence mechanisms of the coral bleaching pathogen Vibrio shiloi*. Proc 9th Int Coral Reef Symp.

Bruckner AW, Bruckner RJ (in press) *Coral predation by Sparisoma viride and lack of relationship with coral disease*. Proc 9th Int Coral Reef Symp.

Dinsdale EA (in press) *Abundance of black-band disease on corals from one location on the Great Barrier Reef: a comparison with abundance in the Caribbean region*. Proc 9th Int Coral Reef Symp.

Richardson LL, Aronson RB (in press) *Infectious diseases of reef corals*. Proc 9th Int Coral Reef Symp.

Weil E, Urreiztieta I, Garzón-Ferreira J (in press) *Geographic variability in the incidence of coral and octocoral diseases in the wider Caribbean*. Proc 9th Int Coral Reef Symp.

Web site resource (cited in text): World Conservation Monitoring Centre (WCMC) Web site of observational data of coral diseases from 150 sites worldwide: www.unep-wcmc.org/marine/coraldis/

Coral Reefs: Invaded Ecosystems

Lucius G. Eldredge [1] *and Jamie K. Reaser* [2]

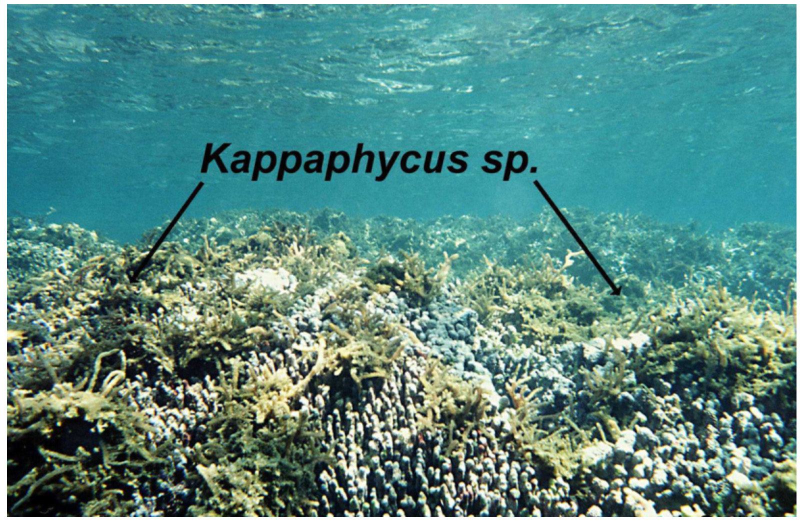

Photo: J. Smith

***Kappapycus striatum*, an invasive red algae (*Rhodophyta*) in Kaneche Bay, Oahu (Hawaii, USA)**

Statement of Issue

INVASIVE species are organisms (plants, animals, or other organisms) that have been moved from their native habitat to a new location where they cause significant harm to (or significantly threaten) economic systems, the environment, or human health.

Society pays a great price for invasive species – costs measured not just in currency, but also unemployment, damaged goods and equipment, power failures, food and water shortages, environmental degradation, loss of biodiversity, increased rates and severity of natural disasters, disease epidemics, and even lost lives.

The prevention and control of invasive species presents scientific, political, and ethical challenges. The process of invasion is often complex, resulting in considerable scientific uncertainty. Invasive species are in part a symptom of land use and climate change, as well as a result of the globalization of trade, travel, and transport. Implementing effective prevention and control measures may be costly and require new policy approaches, as well as significant advances in ecological knowledge and natural resource management.

Although terrestrial invasions have received much attention, the presence and impacts of invasive species in marine environments are little known in comparison. The marine patterns and trends of invasive species, with particular attention to coral reef ecosystems, were addressed at the 9th ICRS.

State of Knowledge

Vulnerability: Temperate vs. Tropical Systems

In temperate marine systems, invasive species are well-documented causes of environmental disturbance, disrupting native communities and having a negative impact on fisheries. Less is known about the impact of invasive species in tropical marine environments, especially on coral reef systems. Recent evidence from surveys in Australia, Hawaii, and Guam dictate that tropical and subtropical areas are also susceptible to invasion, but that the detection of invasive species may be hampered by our inability to make quick and accurate taxonomic identifications. Furthermore, most of the studies undertaken thus far have been limited to surveys in harbors and ports, where environmental conditions are usually quite different from those required by reef-building corals.

The Invaders

Non-native organisms, representing a wide variety of species, have been detected in virtually every marine environment. In the Hawaiian Islands alone, nearly 340 non-native species have been found in marine and brackish waters. Because the introduction of these organisms is influenced by human activities, non-native species are frequently associated with artificial substrates or harbors.

While the majority of non-native species remain confined to these areas, others invade into nearby habitats, including coral reefs. Some species spread, establishing populations

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along coastlines and throughout island chains. Artificial substrates and harbors are, thus, both "hot spots" and epicenters of marine invasion.

Some types of invasive species are able to spread faster than others. The establishment and rate of spread of a species depends on several factors – for example, the biological characteristics of the organism, the physical nature of the environment, and the types and rates of movement along invasion pathways (see "pathways" below).

Many invasive species possess biological characteristics that enable them to produce large qualities of offspring (typically larvae), as well as tolerate wide ranges and large fluctuations in temperature, salinity, and water quality. In addition, the invasive species might also have specialized strategies for asexual reproduction, herbivore or predator resistance, or competition.

Invasive species are more likely to establish and spread if they are moved into environments that are physically similar to systems in which they evolved or systems in which the species composition has already been severely disturbed. From the perspective of the invader, important physical characteristics of marine systems may include: tolerable water chemistry and quality, availability of appropriate substrates for colonization, and connectivity to habitats needed for reproduction and the growth of different life-history stages.

Pathways of Invasion

Pathways are the routes by which invasive species are moved from one location to another, whereas *vectors* (or *modes*) are the specific means of transport in or on which invasive species travel. One pathway may involve numerous vectors.

Sometimes invasive species are moved intentionally (someone wants to do something with the organism), while other movements are unintentional (someone wants to do something with another product and the invasive comes along as a "hitchhiker" or "stowaway").

Common marine pathways/vectors include:

Intentional: releases and escapes from aquaculture, mariculture, and aquaria; as well as fisheries stock enhancement (sport and commercial).

Unintentional: ballast water discharge, hull fouling, oil platform relocation, or as accidental "hitchhikers" associated with intentional releases.

For many specific localities, the dates and pathways of invasion are unknown. This can make determining the species' geographic origin, and thus its identity, very difficult.

Sometimes marine invasives carry parasites, pathogens, and other associated organisms along with them, further compounding the ecological and economic problems.

Implications for Management and Policy

- *Ecological Impacts:* Invasive species are known to displace, out compete, or prey upon native species. They may also spread pathogens and parasites. The negative impacts can cascade throughout the entire food chain.

- *Socio-economic Consequences:* When invasive species negatively impact commercially desirable native fish, fisheries catches and profits decline. For some Small Island Developing States, declines in fisheries may also mean increased challenges in meeting local consumption needs. In recent years, the aquaculture industries (for example, shrimp farming) have been particularly hard hit by introduced diseases, resulting in significant economic losses and unemployment. Coral reefs dominated by invasive species may be less attractive to tourists, and thus threaten the stability of communities that are heavily dependent on eco-tourism.

- *An Example of Impacts from Hawaii:* In Hawaii, many non-native algal species have undergone massive blooms, spreading rapidly and creating large beds composed of a single species of non-native algae. The once highly diverse and complex coral reef ecosystem is completely modified. "Habitat shifts" such as these have a direct, negative impact upon the US $800 million per year that Hawaii earns from marine tourism. Furthermore, some of the algae pile into windrows on beaches, causing public health concerns and additional impacts on tourism.

Specific Recommendations for Action

- Raise awareness of the problem with governments, relevant industries, and local communities (especially those closely associated with coral reefs).
- Encourage the enforcement and strengthening of policies that seek to minimize the spread of invasive species in marine environments.

- Build stronger capacity for the identification of marine invasive species. This includes enhanced information sharing among taxonomic experts globally, new tools for identification (including guides and molecular analyses), and training for taxonomists.
- Establish a pool of specialists interested and willing to make species identifications as expeditiously as possible, a program for voucher specimens to be deposited in dedicated museums, and a rapid response system to investigate new and unusual sightings.
- Establish scientifically-based risk assessments and risk management programs for the introduction of marine organisms.
- Support and undertake studies of the presence and impacts of invasive species on coral reef systems, as well as methods to prevent and control invasion. Biological, social, and economic impacts should be considered. Environmentally-sound control should be emphasized.
- Reduce the vulnerability of coral reef systems to invasion by minimizing pollution, sedimentation, and physical degradation.

Useful References and Resources

This synthesis was prepared from papers presented at the *9th ICRS, Mini-Symposium E8 Coral Reef Non-indigenous and Invasive Species*. Authors and titles of presentations can be found at www.nova.edu/ocean/9icrs

Coles, S.L., R.C. De Felice, LG. Eldredge, and J.T. Carlton. 1999. "Historical and recent introductions of non-indigenous marine species into Pearl Harbor, Oahu, Hawaiian Islands." *Marine Biology* 135:147-158.

Eldredge, L.G. 1987. "Coral reef alien species." Pages 215-228 in Salvat, B. (ed.). 1987. *Human impacts on coral reefs: facts and recommendations*. Antenne Museum E.P.H.E., French Polynesia.

Eldredge, L. G., and C. M. Smith. 2001. *A guidebook of introduced marine species in Hawaii.* Bishop Museum Technical Report 21.

Hutchings, P. 1999. "The limits of our knowledge of introduced marine invertebrates." pp. 26-29 in the other 99%. *The conservation and biodiversity of invertebrates.* Transactions of the Royal Zoological Society of New South Wales.

Checklist of Hawaiian marine invertebrates [each species noted as native, introduced or cryptogenic]. www2.bishopmuseum.org/HBS/invert/list_home.htm

Marine invasions in Hawaii. www.botany.hawaii.edu/Invasive/default.htm

National Invasive Species Council. 2001. National Invasive Species Management Plan. www.invasivespecies.gov.

Crown-of-thorns and Other Coral Predators

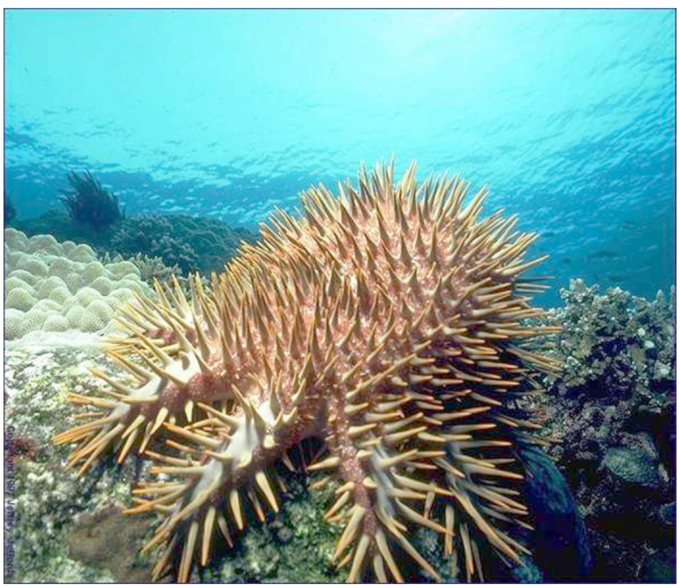
Ian Miller [1]

Statement of Issue

THE crown-of-thorns (COTS) starfish (*Acanthaster planci*) is a coral predator. This starfish may form aggregations, termed outbreaks that far exceed the carrying capacity of their coral prey. Since this discovery in the 1950s, COTS have been found responsible for mass mortality of hard corals throughout the Indo-Pacific. Two species of the Muricid gastropod *Drupella* (*D. cornus* and *D. rugosa*) are also coral predators. To a lesser extent, *Drupella* outbreaks have also caused mass mortality of corals in the Indo-Pacific. Despite years of research no single cause of outbreaks has been found.

State of Knowledge

Papers presented at the 9th International Coral Reef Symposium provided the following results:



Crown-of-thorns starfish (*Acanthaster planci*) devours hard coral in Batangas, Philippines

Photo: Jeffrey Jeffords, divegallery.com

- *Drupella* will "switch" in food preference. When preferred food corals die from a bleaching event, *Drupella* then feed on surviving non-preferred coral species.
- *Drupella* can adapt their behavior to compensate for large variations in seawater temperature.
- COTS outbreaks appear to originate from a source population (primary outbreak) and then spread (secondary outbreaks) by planktonic larvae on prevailing water currents.
- On those reefs subjected to COTS outbreaks the ability of the coral community to recover will depend strongly upon the disturbance regime of the area in question.
- Many populations of demersal fish species remain relatively unaffected by COTS outbreaks.
- COTS growth is indeterminate and they can change size depending upon food availability.
- There is circumstantial evidence that the removal of fish predators is a factor promoting COTS outbreaks in the Red Sea.
- COTS in the Red Sea are genetically divergent from other northern Indian Ocean populations.

Management Implications

The importance of outbreaks to the coral community and hence to the long-term health of the reef ecosystem cannot be underestimated. COTS and *Drupella* selectively feed on fast-growing corals. If feeding pressure is low, or if there is enough time between outbreaks, the removal of fast growing corals creates space for slower growing and rare corals to persist helping to maintain species diversity on reefs.

Repeated outbreaks can lead to the degradation of reefs. For reefs under stress (for example, nutrient loading, sediment, overfishing and elevated temperatures) which have less capacity to recover, outbreaks of corallivores can lead to fundamental changes in community structure. This is of particular concern given the threat that global climate change poses to coral reef ecosystems. Striking a balance that maintains reef health and hence the ability of a reef to recover from disturbance (such as a COTS outbreak) is of major concern for managers.

Specific Recommendations for Action

- Address overfishing and nutrient enhancement due to terrestrial runoff, which have been implicated as possible

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causes of outbreaks. Though the exact role that human modification of the environment plays in the initiation of outbreaks remains debatable, in neither case is over-fishing nor excessive terrestrial run-off considered desirable for maintaining reef health.

- Establish integrated monitoring programs that gauge local impacts due to fisheries, changes to water quality, and the effects of coral predators. Monitoring will provide a 'benchmark' that gives managers a basis for making decisions on what levels of use are acceptable for a given management situation. It also provides the background against which managers can target research to address their particular needs. Ongoing monitoring studies are essential for the informed management of coral reefs. They must be based on sound sampling designs that are clearly defensible.

Useful References and Resources

This paper is based upon presentations at the 9th International Coral Reef Symposium, Mini-Symposia E9, *Acanthaster and Drupella on Reefs*. Authors and titles of presentations can be found at:
www.nova.edu/ocean/9icrs/

Birkeland C.E and Lucas J.S 1990 *Acanthaster planci : major management problem of coral reefs*. CRC Press, Boca Raton, Florida. 257p

Sapp J 1999 *What is natural? : coral reef crisis*. Oxford University Press, 1999. New York. 275 p.

English, S., Wilkinson, C. and Baker, V. (1997) *Survey Manual for Tropical Marine Resources* (2nd Edition). Australian Institute of Marine Science. Townsville.

Functional Roles of Sponges on Coral Reefs

Janie L. Wulff [1]

Statement of the Issue

ALTHOUGH a small group of carbonate excavating sponges can dismantle reefs, and some sponges can overgrow corals, it is now known that sponges also substantially benefit coral reefs and associated ecosystems. Sponges benefit reefs by efficiently filtering small (<5um) organic particles from the water column, binding live corals to the reef frame, facilitating regeneration of broken reefs, providing food for spongivores, sheltering juvenile crustaceans such as spiny lobsters, and harboring nitrifying and photosynthesizing microbial symbionts. Sponges uniquely perform many of these functional roles, and possibly others not yet known. However, sponges have not been included in most monitoring programs and assessments due to difficulties in identification and quantification. At the 9th ICRS, it was agreed that greater attention should be focused on sponges and their roles in reef function, particularly in light of recent documentation of rapid losses of sponges from coral reefs and closely associated ecosystems.

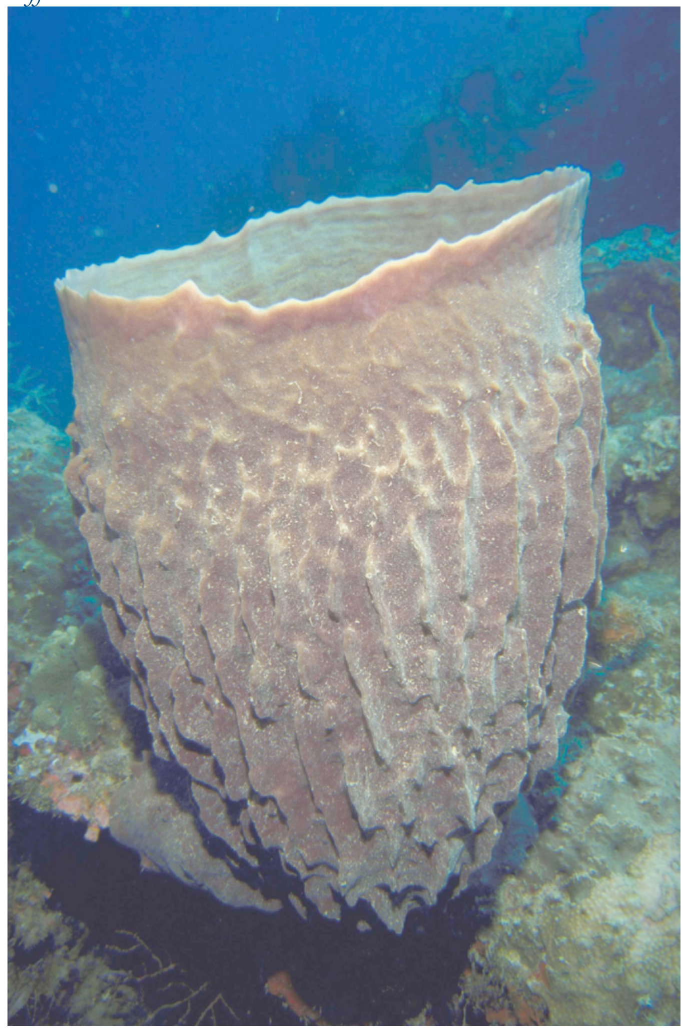

Photo: Gerald R. Allen

Barrel sponge on patch of reef in Raja Ampat, Indonesia

State of Knowledge

Interrelated aspects of the functional roles of sponges on coral reefs can be categorized as (1) interactions with unicellular organisms as symbionts, pathogens, and food; (2) interactions with macroscopic organisms as mutualists, competitors, and predators; and (3) distribution and abundance patterns on geographic and habitat scales.

1) Interactions with unicellular organisms as symbionts, pathogens, and food: Sponges simultaneously feed on, are inhabited by, and suffer disease caused by microorganisms, and it is not known how, or even if, these different interactions influence each other. Concern that sponge disease may be increasing is raised by recent documentations of dramatic losses of sponges from a diverse sponge community in Panama, from large areas of Florida Bay in the USA, from a population of a common species in New Guinea, and from various populations of a conspicuous species throughout the Caribbean. Losses from coral reefs of commercially harvested species to disease have previously been documented. Disease may also be devastating other sponges, but it is difficult to determine because long-term monitoring of sponges in permanent quadrats is rare, and sponges can die and deteriorate quickly, rendering losses invisible without prior detailed site-specific information.

Symbionts of a wide variety of unicellular taxa have become associated with sponges, apparently benefiting both partners in some cases, and influencing the entire system by contributing biochemical talents not inherent to sponges. Some sponge disease might be caused by

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normally beneficial or benign microbial symbionts, if environmental conditions change such that associations are no longer favorable.

It is not known if vulnerability of sponges to microbial pathogens is influenced by their constant internal exposure to water column microbes by feeding currents, or if sponges can consume potential pathogens. Ecosystem level importance of efficient water column clearing by sponges as they feed, first demonstrated by Reiswig, is confirmed by cascading problems associated with recent sponge die-offs in Florida Bay.

2) Interactions with macroscopic organisms – mutualists, competitors, and predators: Apparently more than other reef organisms, sponges live intimately associated with a variety of sessile and mobile organisms, which may significantly influence the success of both partners. Negative repercussions of losses of sponges engaged in these associations range from the loss of juvenile spiny lobster shelter to dramatically increased coral mortality. Some interactions of sponges, especially with predators and competitors, are mediated at least in part by chemistry; presumably the intriguing bioactive chemistry of sponges, that has made them so interesting to pharmaceutical developers, has evolved in this context of protection from potential enemies. Understanding the ecological context for evolutionary development of novel chemistry, e.g., deterence of specific predators or pathogens, can help to focus attention on potentially useful species and contribute to understanding the mechanisms of evolution of bioactive chemistry. However, while pharmaceutical interest in sponges can provide additional sources of funding and impetus for biodiversity conservation, it also raises serious concerns about resource ownership and irresponsible collecting practices.

3) Distribution and abundance patterns on geographic and habitat scales: Surprising results from studies of geography of species boundaries and similarities among sponge assemblages caution us to take care in inferring connections between distant sites. Geographic history plays a large but not a readily predictable role in determining how closely related faunas of adjacent regions or provinces are. High estimates of degrees of endemism, which will increase much more if cryptic species continue to be identified at the present rate, compel us to pay attention to details of distribution data in the design of protected areas aiming to conserve diversity. On a smaller spatial scale, local physical features and environmental factors are more important in determining differences among adjacent local faunas. Understanding constraints on distribution of sponges in adjacent habitats can serve as the basis for using sponges as environmental indicators; sponges may be especially useful for habitats in which stresses (for example, turbidity, storm waves, predators) are difficult to evaluate directly because they are intermittent. Understanding how the reef dismantling action of excavating species may be enhanced by human activities, especially nutrient overloading, may be of particular importance in some areas.

Chief concerns about sponges include: 1) the extent of disease may be increasing, but is not documented due to inadequate monitoring; 2) what appear to be large populations of wide-spread species may actually be more vulnerable small populations of distinct species; 3) environmental change may alter associations with symbionts and other intimately associated organisms; and 4) sponges may play additional functional roles not yet

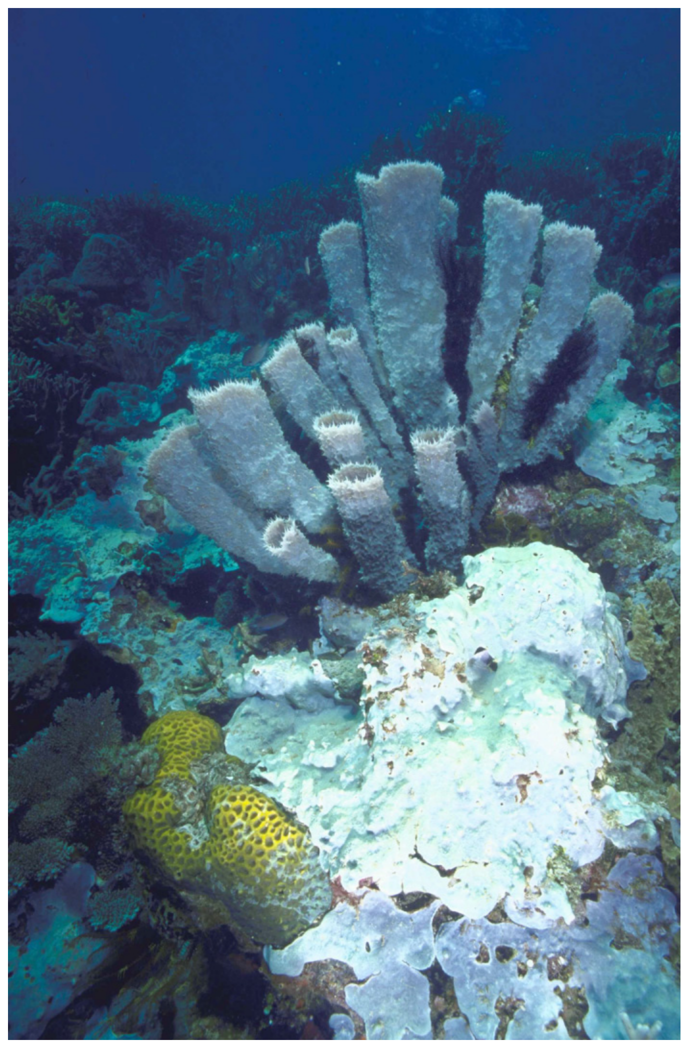

Photo: Roger Steene

Sponges with crinoids and corals on reefs of the Calamaines Islands, Philippines documented but yet vital to reef health – some of the roles that sponges play on reefs that now seem obvious were unknown a short while ago.

Management and Policy Implications

Priorities for sponge monitoring and assessment include:
- keeping track of the abundance of sponges and signs of disease;
- documenting boundaries of species and of faunal assemblages so that appropriate areas can be protected;
- learning about specific constraints on sponge distribution in order to make use of sponges as environmental monitors; and
- continuing to learn about functional roles of sponges on coral reefs.

Specific Recommendations for Action

Careful taxonomy is necessary for clear communication about using particular species as environmental indicators, for bioprospecting, and for determining species boundaries and degrees of endemism for conservation purposes. Guidance for taxonomy can be found in Rützler (1978) and Hooper & van Soest (in press). Emphasis should be given to training the next generation of taxonomists, and incorporating sponge identification in training modules for monitoring.

Permanent transects or quadrats must be used for monitoring sponges if there is any possibility that disease is an issue, because diseased sponges can disappear quickly, without a trace. While repeated random sampling can be demonstrated to provide statistically reliable results, it does not provide confident information on disappearance of organisms between sampling dates and is not adequate for monitoring sponges. Guidance for various aspects of monitoring can be found in Rützler (1978) and Wulff (in press).

The volume of sponges present in an area—even crudely estimated—is a better measure of their abundance than percent cover or number of individuals. Sponges consume food (clearing the water column), provide food for spongivores, and possibly even bind live corals and broken corals to the reef, in proportion to the volume of live sponge present on the reef.

Sponges living within crevices and under corals can be quite abundant, filter seawater efficiently, and may be especially important in enhancing coral survival and stabilizing coral rubble. However, cryptic sponges are invisible to video and other photographic monitoring methods and so must be assessed and monitored more directly.

Useful References and Resources

This paper is based upon papers and posters presented at the 9th ICRS, in Symposium A15, *Functional Role of Sponges on Coral Reefs*, as well as in minisymposia on Bioerosion and on Biogeography.

Rützler, K. 1978. In: Stoddart, D.R. & Johannes, R.E., eds. *Coral Reefs: Research Methods. Monographs on Oceanographic Methodology 5*, UNESCO, Paris: 299-313.

Diaz, C., Rützler, K. in press. "Proc. Int. Conf. on Scientific Aspects of Coral Reef Assessment, Montoring, and Restoration." *Bull. Mar. Sci.*

Wulff, J.L. in press. "Proc. Int. Conf. on Scientific Aspects of Coral Reef Assessment, Monitoring, and Restoration." *Bull. Mar. Sci.*

Hooper, J.N.A, van Soest, R.W.M. in press. *Systema Porifera.*

Requests for help with any aspect of sponge biology, ecology, systematics, chemistry, and monitoring, can be addressed to an internationally subscribed Sponge List at: www.PORIFERA@JISCMAIL.AC.UK

Targeted, Applied, and Systematic Research to Benefit Coral Reef Management

Anthony J. Hooten [1]

Statement of Issue

ONE of the most significant challenges facing all nations with coral reefs and associated resources is to clearly understand the impacts from changes in climate versus local human activities, and to use this information effectively in protecting their products and services. Over the past 30 years, the volume and diversity of information about coral reefs has steadily increased, and efforts are underway to enhance management based upon the knowledge already gained. However, significant gaps in our basic understanding of coral reef ecosystems remain, and management will eventually be limited without advancement in scientific understanding (Knowlton 1998; Buddemeier and Smith 1999). Coordinated, scientific frameworks are needed that can generate relevant information to advance the capacity of management, whether through social or natural resources management interventions. Discussions were held at the 9th ICRS and other venues as to the nature and scope of targeted, applied and systematic research that is needed to benefit coral reef management

Shallow reef coral with fish

Photo: Gerald R. Allen

Background and State of Knowledge

Since 1998, the World Bank has conducted a series of consultations with scientists in various regions around the world, including at the 9th ICRS, with the purpose of developing priorities for targeted investigations that will benefit management and policy: to examine root causes and differentiate global trends (such as increases in sea surface temperature, changes in chemical and nutrient cycles, persistent organic pollutants, increases in disease frequency) from localized anthropogenic effects (such as sediment loading, resource extraction and nearshore pollution).

The number of outstanding questions about coral reef ecosystems far exceed the scope of this summary; however, some key questions with practical implications for management include the following:

- Are factors surrounding climate change more critical to coral reef condition than local, anthropogenic stresses?
- Will coral reefs be resilient in the face of projected climate change over the next 50-100 years?
- What will be the final state of coral reefs and associated ecosystems if coral abundance decreases dramatically over time?
- How can we measure resilience in coral reefs? To what degree do Marine Protected Areas contribute toward resilience and maintenance of biodiversity?
- If a coral reef experiences a phase shift, is it permanent? If not, how long might it last? Are there ways to reverse the changed state?
- How fast will change occur within coral reef ecosystems? Do coral reefs experience net erosion when corals are no longer predominant? If so, how rapidly?
- What are the most important factors influencing recovery? Can people help facilitate recovery?

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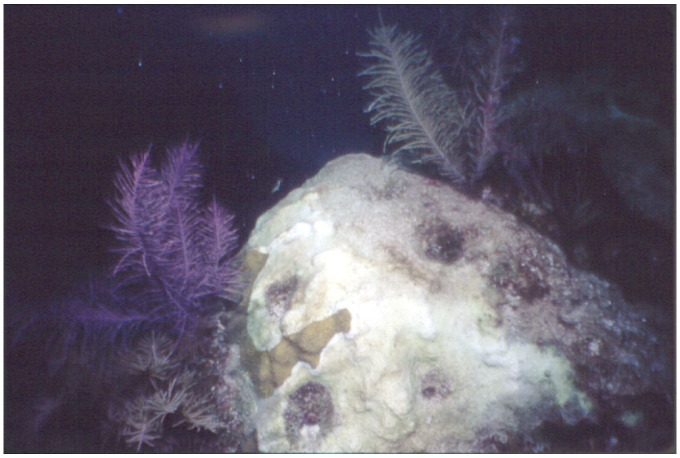

Photo: Laurie L. Richardson

Plague type III on *Montastraea annularis*. (Colony shown is >2 m diameter.) Plague has emerged in three forms on reefs of the Florida Keys. The latest form, type III, targets the largest colonies of *Montastraea annularis* and *Colpophyllia natans*. This is one of the most virulent of coral diseases and has recently spread to the Caribbean. It is caused by a pathogenic gram-negative bacterium that may be a new genus.

- In addition to temperature, to what extent is coral bleaching affected by other factors, such as light, sediment, nutrients, and pollutants (and in what combinations)? Will the presence of other stresses accelerate or retard bleaching?
- Why are some corals more immune to stress than others?
- Why are coral diseases more prevalent in some regions than others? Will diseases expand to other regions?
- How rapidly do larvae from adjacent or other reefs repopulate coral reefs?
- What is the relationship between distance and larval transport? Between coral and fish larvae and spawning aggregations?
- To what degree do other species depend on the structure created by corals?
- To what degree is maintenance of species diversity crucial to coral reef health?

Why do so many fundamental questions remain? Because coral reefs are complex, dynamic systems. The organisms that comprise them and the parameters that influence them combine to regulate their abundance and distribution at spatial scales ranging from microns to kilometers, and on time scales ranging from minutes to decades (Hughes, et al. 1999; van Woesik 2001). These multiple variables are also compounded by the complexities of human interactions by taking material away from (for example, over-fishing) or adding to (for example, pollution) coral reefs. Such factors present significant challenges in designing investigations that will provide meaningful answers to managers and policy-makers within a reasonable period of time. But even over the past 20 years the coral reef scientific community has, other than document decline, failed to collectively address the appropriate responses and information demands concerning coral reefs in many regions of the world (Risk 1999). Targeted, coordinated and systematic investigations have the potential to focus on the gaps in our knowledge about coral reefs, so that we may better relate information to management actions appropriately, and cost-effectively, to protect them (Done and Lloyd 1999; Scully and Ostrander 2001; Nyström et al. 2001).

Specific Recommendations

The recommendations stemming from the majority of consultations reinforce that while significant changes are obvious in many coral reefs, the root causes of these observed changes are still not well understood. The majority of the consultations were consistent in listing similar outstanding questions about coral reefs (see Background and State of Knowledge on previous page).

- Most researchers agreed that specific investigations are needed to improve basic understanding of coral reef biophysical processes that influence coral reef environments, community responses to disturbance, and resilience capacity.
- Investigations should include a range of screening, monitoring and experimental design, testing specific hypotheses, and investigating multiple variables.
- The majority of researchers stressed the need for longer-term studies (at least 10 years), to better understand temporal and spatial variability in population dynamics and recruitment, and how this information can be applied in a management context.
- Marine Protected Areas (MPAs) were also consistently identified as a potential focus to quantify their effectiveness in protecting habitat and fisheries.

Relevant Actions Being Taken

Based on the series of consultations, the World Bank is further developing the Targeted Research program with funding sought from the GEF and other co-financiers. Further discussion with potential co-financiers will also be taking place during this period to address the following actions:

- Promote the establishment of targeted research networks between governments and institutions that can leverage information and resources to strengthen the applied scientific information base specifically for the benefit of management and policy.

- Proceed with the completion of the project proposal to the Global Environment Facility for Targeted Research under the operational programs for International Waters and Biodiversity.
- In conjunction with the proposal, develop partnership arrangements with other interested research institutions and foundations in expanding targeted research sites worldwide.
- Identify and recruit qualified representative researchers to participate in thematic subgroups that will contribute to a guiding panel to synthesize research, revise targeted investigative priorities and help guide management interventions.

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Scully, E. P. and G. K. Ostrander. 2001. "Corals and phase shifts-Letters," *TRENDS in Ecol. & Evol.* Vol 16 No. 3, March 2001. Pp 126-127

Scientific and Technical Cooperative Agreement in the Area of Coral Reefs between the Australian Institute Of Marine Science and the Great Barrier Reef Marine Park Authority both of The Commonwealth of Australia and the National Oceanic and Atmospheric Administration of the United States of America. http://orbitnet.nesdis.noaa.gov/orad/sub/sub_pdf/crbpub_au_us_arrangement.pdf

CORDIO: Coral Reef Degradation in the Indian Ocean: www.cordio.org

Coral Reefs and Global Change: Adaptation, Acclimation or Extinction? The purpose of the workshop was to review and synthesize findings of various aspects of coral reef research with implications for research, assessment, and management. The several key recommendations developed from this workshop were echoed by the series of consultations that have followed to date. Please visit Web site at: http://coral.aoml.noaa.gov/themes/coral_cg.html.

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Designing and Implementing Effective Marine Protected Areas

Michael B. Mascia,[1] Leah Bunce,[2] Ghislaine Llewellyn,[3] and Meriwether Wilson [4]

Statement of Issue

MARINE protected areas (MPAs)—including underwater parks, fishery reserves, wildlife sanctuaries, and the like—are an increasingly popular policy instrument designed to conserve coral reefs and sustain reef benefits for society. A marine protected area (MPA) is "any area of the intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment" (IUCN, 1988). Explicit reference is made to "no-take" MPAs (that is, MPAs where no extractive uses are permitted) when discussions are restricted to this particular category of MPAs. MPAs have been demonstrated to increase coral reef fish and invertebrate abundance, biomass, and species richness, as well as redistribute stakeholder access to reef resources and thus redistribute wealth in coastal communities. The promise of MPAs as a tool for biodiversity conservation and sustainable development has yet to be fully realized, in part because both the natural and social science underlying effective MPA development and management are poorly understood. Presentations at the 9th ICRS underscored the scientific uncertainty that surrounds the biophysical design of MPAs, but provided some basic guidance for policymakers.

Photo: Barbara Best

Manager and assistant proudly display the results from community-based fish surveys at Gilutongan Marine Sanctuary, Cebu, Philippines

State of Knowledge

Siting of MPAs

There was general agreement that coral reef MPAs should be established in high quality habitats located either in the midst of ocean gyres or in "upstream" locations. Research indicated that coral reef MPAs are more likely to function as relatively independent units than interdependent ecological systems, especially over large spatial scales. Research also indicated that the biological performance of "no-take" MPAs is not correlated with their spatial extent, suggesting that bigger is not necessarily better. Presenters noted that reef management efforts, including individual MPAs and MPA networks, must match the scale of relevant ecological processes to sustain ecosystem goods and services.

Several presentations provided insights into the sociopolitical characteristics of effective coral reef MPAs. MPA effectiveness depends upon the larger matrix of coral reef management initiatives. If adjacent areas are not well managed, MPAs will be less likely to maintain productive coral reef ecosystems. Devolving authority for MPA development and management to local governments, user groups, and non-governmental organizations spurs MPA establishment and enhances MPA management effectiveness. Collaborative MPA management structures, however, appear to offer the greatest potential for linking national resources with local interests and knowledge.

Emerging Best Practices

The rules governing resource use within coral reef MPAs must be clear, easily understood, and easily enforceable.

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Likewise, internal and external MPA boundaries must be easily recognized by resource users and by enforcement personnel.

MPA decision-making must be an adaptive and broadly participatory process. Such processes permit social learning, draw upon diverse sources of knowledge, build trust, and enhance the legitimacy of MPA rules and regulations. Exactly *how* and *when* participation should occur was a matter of contention. Mechanisms must be established to ensure that stakeholder representatives are accountable and responsive to their constituents. Finally, differences among stakeholders with respect to their beliefs (that is, perceptions of how the world works), values (that is, perceptions of what is good, desirable, or just), and interests (that is, desired outcomes) often hinder MPA development and management, reflecting the need for decision-makers to agree on *process* before trying to decide *outcomes*.

MPA Management and Administration
Clear management goals and objectives, as well as environmental education and outreach initiatives, facilitate effective MPA management. Devolution of authority for enforcement could enhance capacity; there is a need to design enforcement systems that promote accountability among enforcers and appropriate (not draconian) penalties for noncompliance with MPA rules and regulations. It is important to monitor both biological *and* social performance indicators, collecting baseline data, and sampling at multiple spatial and temporal scales. These monitoring activities should inform site development, measure change over time, and provide the basis for adaptive management. Enlisting stakeholders in the collection and analysis of research and monitoring data educates participants and builds capacity and trust.

Relevant Actions Being Taken to Address the Issue

In recent years, scientists and practitioners have focused tremendous effort upon the development and management of effective coral reef MPAs. Local, national, and international conservation organizations and government agencies are actively working to develop effective coral reef MPAs in dozens of countries around the world. The ecological theory of ecological no-take MPAs has been exhaustively reviewed by an international team of scientists under the auspices of the National Center for Ecological Analysis and Synthesis (NCEAS) in the United States (Web site: http://www.nceas.ucsb.edu). The social theory of coral reef MPAs is in its infancy, but promising research initiatives are underway in the United States and abroad.

Management and Policy Implications

Scientific research on the development, management, and efficacy of MPAs has significant implications for coral reef MPA policy and site management. Incorporating the best natural and social scientific knowledge available into coral reef MPA development and management as "working hypotheses" does not guarantee site effectiveness, but it should increase the probability of success. The following section outlines select recommendations for coral reef MPA development and management, based on the scientific evidence presented at the ICRS.

Specific Recommendations for Action

- *Remember the surrounding environment.* As one of many coral reef management tools, MPAs should be designed to complement existing fisheries management and integrated coastal management initiatives. MPAs alone may be insufficient to conserve biodiversity and support productive and sustainable fisheries.
- *Place MPAs where they have a chance to work.* High quality habitat is essential for MPAs to conserve marine biodiversity and support sustainable fisheries.
- *Focus on effectiveness.* If well designed and managed, smaller MPAs can provide greater benefits than poorly designed and managed larger MPAs.
- *Target MPAs at relevant scales.* Conservation efforts need to match the scale of ecological processes and human activities that threaten these processes. Because larval dispersal appears to be a more localized phenomenon than earlier recognized, MPAs separated by long distances are unlikely to serve as part of a functionally interconnected whole.
- *Share authority for MPA establishment.* National governments can stimulate development and establishment of MPAs by sharing their authority to designate MPAs with local governments, non-governmental organizations (NGO), and resource users.
- *Share authority for MPA management.* Delegating full or partial responsibility for MPA management to NGOs, user groups, or local communities can enhance site effectiveness.
- *Make MPA rules and boundaries clear.* Clear MPA boundaries and clear rules governing MPA resource use facilitate compliance and simplify enforcement.

- *Encourage adaptive decisionmaking.* If a MPA is not meeting its policy objectives, decision-makers should not hesitate to revise the rules governing MPA resource use and decisionmaking in an effort to enhance performance.
- *Encourage participatory decisionmaking.* Bringing diverse stakeholder groups into MPA decisionmaking processes can improve the substance and legitimacy of these decisions.
- *Make stakeholder representatives accountable to their constituents.* To ensure that representatives further constituent interests rather than their own, establish mechanisms (for example, elections, consultative sessions, or open meetings) to foster accountability.
- *Decide on process before deciding on substance.* Identifying basic rules and criteria for decisionmaking (i.e., process guidelines) before attempting to make substantive choices about MPA rules and regulations may help to reduce conflict and facilitate informed choices.
- *Share authority for enforcement.* Enlisting the aid of resource users and others in MPA enforcement efforts will enhance enforcement capacity and likely increase compliance with MPA rules and regulations.
- *Build accountability into enforcement.* Establishing mechanisms to ensure that enforcement personnel are accountable for their actions will foster more fair and active enforcement of MPA rules and regulations.
- *Make punishment fit the crime.* Excessive penalties for noncompliance undermine the legitimacy of the enforcement system and encourage further noncompliance.
- *Establish advisory committees.* The guidance of broadly representative advisory groups enhances MPA effectiveness through improved decisionmaking and increased legitimacy.
- *Set goals and rank threats.* Setting goals and ranking the threats to achieving these goals facilitates identification and prioritization of necessary management responses.
- *Collect social and biological baseline data.* Baseline data can enhance MPA effectiveness by informing the design of both biophysical and governance systems. The presence of social and biological baseline data also permit more accurate measurement of MPA performance.
- *Measure both biological and social performance.* MPAs usually have both biological (e.g., maintain viable fish stocks) and social (e.g., enhance livelihoods of fishermen) objectives, so it is critical to measure both biological and social performance indicators in order to evaluate MPA effectiveness over time.
- *Sample wisely.* Data must be gathered at socially and ecologically relevant temporal and spatial scales in order to inform adaptive MPA management.
- *Make research and monitoring participatory.* Enlisting stakeholders in data collection and analysis educates participants, builds capacity, and fosters trust.

Useful References and Resources

This synthesis is drawn largely from Mascia, M.B. 2001. *Designing Effective Coral Reef Marine Protected Areas: A Synthesis Report Based on Presentations* at the 9th International Coral Reef Symposium. Special Report to the IUCN World Commission on Protected Areas – Marine. Washington, DC: International Program Office, National Ocean Service, National Oceanic and Atmospheric Administration.

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Ecological Applications special issue (in press) on ecological theory of marine reserves.

Scientific Consensus Statement on Marine Reserves and Marine Protected Areas. Web site: www.nceas.ucsb.edu

Marine Affairs Research and Education. Web site: www.mpanews.org

Examples of Coral Reef Management: Great Barrier Reef

Alison Green [1]

Statement of Issue

THE Great Barrier Reef (GBR) is the largest coral reef ecosystem and marine protected area in the world. The GBR is a multiple use Marine Park (343,500 square kilometers {km^2} in area), of which 4.7 percent (15,991 km^2) is a "no take area." It is also the largest World Heritage Area, and one of the few that meets all four natural world heritage criteria.

The Great Barrier Reef Marine Park is widely recognised as one of the best-managed coral reef ecosystems, and it is often used as a model for other marine protected areas. There are several reasons why the GBR is considered well-managed, including the fact that this huge area is under one system of management lead by the Australian Government's Great Barrier Reef Marine Park Authority (GBRMPA). Presenters at the 9th ICRS described GBRMPA's approach to management, and how managers and scientists work together to provide the best scientific information for management.

A Marine Park boat berths next to a fishing vessel

Photo: Great Barrier Reef Marine Park Authority

State of Knowledge

GBRMPA has been managing the Great Barrier Reef Marine Park since it was established in 1975, and has learned many lessons about how to manage coral reefs, having tested and used a variety of management techniques over the last 25 years. One important lesson has been that management must be adaptive and able to keep changing in response to new information and emerging needs.

Another important lesson has been that coral reef management requires a strong legal framework. As a result, management of the Marine Park involves the use of a combination of management tools including the *Great Barrier Reef Marine Park Act*, zoning plans, reef-wide policies, permits, plans of management, and regulations.

The GBR is also considered to be well managed because there is a strong scientific basis for management, since Australian reefs are among the most studied and monitored in the world. The reefs are also generally in good condition, although some areas have been impacted by human activities.

The good condition of most reefs on the GBR is not entirely due to management. Many reefs are a long way offshore and receive some degree of protection by their distance from land. Coastal human populations, and their associated pressures on the marine environment, are also lower than in many other countries where reefs occur. While that may be true, there are still some critical issues threatening the Great Barrier Reef Marine Park and World Heritage Area which need to be addressed.

Relevant Actions Being Taken to Address the Issue

Over the last few years, GBRMPA has adopted a critical issues approach to management. This has involved identifying issues believed to be critical for the successful management of the Marine Park and World Heritage Area,

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Photo: Great Barrier Reef Marine Park Authority

Tourism management of the Marine Park is a complex exercise that focuses primarily on ensuring ecological sustainability

which require a targeted management response. They are: maintaining conservation, biodiversity and world heritage values of the site, ensuring ecologically sustainable uses (especially fisheries, tourism and recreation), and reducing land-based impacts on water quality.

To address these issues more effectively, GBRMPA's institutional arrangements are structured around critical issues groups, which provide a strategic, policy-based approach to these issues. Policies developed by the critical issues groups are implemented through developing and implementing zoning and management plans, environmental impact assessment and permitting of use. Compliance, surveillance and enforcement programs are managed through a Day-to-day management unit jointly funded by GBRMPA and the State Government of Queensland. Since management actions have the potential to impact on a wide range of stakeholders, GBRMPA places a high priority on stakeholder liaison and consults with interest groups on a regular basis through a variety of committees.

Key management initiatives currently underway include:

- **Maintaining the conservation, biodiversity and world heritage values** of the site through the Representative Areas Program, which is aimed at the identification and protection of representative examples of all habitats and communities in the Marine Park and World Heritage Area. This is one of the most comprehensive and challenging projects ever undertaken by the Authority.
- **Fishing** is the largest extractive activity in the Marine Park and World Heritage Area, which includes commercial, recreational and Indigenous fisheries. GBRMPA considers that all fisheries in the Marine Park must be ecologically sustainable and if not, the Authority will seek, in collaboration with fisheries management agencies, to minimise ecological impacts. The current focus is on the trawl and reef line fisheries.
- **Tourism** is the principal commercial use of the Marine Park, and tourism management is a complex exercise with issues including access, permits and best

environmental practices. Tourism management focuses primarily on ensuring that the industry is ecologically sustainable through management of heavily used sites, industry training and best environmental practices. Future directions will focus on partnerships with industry and performance based management.

- The ecosystems of the Great Barrier Reef owe their existence and continued health to suitable **water quality** environments. However, catchments adjacent to the reef have altered extensively since European settlement, which has led to a substantial increase in sediment and nutrient input to the reef from terrestrial discharge. Pesticide residues also continue to be found in coastal ecosystems. Reduction of land based pollutant loads entering the Marine Park is seen as the most important water quality issue facing the World Heritage Area .

Science and Management

Science plays an important role in the management of the GBRMP and WHA, since GBRMPA is committed to ensuring that management decisions are based on the best scientific information available. The Authority, as a matter of policy, has chosen to obtain this information primarily from external research agencies, consultants and institutions. Therefore, it is essential that managers maintain strong links with scientists, and provide a clear indication of information needs for management.

To manage this process, the Authority has employed a group of scientists who act as information brokers between scientists and managers. Their role is to identify information needs for management, co-ordinate relevant research tasks, ensure that scientific results are presented in a way that is useful to managers, and assist managers in the interpretation of scientific issues.

While research is a major focus of the organisation accounting for a considerable proportion of the Authority's annual budget and staff time, available resources for research are limited. Therefore, it is important to ensure that they are focused on only those tasks that are directly relevant to the Authority's highest priority management needs.

In order to do this, GBRMPA has taken a proactive approach to setting the research agenda for management. Last year, the Authority undertook a detailed process aimed at clearly identifying and prioritising research needs for the critical issues management of the Marine Park and World Heritage Area.

The outcome was a comprehensive list of the Authority's high priority research tasks across all of its critical issue and major support groups. This is of great benefit to GBRMPA, because it provides a strategic framework for the Authority to make informed decisions regarding which research projects to support. It is also beneficial to scientists, because for the first time GBRMPA has taken the initiative of proactively informing scientists of our information requirements.

Given the fundamental role that the research priorities will play in setting GBRMPA's research agenda, this list will be a living document that is updated and reviewed on a regular basis to ensure that the priorities remain current and relevant to the Authority's management needs. Finally, and perhaps most importantly, managers will need to maintain a close partnership with scientists so that together we can produce the best scientific basis for the management of the Marine Park and World Heritage Area.

Useful References and Resources

This paper is based upon presentations at the 9th International Coral Reef Symposium, Mini-Symposia B6, *Managing the World's Largest Coral Reef Ecosystem.* Authors and titles of presentations can be found at www.nova.edu/ocean/9icrs/. Further information on the GBR and its management is available on GBRMPA's Web site at: www.gbrmpa.gov.au

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Great Barrier Reef Catchment Water Quality Action Plan. www.gbrmpa.gov.au/corp_site/key_issues/water_quality/action_plan/index.html

Challenges to Management of Coral Reef Ecosystems

Dave Gulko [1]

Statement of Issue

MANAGEMENT of coral reef resources has been around for centuries, practiced to various degrees by many indigenous peoples at the village and tribal level. However, management of such resources by governments at a scale beyond food-based fisheries is relatively new. With a few notable exceptions (see chapter on Australia's Great Barrier Reef), management of coral reefs at an ecosystem level is only now becoming a focused goal in many areas. The need for such an approach goes beyond the highly visible and publicly-recognized global bleaching events and regionalized disease outbreaks, and takes into account a wide suite of anthropogenic impacts which together can cause cascade effects throughout the complex trophic and symbiotic webs that characterize most coral reef ecosystems. The papers presented at the 9th ICRS synthesized the status of coral reef resources and management response at the country and regional level and highlight the need for better coordination and communication between coral reef managers.

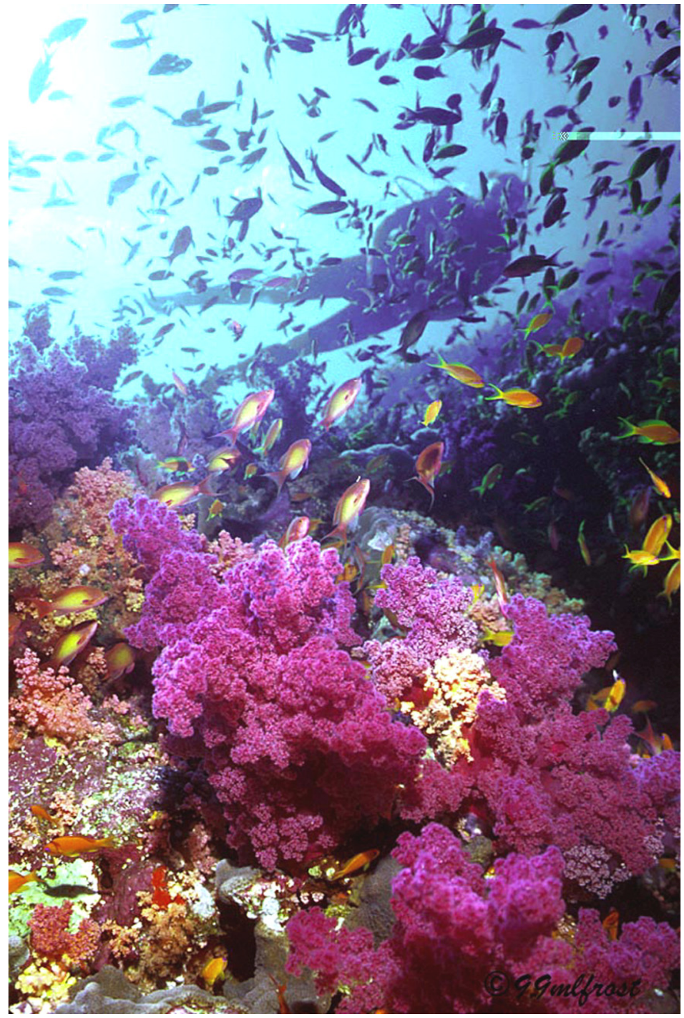

Photo: Mary L. Frost

Redsea Reefscape with pink soft corals, schooling orange anthias and the silhouette of a diver in the background, Egypt

State of Knowledge

The management issues that various resource management groups deal with can be divided into three broad categories: Intra-country, Inter-country, and Global management issues.

Intra-Country Issues

These impacts and management issues exist at a localized scale and are dealt with solely within a single geo-political framework, often by a single, local management agency, community-based management or the focal subject of a non-governmental organization (NGO). Decision-making can be either limited to select government officials or involve wide-scale public buy-in at an extremely localized level. Some issues that might be addressed at this level include dynamite fishing, cyanide fishing, alien species concerns, endemism impacts, coastal development, and deforestation.

Inter-country Issues

These are impacts and management issues that exist at a regional scale, often over-lapping a number of countries' borders and management jurisdictions. As such, they have to be dealt with by a suite of management agencies, often with the guidance of an international body or NGO. Some issues that might be addressed at this level include broad-based over-fishing, the live fish trade, *Acanthaster* outbreaks, disease outbreaks, marine debris issues, etc.

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Global (International) Management Issues
These are impacts and management issues that` occur on a scale where the impacts are experienced across a number of coral reef regions, often in more than one ocean. While these usually encompass the most well-known of impacts, and those which receive the most press coverage, these topics by their very nature often prove the most elusive to manage or to minimize their impacts on reef ecosystems. Generally, any management response that requires the creation or modification of international agreements and treaties is extremely time consuming. Some issues that might be addressed at this level include global bleaching events and international trade in marine ornamentals and corals.

Overarching Issues
Interestingly, the one management paradigm that can often transcend these three different scales is the creation of no-take reserves; not surprisingly, much discussion has recently taken place regarding this approach (please see Chapter on Designing and Implementing Effective Marine Protected Areas).

A second all-encompassing realization has been the need to shift away from species-level towards ecosystem-based management approaches. The role of ecology in marine resource management is only now starting to take on the standing that it has had in terrestrial systems for decades. The rapid loss of live coral cover in the past couple years has led to a closer inspection of the role of synergy between land-based organic pollution, sedimentation, overfishing, disease and coral bleaching. Such synergy is thought to have enhanced phase shifts on coral reefs in some areas where algal proliferation has resulted in a shift from multi-species coral reefs to reefs dominated by only a few species of fleshy algae.

Relevant Actions Being Taken to Address the Issue

Intra-country Management
In many areas, existing resource management authorities are suspected of improperly managing extractive reef resources and are resistant to effective change. Frequently, however, it is the field managers that work for, or are associated with, such authorities that are most aware of the impact problems and are raising (or at least acknowledging) this concern. This suggests that a major stumbling block to effective coral reef management at all levels is the disconnect between coral reef scientists/field resource managers and the policy makers who can change the rules/regulations. Often at the governmental level there is a substantial lag between awareness of a resource problem and ground-level management implementation, often leading to continued degradation of local coral reefs. Many areas have circumvented this issue through empowering small communities adjacent to reef resources to take an active role in their management. Usually, these efforts are associated with attempts to increase depleted local fishery resources. Throughout the tropics there are many success stories from such community-based management, but these are frequently extremely small-scale, associated with small villages, and rarely with developed coastlines or urbanized areas. Some areas are even reverting to traditional management schemes such as the Hawaiian *ahupua'a* or the Bohol Philippines' *sona*, which emphasize management of both land and sea in a small area. The success of empowering local communities to assess, monitor, and manage their coral reef resources may be dependent on the range of locally and regionally-generated impacts and the direct support provided by the regional governments and international community.

There is a recognized need to more actively involve both tourism and fishery stakeholders in government management decisions. In Florida (USA) attempts to involve such stakeholders in the planning process to designate a small, remote no-take reserve has taken over three years, and has been complicated by recreational fishing interests. In other areas such as the Philippines, country-wide stakeholders' planning meetings have been held to identify key players and emphasize the population dynamics, cultural processes, and resource use associated with decisions related to the country's coral reefs. In general, smaller countries seem to be more aware of the importance of coral reef impacts on tourism than larger countries with such resources (such as the United States); one result of this is a greater focus on the effects of land-based reef impacts in many of these countries. A twist on this is the realization by certain jurisdictions that tourism itself can serve as a major impact to coral reef resources. Such a shift in reef resource management requires a paradigm shift away from decades-old rules, regulations, and agency mandates that have focused on extractive uses towards new approaches that deal with non-extractive impacts and the economic value of the resource from an ecosystem (versus extracted species) viewpoint.

There is also recognition that rapid ecological assessments must be done in many of these areas prior to resource management decisions and policies being implemented. Such assessments catalog not only the biodiversity present in an area, but also note other important ecological factors such as reef three-dimensional complexity, biomass estimates, trophic complexity, invasive species, habitat mapping, endemism, along with anthropogenic impacts present in the surrounding area. With appropriate training, non-professionals may provide much of this data. Such volunteers may provide local and regional governments with a low-cost source of needed data to manage their coral reef resources.

Many areas are actively creating MPAs that equate broad protection over a wide area, but numerous coral reef managers professed that many of these reserves are effectively "paper parks" without active management, and most are sorely lacking in active enforcement. While zoning within MPAs appears to provide for broad user group acceptance, few effective examples exist that are well managed, monitored, and enforced. Some areas, such as Guam and Brazil are actively incorporating coastal zone management strategies into MPA planning. Recognizing the frequent failure of government to properly support marine reserves, some MPAs are starting to focus on alternative income sources to support needed management activities. For example, initiating user fees from both fishers and tourists in order to meet long-term conservation and sustainability goals.

Inter-country Management

Ineffective overfishing controls have region-wide impacts on coral reefs. Issues such as lack of coordination at a regional level, and in some cases, regional scale mismanagement of fisheries resources is contributing to difficulties in management of reef resources within individual countries.

In order to protect large-scale ecosystems or important source/sink reef areas, some regions are considering creating cross-boundary MPAs. Active discussions concerning the Mesoamerican Barrier Reef System, which extends from the Mexican Yucatan Pennisula to the Bay Islands in Honduras, may serve as a precedent for creation of regional plans to facilitate both conservation and sustainable use for transboundary ecosystems. While government commitments to such undertakings are essential, international agencies such as the World Bank, the Global Environmental Facility and others, are often critical to facilitating such action.

Many areas (Caribbean, Southeast Asia, South Pacific, North Central Indian Ocean) are promoting the need for greater efforts on a regional/international scale to educate

Photo: Alan White

Community-based monitoring with quadrat, Philippines

policy makers within both coral reef and non-coral reef countries regarding coral reef management issues. The urgency of such ecoregional planning is starting to be expressed in Southeast Asia where Indonesia, Malaysia and the Philippines have all recently produced independent Management Framework Plans that are being merged in order to effectively deal with issues related to the Sulu-Sulawesi Marine Ecoregion.

Global (International) Management

Protection of ecosystems through the designation of protected status for single coral reef species (such as *Acropora cervicornis* and *A. palmata* in the Caribbean) may have impacts on a wide scale by directly influencing industrial nations' policy decisions on international commerce, funding and technical assistance. Outside of CITES Appendix II listing for stony corals, no international legal protections currently exist that protect stony corals from a wide range of impacts outside of direct trade. Protection of coral species and species assemblages may be one of the few existing mechanisms available to almost all governments, designation of which might also benefit associated coral reef organisms and the ecosystems upon which they depend. When such protected status is made by a major industrial or financially-important government, it may play an important international educational role and may also serve to affect other countries' coral reef policy decisions from the administrative top down.

International measures often involve going before international organizations that are uneducated in regards to the importance of, or impacts to, coral reef resources. The creation of international laws, while extremely slow in occurring, may offer some of the widest positive impacts in regards to modifying behaviors at the international, regional and country level. For example, once the impacts

Photo: Coastal Resources Center, URI

Tourist destination on Lurik Island, Indonesia

of anchoring damage caused by large vessels was brought to the International Maritime Organization, the organization adopted a new rule under international law that allows countries to establish no-anchoring areas for large ships.

The trade in non-food marine products (bioprospecting and the marine ornamental trade) is starting to raise concerns regarding private industry (usually from the United States, Japan, or Europe) depleting biodiversity on isolated reefs around the globe. More than one region has raised concerns regarding such "biopiracy" leading to extirpation of unique or rare species, and has strengthened the call for regulated trade at an international level. In some areas the view is that local communities are overwhelmed by their government's improper management in accommodating private industry extraction, suggesting that solutions need to occur at an international level that works directly with community-based resource management. Creation of World Heritage Sites and Biosphere Reserves might serve to facilitate this, though in the case of the Gulf of Mannar Biosphere Reserve this has not happened, suggesting the need for greater international oversight of these important coral reef areas.

Recommendations

Lack of funding, insufficient public recognition of the impact of the problem, and (the resulting) lack of policy-maker focus on the issues are limiting effective coral reef management. While there is wide spread agreement by coral reef managers as to the effectiveness of no-take refuges, the creation and active maintenance of such refuges differs greatly amongst countries and regions. The importance of community involvement in active management of reef resources is recognized at all levels, yet tends to be most effective within single countries with isolated communities that are least impacted by industrialized/ commercialized business interests which often influence governmental decision-making.

Useful References and Resources

This paper is based upon presentations made at a symposium on International Coral Reef Management Perspectives at the 9th International Coral Reef Symposium, October 23–27, 2000, Bali, Indonesia. Authors and titles of presentations can be found at:
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Coral Reefs Fisheries

Charles Birkeland [1]

Statement of Issue

AT the 9th ICRS, presenters discussed the rapid economic and human population growth that has been putting unprecedented stress on coral reef fisheries isolated and far from urban centers, as well as those near concentrations of humans. Technological developments have allowed depletion of breeding stocks by providing the ability to harvest thoroughly and by allowing access to all previous natural refuges.


Napoleon wrasses in a cage

Photo: Mark Erdmann

State of Knowledge

Traditional Techniques
When fishers used traditional techniques, and human populations were low, coral reefs were able to provide subsistence fisheries for hundreds of years. Nevertheless, archaeological evidence shows that obligate reef fishes such as scarids, acanthurids, lutjanids, and serranids underwent large reductions in size distributions over the centuries in the Caribbean due to localized fishing pressure using traditional techniques. Historical evidence also indicates that there was also a shift in prevalence of fisheries from high to low trophic levels. Pelagic fishes such as carangids and clupeids showed little change and there was a general shift from reef-associated to pelagic fishes as the reef fishes declined.

The traditional fishing techniques used in the Pacific have provided sustained subsistence, but modern techniques (dynamite, poisoning, scuba) are becoming widely used in some areas such as Indonesia. These techniques have had a major impact on resource sustainability and habitat integrity and are now one of the major concerns of fisheries resource managers and law enforcement bodies in tropical countries.

Life History Information
The diversity of coral reef systems brings about intense predation pressure and competitive interactions for small fish, especially for recruiting juveniles. Many of the larger species that are targeted by fishers grow rapidly to adult size before reaching sexual maturity, probably to escape the risks of predation and competition for space. After reproduction begins, the fish are long-lived and slow-growing. For pelagic fishes, which reach sexual reproduction early and continue to grow rapidly, size can be used as a proxy for age in management calculations. But in long-lived, slow-growing species of coral reef fishes, size is not a good proxy for age and so age must be assessed directly through otoliths or other morphological indicators. Life-history aspects of coral-reef fishes that require the use of age rather than size include sequential hermaphroditism and rapid growth to adult size before sexual maturity is attained.

Eritrea Case
Most reef fisheries are already overdeveloped towards economic goals but require much improved management towards the goal of sustainability. In order to do this, nearly US $5 million dollars has been invested to promote the development of artisanal fishery and limit the development of the industrial fisheries system in Eritrea. In this nation the fisheries are being developed with ecosystem and precaution approaches by using multiple social and natural science criteria rather than maximum sustainable yield alone.

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The Analytic Hierarchy Process (AHP) is a method by which complete or incomplete data sets, local knowledge, catch per unit effort (CPUE) information, and expert judgement can complement each other to be combined into an optimization model. Multicriterion assessment methods are used to measure intangible aspects such as habitat quality, preferred fishing locations, behavior of different gear types, and opinions of local fishers. Science is never complete and consideration of multiple socioeconomic factors increases the reliability of CPUE and the efficacy of no-take reserves.

Ecological and No-Take Reserves:
In present times, no-take reserves are being shown to sustain higher levels of reef fish abundance and larger sized fishes for reef-associated species. Pelagic fishes, such as carangids, showed no significant differences inside and outside the reserves except in selected large reserves where small pelagics can thrive. Since the life-history characteristics of pelagic fishes allow them to sustain exploitation at a higher level than do coral-reef fishes, they tend to survive the pressure of overfishing.

The effects of fishing activities on coral reef ecosystems include long-term shifts from coral to algal-based systems, ghost fishing by derelict gear, bycatch, anchor damage and grounding of fishing vessels. The complexity of interactions among coral-reef resources makes the usual management approaches of restrictions of gear type and catch quotas ineffective and with unpredictable results. Therefore, the present method used for U.S. coral reefs is the holistic approach of establishing ecological no-take reserves. The U.S. Coral Reef Task Force has set a goal of protecting a series of reefs as reserves, which represent a variety of reef habitats. The ultimate goal is to set aside at least 20 percent of U.S. reefs by 2010. It is only with the holistic approach that we can expect to effectively maintain ecosystem integrity and fisheries sustainability. The long distance dispersal of the larvae of many species indicates that management of a number of fishery species requires coordination on an international scale.

Relevant Actions Being Taken to Address the Issue

The realization that the most viable management option for reef fisheries is to establish no-take reserves has led other countries besides the U.S. and Australia to take this approach. A 1998 law in the Philippines mandates local governments to set aside up to 15 percent of nearshore waters as fish sanctuaries or no-take reserves. This trend is starting to take hold. Since 1990, more than 400 small no-take areas have been established in the Philippines. Indonesia is also showing interest in this approach as well as other Asian and some Caribbean countries.

Management and Policy Implications

Technological advances have provided humans with the means to gain access to all natural reserves and deplete entire breeding stocks. Modern fishing apparatus and techniques can be destructive to habitats for adults and juveniles on an unprecedented scale.

Specific Recommendations for Action

- Modern techniques that are destructive to the habitat (for example, explosives, poisons, dredging) and equipment that allows complete access to all the breeding stocks (the use of scuba with fishing gear) should be prohibited.
- Because of the complexities of the coral-reef ecosystem, the holistic approach of marine reserves should be implemented.

Useful References and Resources

This paper is based upon presentations at the 9th International Coral Reef Symposium, Mini-symposium C5, *Coral Reef Fisheries.* Authors and titles of presentations can be found at www.nova.edu/ocean/9icrs/.

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Coral Reef Restoration in the Next Millennium

William F. Precht [1] and Richard E. Dodge [2]

Statement of Issue

CORAL reefs around the world have changed dramatically over the past two decades. Many types of disturbance—separately and in combination—are changing the face of reefs. These include: hurricanes, coral bleaching, diseases of corals and sea urchins, over-fishing, destructive fishing, nutrient loading, sedimentation, hyper- and hypothermic stress, various forms of pollution, harvesting of reef invertebrates, coral mining, trampling by tourists and divers, and the destruction and devastation caused by ship anchors and groundings. It is obvious that this resource needs protection, and that many of the cited anthropogenic causes can be reduced or avoided by implementation of scientifically-based management programs.

Photo: Florida Keys National Marine Sanctuary

The freighter Miss Beholden being pulled off the Sambo Key reef, Florida Keys National Marine Sanctuary

At the present rate of destruction, reef ecosystems will likely suffer continued significant degradation, possibly to the point of irreversible decline. Accordingly, one appropriate course of action is to replace or restore damaged and disturbed reefs with functional ecosystems at a rate resulting in no-net loss of ecosystem value (that is, rate of reef destruction offset by rate of reef repair). While a potentially worthy goal, the discipline of coral reef restoration is in its infancy. Not only do managers and policymakers need to understand the effects of human-induced disturbances and to be able to properly assess these damages, they also need the knowledge, understanding, and tools to successfully develop restoration efforts on degraded reefs under their stewardship. In addition, it may be futile to attempt restoration unless some chronic causes of degradation, such as pollution or sedimentation, are first reduced or eliminated. These issues were addressed at the 9th ICRS and relevant findings are presented.

State of Knowledge

To date, most coral reef restoration programs have been focused on the physical damage caused by humans. Of these, ship groundings are among the most destructive chronic anthropogenic factors causing significant localized damage on coral reefs and have been the focus of many early attempts at reef restoration. In fact, much of what we know about the rehabilitation of coral reef systems stems from our work in trying to repair reefs injured by vessels that have run aground.

The main themes in reef restoration include:

- The most widely accepted definition of restoration is "the return of a habitat to a close approximation of its condition prior to disturbance." This includes placing all restoration efforts in a landscape context where the restored patch is integrated into an ecosystem.
- As we move into the new millennium, it will be imperative that we restore anthropogenically disturbed reefs to a level that closely resembles (both functionally and aesthetically) a pre-injury baseline.
- Available technology allows us to grossly recreate almost any lost physical structure.
- Research is ongoing to determine best substrates and expected interactions of substrates composition, texture, orientation, and design with the damaged environment and biota desired to be restored.

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- Developing countries could be aided by the development of low cost and low-tech restoration programs.
- Coral nursery programs, the use of cultured coral larvae, and larvae attractants could be a bellwether for returning coral cover to damaged reefs.
- The quantity of reef restoration projects has been slowly increasing over the past decade. Compared to terrestrial and wetland restoration, which range in the 1,000's of implemented projects, coral reef restoration is in its infancy (10's of projects).
- Finding appropriate solutions to a particular damage scenario is often hampered by a general lack of quantitative descriptions of the ecological effects of anthropogenic disturbance on coral reefs and an even greater lack of data describing the direction and rate of natural reef recovery. Therefore, there is little basis for understanding what works, what does not, and why.

Implications for Management and Policy

- Hypothesis-driven, ecological research coupled with quantitative assessment and long-term monitoring programs are the keys to answering these critical questions in reef restoration.
- Restoration results may vary significantly with methods and at different locations. If restoration designs are not meeting the desired objectives, modifications should be considered. The use of adaptive management techniques to guide future restoration efforts can also be an important approach.
- Developing successful restoration efforts in the future will depend upon acquiring and applying a scientific base to this emerging discipline. In addition, because of the infancy of this enterprise, the continued sharing of information will be vital to improving restoration strategies over time. The status of reef restoration has advanced a great deal in a short time; as reef scientists and managers, we should be excited about the opportunities that lie ahead.

Specific Recommendations for Action

- Develop and implement hypothesis-driven, ecological research coupled with quantitative assessment and long-term monitoring programs to address critical questions.
- Formulate and test hypotheses about the response of both corals and reefs to disturbances and about the process of reef recovery, to establish:
  - (1) the degree to which corals and coral reefs have the capacity to naturally recover,
  - (2) how intervention in recovery can retard or enhance the process (or have no effect),
  - (3) the scientific protocols necessary to design and implement restoration strategies, and
  - (4) a scientific baseline for developing quantifiable success criteria, and the efficacy of the restoration effort.

Useful References and Resources

This paper was prepared from presentations at the 9th International Coral Reef Symposium, Mini-Symposium D4 *Coral Reef Restoration in the Next Millennium*. Authors and titles of presentations can be found at: www.nova.edu/ocean/9icrs/

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Damage Assessment and Restoration Program of NOAA. Web site: www.darp.noaa.gov/

New International Measure to Prohibit Anchoring on Coral Reefs by Large Ships

Lindy S. Johnson [1]

Statement of Issue

ANCHORING by ships on coral reefs can destroy and degrade a significant portion of these fragile and valuable habitats. The dragging and swinging of large anchor cables and chains destroys coral heads and creates gouges and scars that destabilize the reef structure, which can take thousands of years to build. The regeneration of coral reefs from such damage may never occur. At the 9th ICRS, information was presented on international efforts to address the damage from the anchoring of large ships.

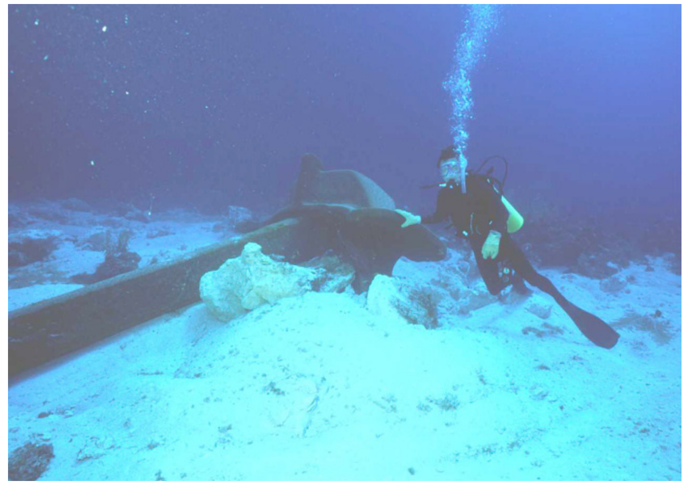

Photo: G.P. Schmahl

Freighter anchor on the Tortugas Bank, Florida, United States, which is now part of the Tortugas Ecological Reserve and off limits to anchoring

Relevant Actions Being Taken to Address Issue

In December 2000, the International Maritime Organization (IMO), a Specialized Agency of the United Nations that addresses international shipping issues, adopted a new rule under international law that allows countries to establish no-anchoring areas for large ships. Such areas may, after submission to IMO, be established in areas where anchoring is unsafe, unstable, or particularly hazardous or where anchoring could result in unacceptable damage to the marine environment. Coral reefs do not provide for stable anchoring, and anchors and anchor cables and chains of large ships also cause devastating harm to coral reefs.

The adoption of no anchoring areas by IMO will assist ships steer clear of these areas by requiring that all countries producing charts for international navigation mark such areas on their charts. The no-anchoring areas measure focuses on prevention of damage, instead of enforcement and liability for damages.

In the first application of this new rule, the IMO also adopted a U.S. proposal to establish three mandatory no anchoring areas for all ships for the unique reefs of Flower Garden Banks National Marine Sanctuary. These areas went into effect on June 1, 2001. In July 2001, IMO's Subcommittee on Safety of Navigation approved the establishment of three mandatory no anchoring areas in the vicinity of the Tortugas, off the coast of south Florida. These areas will be considered and hopefully adopted by the Maritime Safety Committee when it meets in May 2002.

The International Coral Reef Initiative has formed a Working Group on No Anchoring Areas, which will produce documentation to assist countries in submitting proposals to establish such areas to the IMO. This documentation, as well as examples of proposals which have already been submitted will be displayed on the ICRI Forum Web site: www.icriforum.org.

Useful References and Resources

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The How and Whys of Socio Economic Assessments

Leah Bunce [1] and Nohora Galvis [2]

Statement of Issue

INCREASING emphasis has been placed on the human dimension of coral reef management as managers recognize the importance of understanding the people who use and depend on coral reefs. As a result there has been growing interest in incorporating the *social* sciences into reef management. Socioeconomic assessments provide a starting point for incorporating these fields of science into the design of more operational and acceptable management plans by providing insight into the cultural, social and economic background of various stakeholder groups. Yet, there is a lack of knowledge of how to conduct these assessments and why they are useful to reef management programs.

Scientists and managers at the 9th ICRS discussed alternative methods for conducting socioeconomic assessments and the importance of the results for reef management programs. The session speakers presented a variety of approaches for conducting socioeconomic assessments ranging from more structured, quantitative approaches to more participatory, interactive and qualitative methods.

Photo: Coastal Resources Center, URI

The human dimension is a critical aspect of effective and sustainable coral reef management, which socio-economic assessments help address

State of Knowledge

Short-term Socioeconomic Assessment
One of the most straightforward approaches to conducting socioeconomic assessments is a short-term socioeconomic assessment involving observations of user-group activities, focus groups with key informants, and semi-structured surveys. The assessment can be used to develop a sketch of the short-term and long-term social and economic impacts of a marine system on user groups or to determine demographic characteristics, such as population growth rates, education levels and migrant ratios. In addition, data can be used for econometric analysis (regression) to determine relationships between variables (for example, catch is positively related to whether the fishermen in the household make daily trips). The socioeconomic assessment is only the first step toward a larger participatory management process.

Use of Multivariate Analysis
Several presentations detailed the analyses used to understand stakeholders and reef uses, particularly focusing on multicriteria analysis. Multivariate analysis was used to identify the variables responsible for the success of marine sanctuaries. Using this approach, data was collected on select variables allegedly impacting community based marine sanctuary success. Similarly, multicriteria analysis was used to investigate the relationships between ecological indicators (living coral cover, number of commercial species seen per dive and underwater visibility), social indicators (number of fishermen, number of tourists), and economic indicators (fisherman individual profits, profits from dive operations).

Town Resource Cluster Analysis
Town Resource Cluster Analysis (TRC-Analysis) was presented as a framework for describing and examining the

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relationship and inter-dependencies between resource systems and social systems. The analysis involves identifying town clusters of coastal communities associated with primary and secondary fisheries resource catchments and using this information to determine the location and type of social impacts associated with the fishing industry and management regimes. Trade off analysis, a combination of stakeholder analysis (identification of stakeholders and their interests) and multi-criteria analysis (development of management criteria, evaluation of alternative management scenarios), draws on participatory approaches and consensus building to bring together diverse options through shared discussions of priority issues. This approach enables decision-makers to gain an understanding of stakeholders' preferences for different management options and their consequences on stakeholders.

Who to Study

An important aspect of conducting socio-economic assessments is determining *who* to study. Studies often target the easily-defined groups of people, such as local residents, subsistence or commercial fishers, or dive tourists. When defining whose values are to be considered, socio-economic assessments for natural resources follow the thin line between being too specific about the user groups (and thereby not counting valid "holders of value") and being too global (and thereby running the risk of an invalid, overly-general result).

Utility of Socio-economic Assessments

The utility of socioeconomic assessments, both from the *results* of socioeconomic assessments as well as the *process* of collecting the data was discussed. Information can assist reef managers in formulating appropriate plans for reef management. For example, data collected on the sociocultural, economic and political aspects of community based marine sanctuaries were used to determine the variables associated with the success of marine sanctuaries (population size, a perceived crisis, successful alternative income projects, relatively high level of community participation, continuing advice from the implementing organization and inputs from the municipal government). This information is useful not only for the managers at the studied sites, but others considering establishing marine sanctuaries. Similarly, the results from a socioeconomic assessment were used to determine the social and economic impacts of reserves in the Florida Keys National Marine Sanctuary, such as dive/snorkel operators have experienced a slightly positive economic impact and a negative social impact in the form of increased crowding inside reserves since reserve establishment. A socioeconomic analysis was used to recommend policies for local marine management, specifically the need for restrictions to protect local fishermen's rights to fishing grounds and the need for greater links between agriculture and fisheries policies. The identification of social and resource systems, specifically town clusters, was used to determine the social impacts of the fishing industry and management regimes, facilitate more directed community involvement programs, and provide basic information on community stability, social resilience, sensitivity to change, community well being and social capital. The results of multicriteria analysis assist in decision making and reaching consensus between the community of users, researchers, ecologists and managers. Multicriteria was used to assess conflicting preferences and in the process stimulate communication among stakeholders.

Value of the Process

In addition to the value of the results of a socioeconomic assessment, the actual *process* of conducting the socioeconomic assessment can assist managers, particularly in establishing a foundation for participatory projects. Participatory approaches to conducting socioeconomic assessments can help reef managers both to collect the socioeconomic information and establish productive and pro-active relationships with the stakeholders. This can help to build a common understanding of management issues among stakeholders and to identify commonly agreed management objectives. It can also help establish greater commitment to reef management plans that reflect these common objectives. Socioeconomic information can assist in incorporating stakeholders into decision-making, including planning projects. The value of the process of conducting trade-off analysis not only led to a consensus on a decision, it also provided opportunities for trust building, consensus building, empowerment and knowledge dissemination.

Relevant Actions Being Taken to Address the Issue: Case Studies

The case studies highlighted in the presentations illustrated the value of socioeconomic assessments to reef management. A socioeconomic assessment to identify the short and long-term socioeconomic impacts of the Florida Keys National Marine Sanctuary reserve system on consumptive and non-consumptive marine user groups in Key West has proven useful for subsequent management of the FKNMS. Multivariate analysis identified the key factors affecting success of marine sanctuaries in the


Photo: Coastal Resources Center, URI

Fish and prawn farming in Indonesia

Philippines, which is useful to managers both in the Philippines and other managers considering establishing marine sanctuaries. Socioeconomic data can serve as the foundation for a participatory project design workshop, which in turn can be used to produce a vision for managing an area. Trade-off analysis has helped to establish a stakeholder group which continues to lobby government, participate in the decision-making process, and pursue co-management arrangements. Socioeconomic assessment was useful in determining future management strategies for a local area based on the findings that migration is the major driver of human population growth in the area and that migrant households are heavily dependent on fishing income. A multicriteria analysis in the National Park Corales del Rosario and San Bernardo, Colombia, assisted in the selection of relevant indicators to assess the effectiveness of management from different perspectives and enhanced collaborative monitoring programs for more objective decision making.

Management and Policy Implications

Socioeconomic assessments play a critical role in reef management. It is, therefore, imperative that they be better incorporated into the decision-making process that has traditionally focused on ecological data. A range of recommendations for improving the incorporation of socioeconomics into reef management is provided. Because socioeconomic assessments often contribute to stakeholder participation in decision-making, recommendations are also provided related to stakeholder participation.

Specific Recommendations for Action

- Consider socioeconomic assessments as a means of building stakeholder participation, developing a synthesis of management goals, developing long-term plans and ensuring a balance between ecological, social and economic factors in reef management
- Use multivariate analysis of data to correlate socioeconomic variables with other aspects of management, such as to determine which variables contribute to successful protected areas or which variables (for example, income, education level) were impacted by a particular management strategy (for example, fishing restrictions, awareness program)
- Include social data concurrently with ecological information through such analyses as Town Resource Cluster Analysis, which defines clusters of coastal communities associated with fisheries resource catchments to determine the social impacts of fisheries structures and management regimes
- Conduct socioeconomic assessments such that they address the social, economic, political and institutional context in which a system is operating
- Build multiple stakeholder participation through trust building, inclusiveness, information sharing and the validation of local knowledge and experience
- Realize that successful participatory approaches depend on institutional pre-conditions including: proactive government agencies that foster public participation, inclusion of all elements of society in decision-making, shared responsibilities at all stages of decision-making, and free flowing information sharing and communication
- Ensure stakeholder participation occurs at all phases, there are representatives from all the stakeholder groups and that these representatives adequately cover the diversity of interests with the groups, the process is open and flexible and there are opportunities for general public input.
- Include in the monitoring programs the spatial and temporal measurement of socioeconomic indicators useful in decision making.

Useful References and Resources

This paper is based upon presentations at the 9th International Coral Reef Symposium, Mini-Symposia C1, *Bringing Social Sciences and Economic Issues into Coral Reef Management.* Authors and titles of presentations can be found at: www.nova.edu/ocean/9icrs/.

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The Economic Importance of Coral Reefs

Helge Peter Vogt [1] and Alan White [2]

Statement of Issue

HEALTHY coral reefs provide the economic base for millions of artisanal fishermen and thousands of small and large tourism enterprises in tropical countries. In many areas, the economic value of these contributions is poorly understood. The overexploitation of reef species and the widespread deterioration of the reefs are threatening this natural resource that often forms the sole source of income. Thus, both policy-makers and reef managers urgently need to suggest and implement measures to arrest the decline of this crucial natural resource, to mitigate the detrimental economic effects on coastal dwellers and businesses and to raise the awareness about the large economic contribution made by this resource to coastal economies.

Photo: Coastal Resources Center, URI

Process of drying fish; Lampung, Indonesia

State of Knowledge

Despite their major economic importance, pioneering work to assess the value and economic implications of coral reefs started only recently. In this specialized area where economic and ecological issues are closely intertwined, thorough analysis of the present situation and specific recommendations for sustainable reef use were presented during a session of the 9th ICRS. A consensus exists that human induced reef destruction and overexploitation is often driven by economic forces. Disturbing quantitative data were presented which estimated the economic losses to society due to blast fishing, overfishing and increased sedimentation levels for reefs in Indonesia and the Philippines. However, positive signs involving the involvement of local communities in reef management as well as in the sharing of economic benefits were also shown for Indonesian and Philippine reefs. Studies aimed at improving the understanding of the mechanisms driving local reef management indicated that co-operation between national agencies, non-governmental organizations (NGOs) and local communities require better communication and a closer consultation process. Conflicts between stakeholder groups may also hamper the progress of sustainable reef use. At the 9th ICRS it was agreed that ways of involving all reef users in the management process were suggested, including a sustainable funding mechanism.

Relevant Actions Being Taken to Address the Issue

The examples of Apo and Gilutongan Islands, Philippines, show that under the specific conditions of these small islands, (1) selected reef areas can be successfully protected if managed by local communities and (2) the fishing communities can benefit financially from improved fish catch and tourism to the island. Pearl farms in Indonesia generate employment opportunities as well as protecting selected reef areas. However, some fishermen have lost fishing grounds and have thus suffered economic losses. Various case studies have quantified the considerable economic opportunities and benefits if reef areas are utilized and managed in a sustainable way. Case studies have also shown that by raising the economic valuation of reefs in the local management context, a better awareness results that encourages some local governments to invest more in their coral reef protection programs as a regular feature of the government's budget and activities.

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Management and Policy Implications

In various presentations, the involvement of all stakeholders in the co-management of coral reefs was seen as a key requirement for sustainable reef use. Furthermore, stakeholders need to be convinced that sustainable reef management practice provides them with sufficient economic benefits. Further specific actions to enhance the current reef use patterns were made on local, national, and global levels.

Specific Recommendations for Action

At a local level:

- Initiate programs in which users or tourists are asked to pay a user fee, such as a voluntary hotel room fee. A user fee for small marine protected areas can more than cover the cost of protecting the reef complex from destructive fishing and other illegal activities.
- Establish co-management structures, involving fisher folk and tourist operators, that can address conflicts and add economic benefits.

At a national level:

- Identify the total economic value of reefs on a national level based on currently available models in relation to the probable costs of management
- Identify costs to society caused by unsustainable reef use on a national level based on existing work in Indonesia and the Philippines and incorporate in cost-benefit analysis to highlight the cost effectiveness of preventive management for reefs.

At a global level:

- Compile all major findings on quantitative economic values and add as a module to an existing global database for example ReefBase.
- Enhance government and NGO assistance to communities to optimize effective and long-lasting communication links to channel management advice
- Reduce overall fishing effort by focussing on a collaborative enforcement between government agencies and the communities.
- Promote practical management regimes that involve stakeholders in the resource base.

Photo: Barbara Best

Dive boats tied up at mooring buoys on the edge of Gilutongan Marine Sanctuary, Cebu, Philippines

Useful References and Resources

This paper is based upon presentations at the 9th International Coral Reef Symposium, Mini-Symposia C1, *Bringing Social Sciences and Economic Issues into Coral Reef Management.* Authors and titles of presentations can be found at:
www.nova.edu/ocean/9icrs/.

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Cesar HSJ (ed) (2000) "Collected Essays on the Economics of Coral Reefs," *CORDIO*: 243 pp

Web site: http://www.economics.iucn.org includes downloadable papers such as *Economic Values of Protected Areas.*

Building the Capacity of Those Who do the Work

John E. Parks,[1] Ghislaine Llewellyn,[2] Ian M. Dutton,[3] and Robert S. Pomeroy [4]

Statement of Issue

The path to effective coral reef management and conservation involves several steps (see Steps A-D, Figure 1). Scientists and practitioners together form an important and complimentary partnership in navigating the path to effective management. The symbiotic (or interdependent) relationship between researchers and practitioners has been inadequately recognized in most management efforts historically, leading to ineffective coupling of knowledge and action.

This paper summarizes results and policy recommendations aggregated from nearly 40 papers presented during the single largest mini-symposium held during the 9th ICRS Symposium and brings together the state of knowledge regarding the application of and learning on various management tools in global coral reef ecosystems during the past decade.

Summary results from the 9th ICRS can be categorized within three areas of learning: (1) determination of factors of success; (2) documentation of factors that limit the impacts that have been achieved to date; and (3) notable progress in the practice of applied coral reef science.

State of Knowledge

Shared Factors of Coral Reef Management Success

Over half the papers in this mini-symposium documented factors that either led to successful or failed coral reef conservation, allowing lessons to be drawn from specific sites. Many of the factors identified and analyzed were social and institutional variables that are often overlooked when considering the complexities of coral reef management. Among the scores of factors discussed, four stood out as the most commonly shared across study sites:

Photo: John Parks

Small group workshop for those who do the work

(a) Demonstration of Economic Benefits: With the majority of the world's population living in the coastal zone and dependent upon the natural resources therein, building capacity for *in situ* biodiversity conservation typically requires some degree of congruence with economic needs when people are involved. Nearly two-thirds of all papers cited the critical role of demonstrating short and long-term, tangible economic benefits of management tools to reef resource users.

(b) Collaborative Management Arrangements: The degree of success experienced was in part determined by how well management responsibilities and partnerships were established. Many presentations advocate using a collaborative management (co-management) approach to ensure conservation success, where both the local communities/users and government agencies share an appropriate level of responsibility and participation in the employment of management tools.

(c) Integration of Traditional Knowledge and Science: In-depth traditional knowledge and

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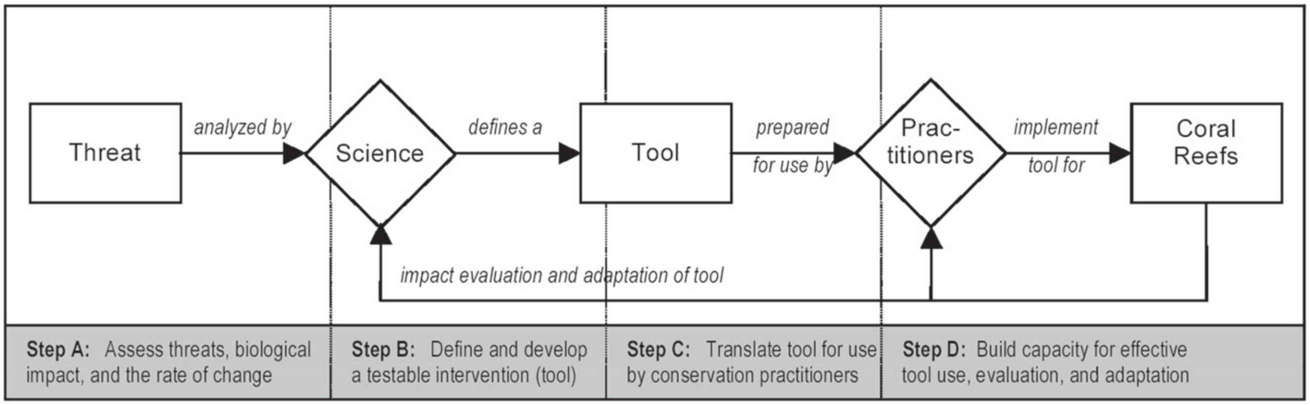

Figure 1: Key steps in the path to effective coral reef management and conservation.

elaborate systems of customary marine resource management practices are a part of the cultural identity of many coastal residents today. Typically such practices have been weakened or lost as a consequence of global cultural change, as well as the fact that such practices alone are insufficient to address the litany of threats present. Half of all studies found that when customary practices and sources of traditional knowledge are appropriately and effectively integrated with contemporary management approaches, conservation success is increased.

(d) Clear, Equitable, and Integrated Governance: Appropriate property rights arrangements are essential for long-term coral reef conservation success. Minimization of conflicts, clear and equitable delineation of resource tenurial rights, and legal support from policy makers were all seen as critical components in achieving this factor. There was also tentative evidence that linking management initiatives across different levels of governance, from site to national levels, increases the effectiveness and efficiency of conservation effort(s).

Limitations to the Conservation Achieved

Despite the remarkable learning that has been done to determine factors of success in coral reef management, the mini-symposium papers illustrated a harsh reality: the impact achieved to date has been limited, and there are failures to match each success story documented. Limitations in this regard were identified in three areas:

(a) Impact Is Bound at a Site-Level: With the majority of papers given (two-thirds) focusing their studies at a single site, the learning that has been associated with it is site-specific and difficult to confidently extrapolate lessons for a broader, geographic scale. Moreover, only one-fifth of papers presented reported being in a replication phase where site-specific approaches and lessons are actively being applied elsewhere.

(b) Limited Documentation of Intervention Impact: Only one-third of all studies presented contained any documented impact resulting from the use of a particular intervention, whether in terms of conservation or increased degradation. Moreover, of these cases, conservation successes and failures were evenly reported, and the impact reported was limited to a few biological and/or socioeconomic indicators of conservation success.

(c) Few Long-Term Financing Mechanisms Attempted: One of the largest limiting factors to building the capacity needed for effective management is the lack of financial resources that provide for long-term, strategic capacity building for conservation success. Few long-term financing of management efforts are being tested and of these, only a few were hailed as promising mechanisms. There was also a clear lack of consensus on agreed (or acceptable) measures of success and on what indicators can most cost-effectively be measured.

Improvements in the Practice of Applied Conservation Science

Conservation practitioner awareness of how to use science for coral reef management is improving. While measuring conservation impact is limited, the techniques and methods to do so have improved greatly. The result is a continually improving applied science context from which practitioners can draw skills and capacity. Donors, research scientists, and managers are forming innovative partnerships and learning arrangements with conservation practitioners to improve the scientific techniques underlying the practice of day-to-day coral reef management. Despite this collaboration, however, there remain both significant gaps in our knowledge of fundamental phenomena of importance (e.g., larval dispersal patterns) and significant barriers to the integration of science in conservation management programs. Relatively few donor agencies seem prepared to invest in the scientific effort necessary to develop proper experiments (often applied ones) in conservation science. As a consequence, our learning capacity is limited and we face real risks of drawing the wrong conclusions about the efficacy of particular approaches to conservation management.

The results from using coral reef management tools over the last ten years are mixed. While there is a better understanding of how to use tools successfully and apply science effectively at certain sites, these efforts are still limited to typically site-specific conservation impact with poor capacity to support or evaluate such measures long term. As one attendee at the mini-symposium put it, "I come away feeling excited about what we are learning, but pessimistic as to whether or not our efforts will be enough in the future."

Management and Policy Implications

It is clear that, worldwide, capacity has increased to use coral reef management tools, and that learning has occurred at a number of sites using these tools. However, because of the highly dynamic and global nature of threats facing coral reefs, capacity for coral reef management and conservation must evolve beyond where it is today. The evidence is clear: despite the notable successes experienced at specific sites, we continue to lose coral reefs worldwide. How then do we build capacity beyond a site-level to meet the changing nature of the threats present? How can we better learn to use and adapt the tools that are available to us at a level that operates at an appropriate scale to that of the threats?

The following are a set of policy action items to build coral reef management and conservation capacity at an appropriate level in the 21st century.

POLICY NEED 1: Adequately Understand and Predict the Role and Influence of People

If we can adequately come to understand ourselves and social influences, then we will better understand where and how to build long-term capacity for coral reef management. But getting to this point is the challenge at hand, one which cannot be reached with a shortcut.

POLICY NEED 2: Conservation Impact Achieved at Scale Necessary to Meet Threats

There is an immediate need to develop an appropriate level of management capacity that will operate at a scale comparable to the litany of globalized threats which presently face coral reefs.

POLICY NEED 3: Long-Term Shared Management Responsibility

Half of all cases presented have moved from either strictly a community-based approach or strictly a centralized, command-and-control approach to an arrangement where the management of coral reefs are shared between local constituencies and government agencies, thereby allowing for increased capacity to use the tools available and shared management responsibility over them.

Specific Recommendations for Action

The following are a set of action items for policy makers that will contribute to ensuring that the necessary capacity exists to use available tools effectively.

- *Expand the Participation and Integration of People in Management*
  The devolution of management over coral reefs and other coastal resources is underway worldwide. To be implemented effectively, management capacity must be built at a level where local resource users and coastal residents are effectively engaged in management process and actively participating in the application of relevant interventions. This in turn helps to engender ownership over management processes and galvanize public support for such efforts. Local stakeholder participation is essential to coastal conservation success and should be continued and appropriately expanded. In particular – and as cited by over 80 percent of the papers presented – traditional management can, is, and should be integrated with the science behind the tools that are being used for conservation. This was one of the most strongly voiced policy recommendations across the 40 papers.

- *Improve the Science Explaining Human Behavior and Societal Influence*
  It is not enough to understand that people's actions effect coral reefs; we must also learn how to predict the impact of human behavior on coral reefs based on the social and legal issues at hand. Accordingly, the session recognized that priorities for management and finances need to be driven by social criteria as well as ecological and biogeographical ones. Our ability to strategically act to foster successful management is first dependent on our ability to predict and counter the social operating conditions negatively effecting adjacent coral reefs. Applied marine conservation science must include behavioral research in order to improve the integrity and efficacy of management and policy actions.

- *Increase Support to Those Who Actually Do the Management Work*
  The financial support for actually doing coral reef management is limited and highly competitive to secure. While financial support to scientific research and in the development of marine conservation tools is important, future funding must be made available for practitioners who inevitably determine the scale of conservation impact achieved.

- *Manage at an Ecosystem Level, Not Just a Site Level*
  While site-based management is important, replication of site-level lessons and conservation impact needs to be scaled-up at larger temporal spatial scales in order to meet the threats operating. There is a critical need to adapt conservation approaches so that they are able to operate at an ecoregional level in order to safeguard ecological functioning, not just *in situ* biodiversity. To do this, our understanding of biological interconnectivity and representivity must be improved through the exploration of marine corridors and networked conservation efforts at a large spatial scale, given biophysical, life history, and larval recruitment factors.

- *Secure the Support Needed to Operate at a Scale Comparable to Threats*
  There is an acute and immediate need to significantly increase funding allocated for global coral reef conservation work to allow it to operate at a scale that is capable of mitigating globalized threats. While supporting ongoing site-based management and exploring innovative alternative financial mechanisms is critical, the reality is that without the development of a strategic plan for the long-term financing of conservation work that is shared equitably on a global level, management efforts will remain bound at a scale that is unable to result in the effective and sustained coral reef conservation.

- *Establish Learning Networks Across Sites*
  Learning must evolve past being site- or organization-specific if we are to improve the practice of conservation. Networks of sites using similar tools need to systematically test a commonly shared set of assumptions with standardized measures to determine the conditions under which such tools work and do not work at scales beyond the site level. Through such learning networks, group learning and adaptive management can be promoted so that regional and global policy-making guidance can be provided on effective use of coral reef management tools.

- *Improve the Analytic Capacity of Those Working at a Site Level*
  To scale-up conservation impact, learning and adaptation must occur consistently and confidently across sites. Skills building for impact monitoring and evaluation will improve capacity for long-term adaptive management at site and network levels. Appropriate analytical tools to evaluate changes and impact at an ecoregional level are required.

- *Employ Collaborative Coral Reef Management Approaches*
  Collaborative management (co-management) approaches should be used in future coral reef management efforts to establish long-term partnerships of shared and complimentary responsibility between governments and the people and communities who depend upon the goods and service that coral reefs provide.

- *Systematically Integrate Management Efforts*
  As illustrated under Policy Need 2, while many of the cases presented focused on new and innovative approaches to management of corals reefs at the site scale, very few demonstrated how these initiatives can cumulatively impact policy and programs at broader scales. Such impact will be essential if the initiatives begun under the guise of pilot projects or as seed investments are to yield a significant conservation gain in proportion to the threats facing coral reefs. A systematic approach to integration of management efforts can be undertaken in many ways; however, those efforts that employ an integrated coastal management framework seem best placed to achieve

effective governance and to link meaningfully with other initiatives at national scales.

References

This paper is based upon presentations at the 9th International Coral Reef Symposium, Mini-Symposia C2, *Building Capacity for Tropical Marine Biodiversity Conservation: Case Studies and Lessons Learned from Different Approaches to Tropical Marine Ecosystem Management.* Authors and titles of presentations can be found at: www.nova.edu/ocean/9icrs/.

Useful References and Resources

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Communicating Reef Science and Environmental Education

Jayme Perrello [1]

Statement of Issue

AS in every specialty field, reef science has its ample share of jargon, acronyms, and technical terms. What happens, however, when a government agent needs to make a key decision that greatly affects coral reefs, but he or she does not understand this "language?" What kinds of opportunities are lost when we have several scientists working towards obtaining reef status data, but they are unaware of each other's efforts and methodology?

Photo: Reef Check

Reef Check drawing by school child in Indonesia

Questions of this nature were the motivating factors for the facilitation of this session at the 9th ICRS. The session presentations were highly varied and offered insight from several different reef science communication perspectives, such as: how scientists disseminate information to each other, the media, and the general public; the effectiveness of live interpretation; and the approach and methodology involved in educating youth and adults about reef science.

State of Knowledge

Communicating Reef Research

In the process of communicating coral reef research findings, whether it takes place between fellow scientists or scientists and the public, time is often critical. In regards to reporting coral reef monitoring, "…the results of monitoring are most useful, and sometimes only useful, if they are analyzed and presented to users quickly." Strategizing and streamlining of the processing and dissemination of information was encouraged to provide findings most efficiently.

On an opposite note, however, we must also assess the consequences of sharing 'too much' information without taking the time to evaluate the potential outcomes. If the information can be used in an exploitative manner, we may be doing a disservice to the very element we are working towards protecting. For example, one organization limits and protects data on restricted fish species on their public Web site.

In questioning the validity of certain research projects, we often forget to ask if there is an easy means, or venue, for sharing results with other researchers and with the public at large. As we head towards the future, it is highly recommended that we make this a standard of validity.

Sharing Information with the Media

When scientists share information with the media, there is a two-way responsibility. Scientists must speak to the media in a way that is comprehensible and conveys a certain degree of passion or interest for the reef. The media must make an effort to put the subject in an appropriate light, avoid sensationalism and provide accurate and truthful information to the public.

If the scientist does not convey a passion for, or interest in, his or her subject, a large gap is left for the media to fill in. A journalist may be in a situation to search for ways to fill in this gap, to make the story appealing. It is best if the scientist can offer the appeal, as to ensure a more exact story. Scientists are often in a position where they must give gray answers to seemingly black and white questions. One of the main scientific understandings that the media must take to heart is that an 'ambiguous' answer usually

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indicates that there has not been enough research done to give a more definitive answer. It is therefore the responsibility of the media person to convey this ambiguity in a manner that reflects the integrity of the scientist, the subject, and themselves.

Choosing the Right Language
It is imperative that scientists be aware of the language that they are using when they speak to a non-scientist, assuring that their choice of words can be understood and interpreted by the listener. Certainly, there are times in science when there are no lay terms for what is being discussed, and the introduction of new words or concepts is necessary. The responsibility, in this case, lies in the scientist's ability to be aware of new word or term introductions and to define them, and the listener's ability to question unfamiliar material.

In communicating reef science, one of the strongest tools that humans have is other humans. The value of personal connection, the nurturing of ideas and the human investment should not be underestimated. Interpretation of nature is an ever-expansive field and a career pathway that should receive more of our developmental focus.

In a formal evaluation of visitor knowledge of coral biology before and after visiting an exhibit, with and without live interpretation, it was found that live interpretation resulted in statistically significant improvement in the visitor's understanding of coral biology.

Use Universal Concepts and Traditional Culture
As we interpret nature, more specifically the coral reef ecosystem, the use of universal concepts is a very effective teaching approach. People can readily relate to the ideas of finding shelter, satisfying hunger, competing for space and finding a mate. In addition to the presentation of universal concepts, highlighting the intimate relationships that indigenous peoples have developed with their environment is also a recommended interpretive approach. We have a responsibility today to look back upon ancient truths and to integrate them into today's environmental teachings. The interpretive model can be based upon the marriage of the modern day knowledge of marine biology, with the ocean knowledge and practices of the traditional culture.

Coral reef education should be an integral part of all aspects of environmental protection and resource management, beginning with young children, and it should be built systematically throughout a person's lifetime. The process must be tailored to the local, social, culture and political climate. As we look at including indigenous wisdom into modern day practices, we also need to honor the individual ways that cultures have evolved into their modern day state.

Management and Policy Implications

It is easy to lose sight of the global picture when so many scientists and field workers are involved in researching specific areas relative to coral reef ecosystems. This is why it is necessary to always take a step back and review our common goals. In terms of preservation and conservation, time is precious and does not leave room for egocentrism. Perhaps, if Darwin and Wallace had been able to collaborate more in their day, we would have a better understanding of biogeography today.

Recommendations for Action

For Scientists and Media:

- Collaborate on reef science data analysis and dissemination methodologies.
- Report research results in a timely manner.
- Evaluate the content and manner in which reef information and data is publicly shared.
- Demonstrate a mutual respect for each other's field knowledge limitations

For Public Education Facilities:

- provide quality interpretation of the issues at hand.
- Prepare today's youth for tomorrow's oceans.
- Maintain an awareness of the diverse relationships that exist between humans and nature in different countries and cultures.

Useful References and Resources

This paper is based upon presentations at the 9th International Coral Reef Symposium, Mini-Symposia C3, *Communicating Reef Science.* Authors and titles of presentations can be found at: www.nova.edu/ocean/9icrs/.

www.seaweb.org SeaWeb is a project designed to raise awareness of the world ocean and the life within it.

Trade in Coral Reef Animals, Algae and Products: An Overview

Barbara A. Best [1]

Statement of Issue

Giant clam on coral reef in Raja Ampat, Indonesia

Photo: Roger Steene

IN many countries, domestic and international trade in coral reef species and products is driving the overexploitation of reef resources and the use of destructive fishing practices that destroy reef habitats. These unsustainable and destructive practices are altering the ecosystem functions of reefs and greatly diminishing long-term benefits to local communities. Although often referred to as "productive" ecosystems, coral reefs can be easily overexploited and must be carefully managed and monitored. Coral reefs are characterized by many species with relatively low population numbers, many rare species, complex food webs, and tight-nutrient recycling which makes reefs especially vulnerable to overexploitation.

Numerous presentations at the 9th International Coral Reef Symposium addressed various aspects of commercial trade and management issues. An overview of trade issues is presented in this paper, with particular emphasis on issues not covered in other chapters. Major issues associated with trade, both domestic and international, include:

- Overexploitation of reef resources.
- Targeting of spawning aggregation sites.
- Use of destructive fishing practices, such as blast fishing, poisons (cyanide), dredging, trawling and muro-ami drive nets.
- Environmental impacts of seaweed mariculture in reef environments.
- Vulnerability of reefs to extractive uses following bleaching events.
- High incidence of paralysis and death in collectors associated with the inappropriate use of diving equipment (such as hookah rigs).

Please refer to these other relevant chapters as well – *Conservation Biology of Coral Reef Fishes*, *Coral Reef Fisheries, Destructive Fishing Practices, Marine Ornamental Trade,* and *Status Reports* from the Global Coral Reef Monitoring Network and Reef Check.

State of Knowledge

Coral Reef Animals and Products in International Trade

International trade involves live reef substrate ("live rock"), live corals, fish and invertebrates for the marine aquarium trade; live reef fish, giant clams, giant tritons, lobsters, shrimp, clams and snails (*Trochus*) for the live food fish trade; dead and dried sea cucumbers (beche-de-mer), fish, sharks, sea turtles, seahorses, and other invertebrates for the dried food and medicinal trades; and dead and dried

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corals, precious corals (black, red, gold, bamboo), seashells, starfish, and other invertebrates for the curio and jewelry trades. Mariculture of seaweed and other species on and near coral reefs is also increasing, as is black pearl production in lagoon areas.

Trade is also driving the loss of critical habitats associated with coral reef ecosystems, especially mangrove forests and seagrasses. The destruction and loss of mangrove forests occurs for shrimp mariculture and wood harvest; destruction is also occurring due to upland and coastal development.

Geographic Extent of Trade, Overfishing and Destructive Fishing Practices

Many organisms of high economic value have been impacted by overfishing in all coral reef regions of the world, as indicated by the results of Reef Check surveys (see *Reef Check - Status of Reef Health Indicators*). The international trade is relatively mobile, moving from area to area. Even remote reefs are targeted for collection, particularly as nearby reefs are overfished. The targeting and decimation of grouper spawning aggregations has also been widely reported from areas where live reef food fish collection is occurring – over a very short time period, almost the entire adult population can be collected at these spawning aggregations.

The trade in live reef fish has grown in volume and expanded its geographic extent over the last decade. The use of cyanide to stun and capture target species began in the Philippines in the 1960s and spread throughout the Philippines and Indonesia. As the trade in live reef fish has grown, the use of cyanide for the capture of both ornamental and live reef food fish species has spread across the Indo-Pacific region, including the Western Indian Ocean.

Destructive and harmful fishing practices were reported in the following countries and regions: Federates States of Micronesia, India, Indonesia, Madagascar, Malaysia, Pacific Islands, Papua New Guinea, the Philippines, Republic of Mauritius, South Africa, Tanzania, Vietnam.

Marine ornamental fish are presently collected in over 40 countries to supply hobbyists primarily in the United States, European Union, Japan and Canada. Overexploitation, the use of cyanide, and the local loss of rare or endemic species were reported in some countries.

Sea Cucumber Overexploitation

Overfishing of sea cucumbers has occurred in many locals, even while under some sort of management plan. For example, sea cucumber fisheries were closed in the late 1990s, due to decreasing catch rates, in both the Great Barrier Reef of Australia and the Commonwealth of the Northern Mariana Islands (CNMI) (Trianni, 2000; Uthicke and Benzie, 2000). In the CNMI, a pre-harvest stock assessment was not conducted and the fishery was managed based on catch-effort statistics only. This approach was not effective – an analysis revealed that 78-90 percent of the initial population sizes had been over-collected. Pre-harvest stock assessments along with harvest statistics are essential for coherent management.

Seaweed Mariculture

Globally, the collection and mariculture of seaweed generates over US$6 billion per year. Approximately one half of this trade is from the harvest of wild seaweed, and one half from seaweed mariculture. In the tropics, seaweed farms are located primarily on coral reefs or reef flats, where *Euchema spp*. and *Kappaphycus spp*. are farmed for the global demand for carrageenan. Three major types of environmental impacts are identified with tropical seaweed farming in coral reef habitats (Zemke-White, 2000): 1) the effects of introducing seaweed species to a new location, 2) effects from farming operation, and 3) effects of related human activities. Given the spread of seaweed farming in the tropics, possible impacts on coral reefs, and paucity of impact studies, a more comprehensive assessment of potential and realized environmental impacts is needed.

The introduction of alien species of macroalgae may impact reefs by reducing the grazing pressures by herbivorous fishes on native macroalgae, as documented in Kaneohe Bay, Hawaii (Conklin, 2000). Fishes forage far from shelter onto reef flats to feed on preferred algal species that have been introduced into the bay, ignoring less preferred species that are more easily obtainable and potentially allowing these native species to overgrow corals.

Collection for Pharmaceuticals and Mariculture

The collection of coral reef organisms for the pharmaceutical trade is increasing, requiring that appropriate harvest and mariculture strategies be developed. Organisms expressing modular growth, such as octocorals and corals, are often presumed to have "indeterminate" growth, that is, colonies continue growing after reaching maturity. This presumption of


Photo: Coastal Resources Center, URI

Seaweed farming in East Kalimantan, Indonesia

indeterminate growth among modular taxa suggests that colonies readily recover from harvesting, and that they can be easily partitioned to generate brood stock for mariculture. However, one study on the Caribbean gorgonian *Pseudopterogorgia elisabethae*—harvested for the extraction of commercially valuable pseudopterosins—illustrates that this assumption is incorrect (Lasker, 2000). An analysis of growth patterns in *P. elisabethae* indicates that it has "determinate" growth. Therefore, the assumptions about the resilience of colonies to harvesting are probably inaccurate. Species-specific analyses may be required to develop management plans and mariculture techniques.

Vulnerability of Reefs to Extractive uses following Coral Bleaching Events

Several studies have documented shifts in species richness and diversity of fishes at reefs following significant coral bleaching events in 1998. Some of these reefs were reported to be at risk from illicit harvests that threaten recovery of the fish communities from the bleaching events (Donaldson and Myers, 2000).

Rarity of Species and Monitoring Programs

International trade often targets rare and relatively rare species, such as groupers and wrasses for the live food fish trade and rare fish and invertebrates for the live marine aquarium trade; these organisms often command the highest prices. A species may be rare in terms of its numerical abundance or its geographic range. An analysis of rarity in coral reef fish communities confirms some patterns of rarity in communities, but also highlights the generally poor availability of data for marine organisms (Dulvy and Polunin, 2000). The status of a species as rare or common has important implications for local ecological interactions and for conservation and management issues (Caley et al., 2000).

Studies of fishing impacts over small geographic scales may have little statistical power to detect rarity or extinction of large rare species, which theoretically are more vulnerable to exploitation than smaller species due to lower rates of population increases. This in turn may explain why so few studies have documented marine extinction, and highlights the need for large geographic assessments of fish communities to capture the large, rarer species. To understand patterns of biodiversity, many community ecologists now recognize that there is a need to synthesize large-scale phenomena with local processes (Hughes et al., 2000).

Reef Connectedness, and Sources and Sinks

Critical to the management of reef resources is an understanding of how ecologically "linked" or "connected" reef populations are on small, medium, and large spatial scales. Does larval or juvenile recruitment depend upon "sources" other than that particular reef or locale? Or is the population "self-seeding" and relatively independent of other sources of recruitment? Presentations documented both scenarios, highlighting the need to continue studies on the degree and scale of interaction among local populations (Figueira, 2000; Sale, 2000).

The white grunt (*Haemulon plumieri*) is an important component of the reef-based fisheries of the Wider Caribbean, and current indications are that it is on the decline. Spawning/settlement experiments suggest that populations have some degree of self-recruitment; thus local management needs to protect critical habitat and establish marine reserves (Hill, 2000). In a second example, a mitochondrial analysis of genetic structure in the rabbitfish (*Signans fuscescens)* indicated that the population was self-recruiting and that larval dispersal may not be as widespread as is usually assumed among fishes with an early planktonic phase (Ochavillo et al., 2000). This implies that management can be more local in scale. A third example examined the assumption that some reef species with extended planktonic larval stages may have a very broad larval distribution range. The planktonic larval duration for the spiny lobster (*Panulirus argus*) is estimated to be 6 months to one year; this lobster is a major fishery species throughout the Central Western Atlantic. Management of this key fishery species will require coordination on a wide geo-political scale (Yeung, 2000).

The degree to which coral reefs are dependent on other tropical habitats is another important aspect of connectedness. Mangrove forests and seagrass meadows

Photo: Coastal Resources Center, URI

Coral for sale in Lampung, Indonesia

are critical habitats for many reef fishes during some portion of their life-history. For example, one study documented that most reef fish species were absent, or present only in reduced densities, in those bays or island reefs lacking these critical nursery habitats (Nagelkerken et al., 2000).

Deeper Reefs as Spatial Refugia

For some species, deeper reefs may be a spatial refugia that has been maintaining fisheries despite the intense fishing pressures in shallower habitats (Ferreira and Maida, 2000). However, exploitation in these deeper reefs are increasing as the technology develops, and as local fishers move into deeper waters. Enhanced SCUBA technologies and the use of submersibles are allowing the collection of animals from deeper reefs for the aquarium trade. Fishers in the Philippines are draping narrow, but long, fishing nets over reefs that are several hundred feet deep; these nets are left out all night to ensnare fish, molluscs and other invertebrates. Very little is known about the ecology of these deeper reefs or potential impacts from exploitation, and it is extremely difficult to monitor or manage at these depths.

Human Health Impacts of Diving Practices

Collectors face serious health problems due to improper hookah and diving practices that lead to frequent decompression incidences, particularly for the international trade of live food fish, aquarium fish and lobsters. The Diving Fisherman Project is investigating the extent of diving-related injury to indigenous diving communities in East Asia, and providing help and assistance to avoid injuries (Cross et al., 2000). The project estimates that in the Asia Pacific area there are 50,000 to 80,000 indigenous divers, primarily in Indonesia and the Philippines. Mortality among divers is about 4 percent per year; 10 percent have obvious difficulty in walking; 18 percent have experienced some degree of paralysis; 20 percent exhibit clinical signs of spinal cord injuries; and 38 percent are diagnosed with aseptic necrosis of bone. Hookah diving is a dangerous and unsafe way of fishing. Most divers indicated that they do not want their children to take up hookah diving.

Photo: Barbara Best

Child cleaning seashell in Cebu, Philippines

Devastating impacts on collector health from hookah and scuba diving also occur along the Miskito Coast of Central America – close to 100 percent of divers show symptoms of neurological damage, presumably due to inadequate decompression. The industrial fleet has resorted to fishing in deeper waters due to depletion of lobster reserves in shallower waters. The human health impacts of international trade are often ignored, but need to be addressed on a local and global basis through education, improved regulation, reform of the fisheries, and inclusion of collector health considerations in certification schemes.

Management and Policy Implications

Creative trade regulations and market incentives that reward and encourage responsible use of coral reef resources and discourage destructive practices are possible strategies to address the negative environmental impacts of the trade. Central to the use of these market forces and regulations is the concept of *shifting the burden of proof* – commercial users must demonstrate that products are collected sustainably and without the use of destructive practices, rather than the burden falling on others to prove that harm has been done. Creative import regulations and eco-certification schemes can shift the burden of proof onto the commercial users who profit from the use of these resources, and encourage sustainable management in source countries.

Importing countries, whose citizens are driving the demand for some coral reef animals, must share responsibility along with the exporting countries for creating market incentives for sustainable products. For example, importing countries could require individual importers to show documentation that products came from areas under sustainable management; importers would then have to work with the exporters and collectors in the source country to ensure sustainable practices are implemented. Demand can also be driven by educated and well-informed consumers in importing countries, through consumer choice for eco-certified products.

Specific Recommendations for Actions

- Adopt precautionary, ecosystem-based approaches to coral reef management.
- Prohibit commercial exploitation of a species until a management plan has been developed that includes that particular species.
- Develop management plans with strong stakeholder involvement, and balance commercial uses with local uses and needs.
- Utilize environmental performance bonds, posted by commercial operators, as stakeholder investment.
- Establish substantial ecological, no-take areas as integral components of all management plans.
- Zone specific areas for specific uses and users, and establish appropriate monitoring plans for each area and use. Where appropriate, establish well-defined, small geographic areas that can be used as concessions to individuals, cooperatives or communities to increase stakeholder "investment" in sustainable use.
- Address destructive fishing practices through strong enforcement and appropriate fines.
- Share responsibility among exporting and importing countries. Importing countries can require individual importers to show documentation that animals and products were not taken by destructive means, and that they were taken from areas under sustainable management. Stiff fines should be levied on importers for falsification of documentation.
- Address the health impacts on divers from excessive diving and hold commercial operators responsible for diving safety. Include collector health as a component of permitting and eco-certification schemes.
- Educate consumers to the role that consumer choice can play in reducing impacts on reefs.
- Promote environmentally-sound mariculture.
- Characterize the nature, volume, and ecological impact of the marine curio trade, such as seashells, and develop appropriate management strategies.

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Destructive Fishing Practices

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Statement of Issue

DESTRUCTIVE fishing practices (DFPs) are those that result in direct damage to either the fished habitat or the primary habitat-structuring organisms in that habitat (for example, scleractinian corals), and include such well-known problems as blast and cyanide fishing and muro-ami drive nets. DFPs have been recognized as important threats to coral reefs on a regional basis for at least two decades, and are becoming more widespread and globally significant. In fact, in a number of developing countries, particularly those in the center of reef diversity in SE Asia, DFPs represent the most immediate and significant threat to the continued existence of coral reefs.


Photo: Lida Pet-Soude

Dynamite blast-fishing

State of Knowledge

Widespread Use of Destructive Fishing Practices

DFPs are reported from every tropical sea and encompass a wide range of techniques. The two undisputed "heavy-weights" are blast or dynamite fishing, and cyanide fishing for both the live reef fish aquarium trade and the Asian live reef food fish trade. These two techniques are used widely throughout the Indo-West Pacific with an epicenter in SE Asia. Blasting is also common in the Red Sea and Western Indian Ocean. Estimates suggest that up to 80 percent of Indonesian and Philippine reefs have been damaged by blast and cyanide fishing. Other common DFPs in the Indo-West Pacific include muro-ami drive nets, inshore trawling, and trap fishing. An interesting phenomenon prevalent in the Hawaiian Islands is damage from derelict fishing gear, which causes entanglement of marine life, direct damage to the reef, and introduction of alien species. In the Caribbean, DFPs are not as prevalent, although steel trap fishing and lobster traps can result in the crushing of substrate and the use of poisons like bleach are reported.

Impacts on Coral Reefs

Unlike many other anthropogenic impacts on coral reefs, DFPs directly destroy the reef framework, making recovery a long and difficult process even after the acute threat is removed. Studies indicate that the rubble fields created from blasting are a "rough neighborhood" for juvenile hard corals; the constantly shifting rubble buries new coral growth, while the aggressive soft coral mats that often invade these rubble fields are also capable of out-competing and even killing juvenile hard corals. Additionally, DFPs are often species-indiscriminate and have been shown to directly reduce fish diversity. As with most gears with high catchability, DFPs typically lead to smaller average sizes of target species. Just as importantly, DFPs are not limited to reefs near large population centers; rather, a paradox exists whereby the most remote reefs are often the most damaged by DFPs due to a complete lack of enforcement in these regions.

Socioeconomic Causes

The socioeconomic causes of DFPs are complex and vary from place to place. In many coastal communities, poverty and declining catches from conventional fishing techniques encourages fishers to use DFPs. In other areas, however, some recent studies have suggested that it is "greed rather than need" that drives the introduction and spread of DFPs like many criminal activities; it is simply a way to make more money faster than can be obtained from legal occupations. In the case of the live reef fish

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trade, traders and exporters, frequently in collusion with corrupt local officials, have often systematically introduced cyanide fishing. In Indonesia, for example, fishers engaged in blasting and cyanide fishing can easily earn more than government officials or university professors. In one case study, the "outlaw image" was a major incentive for young fishers to take up DFPs.

Management Solutions to Destructive Practices

Regarding solutions to the DFP problem, numerous case studies documented both successes and failures. There is very strong evidence that marine protected areas (MPA) are one of the most effective means of preventing DFPs, especially when a combination of patrols and active marine tourism discourages the use of DFPs. Unfortunately, enforcement activities both inside and outside MPAs are often hampered by persistent corruption, especially in the lucrative live reef fish trade, and by a lack of funding. At times there seems to be an unwritten policy of both conservation non-governmental organizations (NGO) and development agencies that enforcement is a repressive activity that should not be funded in developing countries, even when local communities and DFP practitioners alike agree that strict enforcement is a necessity. Of course, the solution to DFPs clearly must be a balanced and integrated one and beefed-up enforcement capacities and activities must play an important role.

The use of alternative income generation schemes to lure fishers from DFPs has proven difficult and failures seem to outnumber successes. One problem is the lucrative nature of most DFPs; it is often difficult to devise alternative income generation schemes that earn nearly as much as DFPs. Seaweed farming, or mariculture, is one scheme that has shown considerable earnings potential, although in one case the relatively large amount of free time afforded seaweed farmers resulted in "recreational cyanide fishing." Mariculture of target species for both the live reef fish aquarium trade and food fish trades also shows promise. Unfortunately, larger companies often undertake these activities with little benefit to the local fishers otherwise involved in DFPs.

Mixed results have also been achieved in the case of training fishers in non-destructive techniques to replace DFPs. In the live reef fish trade, there have been some successes in converting cyanide fishers to the use of nets for aquarium fish and hook-and-line for live reef food fish, particularly in the Philippines. But few such efforts have yet been implemented in other Southeast Asian countries where cyanide fishing is a problem, such as Indonesia and Vietnam. While training in non-destructive techniques prevents damage to the reef itself, it does not in itself prevent overfishing. For example, hook-and-line fishers have wiped out grouper spawning aggregations in Palau nearly as efficiently as would be the case with cyanide. Likewise, training and regulations in the Philippines to switch fishers from muro-ami—where rocks are pounded along the reef to drive fish into a trap net—to pa-aling—where the fish are chased with hundreds of bubbling air hoses instead—may prevent damage to the reef. But pa-aling still removes up to 50 percent of the standing fish biomass on a reef in one net operation. In short, approaches to reducing destructive fishing need to be coupled with more comprehensive measures to prevent overfishing.

One relatively new solution to reduce DFPs, and cyanide fishing in particular, involves the use of "eco-labelling" or certification to ensure that fish and corals exported for the aquarium trade are harvested at sustainable levels without the use of destructive methods. This approach is being widely advocated by private sector and non-government groups in the United States, the world's largest importing country for the aquarium trade. If combined with tighter regulations to prevent the export of "undesirable aquarium species"—those that do not survive in aquaria due to dietary or habitat requirements or behavioral incompatibilities—certification has the potential to greatly reduce both cyanide fishing and unnecessary mortality of exported fish and invertebrates. It depends, however, on the growth of consumer demand for "environmentally-friendly" fish and other reef species, and willingness on the part of governments of consumer countries to regulate—and possibly restrict—the import of non-certified reef species. Unfortunately, in the case of blast fishing, the majority of the catch is destined for low-value local markets where certification is not an applicable strategy.

Relevant Actions Taken to Address the Issue

Governments, researchers, national and international conservation NGOs and development aid agencies are now realizing the full extent of the DFP problem and are mobilizing to combat DFPs. Research is focusing on both the effects of DFPs, the extent of reef damage caused by DFPs, and methods to enhance recovery from this damage. International NGOs and aid agencies are helping many MPAs beef up enforcement activities and involve the private, marine tourism sector in prevention of DFPs. Government agencies are becoming more actively involved


Photo: Jeffrey Jeffords, divergallery.com

Fish collector employs cyanide in reef fish collection, Capone Islands, Philippines

as well. The U.S. National Marine Fisheries Service is increasing efforts to remove derelict fishing gear in the Hawaiian Islands. The International Marinelife Alliance's Destructive Fishing Reform Initiative, carried out in partnership with a wide variety of other NGOs and government agencies throughout the Asia-Pacific, is using a combination of education for both fishers and government agencies, enforcement, and monitoring of the live reef fish trade to combat cyanide fishing (and prevent its introduction into new source countries), overfishing and other abuses in the live reef fish trade. The Marine Aquarium Council in the United States is leading an effort to establish a certification system for aquarium organisms in international trade.

Management and Policy Implications

DFPs present an immediate and expanding threat to coral reefs throughout the world, with SE Asian reefs in the epicenter of global marine biodiversity at highest risk. Management solutions are urgently needed to address this problem, which threatens to severely degrade a large percentage of the world's most diverse reefs *within this decade*. Priority recommendations for action are included below.

Specific Recommendations for Action

- ***Focus immediate policy and funding initiatives on stronger enforcement against DFPs***. Most countries have laws against DFPs, but glaring legal loopholes must be closed and persistent problems with corruption in the legal system addressed. Specific regulations banning possession and use of key components of DFPs such as blasting caps and cyanide would greatly facilitate enforcement. Hookah compressors should be banned for the capture of live reef food fish (which can be captured with hook-and-line), but may be necessary for aquarium fish collectors even when using best practices. The wholesale ban of compressors is therefore problematic. Banning their use would be unfair to aquarium fishers trying to do the right thing, while allowing compressors creates a loophole for those fishers still using cyanide to catch fish. Policymakers must keep in mind how the nuances between the food fish and aquarium trades have the potential to create incompatibilities in policy. Perhaps even more importantly, enforcement institutions must be educated on the tremendous damage caused by DFPs, while patrol time both inside and outside of MPAs must be greatly increased. Firsthand experience from conservation agencies and suggestions from destructive fishers themselves show that stronger enforcement is an essential prerequisite for curbing DFPs.
- ***Expand and strengthen the world's MPA network***. MPAs are one of the most effective tools against destructive fishing, though properly focused funding assistance is still needed in many tropical developing country MPAs to move beyond "paper park" status.
- ***Fund applied research on restoration of DFP-damaged reefs***. Current reef restoration efforts are largely focused on extremely high-cost rehabilitation of damage from ship groundings. There is an urgent need for inexpensive, low-technology restoration techniques for the vast areas of blast and cyanide damaged reefs prevalent in areas of the Indo-West Pacific. Local community involvement in restoration efforts can both build local support and provide a potential source of livelihood.
- ***Develop and support "ecolabelling" certification systems to provide market incentives against DFPs***. Significant progress has been made by the Marine Aquarium Council and its partners towards developing a certification system sustainable for collection of reef organisms for the aquarium trade, but the system has yet to function in the real world, and it is unclear if and when it will become a major driver of the aquarium fish market. Similar systems might conceivably be applied to live reef food fish and

lobsters, but more study is needed to determine if it is possible to mobilize consumers in Asian markets against DFP-caught products or not. A more promising route for Asian markets may be to pressure and work with industry players themselves to develop an industry code of conduct that could be independently monitored.

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The Marine Ornamental Trade

Paul Holthus [1]

Statement of Issue

THE international trade in marine ornamentals from coral reefs is increasing in many countries and expanding to most coral reef regions. Although the ornamental trade may provide alternative sources of income for some communities, there are still major environmental and management concerns over this trade, including: the use of destructive fishing and collection practices, especially the use of cyanide to stun and then capture fish alive; overexploitation; targeting of rare or endemic species which can bring the highest prices; collection of organisms from deeper reefs; the removal of reef substrate or "live rock"; the collection of inappropriate species that do not survive well in aquaria; high mortality rates associated with improper handling and transport; and the health impacts on human collectors from excessive diving and the use of hookah rigs.

Many developing countries are currently ill equipped to manage this rapidly growing industry. However, many of these animals and products are destined for hobbyists in developed countries, where awareness and concern about the use of reef animals is growing. Increased awareness in both hobbyists and importing countries may be used to generate market incentives for the sustainable management of reef organisms.

At the 9th ICRS, presentations and posters from several symposia addressed different aspects of the marine ornamental trade, including the nature of the trade, environmental impacts, case studies, and strategies and options for addressing the impacts and managing the industry.

State of Knowledge

Extent and Nature of Trade
Over forty countries have a marine aquarium fishery based on coral reef species. It is estimated that over 1000 different species of fish and invertebrates, as well as live reef substrate or "live rock," are presently involved in the trade. At least 20 million fish are captured annually to supply hobbyists primarily in the United States, European

Photo: Paul Holthus

Ornamental fishers and boat on shore

Union, Japan and Canada. Invertebrates are an important component of the trade, constituting about 20 percent of the total export. Some of the major exporting countries include the Philippines, Indonesia, and Fiji. In the Pacific region, the live reef fish trade is increasing in importance, for both food fish and aquarium fish. While this trade has the potential for increasing benefits to local Pacific Island communities, experience has shown that the live reef fish trade can be destructive to reef resources if it is not managed and regulated appropriately. Regional differences exist with regard to the collection of coral; throughout most of the Caribbean, coral is viewed as essential fish habitat, and the collection of coral and life rock is prohibited.

CITES and the Marine Ornamental Trade
All stony corals, live rock and *Tridacna (giant clams)* are listed on Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Exports of Appendix II listed species require permits from the exporting countries that state that the export will not be detrimental to the survival of the species or its role in the environment. However, many exporting countries may not have the resources to fully implement the non-detrimental findings. These permits provide a means to monitor the trade through the annual reports by exporting and importing countries. CITES data indicate the trade in live coral and live rock has increased annually at a rate of 12-30 percent with most originating in Indonesia and Fiji and over 80 percent imported by the United States. Several of the most traded live coral genera are slow growing, and may be vulnerable to overexploitation. More studies are

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needed on the life history characteristics, abundance and distribution of species in trade.

Database for the Marine Ornamental Trade
UNEP-World Conservation and Monitoring Centre and the Marine Aquarium Council are collaborating in the creation of the Global Marine Aquarium Database (GMAD) that will form the first comprehensive quantitative analyses of the trade in all marine ornamental organisms. Information is being collated from exporters involved in the trade. This database will be especially useful for describing the nature and volume of trade in non-CITES animals.

Culturing of Marine Ornamentals
The artificial propagation of marine ornamental species has the potential to supply some of the market demand, alleviating some pressure on wild stocks. In South Africa, propagation of corals was conducted by experimenting with current flow, feeding and light to obtain the optimum growth conditions. The twelve most suitable hard corals were selected for culture from the 36 species tested. In the Solomon Islands, light traps and crest nets have been used to capture juvenile fish. The feasibility of harvesting postlarval coral reef fishes and rearing them in captivity for the aquarium trade is being tested for more than 60 species.

Progress is being made in coral and fish propagation, but cultured ornamentals will remain a minor component of the trade for the foreseeable future. Captive breeding of reef organisms is only about 2 percent of the market for fish and slightly more for corals. Aquaculture of marine ornamentals is growing very slowly due to biological and technical constraints, higher costs of cultured animals, and low demand for cultured products by consumers.

Inappropriate Species in Trade
Although improvements have been made in the husbandry of coral reef animals, there are a large number of species collected and sold for the marine aquarium trade, which continue to have low to dismal chances of surviving in aquaria. Included in this group are most azooxanthellae anthozoans, many filter-feeding invertebrates, and certain fishes. The main reasons that these animals do not survive in aquaria are related to diet and the inability of aquaria to supply sufficient amounts or types of nutrients. Expert hobbyists, retailers and researchers have documented many of these animals, which are inappropriate for the trade; a report compiling all these observations was presented, which includes several hundred species.


Photo: Chuck Savall

A pair of orange, white, and black Clark's Anemone Fish in their green host anemone, Fiji

Case Studies From Different Countries

Brazil: In Brazil, there is high concern for the local extinction of many reef species from the capture of ornamental animals and coastal development. Recent studies point to high rate of endemism (up to 20 percent) in reef fishes.

Fiji: Fiji is one of the major exporters of live reef substrate (live rock), fish and invertebrates for the marine aquarium trade. Careful and systematic collection can result in reduced environmental impacts. The challenge that faces responsible exporters is to educate collectors in sustainable reef management.

Maldives: In the Maldives, about 114 species of live tropical fish are exported, with 20 species making up about 75 percent of the exports. In 1999 more than 160,000 fish were exported, mostly to Europe, earning about US$ 300,000. The trade includes species that are very rare in the Maldives, as well as quasi-endemic species. Collection is depleting many favored species in the country, a concern for the biodiversity of reefs.

South Africa: The marine aquarium trade in South Africa has expanded greatly during the past decade. Most animals are collected from the wild (less than 2 percent are maricultured). Poaching is common, and corals are commonly chiseled off reefs that are already degraded by pollution. Many specimens die during transportation and handling, or from placement in unsuitable aquaria. The future of a sustainable supply of corals for the aquarium trade lies in artificial propagation through mariculture, and efforts are underway to culture local corals for the trade.

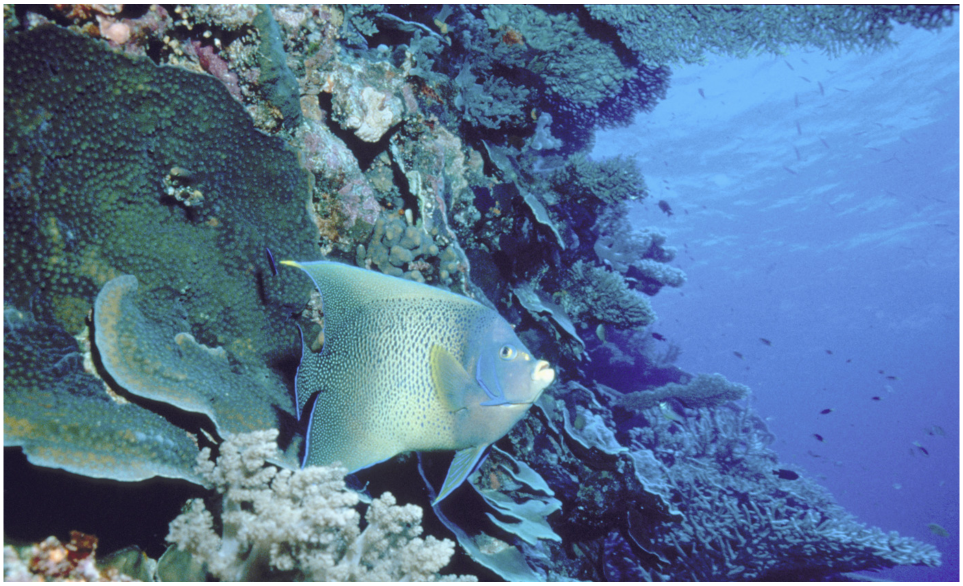

Photo: Great Barrier Reef Marine Park Authority

Angelfish, Great Barrier Reef, Australia

Sri Lanka: For many years the marine ornamental export trade in Sri Lanka was not monitored or regulated, and there were concerns about possible environmental impacts of the fishery. A collaborative program involving resource managers and the ornamental industry was initiated to develop a conservation management plan. Population censuses, along with user assessments, were brought together to produce a plan for the conservation and management of marine ornamental resources that is acceptable to all stakeholders and thus more likely to succeed.

U.S Hawai'ian islands: In Hawai'i, the collecting of reef fish for the aquarium trade has caused multiple-use conflicts between collectors and other users, especially the tourism sector. Intensive monitoring between control areas and collection areas reveals that 8 species targeted by collectors were significantly less abundant (up to 60 percent less) in collection sites. In response to this environmental impact, and with input from the local community, 30 percent of the west Hawai'i coastline was closed to aquarium collecting in 1998. However, latest surveys indicate that impacted areas still have significantly lower abundances.

Shifting the Burden of Proof of Sustainable Use

There has been heightened interest in the trade in coral reef organisms in both importing and exporting countries. Market incentives that reward and encourage responsible use of coral reef resources and discourage destructive practices are being explored as possible strategies to address the negative environmental impacts of the trade. Eco-certification schemes and creative regulations on imports can shift the burden of proof onto the commercial users who profit from the use of these resources, and encourage sustainable management in source countries.

Eco-certification Schemes

If conscientious and increasingly sophisticated marine aquarium hobbyists insist on sustainably collected marine organisms, exporting countries may have an opportunity to maximize their potential in this market. The Marine Aquarium Council (MAC) is an independent, international multi-stakeholder non-profit organization that is developing an eco-certification scheme by bringing together representatives of the aquarium industry, hobbyists, conservation organizations, government agencies, public aquariums, international organizations and others, who have shared interests in the future of the marine aquarium industry, and the marine organisms and habitat it is based on. By creating standards and educating and certifying those engaged in the collection and care of ornamental marine life from reef to aquarium, MAC is providing one potential solution to the problems surrounding the trade. Export countries can benefit in many ways from marine ornamental industry if environmental guidelines are followed. The main challenge is to ensure sustainable reef management by educating collectors, others in the industry and the ultimate buyer.

Importing Countries Must Assume Some Responsibility

Importing countries, whose citizens are driving the demand for aquarium animals, must share some responsibility along with the exporting countries for creating market incentives for sustainable products. The United States, one of the major importers of coral and coral reef animals, is exploring innovative trade measures to ensure that coral reef products were not taken using destructive collection practices, and that corals were collected from areas under sustainable management.

Relevant Actions Being Taken to Address Issue

The Marine Aquarium Council (MAC) is progressing on developing an eco-certification system, which was launched in late 2001. The MAC Core Standards have been released and are available on its website. The MAC Core Standards consist of three components: Ecosystem and Fisheries Management: Collection, Fishing, and Holding; Handling, Husbandry and Transport.

Reef Check is developing and testing a monitoring protocol for MAC certification. The newly formed MAC Science and Monitoring Advisory Committee will review the monitoring system. The committee will provide ongoing support to MAC on science, research, assessment, and monitoring of coral reefs and marine aquarium organisms in relation to certification, sustainability and environmental impacts.

The Philippines has established cyanide detection centers for the testing of live food fish and aquarium fish destined for export.

The U.S. Government continues to work domestically and internationally to improve the ability of customs officials to properly identify corals in trade through training workshops and the development of a coral identification module for Indo-Pacific corals in trade. The book includes photos, descriptions and a key to corals in trade and has been adopted as the standard identification guide for CITES parties. In 2001, two international workshops were held in Fiji and Indonesia, with support from the United States, to promote the sustainable management, monitoring, and identification of corals and coral reef animals in the trade.

Management and Policy Implications

Promoting best management practices, such as through certification schemes and development of management conservation plans that involve resource users, may be the most effective way to ensure sustainable use of resources.

Specific Recommendations for Action

- Develop management and conservation plans that involve resource users, and thus are more likely to succeed. Ecological no-take reserves should be included in the plans.
- Support industry standards and eco-certification systems, such as the MAC system, that promote best practices and the sustainable management of reef resources.
- Develop policy and legislation to improve reef management and conservation in relation to trade, in both exporting and importing countries, and that encourage certification.
- Raise consumer awareness about environmental issues and the role that consumer choice can play in encouraging sustainable management, and encourage hobbyists to demand certified products.
- Develop and implement appropriate monitoring plans for the aquarium trade.
- Encourage exporters to contribute their data to the Global Marine Aquarium Database to ensure that comprehensive information on the trade is available.
- Discourage the collection and trade in inappropriate species that do not survive in aquaria.
- Discourage the collection and trade of rare or endemic species, or those from deep reefs where monitoring and management are difficult.
- Support scientific research that better defines sustainability and encourage scientists to participate in developing monitoring standards.
- Promote the development of viable culturing of ornamentals, and encourage in situ culturing.
- Promote management, oversight and certification schemes that also include diving safeguards for human collectors from excessive diving, and equitable distribution of profits.

Useful References and Resources

This paper is based upon presentations and posters at the 9th International Coral Reef Symposium, including Mini-Symposia "A Sustainable Trade in Marine Ornamentals: Linking Reef Science, Conservation and Use," "Destructive Fishing Practices," and "Status Reports." Authors and titles of presentations can be found at: www.nova.edu/ocean/9icrs/.

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Conservation Biology of Coral Reef Fishes

Terry J. Donaldson [1] and Yvonne Sadovy [2]

Statement of Issue

MANY coral reef fishes are particularly susceptible to overexploitation, not only because of their typical life history traits but also because of their direct and indirect dependence on coral reef habitats, which are also under threat. The presentations at the 9th ICRS reflected the research and concerns of biologists working on a broad range of reef fishes and reef environments regarding the impacts of exploitation and natural impacts on reefs and reef fish communities. Particular emphasis in many of the talks was placed upon the difficulties of detecting and measuring changes in reef fish communities, especially for particularly large or rare species. Moreover, the general lack of information on the biology and habitat requirements of commercially exploited species represents a serious impediment to understanding both natural and anthropogenic impacts. There appears to be a growing consensus that special vigilance is needed to manage and conserve reef fish assemblages.

Three themes were elaborated during this mini-symposium at the 9th ICRS: (1) the increasing and sometimes intensive exploitation of reef fish, often for export, and their vulnerability to such exploitation; (2) the role of habitat, especially at particular life history phases, and (3) the needs and difficulties of monitoring reef fish assemblages.

State of Knowledge

Exploitation of Reef Fishes

Exploitation of reef fishes appears to be increasing, with a pronounced growth in international trade adding pressure to limited resources. In addition to traditional fisheries, pressure is growing on species being taken in new, non-traditional fisheries, such as the marine aquarium trade, the live reef food fish trade and the trade in fish fry for mariculture. The live reef fish trades may be quite selective in terms of both species and are attractive for aquaria or suitable for food in terms of taste, texture, and size – aquarium size or 'plate' size.

Photo: S. Zumbrunn

Nassau Grouper in Grand Cayman

In the Philippines, the live reef fish trade harvests coral trout, *Plectropomus leopardus*, in significant numbers, targeting especially those that are close to first sexual maturation (that is, preferred plate size in restaurants – 30-35 centimeters total length). Ironically, cyanide is often used to "catch" such fish alive; cyanide is used to stun the fish and allow their easy collection. In Australia, this same species represents over 90 percent of all live exports of reef fishes. There is some concern in Australia that the lucrative live reef fish trade will cause excessive expansion of the live fish fishery through reactivation of existing, but dormant, fishing licences, such is the economic promise of this trade. In Sri Lanka, about 200,000 fish are exported each year for the marine aquarium trade, with particularly heavy pressure on certain desirable species (for example, *Labroides dimidiatus*, a wrasse, which represents about 10 percent of the trade in terms of numbers). Both collectors and biologists are expressing concern about the status of some of the more intensively exploited species.

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Critical Role of Habitat
Some fisheries focus heavily on particular life history phases, such as spawning aggregations or nursery areas, where catchability is particularly high, or fish easy to find. Aggregation sites and other specific habitats need to be included in Marine Protected Areas (MPAs), although for some species spawning aggregations may not be spatially predictable enough from year to year to benefit from site-based management. Other approaches include temporal closures. Fry fisheries, which target tiny juveniles of species such as the rabbitfish and groupers, may place excessive pressure on resources, and take high levels of bycatch. These fry fisheries are particularly challenging to monitor and manage.

The importance of alterations to habitat, such as from bleaching or habitat destruction, for reef fish assemblages needs to be recognized and addressed. The massive bleaching event of 1998 severely affected many areas of the Indo-Pacific with some islands of the Indian Ocean suffering 90 percent coral mortality. Surveys in two locations following this bleaching event indicated increased levels of planktivores and herbivores, while corallivores showed clear declines from pre-bleaching levels. There were also changes in species richness. Regrettably, coral-dwelling species adversely affected by coral bleaching, and thus experiencing declines in population levels with a corresponding loss of habitat, may also be threatened with harvest by the live reef fish trade. In the Caribbean, the importance of mangrove and seagrass beds for juveniles of a number of reef species was demonstrated by a study that showed declines in adults of certain species following loss of, or destruction to, nursery areas. The design and management of MPAs need to incorporate key life history phases or habitats such as nurseries or spawning areas.

Monitoring Reef Fish Assemblages
A strong focus of many of the presentations was the difficulty of, and urgent need for, monitoring reef fish assemblages, especially in the case of heavily exploited, or vulnerable species. A particularly acute problem is the monitoring of large and relatively rare reef fishes and there is a need to incorporate age-structured data to distinguish the effects of fishing from natural demographic differences between areas. Some large reef species, such as the Humphead wrasse, *Cheilinus undulatus*, and the Bumphead parrotfish, *Bolbometopon muricatum*, have shown alarming declines in some places. Because these species are wide-ranging and naturally scarce, ‘traditional’ spatial scales and methodologies of underwater visual census are evidently not well-suited to such species. It is clear that


Photo: Coastal Resources Center, URI

Traditional fish trap, Balikpapan Bay, East Kalimantan, Indonesia

dedicated and specially designed surveys are needed. To address this problem, scientists have moved beyond more conventional methods of assessing reef fish populations (that is, through underwater visual census and fishery data) by seeking anecdotal information and the opinions of those knowledgeable about the resource, such as local communities, collectors and traders, through the use of questionnaires or interviews and seeking out export records and logbooks. Fishers have also been directly involved in dive surveys. These ‘alternative’ approaches to data gathering reflect the difficulties in monitoring reef fishes and the general shortage of fishery data collected in reef fisheries. Often, several sources of information are combined as a crosscheck and to form a wider picture. Overall, however, the dearth of information, even on heavily exploited and valuable species, and the special difficulties of monitoring large or rare species, were perceived to be serious impediments to management and conservation initiatives for vulnerable reef species.

Relevant Actions Being Taken to Address the Issue

Approaches to address some of the problems identified were proposed, are under development or are being implemented. Alternative methods for monitoring large and wide-ranging species are being developed and there was increasing interest and confidence expressed in the use of traditional knowledge for better understanding reef fisheries. There is a growing focus on the need to protect and manage reef fish spawning aggregations; the Society for the Conservation of Reef Fish Aggregations (SCRFA) was established in summer 2000 and formerly constituted during the 9th ICRS. Monitoring of reef fisheries and non-traditional fisheries, such as marine ornamentals and juveniles destined for mariculture grow-out in SE Asia, have yet to receive serious attention in most places.

Management and Policy Implications

Collection of information on the past history and current status of reef fish resources is essential for identifying especially vulnerable species and better understanding the effects of different fishing practices. Specific conservation issues include the protection and management of reef fish spawning aggregations and critical nursery areas. The dearth of information on reef fish fisheries, particularly in the Indo-Pacific, seriously undermines management and conservation initiatives and is a key area that needs to be addressed in developing fishery management plans and monitoring protocols at the country level.

Specific Recommendations for Action

- Develop monitoring protocols for large and wide-ranging and rare reef fishes.
- Improve or implement species-specific monitoring systems for reef fisheries; many are not monitored or species are lumped. Many non-traditional fisheries, such as those for the marine aquarium trade, are often not monitored at all.
- Protect critical life history bottlenecks, such as nursery areas and spawning aggregations.
- Increase reliance on, and incorporation of, traditional knowledge in the understanding of reef fishery histories and status where appropriate.
- Protect stressed areas, such as bleached areas, to enhance recovery potential.
- Scrutinize 'mariculture' activities that depend on wild-caught juveniles (as opposed to hatchery produced) for grow-out – these activities are not necessarily sustainable solutions to overfishing or destructive fishing practices.

Useful References and Resources

This paper is based upon presentations at the 9th International Coral Reef Symposium, Mini-Symposium B3, *Conservation Biology of Coral Reef Fishes.* Authors and titles of presentations can be found at: www.nova.edu/ocean/9icrs/.

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Long Term Coral Reef Monitoring Programs: Working Towards a Synthesis of Science, Management, and Policy

Brian N. Tissot [1] and Deborah M. Brosnan [2]

Statement of the Issue

CORAL reefs are complex ecosystems threatened globally with a variety of natural and anthropogenic factors. Scientific monitoring is the primary source of information on reef biology and status. However, monitoring is both a scientific endeavor and a decision-making management tool. As a result, this dual nature leads to controversy and there is considerable debate among scientists about the design and methodology of these programs. Thus, although monitoring programs are often focused on important biological questions, they may have weak links to management and environmental policy. These links need to be strengthened for effective management and intervention.

This paper is a synthesis of presentations and discussions that took place both during and after the 9th ICRS, and included scientists, reef managers and policy-makers. Several major coral reef monitoring programs in the Atlantic, Caribbean, and Pacific, and their relationship to management and policy issues at both the local and national levels, were reviewed.

Photo: Brian Tissot

Monitoring in Mahikona, Hawaii

State of Knowledge

Careful Design, Integration and Cooperation are Important

Although monitoring questions are often based on simple scientific principles and methods, it is a challenge to distinguish natural from human-induced variation. Careful attention to the types of data collected, including indicator species such as benthic algae and temporal patterns in the distribution and abundance of recent and old dead coral, can provide important information on population dynamics.

Monitoring programs require a substantial amount of energy to be established and maintained, and there are institutional barriers to establishing long-term programs. Monitoring is undervalued in comparison to experimental science, and it is difficult to sustain funding over the time scales needed to detect meaningful change. Moreover, holistic approaches that integrate both the causes and effects of human impacts on reefs often require interdisciplinary cooperation, which clash with traditional disciplinary boundaries and funding sources.

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Formulate Realistic Targets

Another important issue is the statistical rigor of monitoring programs. To be efficient, monitoring programs need to be focused on specific testable hypotheses or questions. However, question-driven programs are based on specified experimental designs that require specific target levels of accuracy and statistical error rates. Due to substantial (and non-linear) trade-offs between accuracy and effort, formulating realistic target levels is critical to program design and success. Unfortunately, many monitoring programs are not based on the needs of reef managers and may be overly accurate and thus inefficient with limited financial resources. Statistical rigor can also be increased by using paired control-impact designs, habitat-based stratified approaches and by methods that increase replication or reduce measurement error.

Role of New Technologies

One of the most important long-term drivers of monitoring programs is likely to be changes in technology. Thus, research exploring new methodology is important and rigorous monitoring programs should be adaptive to new methods as they emerge. Increases in the resolution of remote sensing combined with increasing scales of underwater survey work are beginning to provide large-scale data for ecosystem management. However, efficient management at the ecosystem level will require better integration of state and federal policy and cooperation and collaboration among a wide variety of stakeholders.

Relevant Actions Being Taken and Management/Policy Implications

There is a strong need for scientists and resource managers to collaborate when developing and implementing long-term monitoring programs. Reef managers need to develop the specific questions and criteria they need to be effective managers and scientists need to link their experimental designs to these questions. Moreover, policy makers need to use language detailing specific terms and/or outcomes from programs that link science and management issues together. A good example of this type of monitoring program is the West Hawaii Aquarium Project (WHAP). WHAP is run by a consortia of academic scientists working with Hawaii resource managers and biologists to measure the effectiveness of marine reserves created to evaluate the policy-mandated "effectiveness" of the reserves to increase the productivity of an aquarium fishery. WHAP is cost-efficient because it uses highly-trained undergraduate students generated from the QUEST coral reef monitoring workshop to conduct reef surveys (see references).

There is also a need to develop a question-driven decision tree. That is, given a specific management question what monitoring programs and methods are good models. The development of this tool would help facilitate collaboration between scientists and managers and reduce the amount of controversy around methodological and statistical issues. The decision-tree should also include a framework for integrating ecological concepts (for example, disturbance) with the appropriate methodology so there is consistency both within and among programs.

The creation of a question-driven decision tree can be facilitated by developing standards through a national and/or international coral reef monitoring program that all programs could build on and provide a central clearinghouse for data, metadata and survey methodology. Good examples of international monitoring programs exist in the GCRMN/Reef Check model and the ReefBase database. At the National level the USA Coral Reef Conservation Act offers an opportunity to mesh state and federal policy and establish a national coral reef monitoring program. However, to develop an efficient, effective and sustainable monitoring program there is a need to conduct a comprehensive review and synthesis of existing long-term programs and identify gaps in information and methodology.

Specific Recommendations for Action

- Monitoring programs need to be designed with strong links to reef management issues;
- Reef managers need to develop specific questions and criteria and collaborate with scientists;
- Policy should address realistic and measurable scientific/management questions;
- A question-driven decision tree needs to be developed to guide the experimental design of monitoring programs;
- Research on new survey methodology should be ongoing and monitoring programs should be flexible and incorporate new methods;
- There needs to be greater coordination among monitoring programs at the national and international levels and the development of a central clearinghouse for data and methodology.

Useful References and Resources:

This paper was prepared from presentations and discussions at the 9th International Coral Reef Symposium, with special emphasis on Mini-Symposium D2 "*Central Questions, Experimental Design, and Methods of Long Term Monitoring Programs: A Synthesis of Ecological Concepts and Data*." Authors and titles of presentations can be found at: www.nova.edu/ocean/9icrs/

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Coral Reef Biodiversity: Assessment and Conservation

Sheila A. McKenna [1] and Gerald A. Allen [2]

Statement of Issue

WITH limited resources and the increasing degradation of coral reef ecosystems, finding an effective and methodical way to prioritize coral reef areas for conservation is critical. The loss of biodiversity is one of the worst problems. Its most severe and irreversible outcome is species extinction, and often a coral reef area is lost before the rich diversity of organisms living there is properly documented. The establishment of marine protected areas is one means of preserving coral reefs, and their location needs to take into account the biodiversity, overall reef condition, and threats. Coral reefs targeted for conservation should ideally capture the most representative and richest sites to maximize biodiversity conservation impact. Given the immense biodiversity on coral reefs, it is impossible to document all taxa.

An alternative approach is to inventory key indicator groups along with other variables such as endemism, threat, habitat diversity and socio-economic issues. Further, an understanding of the variability in patterns of marine biodiversity is needed. This baseline information is critical for realistic and effective conservation activities. Managers and policy makers need to know what parameter(s) and indicators of reef biodiversity are being used and studied to assess and identify reef areas for conservation, and to make informed and effective conservation decisions. This summary from the 9th ICRS reviews indicators that are used to assess coral reef biodiversity, patterns of marine biodiversity that have been elucidated, and priority areas for reef conservation that have been identified. Case studies of areas in which assessments were made are also provided.

State of Knowledge

Corals as Indicators of Reef Diversity
An analysis of global patterns of coral diversity at three taxonomic levels (family, genus and species) revealed that patterns of reef coral diversity become defined and more detailed as one progresses from the family to the species level. For example, beginning at the genus level, a well-defined Indo-Pacific center of diversity emerges in the Indonesia-Philippines region that is not evident at the family level. Patterns within this center of diversity are apparent at the species level. Reasons for this progression in coral diversity pattern with taxonomic level are partly attributed to continental drift and mass extinctions at the family level, closure of the Tethys Sea and the Central American Seaway at the generic level, and ocean currents and changing climates at the species level.

Photo: Gerald R. Allen

Pseudochromis – a new species found on Conservation International's Marine RAP Expedition of Raja Ampat Islands, Indonesia

Molluscs as Indicators of Reef Diversity
An analysis of 1268 species of molluscs in 10 regions of the tropical Indo-West Pacific found the greatest diversity to occur in the Indo-Australian Archipelago ("coral triangle") with a total of 321 endemic species. Molluscan diversity and endemism is a useful tool for helping to establish the location for survey efforts for coral reef conservation studies.

In addition to diversity and endemism, an increase in understanding of phylogenetic relationships of highly diverse taxa also provides important data for consideration in developing conservation strategies. Results of

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phylogenetic studies of many clades of opisthobranch gastropods on Indo-Pacific coral reefs suggest that the Indo-Pacific represents a historically significant evolutionary and biogeographic unit. An examination of giant clams found the nine extant species to be restricted to the Indo-West Pacific with the West Pacific as the center of diversity. Alarmingly, some species have become depleted and locally extinct in the Indo-Pacific, and rearing and re-introductions are taking place as part of current management practices.

Coral Reef Fishes as Indicators of Reef Diversity
Coral reef fishes are another fauna commonly used as key indicators of diversity to identify conservation priority sites or "hotspots." A zoogeographic analysis involving 2051 species of fish revealed 35 sites of local endemism and regional patterns (Figure 1). The highest endemism was found in the Hawaiian Islands. Additional data analysis revealed a detailed pattern of reef fish diversity in the Indo-Pacific with its center occurring in the Indonesia-Philippines region. Results suggest that this area may be the highest priority for coral reef conservation based on its extremely rich biodiversity, significant endemism, and extensive habitat degradation.

Case Studies on Coral Reef Assessments
In Guam, an intensive survey of the marine fauna suggests that the fauna of even well-studied areas can remain poorly known and that small islands can host several tens of thousands of species. Reef assessments in the Sulawesi Sea, Indonesia, and the northern Saudi Arabian Red Sea used a combination of indicator species and other factors such as diversity and function of habitat, as well as socio-economic data, to identify priority regions for conservation through the establishment of marine protected areas. Within the Atlantic Ocean, the reefs of Brazil were identified as an area for conservation priority due to the small reef area, significant endemism and high risk of habitat loss, due primarily to the high human population and deforestation along the coast.

A global analysis of reef regions for conservation priority was presented. This "equal area grid" analysis involved a map-based approach to show global distribution of species richness and endemism of fish, cone shells, and lobsters. The level of risk from a suite of human threats was calculated for each area, using the "Reefs at Risk" data base from the World Resource Institute. Focusing on regions rich in restricted-range species may be valuable in conserving species. However, the central question is whether to establish conservation projects in target areas under less risk where the probability for success will be greater, or in target areas under severe risk from threats.

Relevant Actions Being Taken to Address the Issue

Developing criteria to set conservation priorities on coral reefs is a relatively new approach and is proving to be a complex issue. No one criterion or set of criteria can be

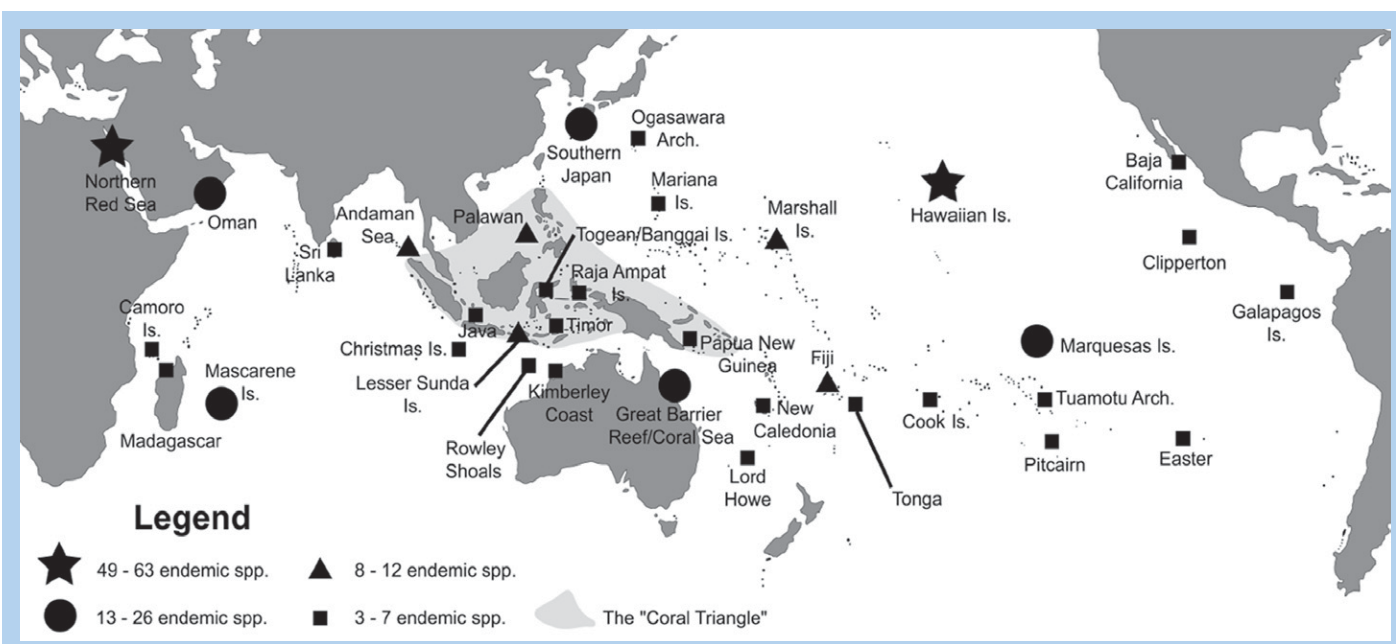

Figure 1. **Hotspots for reef fish endemism in the tropical Indo-Pacific. The "coral triangle" is indicated by shading.**

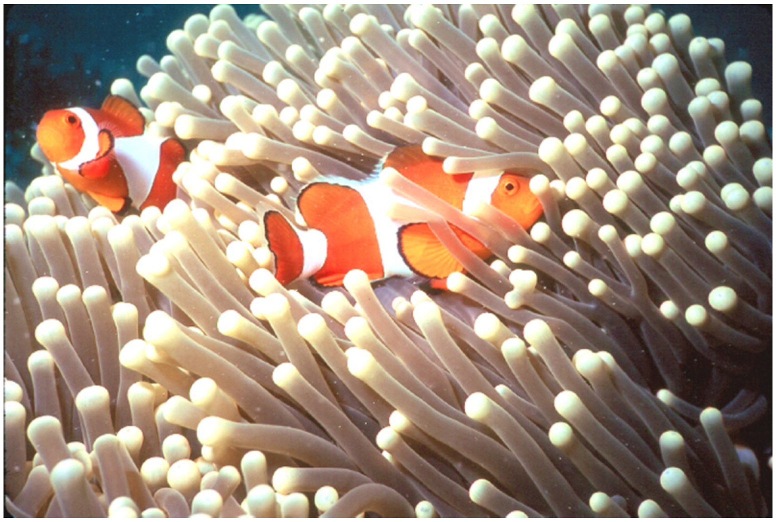

Photo: Steve Turek

Portrait of two orange, black, and white Clownfish (*Amphiron ocellaris*) inside their host – Magnificent Anemone (*Heteractis magnifica*), Malaysia

labeled right or wrong. Coral reef researchers are constantly fine-tuning the methodology and analyzing the data to prioritize reefs for conservation. Gaps in our knowledge of biodiversity and other data such as functional groups and habitat diversity on previously unsurveyed reef regions are gradually being filled. Additional scientific tools are being applied in combination with biodiversity data to aid the process of priority-setting on reefs (e.g. phylogenetic analysis and geology).

Management and Policy Implications

Coral reefs targeted for conservation should ideally capture the most representative and richest sites to maximize biodiversity conservation impact. Managers and policy makers need to know the importance of biodiversity, its patterns, and the various criteria used to prioritize reef areas for conservation. They need to have access to well-designed reef survey assessment reports for effective conservation decisions and activities. This knowledge is imperative to ensure that managers and policy makers set aside reef areas that include the best representation of biodiversity.

Specific Recommendations for Action

- Reduce sources of anthropogenic impacts on reefs, especially those that decrease habitat quality or lead to loss of habitat and loss of species diversity.
- Continue research on the variability of marine biodiversity patterns at multiple scales and on the use of new tools to assess coral reefs for conservation merit.
- Continue research on factors affecting marine biodiversity such as resiliency to disturbance, population viability and persistence.
- Continue studies on previously un-surveyed reef regions to document biodiversity and other criteria for conservation.
- Consider socio-economic issues in tandem with biological data in regions identified for reef conservation efforts, so that realistic activities are implemented to preserve coral reefs.
- Educate all stakeholders (policy makers, managers, local community) on the importance of marine biodiversity.
- Unify efforts to preserve reef diversity among governments, non-governmental organizations, universities, and stakeholders.

Useful References and Resources

This paper was prepared from presentations at the 9th International Coral Reef Symposium, Mini-Symposium D3 *Coral Reef Biodiversity: Assessment and Conservation.* Authors and titles of presentations can be found at: www.nova.edu/ocean/9icrs/

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Monitoring and Assessment of Coral Reefs: Studies from Around the World

Stephen C. Jameson,[1] Robyn L. Cummings,[2] and Hansa Chansang [3]

Statement of Issue

SCIENTIFIC advances in monitoring and assessment that were presented at the 9th ICRS were divided into four main categories: benthic monitoring techniques; population ecology studies; reef fish monitoring; and pollutants, anthropogenic impacts, and community studies. Many researchers demonstrated new and innovative techniques for gathering data and/or used multiple methods to address monitoring and assessment challenges. These advances highlight the usefulness and application of new techniques, as well as the need for addressing information gaps to improve the early warning and diagnostic capabilities of coral reef monitoring and assessment.

Photo: Rob Waara

Diver using a sonar positioning system and video camera to record transect data in the U.S. Virgin Islands

State of Knowledge

Benthic monitoring techniques

In a resource assessment off the northwest coast of Australia, a variety of rapid broad-scale methods were used to produce estimates of marine resources, describe the ecology and structure of reefs and shoals, map seabed types, and measure the size and extent of recent mortality of hard corals. Methods used in shallow habitats included visual transects, fish visual census and remote sensing. On the shoals, video camera transects, acoustics, and sediment grabs were used. Geographic information systems (GIS) were used for designing stratified sample strategies, data analysis and reporting.

A method involving video-camera transects and a sonar positioning system was used to monitor reefs in the U.S. Virgin Islands. Revisiting the same transects produced better statistical power and ability to document change than sampling different transects each time.

To address the change in substrate components from a depth gradient of 10-250 meters in the Bahamas, a method of repeated photographic techniques was used over a three-year period. Results showed that a complex interplay of abiotic and biotic disturbance forces, diminishing light levels, and changing phyletic dominance, accompanied by shifting tradeoffs in competitive abilities, occurs along the bathymetric gradient.

To quantify sexual and asexual recruitment within populations of mushroom corals exposed to chronic sedimentation stress and acute cyclone disturbance, a multi-method approach was used that included size frequency distributions, tagging and recapture of polyps, and genetic analysis. A true indication of population dynamics was obtained only when all three methods were combined, thus illustrating the importance of combining methods and the care required when extrapolating conclusions from limited data.

To gather data on the primary production of reefs around NOAA's underwater Aquarius laboratory off Key Largo, Florida, a newly developed coral respirometer was used. Experiments also provided information on ways to improve the design of the respirometer.

Population ecology of various taxa

One study compared the growth rates of tagged green sea turtles from two reef systems in northwestern Australia. Results showed that age at maturity may differ by decades

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depending on locality, and that population and harvest models produced for some areas are not applicable to all populations.

The use of a video recorder (CRITTERCAM) can be used to explore new aspects of feeding behavior in animals. For example, a video recorder mounted on the backs of endangered Hawaiian monk seals in the French Frigate Shoals, Hawaii, was used to test the hypothesis that seals frequent deep-water coral beds to feed on associated fish assemblages and improve their overall foraging success.

Monitoring in the U.S. Virgin Islands found a wide variation in the settlement density of western Atlantic spiny lobsters, and linked sand substrate with high settlement density. A successful mark-recapture program for *Nautilus pompilius* was developed for use at Osprey Reef, an isolated reef in the Coral Sea off Queensland, Australia. The size, sex, and age structure of the population was characterized for comparison with less isolated populations. The usefulness of public aquaria for research on reef fish behavior was also demonstrated; public aquaria can also be used to increase our ecological understanding of other reef species.

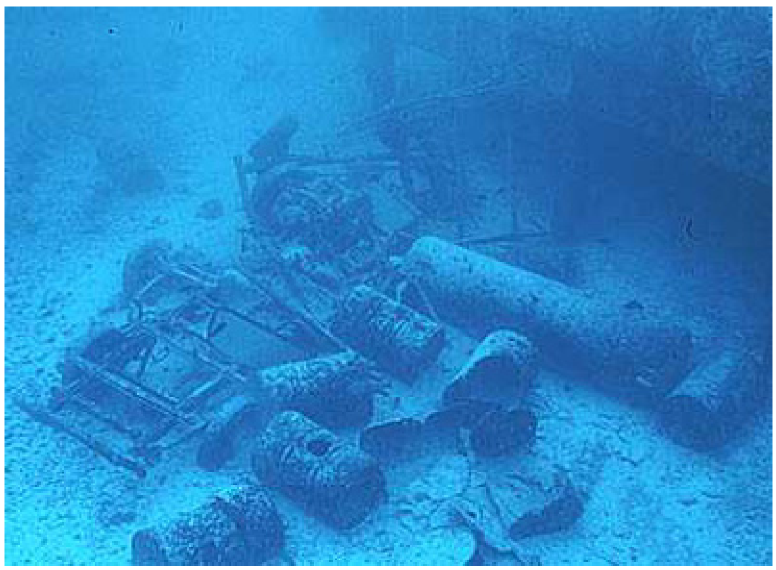
Photo: Phillip S. Lobel

Discarded fuel containers, 55 gallon drums, and other debris found in the nearshore marine environment around Sand Island, Johnston Atoll

Reef fish monitoring

Using underwater footage in a television and video demonstration, species-specific courtship and mating sounds were used to monitor reproduction in reef fish populations. This application can be used as an alternative or supplement to traditionally more destructive and labor intensive methods.

Data collected by Reef Environmental Education Foundation volunteers were shown to be useful in the Florida Keys National Marine Sanctuary to identify species-rich sites as potential management priorities. A collation of butterflyfish diversity and abundance on over 1000 reefs from the Red Sea to the northern Great Barrier Reef was used to suggest that the total number of butterflyfish per transect may be a useful universal indicator of reef quality. A multivariate technique was used to identify reef morphology, exposure, and coral bleaching as major forcing factors in reef fish community structure in the southwestern Philippines.

Visual surveys of reef fish in the northwestern Hawaiian Islands were conducted with particular focus on conservation of the Hawaiian monk seal and its prey. Five times and 15 times greater densities for lizardfishes and moray eels, respectively, were found at Midway Atoll versus French Frigate Shoals. A fivefold less frequent encounter of large jacks was found at Midway Atoll compared to French Frigate Shoals.

Pollutants, anthropogenic impacts, and community studies

An assessment of the status of contaminants in sediments and biota at Johnston Atoll after 70 years of military operations, found the greatest concentrations of contaminants located nearest sites on the islands where hazardous materials were used. One difficulty of assessing the Johnston Atoll sediment data is the lack of comparative measurements from similar but minimally-impaired tropical atolls. Subsequent surveys will provide data to evaluate whether contaminant concentrations remain stable or are attenuating through dispersal. In general, the pattern of contaminant distribution in fishes matches that found in sediments. The occurrence of abnormal demersal damselfish and triggerfish embryos (sensitive indicators of anthropogenic perturbations) was significantly higher at PCB contaminated sites for both species. This technique may allow comparisons at the scale of the home range or territory of species.

In one broad-geographic study, seagrass biomass showed varying patterns from 1993-1999 with some stations increasing by a factor of two (Jamaica), decreasing precipitously (Bermuda), maintaining a value with little variation (Mexico), and showing wide variation about a mean (Belize). C:N:P ratios of the *Thalassia* leaves were determined to estimate localized nutrient excesses and deficiencies. In the Hiddaduwa Marine Reserve, Sri Lanka, a year-long study provided rare data showing that *Halimeda* in the reef lagoon serves as a refuge habitat and nursery ground for a wide variety of marine organisms.

Management and Policy Implications

Many researchers demonstrated new, efficient, economical, and innovative techniques for gathering data and/or used multiple methods to address management challenges. From sonar positioning systems for divers, to video recorders strapped to the backs of monk seals, the innovations and multifaceted approaches exemplify the creativity in the coral reef scientific community. This creativity needs to be supported and encouraged. It is only through this innovation that coral reef managers and decision makers will be supplied with the timely information they need to make critical coastal management decisions.

Methodology and experimental design is another important theme with management and policy implications. Scientists must understand the strengths and weaknesses of their methods and explain these to decision makers – whether it is the statistical power benefits derived from re-sampling permanent transects versus a randomized approach, the need to use multiple methods to fully understand recruitment within coral populations, or the importance of proper monitoring methods to design population and regulatory models for sea turtles. Without understanding these methodological strengths, and especially weaknesses, the information that scientists provide could be biased and/or incomplete and could have serious resource management consequences.

Finally, if we are to move beyond traditional non-diagnostic monitoring techniques (where we monitor change but can not really explain what is causing the change) and towards diagnostic techniques with early warning capabilities, we must explore new coral reef attributes, develop dose response curves for them across a gradient of human influence, and formulate these metrics into indexes. Several researchers presented work in this direction, such as using fish embryos to detect the impacts of PCB's, using C:N:P ratios of *Thalassia* leaves to estimate localized nutrient excesses and deficiencies, and developing an underwater coral respirometer. This work is critical to the future monitoring, assessment and management of coral reef resources around the world.


Photo: Lisa M. Kerr

Normal and abnormal *A. sordidus* embryos. The abnormal embryo on the right displays severe craniofacial and cardiac deformities

Specific Recommendations for Action

This was a mini-symposium with presentations on many diverse subjects and themes. While specific recommendations for action on each subject or theme would be too lengthy for this synthesis, we would like to highlight one recommendation for future action that cross-cuts all categories.

The United States Environmental Protection Agency is exploring the feasibility of developing multimetric indexes of biological integrity (IBIs) for coral reef assessment. Information presented at this mini-symposium along with future targeted monitoring and assessment information will help fill the information gaps necessary to move this new effort forward. This work presents a research strategy for creating coral reef IBI's that outlines the specific areas that need further investigation.

The approach of using IBIs for coral reef assessment is unique with respect to traditional coral reef monitoring and assessment in the following ways:

- Coral reefs are classified so comparisons between similar environments can be made.
- Minimally impaired reference conditions are developed and used to compare against monitoring sites.

- Coral reef IBIs only use metrics that show a quantitative dose-response change in attribute value, that is documented and confirmed across a gradient of human influence that is reliable, interpretable and not swamped by natural variation.
- IBIs are designed to provide a unique early warning and diagnostic capability.
- Well constructed IBIs typically examine two or more assemblages because different organism groups react differently to perturbation. The more diverse the measures used, the more robust the investigative techniques and the more confidence the manager can place in the results.
- This idea must be reconciled with the limitations of the costs of multiple and diverse surveys and the relative availability of reliable scientific methods to measure some assemblages. The most promising IBI approaches will likely be measures of sessile epibenthos, benthic macroinvertebrates, fish, macrophytes, phytoplankton, and zooplankton.

Useful References and Resources

This paper was prepared from presentations at the 9th International Coral Reef Symposium, Mini-Symposium D6 *Monitoring and Assessment of Coral Reefs: Studies from Around the World.* Authors and titles of presentations can be found at: www.nova.edu/ocean/9icrs/

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For more details and progress reports on the development of coral reef indexes of biotic integrity, please visit: www.epa.gov/owow/oceans/coral

For a summary of how IBIs are used in freshwater environments see: Karr JR and Chu EW (1999). *Restoring life in running waters: better biological monitoring.* Island Press, Washington, DC. 206 pp.

Press Statement on Climate Change and Coral Bleaching

Scientific Panel, International Coral Reef Symposium, Bali, October 27, 2000

THE extensive coral bleaching that occurred in 1997-98 has been a source of wide-spread concern among scientists, managers and policy makers. Many of the 1465 papers submitted to the conference concerned key parts of the issues associated with coral bleaching and its association with climate change.

The majority of scientists at the Bali conference agree that climate change is having a significant impact on the world's coral reefs.

Coral bleaching occurs when the symbiotic algae that live in corals become stressed and are expelled. This turns coral white, leaving them in an unhealthy state. Research presented at the conference revealed that corals died in large numbers or were severely compromised after the 1998 bleaching event and that rising sea temperatures have been responsible for recent large scale bleaching and mortality events. Results also showed that this effect was exacerbated by other factors like high light levels and human-related stress.

In Belize, for example, studies have shown that the extent of bleaching and the subsequent death of corals in 1998 was unprecedented in at least the last 3,000 years. This was the subject of a paper by Dr Aronson and colleagues.

"Sea surface temperatures throughout the tropics have shown dramatic increases over the last two decades; as much as half a degree per decade. This is ten times what we are observing globally. As a result, the concern for coral reefs is how much of this increase will continue over the ensuing decades," said Dr Al Strong, team leader in satellite research at the National Oceanic and Atmospheric Administration.

Discussions also highlighted the fact that climate interactions with coral reefs are highly complex and that we need to understand much more than the southern oscillation such as the decade level climate variability. At the same time, as noted by Dr Eakin (NOAA) we have evidence to show similar rates of climate change over geological history and we are able to explain these by natural phenomena. In contrast, the changes we are currently witnessing can only be explained on the basis of human induced impacts.

Similarly, as evidenced in the fossil record, coral reefs have demonstrated recovery from such global scale climatic events historically. However, as noted by Dr Greenstein, Cornell College, this has typically taken between 2 to 100 million years.

Several papers also indicated that increases in sea temperature were not the only concern. A special session within the conference found evidence for a large decrease in coral calcification due the direct influence of carbon dioxide on sea water chemistry. In essence, absorption of carbon dioxide into the oceans increases acidity, which lowers the ability of corals to generate their skeletons.

In view of the multiple issues, it was widely expressed at the conference that coral reefs face a bleak future.

"The fact that all major climate models show that the current increases in sea temperature will continue is a source of major concern. We have insufficient evidence that corals are able acclimate or adapt fast enough to these sorts of changes. This is a clear area for priority research. " said Professor Ove Hoegh-Guldberg, Centre for Marine Studies at the University of Queensland.

In the absence of any clear evidence that acclimation or adaptation will see coral reefs through such future crises, it seems perilous to use this as a reason for little or moderated action.

In the end of his presentation on the 1998 devastating bleaching event in Okinawa, Prof. Yossi Loya, from Tel-Aviv University, Israel, winner of the ISRS year 2000 Darwin Medal, made a call for action: "As a coral reef society, we add our voice to the growing international concern on the issue of global climate change, and call for an effective reduction in greenhouse emissions over the next decade."

Please see next page for list of signatories.

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Professor Ove Hoegh-Guldberg
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Professor Jerry Wellington
Paleoecologist and coral biologist, University of Houston, Texas, USA

Dr Joan Kleypas
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Professor Yossi Loya
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Professor Alan E. Strong,
Physical Scientist/Oceanographer and project leader of HotSpot program, National Atmospheric and Oceanic Administration, USA

Dr. Sue Wells
Co-ordinator, East Africa Marine Programme, IUCN Eastern African Regional Office, Kenya

Response of Coral Reef Builders to Changes in Ocean Chemistry

Joan Kleypas [1] *and Chris Langdon* [2]

Statement of Issue

GLOBAL climate change and the extensive coral bleaching that occurred in 1997-98 has been a source of wide-spread concern among scientists, managers and policy makers. Research indicates that rising sea temperatures associated with global climate change have been responsible for recent large scale bleaching and mortality events. However, increases in sea temperature are not the only concern to coral reef ecosystems from global climate change. There is also evidence that coral calcification will decline due to the direct influence of carbon dioxide (CO_2) on sea water chemistry. In essence, increased absorption of carbon dioxide into the oceans increases acidity, which lowers the ability of corals to generate their skeletons. The direct impacts of changes in carbon dioxide concentrations and ocean chemistry on coral reef organisms and ecosystems are the focus of current research. Relevant findings presented at the 9th ICRS are discussed below.

State of Knowledge

Increase in CO_2 leads to decrease in calcification

Surface ocean chemistry is changing in response to increased atmospheric CO_2 concentrations, and the magnitude of these changes is larger than that experienced by coral reefs for at least 420,000 years, and probably for many millions of years. The oceans' increased uptake of atmospheric CO_2 leads to the formation of carbonic acid, which lowers both pH and carbonate ion concentration. These changes are highly predictable and have been tracked with ocean measurements for over two decades.

In aquarium and mesocosm studies, both scleractinian corals and coralline algae exhibit an essentially linear decrease in calcification in response to these ocean chemistry changes, and primarily to the carbonate ion concentration. The relative decrease in calcification varies between species, and can be dramatic, with coralline algae generally exhibiting a slightly stronger calcification response (25-44 percent) than corals (19-27 percent) to doubled CO_2 conditions. These experiments have been conducted from hours to years, with no adaptive response indicated among the organisms tested.

Implications for coral reefs

At the organismal scale, it is likely that reduced calcification of corals and algae will be expressed as a decrease in extension rate, reduced density (greater fragility), and/or a change in growth form. Within coral reef communities, reduced calcification translates into reduced competitiveness for space, and because the various coral and algae species are likely to exhibit reduced calcification to different degrees, this will likely lead to shifts in community structure. On a larger scale, coral reefs represent the *net* accumulation of calcium carbonate produced by coral reef communities; while the growth of some reef organisms are contributing calcium carbonate, such as corals and coralline algae, other reef organisms are constantly removing calcium carbonate through bioerosion, such as burrowing organisms. Since $CaCO_3$ removal processes are naturally high, a net reduction in $CaCO_3$ production will result in slower or even negative reef growth.

Photo: Chris Langdon

Laboratory facility in Biosphere

Although atmospheric CO_2 had already increased by 25 percent by 1990, and despite the consistent laboratory results showing that calcification of reef builders declines in response to changes in seawater chemistry, coral cores from massive *Porites* colonies (through about 1990) on the Great Barrier Reef do not exhibit an industrial age decrease in calcification. The possible reasons for the laboratory/field mismatch in findings include: (1) massive *Porites* exhibits a smaller calcification response to increased pCO_2; (2) the response is overprinted by some other variable that affects calcification (for example, light and temperature); (3)

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dissolution of $CaCO_3$ sediments provides local buffering of seawater chemistry; and/or (4) some undetected flaw in laboratory studies.

Relevant Actions Being Taken to Address Issue

- As more experiments are conducted on different species and different species assemblages, our knowledge of how specific taxa and coral communities will respond to increased atmospheric CO_2 is improving.
- Although coral and algal calcification appears to behave geochemically (i.e. reflecting surrounding seawater chemistry), physiological studies indicate that the internal biochemistry of these organisms is complex. Several groups have tackled this problem using radioactive tracers to understand how Ca^{2+} and CO_3^{2-} ions are tranported by the organism to the site of calcification.
- $CaCO_3$ saturation state obviously exerts control on coral calcification, but other variables such as light, temperature and nutrients also play a role. Several researchers are attempting to define how these four variables interact to control calcification rate in corals.
- Recent evidence shows that not only will calcification decrease in the future, but dissolution will increase. Quantifying dissolution of carbonate minerals on coral reefs is difficult, but necessary if we are to understand how reef-building processes will change in the future.

Management and Policy Implications

Unlike other major impacts on coral reefs (bleaching, overfishing, etc.), changes in seawater chemistry are truly global in nature, with little evidence of significant regional differences. Future changes in surface seawater carbonate chemistry are directly linked to atmospheric CO_2 concentration, and are therefore highly predictable. In terms of policy, the only perceivable way to stop or reverse the effects of seawater chemistry on corals is to control CO_2 emissions.

In the meantime, managers of our coral reefs may be faced with increasing problems associated with decreased calcification on reefs. Coral communities may experience changes in community structure or a reduced competitiveness with other benthic taxa (both of which will be impossible to attribute to calcification changes alone). Also, unlike the acute effects of coral bleaching, decreases in calcification rate are chronic. These two factors render management difficult, because such effects occur over long time scales and are difficult to measure. As a consequence, reduced calcification on reefs is often not considered an immediate problem, particularly in comparison to mass mortalities associated with coral bleaching. This attitude is understandable, but incomplete in terms of planning for long-term reef survival.

Specific Recommendations for Action

- Reduce other anthropogenic sources of reef stress and degradation.
- Educate reef managers, and also policy makers and the general public about the impacts of changing seawater chemistry on coral reefs; encourage reductions in greenhouse gas emissions.
- Support studies to elucidate: (1) links between coral physiology and calcification; (2) effects of other variables on calcification; (3) species-specific response to seawater chemistry changes; (4) role of dissolution in carbonate budgets on reefs; (5) coral community ecosystem responses to increased atmospheric CO_2.
- Scale up aquarium and mesocosm experiments to field-scale CO_2 "fertilization" experiments. Field experiments will include the effects of natural variability of temperature and light, and will also allow observations of community response.
- Conduct longer term experiments designed to examine coral response to decreased calcification, and how this response is reflected in density, extension, and isotopic composition of growth bands.

Useful References and Resources

This paper is based upon presentations at the 9th International Coral Reef Symposium, Mini-Symposium E1, *Global Climate Change and Coral Reefs: The Science Behind the Prognostications of Gloom*. Authors and titles of presentations can be found at: www.nova.edu/ocean/9icrs/

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Mechanisms and Causal Factors Associated with Coral Bleaching

Ove Hoegh-Guldberg [1] and William K. Fitt [2]

Statement of Issue

THE global, unprecedented mass coral bleaching and mortality event of 1998 caused an avalanche of new information about the causal factors, molecular mechanisms and ecological outcomes of mass coral bleaching. Coral bleaching occurs when the symbiotic algae that live in corals become stressed and are expelled. This turns the coral white, leaving them in an unhealthy state. Presentations of recent studies at the 9th ICRS, approximately two years after the 1998 bleaching event, reveal a greater understanding of the causes and consequences of mass coral bleaching. This is especially important given the projected scenario of more frequent and greatly more intense episodes of mass bleaching and mortality under global climate change.

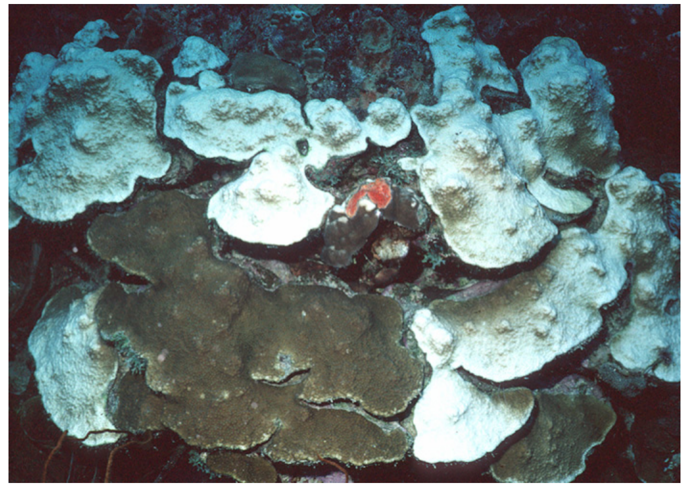

Photo: Andy Bruckner

Bleaching *Montastraea faveolata*, Caribbean

State of Knowledge

Mechanisms associated with coral bleaching

The evidence that increased sea temperature causes bleaching is indisputable. Evidence presented at the meeting also affirmed this. There is also little doubt now that the advent of coral bleaching is accompanied by an massively increased sensitivity to photoinhibition of the dinoflagellate symbionts of corals and other symbiotic organisms. Beyond this understanding, two main mechanisms are under investigation: (1) that thermal stress during bleaching begins with the collapse of the dark reactions of photosynthesis, and/or (2) that there are other lesion points, some of which lie within the light reactions of photosynthesis. While much support can be found for the former idea (for example, light enhancement of bleaching or the "shade effect"), more work is needed to resolve whether one or both mechanisms are at the heart of thermal mass bleaching.

Causal factors associated with coral bleaching

A large number of studies addressed the causal factors that underpin bleaching responses. Much of this was stimulated by an interest in explaining the variability in response that is commonly seen across a coral reef during a bleaching event. While some symbiotic invertebrates bleach (loss of dinoflagellate pigments and/or cells) in response to elevated water temperatures, the occurrence of bleached and unbleached individuals side by side on affected reefs has driven many to seek additional factors or mechanisms. Observations and experiments over the past few years have indicated that light, ultraviolet radiation (UVR), water flow and feeding status modify the primary effect of elevated temperature.

An important issue was raised by a study that measured key photobiological parameters for 5 years in corals growing in Florida. Even during times of non-bleaching, there are significant variations in cell densities, pigment content and photosynthetic parameters that may ultimately affect the interpretation of the response of corals to thermal or other stresses. Natural seasonal variations in these parameters have to be considered if one is to get a complete picture of how symbiont density and condition change. This background information is critical for a more complete understanding of the mechanisms that underlie mass coral bleaching.

Variation in intrinsic response to thermal stress

As well as the extrinsic factors represented by the physical and biological parameters in the environment, intrinsic factors, such as genotype, may influence the response to thermal stress. Biochemical measures of sensitivity to thermal stress within the light reactions of photosynthesis,

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particularly Photosystem II (PSII), revealed significant and large differences—up to 4 degrees centigrade (°C)—in thermal tolerance between individual colonies. Several studies from Okinawa also showed that differences in the susceptibility to thermal stress of corals matched field results in differences in susceptibility of corals and dinoflagellates during the bleaching event in Okinawa in 1998. In addition, there are differences in the susceptibility to thermal stress of symbiotic dinoflagellates, related to differences in dinoflagellate symbiont type and behaviour. How these mechanisms will affect the responses of reefs is still largely undetermined. It was clear, however, from presentations at the 9th ICRS that support for the idea that bleaching may be adaptive remains very weak at best.

Host physiology (another intrinsic factor) can also have an effect on the outcome of thermal stress. Increased concentrations of host pigments (mycosporine-like amino acids, fluorescent pocilloporins or gfp-like compounds) overlying the symbiotic dinoflagellates appear to be able to reduce photoinhibition and ultimately bleaching. Again, ideas that some corals will do better than others are interesting but does not negate the scale of impacts that are likely to occur as sea temperatures continue to increase. The fact that near complete mortality occurred on a number of coral reefs during 1998 suggests that even the thresholds of individuals that have higher thermal tolerances are also likely to be exceeded.

Subchronic impacts of coral bleaching

A greater understanding of the impacts of mass bleaching of reef organisms is required to properly understand the ecological and socio-economic implications of increased coral bleaching under climate change. While much of the earlier work concentrated on whether corals live or die after a bleaching event, only a few studies have asked the question as to whether the physiology of corals and other symbiotic organisms that do survive is compromised at all. The conference saw several studies that indicate that subchronic impacts are indeed very important.

Many studies indicated that tissue thickness, lipid levels and growth, levels of antioxidants, and reproductive output are all severely inhibited in corals that bleach, but later recover their symbiotic dinoflagellates. Clearly, it is therefore incorrect to assume that the reef has "recovered" if its corals recover their symbiotic algae. The potential error of this conclusion is highlighted by one observation that those corals that bleached in 1998, still had not recovered the reproductive output of unaffected colonies two spawning seasons later.

Recovery following coral bleaching

Surprisingly, there are only a few studies on the ecological processes that occur during the impacts and recovery processes on reefs after mass bleaching events. Results from these studies indicate that: (1) Differences in the extent to which gross photosynthesis (P_g) changed relative to Respiration (R) in macroalgae versus corals may explain why thermally stressed reefs may result in macroalgal-dominated ecosystems; and (2) environmental factors (such as ultraviolet radiation) could have a strong effect on the rate of recovery of bleached corals. The ways reefs and the accretion of reef carbonate changes with time after bleaching events is likely to be important and are being explored.

Implications for Management and Policy

While recent results hint at the importance and the types of factors that have an influence on recovery, the study of reefs after bleaching events clearly needs to be expanded. Questions like the extent of variability in animal and dinoflagellate genotypes that differ in their tolerance to stress needs to be explored rigorously as does the genetic connectivity of reefs. These population genetic aspects are crucial to our ability to develop ecological models of how coral reefs might change in the face of rising thermal stress. Only with this information in hand can we truly understand the implications of climate change for these valued ecosystems.

It is also clear that we need to explore the consequences of mass bleaching events. The following questions loom large and are of major importance to both users and managers of coral reefs. Are coral reefs resilient in the face of projected climate change over the next 100 years and how fast will change occur within coral reefs ecosystems if sea temperatures continue to change? Can coral reefs recover and if so, how fast? What will coral reefs look like if coral abundance decreases dramatically over time? Will some corals be more immune than others and hence increase in relative abundance? Will coral reefs erode if corals and their dinoflagellate symbionts are no longer a dominant organism? How much of the present high diversity of coral reefs be lost if coral reefs no longer exist?

Specific Recommendations for Action

An almost universal conclusion of the 9th ICRS was that climate change is a major threat to coral reefs that is already having an unprecedented influence on reef health. The impacts projected suggest that coral reefs will be lost from most regions by the middle of this century if climate change is not slowed. There was little doubt from data presented at the meeting that another degree increase in sea temperature will have dire consequences for coral reefs. While attempts to adapt to changes may represent one response to the projected climate impacts, immediate action must occur on reducing the growth in greenhouse gas emissions if coral reefs are to have any future at all. It is no longer credible to claim that the impacts of climate change generally or specifically (for example, on coral reefs) are debatable.

The reduction in the health and distribution of coral reefs projected under rising sea temperatures has implications for the many industries and societies that depend on coral reefs partly or wholly for livelihoods and income. The reduced productivity and value of coral reefs will mean that societies that depend on coral reefs will have to find alternatives as the climate changes. In some cases, alternatives may exist and these developments (if given time) may occur with minimal disruption to dependent societies. In many other cases, however, it is hard to imagine alternatives for the roles that coral reefs perform. This suggests that there must be an increasing effort placed into understanding how reefs are likely to change and into finding solutions to the decreased ability of tropical coastal regions to support the populations that they currently support. Not to actively meet these challenges will be to ignore a looming problem of a fundamentally huge magnitude.

Responses must encompass both short and long terms. Given the long residence times of most greenhouse gas constituents in the earth's atmosphere, action today will have little benefit for coral reefs over the next 100 years. Sea temperatures are projected to increase by at least 1-3^{o}C by the end of 2100. This suggests that responses that involve socio-economic adaptation to climate change will be crucial in the next 10 to 100 years. Reducing greenhouse gas emissions still are vital however. To state the obvious, coral reefs are ecosystems of enormous value for sustaining (at low cost) millions of people and billion-dollar industries like tourism. Reducing or reversing the rate of increase in greenhouse gases will mean that coral reefs and these inherent benefits have a chance of returning in several hundred year's time. This must be a priority of this current generation.

In considering the shorter term, it is very important to initiate studies and planning of the impacts of climate change on coral reefs. These studies are important if we are to anticipate and implement socio-economic adaptation to climate change. Studies that consider biological, economic and policy responses to sea temperature, reduced alkalinity and sea level rise are vital at this point. Only with these fully integrated studies can we have a chance of responding to these extreme challenges to tropical coastal societies and nations.

Photo: Andy Bruckner

Coral bleaching is associated with increases in sea temperature. *Agaricia* colony in Caribbean

Useful References and Resources

This paper is based upon presentations at the 9th International Coral Reef Symposium, Mini-Symposia E2a *Global Climate Change and Coral Reefs: Systematics of Bleaching* and A4 *Zooxanthellae in Animal Hosts: A Symposium Honoring the Lifetime Contributions of Len Muscatine and Bob Trench to Algal Symbiosis*. Authors and titles of presentations can be found at: www.nova.edu/ocean/9icrs/

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Coral Bleaching: Geographical Perspectives

Thomas Spencer [1] and Kristian Teleki [2]

Statement of Issue

THE 1980s marked a clear upturn in the reporting of coral bleaching, with the 1997-98 mass coral bleaching and mortality event as the most extensive and severe on record. Coral bleaching occurs when the symbiotic algae that live in corals become stressed and are expelled. This turns the coral white, leaving them in an unhealthy state.

Photo: M. Rard/ECOMAR

Bleaching reef at Reunion Island in April, 2001.

Coral bleaching causes reduced coral fecundity and, when extreme, losses in reef biodiversity, degradation of biological and physical functions of the reef ecosystem, and impacts on adjacent mangrove and seagrass habitats and resources. These impacts are likely to cascade through the sustainability of local fisheries and the local incomes associated with reef-related activities.

Bleaching incidence statistics have been used as both an early signal of global environmental change in the tropical oceans and an indicator of non-climatic stresses, often human-related, in tropical shallow marine environments. Discussions over the likelihood of near-future bleaching patterns have arisen because the phenomenon under study shows intra- and inter-regional spatial variability at within-reef, between-reef and reef province scales, and temporal variability over decadal time-scales at different sites. Some reefs appear to bleach on a regular annual basis (for example, southern Red Sea) whereas other reefs have only recently recorded extensive bleaching (for example, Belize, western Caribbean Basin).

At the 9th ICRS several critical issues were identified, including whether or not there will be a greater frequency and/or greater magnitude of ocean warming events in the near future and, if so, whether or not corals will be able to adapt — in what ways and how quickly — to such a changed climate regime.

State of Knowledge

Improved information base
The last two decades have seen considerable advances in the understanding and prediction of ocean-atmosphere dynamics. Data on temperature and solar irradiance is now available from *in situ* buoy arrays, space-based remote-sensing satellites, and sparser environmental monitoring at reef sites. At the same time, the application of broadly standardised rapid reef assessment techniques, often co-ordinated through international monitoring programmes, has generated a broad base of coral reef status reports for a large number of reef locations throughout the seas.

This improved information base has proved particularly useful in assessing the onset, development and recovery of corals from ocean warming events that have a global footprint. In particular, NOAA/NESDIS satellite-derived sea surface temperatures (SST) 'hotspot' maps have been successful in identifying broad regions where SSTs exceed long-term mean maximum summer month SSTs, thus predicting areas likely (but not certain) to experience coral bleaching. At the same time, the spread of Internet postings of bleaching reports from the field has both tested and extended these remotely derived predictions.

Triggers for bleaching events
Bleaching events appear to relate to seasonal fluctuations in photosynthetic efficiency and densities of the photosynthesising symbiotic alga, the zooxanthellae, within

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coral tissues. Coral bleaching is species specific, and probably relates also to variations in stress resistance within the poorly understood different types of zooxanthellae. While the key trigger appears to be the amplitude and duration of temperature excursions, high irradiance acts as a further trigger for bleaching. Associated climatological and oceanographic changes result in variations in sea surface state, short-term changes in sea level and varying cyclone incidence which act in synergy with the prime triggers. The sequencing of high temperature / irradiance events may reduce coral susceptibility.

High spatial variability in bleaching

Coral bleaching shows high spatial variability at a number of scales – from the colony (variation between different surfaces on the same colony and with colony size), within individual reefs (by depth, between windward and leeward reefs, and in relation to localised upwelling) and between reef systems (inner vs. outer shelf vs. oceanic reefs, in relation to wave exposure, current patterns and regional upwelling processes).

While coral bleaching is related to the warm phase (that is, "El Niño") of the El Niño Southern Oscillation events (ENSO), this relationship is not simple and requires incorporation of a wider range of climatological and oceanographic factors. For example, climatological factors such as cloud cover characteristics at times of high SSTs, and oceanographic factors such as operation of the Indian Ocean dipole oscillation need to be considered. ENSO events themselves vary in terms of their strength and mode of development and nest within longer term climatic patterns, such as the Pacific Decadal Oscillation.

The complexities of both the dynamics of environmental forcing factors and responses at coral colony to reef system scales have implications for the prediction of likely future impacts on reefs of ocean warming.

Relevant Actions Being Taken to Address Issue

- Improvements in the resolution of satellite monitoring of SSTs, from 50 km (AVHRR) to 9 km (Pathfinder) offers the possibility of beginning to establish better linkages between broad scale patterns in the movement of water masses and reef responses at specific field sites. (please visit http://podaac.jpl.nasa.gov/)
- Careful measurements of SSTs, irradiance, water level fluctuations and other environmental parameters, including the role of the sequencing of events, are being taken to better understand environmental triggers for bleaching episodes.
- A focus on the genetic diversity of zooxanthellae populations and their dynamics will allow a better understanding of zooxanthellae – coral interactions under temperature and irradiance stresses.
- Construction of better linkages between coral reef biology and oceanographic processes are underway to better define coral reef recovery and recruitment dynamics.

Management and Policy Implications

Managers and policy makers need to be aware of the issues that surround the explanation of variable bleaching impacts over time and space, including the inherent uncertainties involved. Knowledge of the geographical variation in bleaching impacts and particularly in the location of surviving coral 'refugia' has implications for the re-seeding of damaged reefs, and hence in regional schemes for the conservation and protection of key reef sites. Geographic areas which are known not to bleach, or to regularly survive bleaching, should be afforded increased protection from other human-induced sources of stress. The potential for a greater frequency and/or greater magnitude of bleaching events in the near-future, although not certain, nevertheless requires the development of planned responses to bleaching episodes now which will be robust enough to deal with future scenarios.

Specific Recommendations for Action

- Attempt to reduce human-induced sources of reef stress and degradation so that reefs are better able to deal with high SST / high irradiance events.
- Develop a better knowledge of the connectivity of reef systems to better understanding processes of coral recruitment and reef recovery after bleaching, including a better appreciation of the time scales necessary for regeneration.
- Communicate the natural dynamic of reef systems ('the shifting baseline'), including the importance of sequencing of bleaching impacts with other environmental perturbations.
- Communicate the spatial variability of bleaching impacts and reef recovery processes to enable the development of site specific, rather than standardised, management plans for reef rehabilitation.

Useful References and Resources

This paper is based upon presentations at the 9th International Coral Reef Symposium, Mini-Symposia E2b *Global Climate Change and Coral Reefs: Bleaching Status of Reefs*. Authors and titles of presentations can be found at: www.nova.edu/ocean/9icrs/ and at: www.uncwil.edu/isrs/

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NOAA/NESDIS satellite-derived sea surface temperatures (SST) 'hotspot' maps. Web site: www.coralreef.noaa.gov/ and click on link to "Coral Bleaching Hotspots."

Coral Reef Watch Web site that lists reports from field on bleaching: http://orbit-net.nesdis.noaa.gov/orad/coral_bleaching_index.html

Socio-Economic and Management Implications of Mass Coral Bleaching

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Statement of Issue

THE socio-economic impacts of mass coral bleaching are known in theory, based on the observed consequences from other causes of reef degradation, and include tourism and fisheries in the short term with additional losses to coastal protection and other "services" over time. Studies undertaken in response to the 1997-98 bleaching event provide the first empirical documentation and estimates of these impacts, allowing us to refine our understanding and to better plan effective responses.

The studies presented at the 9th ICRS underscore the potential for well-implemented responses to reduce the extent to which socio-economic losses are felt by coastal communities. For example, one study reports a difference of approximately US$ 7 billion in economic loss for the Indian Ocean region between an optimistic estimate that assumes coral reef recovery (US$ 608 million) versus a pessimistic estimate that assumes no reef recovery ($8.26 billion). Clearly, there is a real opportunity to mitigate expected socio-economic impacts from bleaching, if response measures can be effective in promoting coral recovery.

State of Knowledge

Fisheries

The precarious dependence of subsistence fishers on reef-dependent fisheries throughout tropical developing nations emphasizes the potential for serious socio-economic consequences to result from mass coral bleaching. The vulnerability of these communities to such consequences, including malnutrition, was highlighted, given the few alternative livelihoods available in many instances, notably for island communities. However, the effects of the mass coral bleaching of 1997-98 on fishing communities in Bolinao (Pangasinan), the Philippines and in the Indian Ocean region, at this stage, are subtle if observable at all.

Photo: Coastal Resources Center, URI

Fishing for bait in Indonesia

The composition and health of coral reef ecosystems are important factors in determining the structure of reef-dependent fisheries through the food and habitat "services" reefs provide. Temperature-induced bleaching which affects the condition and diversity of coral reef ecosystems is expected to simultaneously affect reef fish populations, reducing abundance and changing composition and distribution. Population reductions are predicted for species that inhabit reefs for at least part of their life cycle or prey on reef fish. Changes in fish abundance may vary by species, shifting the composition of reef fish populations toward herbivores. Such a shift could negatively impact fishers, as herbivores are lower in value than other species.

Two studies described minor increases in herbivores as expected, but the causality between coral bleaching and these observations is currently vague. One reason for this uncertainty, as well as the lack of other observable impacts, may be that coral bleaching is one of many stresses cumulatively impacting reef ecosystems. When bleaching is superimposed on reefs that are already over-fished, reductions in overall reef fish populations will not be observable since herbivores dominated the fishery prior to

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the bleaching event. It is also suggested that impacts occurring at small spatial or temporal scales may have been masked by fishers changing their fishing habits and patterns. Or the answer may simply be one of time scale, and the impacts to fisheries may become more pronounced once the structure of bleached reefs is further eroded.

Tourism

In the short term, the most dramatic socio-economic impacts from the 1997-98 mass bleaching event are the estimated losses to reef-dependent tourism. These losses were studied in the three diving destinations of Palau; El Nido (Palawan), the Philippines; and the Indian Ocean region, and include:

- US $3-4.6 million financial losses in Zanzibar and US $ 13-20 million in Mombasa (Westmacott et al.),
- US$ 3 million and US$ .02 million financial losses in the Maldives and Sri Lanka respectively (Wetsmacott et al.),
- US$ 15 million loss in net revenue to the Philippine economy (Cesar et al.),
- and losses to the diving industry in Palau of approximately US $350,000 each year following the bleaching event (Graham et al.).

These estimates are potential losses resulting from coral bleaching, and in some instances such as East Africa, have not been demonstrated as actual losses in practice. The manifestation of these losses are multi-dimensional and include a) impacts on tourist destination choice, which results in lost visitation and therefore a total loss of tourism revenue, b) impacts on choice of activities pursued, which may cause reduced coral reef-related revenue, and c) reductions in tourist satisfaction of the diving experience as a result of degraded reef conditions.

Understanding the influence reef degradation has on diver decision-making is also important to predicting the economic impact of bleaching events. It is related first to tourist knowledge of the marine environment and coral bleaching and subsequently to the influence this understanding wields on consumer choice and satisfaction. Each of the studies reported relatively low tourist awareness of coral bleaching, at typically 25-50 percent of the respondents surveyed. Low awareness among survey respondents may be because study surveys were undertaken in areas that were heavily bleached and knowledgeable divers had already exercised their decision to go elsewhere.

However, of those that were aware of coral bleaching, relatively high percentages (approximately 75 percent) testified that coral bleaching either had negatively impacted their overall dive experience or would impact their destination choice. This strong relationship was true in cases of direct questioning about coral bleaching; more indirect approaches attempting to link bleaching impacts with willingness to pay were less clear in suggesting how reef degradation impacts consumer welfare. These results indicate that increased public awareness about coral bleaching in the future may create a more discerning dive consumer, increasing the influence of coral reef condition in destination and activity choices, as well as overall satisfaction.

Implications for Management and Policy

There are two key factors limiting the development of responses to mass coral bleaching. The first is the major issue of global climate change as a causal factor. The second is the lack of scientific answers to important management questions. While these challenges should be accounted for in a strategic response to mass coral bleaching, neither global warming nor uncertainty should preclude some sort of earnest response. Managers can begin by implementing known approaches to foster coral resiliency and recovery in damaged coral reefs. The elements of any management approach should include the following guiding principles:

- Mass coral bleaching is one of a number of stresses that cumulatively threaten coral reef ecosystems and must be addressed within this larger context.
- Management can be undertaken in the absence of complete scientific understanding of the specific causes and consequences of mass coral bleaching and should be implemented adaptively.
- Management should aim to create situations that maximize the potential for coral reef resiliency to mass bleaching and recovery after these events.
- Management-oriented research is needed to elucidate the conditions that bolster coral resiliency and promote recovery as well as to refine predictions on the extent and implications of future events.
- Ultimately, responding to mass coral bleaching will include addressing global climate change through reductions in CO_2 emissions.

Recommendations for Action

Management responses can generally be divided into strategies directed toward coral reef ecosystems, and

Photo: Coastal Resources Center, URI

Tourist resort in Indonesia

strategies directed exclusively toward mitigating the socioeconomic impacts of mass bleaching on coastal communities. To address the ecological issues, the principle articulated here—that management should aim to create situations that foster coral resiliency and recovery—suggests two strategies. The first strategy is to implement responses that generally promote coral health. This recommendation recognizes that bleaching is one of many stressors with the potential to impact coral reefs. It is possible that healthier reefs will be less vulnerable to mortality from bleaching. However, this assumption needs to be further investigated by the research community since the more pristine reefs in the Indian Ocean were the worst affected by the 1998 mass coral bleaching event.

The second strategy is to identify and pursue responses that are specific to bleaching. Opportunities for bleaching-specific responses need to take into consideration variations in local conditions. These options might include, for example, adjusting fisheries management on bleached reefs to protect species population composition and species that are useful in maintaining coral health during bleaching events (that is, herbivores that scrape algae off dead coral maintaining suitable surfaces for coral larvae recruitment). Tourism destinations will vary to the extent that they are impacted by coral bleaching – ecologically, economically and in their ability to mitigate the impacts of bleaching through diversification. Being able to predict a destination's resiliency in spite of degraded reef conditions will provide a rationale for planning emergency assistance. The degree to which tourism will be impacted is related to the ability of a destination to maintain its status and reputation even in the face of reef degradation, by promoting other unrelated attractions. Impacts to the diving industry can be mitigated by diverting divers' attention to other focal points such as wrecks or, perhaps, by involving divers in coral bleaching monitoring as an attraction. However, such diversification is not inevitable and may not be easy. For example, although resorts in El Nido, Philippines have been shifting market segments from divers to honeymooners in response to reef degradation, a notable loss is nonetheless observable, estimated at US$ 1.5 million annually.

Management, research and policy responses to mass coral bleaching will be most effective when coordinated. Such coordination needs an appropriate framework - such as Integrated Coastal Management (ICM) - to operate in. ICM is appropriate as it incorporates adaptive management, has the capacity to address the multiple stressors which cumulatively impact reef condition, and has already been promoted as the recommended response to related issues, including global climate change and coral reef management.

ICM planning should begin by focusing on general coral reef management, which considers the multitude of stressors that cumulatively have the potential to impact reef condition. Essentially, it involves identifying reefs and the circumstances that currently threaten reef condition or have the potential to do so. Based on the threats identified, strategies are implemented to address both stressors that impact reefs directly, for example, destructive fishing or anchor damage from diving boats, and indirectly, such as sedimentation or pollution. These strategies can include land-use and fishing regulations, zoning schemes including MPAs, and passive or active rehabilitation of damaged corals. Additionally, general reef management should include monitoring protocols to keep a pulse on reef health, and public education initiatives to create and maintain a constituency for reef management and conservation.

One of the threats that needs to be considered during the ICM planning stage is coral bleaching. The bleaching consideration should be superimposed on the composite picture already established for the reefs being managed. Based on our current understanding of coral bleaching, predictions should be made about the likely impacts of future events under optimistic, average, and pessimistic scenarios. Key questions that need to be addressed in the assessment are:

- Which reefs are most and least likely to be impacted by coral bleaching?
- Are the reefs expected to be more resilient "source" or "sink" reefs?
- Are "source" reefs that are expected to be resilient currently threatened by another anthropogenic stress that can be addressed by management actions now? What actions are required?
- What are the likely impacts to diving destinations in the area being managed?
- To what extent will these destinations and diving operations be able to diversify to maintain their reputation and status should local reefs become degraded?
- How will reductions in catch affect local fishers, including subsistence fishers?
- To what extent are opportunities for alternative or supplemental livelihood available to fishers should the fishery collapse as a result of coral bleaching?

Contingency plans can then be prepared to most efficiently respond to likely or catastrophic impacts. Contingency plans should include emergency response protocols for both research and management. The research protocol should establish a procedure for documenting the severity, extent, and recovery from the bleaching event in detail so that the experience can be incorporated into future management efforts. The management protocol should be prepared to offer emergency assistance to fishers – especially subsistence fishers – and tourism operators that are unable to avoid losses due to coral bleaching. Management protocols should include a procedure for reviewing and responding to scientific assessment of the bleaching event as it becomes available. Such review may suggest creating or revising MPA boundaries to protect resilient source reefs from other anthropogenic stresses, facilitating post-bleaching recovery.

Contingency plans should also include non-emergency responses that can be implemented either prior to or following bleaching events, such as:

- Diversification of local tourism industries and/or opportunities available to fishers.
- Public education on mass bleaching to help prepare communities for bleaching events and create a constituency for climate change.
- Briefing government representatives on the implications of mass coral bleaching locally, so that these considerations can be voiced in international forums.
- Assessing the feasibility, cost and likely success of coral reef restoration or rehabilitation.

Implementation of ICM planning and response recommendations is most needed in tropical developing nations that host most of the world's reefs. Policymakers need to address the gap in required funding and human capacity that is often in short supply in these countries. Since tropical developing nations are most likely to be affected by mass coral bleaching and are also the least responsible for global warming, appropriate policies should be established to compensate for this inequity through the provision of assistance.

Funding and human capacity must be made available at a local level to implement management, monitoring, and, when necessary, rapid response. Rapid response assessments of bleaching will be most useful to management efforts when they are comparable, meaning that assessments must be standardized and funding must be available to implement these efforts in a timely manner. Standardization requires adopting a monitoring protocol, establishing training programs on the selected technique, and facilitating access to expert advice for less experienced researchers.

Evaluation is both the basis for genuine adaptive management, and a forum where cohesion between research, management, and policy communities can significantly enhance the effectiveness of response. Adjustments to mass coral bleaching response strategies should reflect the best scientific information. More informed predictions as to the severity and extent of future mass bleaching events will assist the policy community in its difficult work. There are already good examples of evaluation studies at both the global scale and the regional scale. The next step is to translate this new information into strong policies.

Conclusions

The extensive coral mortality caused by the 1997-98 mass coral bleaching event raised serious concern over the ecological and socioeconomic implications of bleaching events, the expected severity and frequency of future events, and the future of coral reefs. Three years after this event a preliminary picture of its impacts is coming into focus that underscores the necessity for management, policy, and research responses to mass bleaching. The ecological impacts of mass coral bleaching have been demonstrated to be severe, with massive losses in coral cover and diversity, as well as in other coral reef-associated organisms. These losses occurred from local to oceanic scales, and with the increasing frequency and severity of ENSO events driven by global climate change, the degradation of coral reefs due to mass coral bleaching can only be expected to increase. Economic losses to reef-dependent tourism are the most significant economic impacts observed thus far. However, the potential for serious socioeconomic impacts to reef-dependent fishing communities as degraded reefs continue to erode justifies critical concern and attention.

Effective responses to mass coral bleaching are hampered by scientific uncertainty, our inability to respond to global climate change in the short term, and insufficient financial and human resources. However, these challenges cannot justify inaction. Rather they underscore the primacy of developing adaptive strategies and capacity so that countries and communities are prepared for future mass bleaching events. Responses should reflect that mass bleaching is one of many stressors cumulatively affecting coral reef communities and begin by implementing actions that promote coral health generally. Mass bleaching is one of these stressors and necessitates identifying and planning for the expected ecological and socioeconomic impacts from future events. Effectively implementing adaptive management will require support from both the research and policy communities to provide the technical information and financial and human resources needed for success. The policy community faces two great challenges. First, to commit the resources needed for successful implementation of coral reef management in the developing nations that host most of the world's coral reefs. Second, to address global climate change through reductions in CO_2. Mass bleaching creates a broad constituency and justifies efforts to address global warming, as it foreshadows the potentially larger impacts to come about through unabated global warming.

Photo: Coastal Resources Center, URI

Child fishing in North Sulawesi, Indonesia. The future of millions of people depend upon healthy reefs and oceans

Useful References and Resources

This paper is based upon presentations at the 9th International Coral Reef Symposium, Mini-Symposia E4 *Global Climate Change and Coral Reefs: Coral Bleaching: Assessing and Linking Ecological and Socio-Economic Impacts, Future Trends and Mitigation Planning.* Authors and titles of presentations can be found at: www.nova.edu/ocean/9icrs/

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The International Coral Reef Initiative (ICRI), Web site: www.icriforum.org

WEB LINKS

Please note that some web site URL's listed in the report have been updated since publication.

ORGANIZATIONS

- Conservation International
- International Society for Reef Studies
- US Agency for International Development
- World Resources Institute

INTRODUCTION

- 9th International Coral Reef Symposium
- International Coral Reef Initiative

GLOBAL STATUS OF CORAL REEFS

- Global Coral Reef Monitoring Network
- ReefBase
- Reef Check

STATE OF RESEARCH KNOWLEDGE

- Australian Institute of Marine Science - Reef monitoring methods
- Coral reef degradation in the Indian Ocean
- National Invasive Species Council
- UNEP Caribbean Environment Programme - Land-Based Sources of Marine Pollution
- University of Hawaii - Marine invasions in Hawaii
- Workshop: Coral Reefs and Global Change: Adaptation, acclimation or extinction?
- World Conservation Monitoring Center - Coral diseases data

RESOURCE MANAGEMENT

- Damage Assessment and Restoration Program
- Florida Keys National Marine Sanctuary
- Great Barrier Reef Marine Park Authority
- Marine Affairs Research and Education
- National Center for Ecological Analysis and Synthesis

SOCIO-ECONOMICS AND CAPACITY-BUILDING

- SeaWeb

Trade and Management

- CITES – Convention on International Trade in Endangered Species of Wild Flora and Fauna
- Marine Aquarium Council
- Secretariat for the Pacific Community
- TRAFFIC – WWF/IUCN Wildlife Trade Monitoring Programme
- UNEP-World Conservation Monitoring Centre
- US Coral Reef Task Force
- The WorldFish Center (formerly ICLARM)

Assessment and Monitoring

- Marine Programme, World Conservation Monitoring Centre
- UNEP Convention on Biological Diversity
- US EPA's Coral Reef Protection site
- West Hawaii Aquarium Project
- Workshop: Quantitative Underwater Ecological Survey Techniques

Global Climate Change and Coral Reefs

- Biosphere 2 Coral Reef
- Coral Reef Watch
- Global Coral Reef Monitoring Network
- Global Ocean Data Analysis Project
- International Coral Reef Action Network
- International Coral Reef Initiative
- NOAA Coral Bleaching Hotspots
- Reef Education Network