The Management of Coral Reef Resource Systems

Edited by
John L. Munro and Patricia E. Munro

ICLARM International Center for Living Aquatic Resources Management

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Proceedings of a Workshop held
at the Australian Institute of Marine Science
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PREFACE

Coral Reef Resource Systems

This volume reports on the proceedings of a scientific workshop, organized by the International Center for Living Aquatic Resources Management (ICLARM) and held at the Australian Institute of Marine Science (AIMS), in which the primary purpose was to identify ways in which international collaborative efforts in coral reef resources research and management can be coordinated to greatest effect. A secondary objective was to advise and assist ICLARM and the Government of Australia in establishing priorities for research on the management of coral reef resource systems.

A resource system is the set of entities, factors and parameters which produces a harvestable resource. It includes the human dimension in addition to the biological and ecological aspects. In the context of coral reefs, research on the resource systems encompasses an enormous array of topics, each of which poses difficult research questions in sociology and economics and in the use of and development of adjacent terrestrial resource systems; all in addition to aspects of biology and ecology of the reef-dwelling organisms.

By convening a diverse group of talented scientists from around the globe, including a substantial number of Australians, we were able to focus our efforts on priority topics in the wide array of problems which are encountered in the management of coral reef ecosystems, particularly in developing countries, and to bring the combined talents and experiences of the group to bear on questions of international collaboration and the wise deployment of research funds.

The meeting concluded the following:

- To understand and manage coral reef resource systems, we need to monitor the effects of global climatic and environmental change on coral reef ecosystems and to develop integrated coastal area management systems for the control of resource exploitation and of siltation, eutrophication, contamination and physical degradation.
- The measurement and maintenance of biodiversity of coral reef systems is now perceived as a topic of the greatest importance and this leads to an increased need for studies of the biology and ecology of coral reef organisms. Systems for selection and management of marine protected areas are needed if conservation efforts are to be effective.
- Ecosystem modeling and parameterization of coral reef communities are required, both to conserve the communities and to assess and manage multispecies, multigear, coral reef fisheries.

- Community-based co-management systems for natural resources are being strongly advocated in many quarters, but there is little experience in developing such systems.
- Fisheries enhancement and ranching of coral reef fish and invertebrates by rearing and release of selected species is a major topic for research but little progress has been made to date.
- The development of aquaculture systems in coral reef areas, species selection, and genetic selection and manipulation for improved domestic breeds are topics which must be addressed at an early stage.

The following pages present brief but comprehensive accounts of key areas affecting the research for management of coral reef resource systems and, hopefully, will contribute significantly towards managing coral reef resource systems in developing countries, despite the opposing pressures of massive population growth and concomitant pressures on the resource systems and the environment.

The specific recommendations arising from this workshop (p. 1-3) are relevant not only to ICLARM and its particular goals and objectives, but also to other agencies which are concerned with management and research on coral reefs.

It is pleasing to be able to report that in the interval between the completion of the workshop and the publication of this volume, projects have been launched by ICLARM in many of the proposed areas, including the ReefBase Project, which is developing a global database of coral reefs and their resources. A coastal fisheries co-management project includes coral reef fisheries, and new initiatives have been launched in aquaculture of coral reef animals and enhancement of fisheries. Multispecies models relevant to the management of coral reef fisheries are being developed and ICLARM has widened even further its collaborative research linkages with institutions and individual scientists concerned with the management of coral reef resource systems.

John L. Munro
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ABSTRACT

This volume reports the proceedings of a scientific meeting to identify ways in which international collaborative efforts in coral reef research and management can be coordinated to greatest effect. A secondary objective was to advise ICLARM and the Australian Government in establishing research priorities towards managing coral reef resource systems. Brief summaries of the status of coral reef resources and research needs in a number of countries are provided, together with papers on factors influencing reef productivity and management. Recommendations for international collaboration include: formation of linkages between research organizations into research groups, and between regional networks of monitoring and management groups; and networking and coordination in three specific areas - common definitions; models, methods and data; and possible management solutions.

ACKNOWLEDGEMENTS

The costs of the workshop, including the publication of this volume, and of travel costs of invited participants from the Commonwealth, including Australia, and from developing countries in Asia and the Pacific and those from ICLARM were met from a grant from the Australian International Development Assistance Bureau (AIDAB).

The International Centre for Ocean Development (ICOD) funded the participation of two participants from the Indian Ocean Region and two from the Caribbean, thus adding considerably to the depth of expertise and experience brought to bear on the deliberations.

The costs of other participants were met from ICLARM core funds.

Persons who were invited to participate in the workshop were selected on the basis of their expertise, current research fields and their knowledge of specific regions. In making the selections, we were very conscious of the fact that the people whom we selected are probably also the busiest and the most in demand on a variety of fronts. We are very grateful to them for agreeing to participate in the interests of furthering international collaboration in the management of coral reef resource systems and launching a coordinated initiative in the management of coral reef resources.

The generosity of AIMS, through its Director, Dr. J.D. Baker, in providing the venue for the workshop, together with excellent support facilities in an atmosphere of scientific excellence, is most gratefully acknowledged.

PART I: WORKSHOP OUTPUT

Recommendations of the Workshop

1. Preamble

The workshop recognizes that management must be holistic and consider not only the fish and coral reef resources but also the ecological, social, economic and political aspects. The goal of management must be ecologically sustainable use. Resource management is accomplished by management of people and their activities.

2. Recommendations for International collaboration and coordination

a. The workshop endorses the need for international collaborative efforts in coral reef resource management. These collaborative efforts must involve host-country scientists in all steps, and enhance their capacity.

b. Networking and coordination are needed in three specific areas:
   - common definitions;
   - models, methods and data that are useful in understanding the coral reef resource systems (a specific data gap was identified in the fisheries component); and
   - possible management solutions.

c. The specific institutions and agencies which are best qualified to coordinate these networking initiatives:
   - common definitions (the ASEAN/Australia Marine Sciences Project: Living Coastal Resources);
   - models, methods and data on fisheries and fishers (ICLARM); and
   - possible management solutions (ICLARM).

d. There is a need for the collection, synthesis and exchange of information if pointless duplication of effort and wastage of valuable research funds are to be avoided. Research that is organized around research groups (loose aggregations of organizations) has been shown to be a way of ensuring the diffusion of information, and should be pursued in this case. Linkages should be created between regional networks of monitoring and management groups (such as IOC, SPREP, CARICOMP, PACICOMP, COMARAF, ICLARM and various French agencies in Polynesia and elsewhere) to form a global network, particularly through the development of newsletters, workshops, conferences and training opportunities.

e. Collaborative projects, particularly those involving exchange of personnel between regions, should be supported.

f. These collaborative projects would be enhanced by a high degree of standardization of methodologies.

3. *Recommendations to AIDAB and to Australian institutions*

a. Noting the success of the ASEAN/Australia Marine Sciences Project: Living Coastal Resources, and particularly the fact that its manual has been selected as a model by UNEP for monitoring at a global level, it is recommended that:
   - means should be sought within the donor community to strengthen the project and to assist in the development of similar projects in the Indian Ocean and the South Pacific;
   - consideration be given to directing funds from the Australian Tropical Marine Ecosystems Initiative towards activities which draw upon the successful aspects of the project.

b. Resources should be provided to enable Australian centers in Townsville and elsewhere to support the strengthening of graduate and postgraduate programs in developing-country universities through the conduct of appropriate projects, in line with the research needs identified by the Working Groups. Assistance could include Australian supervisors making regular visits to these universities.

c. If INTROMARC is established, it should have roles in coordination and networking, training and the provision of funding and other forms of support for institutional strengthening in developing countries and the facilitation of appropriate research programs.

d. The workshop participants, having noted the worldwide lack of taxonomic reference work on corals, recommended that present efforts at AIMS to create a distributable taxonomic database of corals, be encouraged to cover all corals of the world and to interact with the ReefBase project (below).

e. The workshop participants, having considered ICLARM's plan for a global database on coral reefs, endorses this effort as worthy of funding by the Australian Government.

4. *Recommendations to ICLARM*

a. ICLARM should:
   - investigate ways in which fisheries management can be integrated into the context of environmental management;
   - undertake research to identify ecological, biological, social and economic impacts of tourism on coral reef ecosystems and determine sustainable levels;
   - conduct research to evaluate marine protected areas as tools for coral reef management; and
   - examine alternative management options for coral reef fisheries in a range of societal contexts, including community-based management systems.

b. ICLARM should develop methodologies for cost-effective data acquisition in coral reef ecosystems (including socioeconomic aspects), models to aid in analysis and conceptualization and across-site comparisons, and train people in their utilization.

c. ICLARM should give strong emphasis, when developing ReefBase, to complementing and supporting other existing or planned national and regional databases related to coral reefs (as outlined in the report of Working Group 4).

d. ICLARM should continue work on identifying and researching the basic biology of prospective species for aquaculture and resource enhancement, concentrating on appropriate local technologies for research into farming systems.

e. ICLARM should include assessments of environmental and genetic impacts of aquaculture and resource enhancement projects throughout their development, in collaboration with appropriate expert groups.
f. An early objective for INTROMARC or ICLARM should be the development of a set of guidelines for the evaluation of resource assessment projects. This should expressly include evaluation of the social and economic context of such projects.
g. ICLARM should evaluate the potential social and economic impacts of aquaculture and resource-enhancement programs.

Reports of the Working Groups

Four Working Groups were convened on the second day of the Workshop:

1. *Conservation of reef systems and their biodiversity*
2. *Management of coral reef resource systems, particularly fisheries*
3. *Increasing sustainable yields from coral reef resource systems by aquaculture and fisheries enhancement*
4. *Database development and modeling of coral reef ecosystems*

The objectives of the Working Groups were to:

- recommend ways in which international collaborative efforts in coral reef resources management can be coordinated to greatest effect;
- assist the Government of Australia in identifying methods for implementing the Australian Government's initiative in tropical marine ecosystem management; and
- advise and assist ICLARM in establishing priorities for its research program on the management of coral reef resource systems.

Working Group 1: *Conservation of Reef Systems and Their Biodiversity*

Members:
J.J. Polovina (Chairman)
B. Lassig (Rapporteur)
T. Done
D. Kinsey
R. Laydoo
J. Lough
S. Massel
A. Mitchell
S. Sudara
Suharsono

The Working Group recommended that international collaborative efforts in coral reef resources management could be coordinated to greatest effect by:

- linkage of regional networks;
- newsletters (including the use of e-mail);
- workshops, conferences and training;
- collaborative projects (including exchange programs); and
- standardization of methodologies.

In respect of the Australian Government's initiative in managing tropical marine ecosystems, the Working Group recommended consideration of an extension of the successful ASEAN-Australian model research program. The initial geographic focus should be on the Indian Ocean - West Pacific region, with networking to other tropical regions. Activities should include:

- workshop training in relevant methodologies, including monitoring;
- collaborative development of training programs by all parties;
- training associated with fieldwork/trials;
- representation of all parties on management committees; and
- expansion of the funding base to international sources, with long-term commitments required for monitoring programs.

The research program should have provision for networking into the global scene and interacting with groups such as ICLARM, SPREP, CARICOMP, COMARAF and various French agencies.

The benefits to Australia would include improved perception of global trends and standardized approaches to allow direct comparisons.

The Working Group categorized their perceptions of priorities for ICLARM's Coral Reef Resource Systems Program as: investigations of the impacts of tourism, production (fisheries, mariculture, mining) and land-based activities (urban development, forestry, waste management), which should be studied in terms of impacts on the ecosystem and in terms of socioeconomic factors. Acceptable levels of impacts need to be evaluated in respect of these uses.

It was suggested that the facilitation and coordination of monitoring of coral reef ecosystems should be given high priority. Production of an international monitoring manual should be considered, taking into account the outcomes of meetings of the IOC and of NOAA, NSF and EPA in the USA. The manual should take into account the ASEAN-Australia Methodology Manual and the CARICOMP Manual and cover the habitat to be monitored, the scope of the monitoring and its design, the analysis of data, and should recognize long-term issues such as those pertaining to biodiversity.

Research on the temporal and spatial dynamics of coral reef ecosystems is of much importance and includes demographic research on processes such as recruitment, growth, mortality and migration and their interactions within coral reef ecosystems. Questions of community structure and dynamics are important, as is the issue of connectivity among reefs.

Management strategies need to be preceded by inventories of reef status and habitat and resource mapping. The optimal design and representativeness of marine protected areas (MPA) is of great importance.

There is a need to integrate fisheries management with the broader context of environmental management and for the development of education and information programs.

The Working Group concluded that high priority research areas included:

- the integration of fisheries management in the context of environmental management;

- the impacts of tourism on coral reef resources;
- the facilitation and coordination of monitoring, including research on monitoring methods; and
- the design and evaluation of MPA, including assessment of the benefits to local inhabitants.

Working Group 2: *Management of Coral Reef Resource Systems*

Members:
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J.D. Woodley (Rapporteur)
A. Cabanban
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R. Galzin
E. Hviding
G. McPherson
S. Mohammed
I. Poiner
G. Russ

The Working Group initially addressed and discussed the concept of "resource systems" with reference to coral reefs, and particularly to fisheries. As defined in recent ICLARM contributions, this use of the concept contains the following elements:

- the fish resource (referring to all living aquatic resources harvested from the reef - finfish, shellfish, algae, coral, etc.);
- the fishery (referring to interactive sets of human activity relating to the perception, appropriation, exploitation and transformation of the fish resource);
- the ecosystem (referring to the interactive sets of organisms, the physical and chemical environments and the interactions between them); and
- the ecoregion (referring to the broader factors which interact with the foregoing; these include pollution from land-based sources, and the economic, political and policy environments).

A comprehensive definition such as given above of the "coral reef resource system" concept allows for a great number of dimensions to be addressed and taken into account. This approach was taken by the working group's discussions, as summarized below.

Coral reef resource management must be holistic. It must consider not only the fish resources, but also a diverse set of interactions and linkages: ecological, geographical, social, economic and political.

The ultimate goal of management of coral reef resource systems must be sustainable use, although specific goals may differ. Decisionmakers in different countries, and in different levels of society, act in different contexts (related to variations in environment, socioeconomic status or political culture), and have specific goals which in some cases do not include long-term sustainability but rather short-term maximum economic benefit. The working group noted that even management for the purpose of conserving pristine coral reefs usually entails an important human dimension in excluding resource use activity.

Resource management is the management of people and their activities. There is a range of societal contexts for human activity associated with the utilization and management of coral reef resource systems; from more developed societies (e.g., the management of the Great Barrier Reef, Australia) for which there are many options for management, to a state of "Malthusian overfishing" (e.g., Lingayen Gulf, Philippines), for which management options may be more limited. To accomplish effective and holistic management, it is important to involve all users (including scientists) in all steps of the decisionmaking process.

General options for the management of coral reef resource systems and their associated fisheries include, among others:

- Centralized legislation, monitoring and enforcement of fishery regulations. These methods are typical of fisheries in developed countries, where compliance is tied to formal legal/administrative structures.
- Community-based management based on the devolution of power and, ideally, a linkage (through education) between scientific knowledge and local perceptions. Such forms of management often build on customary marine tenure systems, though they may also be envisaged in contexts where traditional systems do not exist. They may coexist or conflict with more formalized legislative measures.
- In the context of Malthusian overfishing, the creation of alternative occupations, thereby easing the pressure on the fish resource. This radical approach involves nonfisheries sectors directly.

Resource management entails the regulation of activity and the relative evaluation of alternative uses. Therefore, management measures have an inherent political dimension through which they relate to other sectors beyond the fishery. Also, the ecological processes of coral reef systems have strong links with adjacent ecosystems (including mangroves and terrestrial systems) and their usages. Some of the most urgent challenges of coral reef management relate to degradation through such links, for example terrestrial runoff.

The specific problems and impacts of resource system mismanagement and coral reef ecosystem degradation were discussed by the Working Group. The global range of these issues is described in the regional reports on the status of coral reef resources systems and current research needs (summarized in Table 1).

Table 1. Problems of and solutions for coral reef management (based on the regional reports on the status of coral reef resource systems and current research needs).

	Country or area							
	Philippines	Thailand	Indonesia	French Polynesia	Maldives	East Africa	Eastern Caribbean	Jamaica
Problem								
Siltation	*	*	*	*	*	*	*	*
Eutrophication	*	*	*	*	*	*	*	*
Destructive fishing	*	*	*	*		*		
Overfishing	*		*	*	*	*	*	*
Collection of corals	*		*	*			*	
Tourism		*	*	*	*	*	*	*
Coral mining			*	*	*	*		
Bleaching		*(1992)	*(1983)	*			*	
Oil pollution			*					
Unexplained deaths					*	*	*	
Lack of protection of parks							*	
Storms	*	*		*	*		*	*
Solution								
Artificial reefs	*	*	*	*			*	
Marine parks	*	*	*	*	*	*	*	*
Involvement of people	*	*	*		*		*	*
Management plan	*	*		*			*	*
Anchor buoys		*			*		*	*
Networking							*	

Similar impacts on reef resources, differing in degree, are reported from each region. They are pollution (sediments, nutrients, industrial wastes), overexploitation and habitat destruction (in coastal construction, agriculture, fishing, tourism).

Impacts result not only from human activities within the immediate coral reef system, but from activities in adjacent systems, such as deforestation, urban development and mining in terrestrial watersheds, or the destruction of mangroves for various purposes.

The major forces driving human impacts are economic development and increasing human population. Overexploitation and other destructive practices in small-scale fishing, while facilitated by ignorance of their negative consequences, are driven by economic necessity.

In the regional reports, the following are the principal measures proposed for mitigation of human impacts:

- population control;
- environmental education at all levels: politicians, planners, entrepreneurs, people;
- training of environmental managers and enhancement of their resources;
- environmental engineering in watershed management, waste disposal, coastal construction, etc.;
- promotion of community-based fishery management systems;
- development of alternative livelihoods; and
- creation of marine protected areas.

The regional reports identified the following areas in which further research was needed. These are summarized in Table 2.

THE MANAGEMENT PROCESS. The Working Group identified the following steps:

1. Set management goals.
2. Define the coral reef resource system, in terms of its boundaries and interactive linkages.
3. Understand the resource system.

Table 2. Research needs for coral reef management (based on the regional reports on the status of coral reef resource systems and current research needs).[a]

	Country or area							
	Philippines	Thailand	Indonesia	French Polynesia	Maldives	East Africa	Eastern Caribbean	Jamaica
Marine parks advantage	*	*	*	*	*			*
Marine parks size	*		*	*				*
Linkages with seagrass and mangroves	*	*	*					*
Reef biology and ecology	*	*	*	*	*	*	*	*
Fish statistics	*	*		*	*			*
Multispecies modeling	*	*	*					*
Hydrography	*			*			*	*
Replenish corals and reef populations	*	*		*				*
Calcium budgets		*		*				
Causes of reef degradation		*	*		*			
Economic valuation		*	*	*	*			
Environmental impact education		*	*	*	*	*		
Current status						*	*	
Map critical habitats						*	*	*
Motivation theory	*			*				*
Gathering/gleaning	*			*				
Resource predictability	*	*	*	*	*			
Resource exploitation guidelines	*	*	*	*	*			
Better resource utilization	*	*	*	*				
Sustainable development	*	*	*	*				

[a]Includes suggestions by McManus (this vol.).

This understanding resides in models which assist the data collection, but we must be aware of how valid any model is, and the comprehensiveness of the data on which our assessments are based. Specifically, a major gap in data on coral reef fisheries was identified: There is a need to develop methodology to facilitate data collection on artisanal coral reef fishery systems, to develop modeling of such systems, and to encourage compilation and analysis of existing datasets.

4. Identify problems and critical processes, key habitats and key constraints on management.
5. Identify possible problem solutions. This will require a broader knowledge of alternative solutions tested elsewhere (including those that have not worked). Also, it may involve the presentation to decisionmakers of alternative scenarios.
6. Validate management solutions. This should be a continuing process involving, if necessary, the reformulation of management goals and measures.
7. Implement successful solutions. It was recognized that in some cases solutions are implemented which are based on imperfect knowledge and can only be validated after implementation. The important point is to ensure that validation occurs, as this is often left out of development projects. The implementation of community-based management systems will require a strategy of building on existing community perceptions and knowledge and on existing sociopolitical institutions.

Steps 1-7 are part of an iterative process. Once the first step is completed, one might return to the beginning to refine the process or move to the third step to refine the models and data collection.

There was some overlap in the responses to the three objectives discussed by the Working Group, which addressed the first in most detail, then commented on the others.

INTERNATIONAL COLLABORATION. The Working Group felt that international collaborative efforts in coral reef resource management can be coordinated to greatest effect if the following steps are observed:

- Host-country scientists are involved in project planning and execution from the very beginning, at all intermediate stages and in project evaluation.
- Management goals are locally discussed and derived, and not assumed or imposed by an external agency.
- Host-country scientific and management expertise and resources in less-developed countries should be enhanced by, for example, provision of training, library materials, equipment and networking with developed countries.
- Networking, the sharing of data and ideas, should be encouraged between all regional territories.

Possible areas for collaboration include:

- training;
- system definitions;
- sharing knowledge about common species;
- networking of resource persons and managers;
- casebooks of possible solutions;
- the use of remote sensing in resource surveys;
- studies on coastal ecosystem interactions; and
- the management of terrestrial runoff.

PRIORITIES FOR ICLARM. In order to assist ICLARM in establishing priorities for the proposed research program on Coral Reef Resource Systems, the Working Group used the management process (steps 1-7), discussed above, as a basis for determining which areas required international collaboration or strategic research.

It was agreed that management plans have to be developed in-country or onsite and cannot be imposed from outside. Therefore it is the planning process and the skills in each planning step that can be transferred, rather than the management plans themselves.

The Working Group then went through each of the steps to see which were important areas for collaboration.

1. Setting goals: This was seen as country- and, possibly, site-specific, to be carried out in-country. No collaboration needed.
2. Defining systems: This is also an area that depends on local conditions. However, there is a need for common definition of terms (i.e., what is a reef, what components are used in calculating reef area, etc.). These standard definitions are necessary in order to compare across sites. Common definitions can be determined by informal working groups or through projects (e.g., the ASEAN-Australia Marine Sciences Project).
3. Understanding systems: There is tremendous scope for collaboration in this area, both in analytical models, in data acquisition and in data comparison (thus, data sharing is important). Australia has similar species and conditions to much of the Indo-Pacific, and Australian researchers have contributed much at the organism and ecosystem levels. Thus, much of the collaboration here should closely involve Australian institutions and researchers. There is, however, a major data gap in the fishery component. There is a need to develop methodologies for rapid and cost effective data acquisition, to develop models to aid in analysis and conceptualization, to develop across-site comparisons and to train people in their utilization. There are few Australian experts. ICLARM has identified this as a major area of future research and has some comparative advantage in this area.
4. Identifying critical processes: This should follow as an outcome of Step 3. There appears to be some Australian expertise in methodologies to assist this process.
5. Identifying possible solutions: The presentations covering the current status of reefs identified few possible solutions (see Table 1). There appears to be a need to compile and share information on the range of solutions, particularly in the area of indigenous knowledge and community-based management. This is a research area ICLARM proposes to develop.
6. Validating solutions.
7. Implementing solutions. Both of the above steps are necessary, but it was felt they are not areas for collaborative strategic research.

THE AUSTRALIAN GOVERNMENT INITIATIVE IN TROPICAL MARINE ECOSYSTEM MANAGEMENT. The Working Group felt that the question of international collaboration was relevant here. In addition, the Group was asked to comment on the AIDAB consultant's report (see p. 116-117) that addressed this question.

There was a measure of agreement with the aims and substance of this report. But the major criticism was that it embodied too much of a top-down approach, with insufficient emphasis on local participation. For instance, in the case of tools for local education, it will not be Australians who can "get the message across".

Also, the diversity of the resource system was not fully appreciated. It is unlikely that a single manual, written at a workshop in Townsville, would be appropriate and usable by extension workers in all countries across Southeast Asia and the Pacific. Advice and consultation on the management options to be recommended would be valuable, but the actual manuals must be tailored to the local culture and environment.

The GBRMPA model of reef management, admirable though it is in the Queensland context, cannot be considered directly transferable to other-country situations.

Finally, the Working Group recommended replacing the "large-workshop-in-Townsville" approach with in-country training workshops. They are more effective because (1) more people could be trained in each host country; (2) the instructors are exposed to the specific host-country environment; and (3) the instructors are forced to consider the limitations of host-country resources.

Working Group 3: *Increasing Sustainable Yields from Coral Reef Resource Systems by Aquaculture and Fisheries Enhancement*

Members:
J. Benzie (Chairman)
G. Preston (Rapporteur)
P. Doherty
M.H. Maniku
J. Munro
R. South
S. Woodley

Resource enhancement was defined as improving sustainable production from fisheries through the application of technology. Enhancement is distinct from management, which does not require technological intervention, but cannot operate independently of it.

It was noted that there was a requirement to identify more precisely the needs of developing countries in this area. The group felt that, from the developing-country viewpoint, ICLARM should continue to give priority to activities that increase employment, income-earning opportunities and food production for coastal villages. However, the reasons for enhancing resources may not only be economic, but may also be to restore reefs that have been degraded by exploitation or other causes.

The group identified several areas of need in aquaculture and resource enhancement.

PROSPECTIVE SPECIES. Studies are needed on the life history, reproductive biology and ecology of prospective species for use in aquaculture and resource enhancement. Species of primary interest would normally be those with a high value, which can be propagated, husbanded and harvested using low-technology methods. For economically oriented resource enhancement, preferred species would give a product that can be absorbed by local markets or exported without the need for costly infrastructure.

For fish, those species that are low on the food chain are of most interest. Some large herbivorous or omnivorous species, such as bumphead parrotfish and Maori wrasse, may have high growth rates which would make them good candidates for enhancement. However, stocking of predators should not be ruled out. The trophic pyramid on overexploited reefs is usually flattened, since predators are normally removed first by fishing. In some cases, it may be possible to stock predators such as groupers, snappers or emperors.

Key invertebrate species include those currently exploited sessile resources with wide distribution in the Indo-Pacific, such as sea cucumbers, pearl oysters, giant clams, trochus and green snails, as well as selected Caribbean species, such as queen conch and Caribbean spider crab.

Other groups that may also merit consideration include agarophyte algae, coralline algae for use in bone implants and species that may be used to derive pharmaceuticals and biologically active compounds, as well as sponges and decorative shells for collectors or for handicraft manufacture. Enhancement of heavily exploited specimen shell resources in some Southeast Asian countries (giant clams, bailer shells, triton shells) may be justified in both economic and environmental terms.

Many other species may also merit consideration, some of which may be site-specific. Many reef organisms are edible and studies of their life histories may show them to be amenable to culture or enhancement.

ENVIRONMENTAL IMPACTS. Studies of the environmental impacts or implications of resource enhancement or aquaculture activities are needed. We do not presently know what factors may limit the biomass of some species, including bêche-de-mer, giant clams and pearl oysters, which can reach very high standing stocks if left alone under favorable natural conditions. The standing stocks of some fish species also vary widely according to variations in recruitment, and often appear to remain well below carrying capacity. An understanding is also required of the potential carrying capacity of a given reef system to absorb additional biomass that may be loaded into it.

The ECOPATH II model may be useful in predicting the ecological effects of manipulating the recruitment of a given species through resource enhancement.

INTEGRATED STUDIES. More detailed, integrated studies, such as biotechnical research on strain selection, research into farming systems for species for which aquaculture has already proved successful and technology research, development and transfer are required.

This would include hatchery techniques and technology for key species, as well as spat and fry collection technologies as substitutes for hatcheries, and associated practices such as habitat modification for juvenile protection, aggregation systems, etc. It was noted that fish can be aggregated by regular feeding, a characteristic capitalized on by the tourist diving industry. Japanese restocking programs use acoustic feeding-stations in red porgy culture and subsequent harvesting. What is the potential of this type of aggregation in reef-based systems?

The use of light-traps is of great interest in this regard. Even relatively early juvenile fish have a high value as farming seed stock in some areas. The ongrowing of larvae to juveniles (rather than to adults ready for consumption) could be a viable industry in some areas.

The commercial development of light-traps might be worthwhile, especially if they could be simplified and produced for a relatively low cost. However, it was noted that the potential exists for commercial operators to use them in inshore waters where the effect might be to reduce natural settlement.

Anything done on a reef system will have downstream effects on other reefs and these effects need to be considered. Genetic analysis as a means of evaluating the effects of an enhancement program on wild populations, and of discriminating between different populations, will be required at a fairly early stage, once the basic biotechnology has been worked out.

SOCIAL AND ECONOMIC ASPECTS. Studies of the socioeconomic effects of aquaculture and questions of tenure are integral to any research program. Enhancement should be accompanied by the development of community-based management systems. Studies are needed on effective means of implementing such systems where they are absent. Legal constraints on the use of marine areas in the tropics are often blurred and comparative studies of various marine tenure systems, which are highly variable between countries and regions, would be of benefit.

Evaluation of the potential social and economic impacts of aquaculture, and resource enhancement programs are essential. Social considerations should be a precursor to biotechnology development, while socioeconomic issues should be addressed concurrently with it.

TRAINING AND EDUCATION. There is a need for training in all the above areas but this needs to be applied in a discriminating manner. Emphasis should be given to training programs that enable students to carry out at least part of their work in their home countries. Training should be project- or vocation-oriented where this is feasible, but this should not be an overriding requirement. Short courses should be avoided since experience shows that there is an oversupply of this type of training (at least in the Pacific).

CONCLUSIONS. The principal aims of this workshop were noted as being to identify international collaborative research opportunities and coordination mechanisms; to assist the Australian Government to identify methods for implementation of its initiative; and to advise and assist ICLARM to establish priorities for its proposed research program on coral reef resource systems. In line with these aims, the following suggestions were noted:

- Aquaculture in coral reef lagoons cannot be considered in isolation from other problems of fisheries management, or from the mundane obstacles to development, including the general lack of infrastructure, technically trained personnel, maintenance and support facilities, and public finance, that prevails in developing countries.
- There is a need for the collection, synthesis and exchange of information if pointless duplication of effort and wastage of valuable research funds are to be avoided. Research that is organized around research groups (loose aggregations of organizations) has been shown to be an effective way of ensuring the diffusion of information, and should be pursued in this case.
- Resources should be provided to enable Australian centers in Townsville and elsewhere to support the strengthening of graduate and postgraduate programs in developing-country universities through the conduct of appropriate projects in line with the research needs identified above. Assistance could include Australian supervisors making regular field visits to project sites.
- If INTROMARC is established, it should have roles in coordination and networking, training, and the provision of funding and other forms of support for institutional strengthening in developing countries and the facilitation of appropriate research programs.
- An early objective for INTROMARC or ICLARM should be the development of a set of guidelines for the evaluation of aquaculture or resource enhancement projects. This should expressly include evaluation of the social and socioeconomic context of such projects and the selection of suitable species.

GENERIC ISSUES. The group noted that the funds presently earmarked for the establishment of INTROMARC in Townsville are only adequate to allow for a relatively small program over a short timeframe. Extension beyond this period may result in the diversion of AIDAB and other funds from existing or planned regional or bilateral marine resource development activities. It may also result in another agency becoming active in the field of fisheries and marine research training, an area which presently suffers from poor coordination. The Australian government will therefore need to consider INTROMARC's role carefully and should also seek the views of the intended beneficiaries of the program on its priorities, relative to other marine resource development activities.

Working Group 4: *Database Development and Modeling of Coral Reef Ecosystems*

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MODELING OF CORAL REEF ECOSYSTEMS. The Working Group expressed a need for models that would enable researchers to study reefs quantitatively. Such models should refer to the coral reef system as a whole. They should serve management needs and produce outputs that are usable for managers. The models should link up with other related models such as bioeconomic and socioeconomic models.

Examples of approaches/models that are perceived to be useful are:

- calcium metabolism models;
- trophic models (e.g., ECOPATH);
- respiration models;
- cellular automata and related spatial models;
- Multispecies Virtual Population Analysis (MSVPA); and
- multivariate (statistical) models.

DEVELOPMENT OF A GLOBAL CORAL REEF DATABASE. The Working Group noted that there is a clear need for a global database on coral reef systems, such as has been proposed by ICLARM, and that this should complement and bring together similar regional databases in a global framework. This need was expressed in many papers presented on the first day of the workshop, especially by colleagues from developing-country institutes. The workshop also noted there should be a close link between the data contained in a global coral reef database and the data needed for models.

There is also a need to standardize and classify information collected on reefs in order to make this information comparable as a precondition to global research on coral reefs. The Working Group was aware of the UNEP-IOC-WMO-IUCN Long-Term Global Monitoring Pilot Project on Coral Reefs and the database that will emerge out of that exercise. It was suggested that there should be a close cooperation with that project and that their data should eventually be distributed through the proposed global database.

It was also suggested that the database should take into account the recommendations of the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in June 1992.

Description of the proposed database. The database should have global coverage of coral reef systems. Individual reefs could be the units to which all relevant data are attached. Information on seagrass beds and mangroves as closely related ecosystems should also be included.

The database should contain two types of information:

1. general descriptions of reefs (e.g., type of reef, total area, area by type, etc.) on the country level and on the level of individual reefs; and
2. time series of the following:
   - monitoring data, such as collected by the UNEP monitoring project,
   - renewable and nonrenewable harvests,
   - nonextractive reef uses,
   - species abundance,
   - stresses and
   - management regimes.

The database should draw on published information which must be referenced.

Wherever possible, raw data or the lowest level of aggregation of information should be maintained. The type and the structure of the information should be usable for existing and perceived models on coral reefs. In doing so, it is hoped that the database will lead to "model-driven" data collection.

The database should not contain biological or taxonomical information on species but rather link with existing databases such as FishBase (developed at ICLARM) for fishes and CoralBase (developed at AIMS) for corals.

The database must be linked to a high-level GIS to make use of existing and upcoming maps and analytical routines (e.g., Digital World Chart). The database must make use of existing and emerging standards in order to be accessible for other/new analytical systems.

Networking. To collect all the information needed, it is suggested that a network of collaborators be maintained. Given that the database should contain only published information, the project should encourage and help collaborators to publish their data, e.g., by providing a publication outlet suitable for the information required by the database. The emphasis on publications ensures that collaborators get credit for their work. Every collaborator should get a copy of the database and will thus be able to evaluate his/her own data in a global framework.

Distribution of the database. The main clients of the database will be scientists, especially those in developing countries. Additional clients will be resource managers, conservation agencies, nongovernmental organizations and students. Other users will be the news media and the private sector.

It was suggested that the database be distributed free to collaborators throughout the tropics. Distribution should be done through a limited number of regional outposts by a well-trained resource person. Training courses should be conducted at these outposts where participants from the region could be supplied with all the needed software (the database plus analytical routines plus related software) and, possibly, with a suitable computer. In this way, it might be possible to achieve a snowball-effect in making the database available.

The database and the related routines should be copyright-protected in order to prevent commercial use by others.

Cooperation with other projects. The database should not only contain data contributed by its network of collaborators but also act as a host to related databases which are developed and maintained by other projects to make this information available, e.g., FishBase, CoralBase, or oceanographic and meteorological databases. The database should collaborate with the following projects/institutes:

- UNEP-IOC-WMO-IUCN Monitoring Project (see above);
- ASEAN/Australia Marine Science Project, Townsville, Australia (monitoring of Southeast Asian reefs);
- World Conservation Monitoring Centre, Cambridge, United Kingdom (mapping, protected areas);
- IUCN/SSC Coral Reef Fish Specialist Group (mapping of reef fishes);
- Caribbean Coastal Marine Productivity Project (CARICOMP) (monitoring of Caribbean reefs);
- Global Resource Information Database (GRID), UNEP;
- Reef Ecology Database (AIMS);
- GBRMPA (several related databases);
- National Resource Information Centre (NRIC), Canberra; and
- UNEP Regional Co-ordinating Unit of the Caribbean Environmental Programme (prototype spatial database for the wider Caribbean).

PART II: STATUS OF CORAL REEF RESOURCE SYSTEMS AND CURRENT RESEARCH NEEDS

The Status of Coral Reef Resource Systems and Current Research Needs in the Philippines

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CABANBAN, A.S. and A.C. ALCALA. 1994. The status of coral reef resource systems and current research needs in the Philippines, p. 16-18. *In* J.L. Munro and P.E. Munro (eds.) The management of coral reef resource systems. ICLARM Conf. Proc. 44, 124 p.

The resources in the coral reefs of the Philippines include algae, invertebrates such as lobsters (*Panulirus* spp.), giant clams (*Tridacna* spp. and *Hippopus* spp.), food fishes such as *Caesio*, *Pterocaesio*, *Plectropomus* and *Epinephelus* spp., and species for the aquarium trade. Coral has been exported in large volumes but no estimates of its biomass or productivity are available. Likewise, there are few estimates of harvests of the commercially important invertebrates (Alcala 1981).

In contrast, more information is available on the productivity of fishes in coral reefs. The contribution of coral reef fishes to the total fish production of the Philippines was estimated at 10-15% (Carpenter 1977; Murdy and Ferraris 1980) and production rates range from 1 to 20 $t \cdot km^{-2} \cdot year^{-1}$ (Smith et al. 1980; Alcala 1981; Marten and Polovina 1982). In addition, exports of coral reef fishes for the aquarium trade are sizeable and are one of the top ten dollar-earners in the country (Albaladejo and Corpuz 1981).

Status of the Coral Reef Ecosystem, Corals and Coral Reef Fishes

Various studies that can contribute to the general understanding of the coral reef ecosystem are available but gaps in present knowledge do not permit detailed modeling of the ecosystem. Data are available on foraminiferan (Glenn et al. 1981) and zooplankton abundance

(Walter et al. 1981), algal diversity (Chan 1981; Cordero 1981; Meñez and Calumpong 1981), coral diversity and abundance (Hodgson and Ross 1981; Nemenzo and Montecillo 1981; Ross and Hodgson 1981), and ichthyofaunal diversity and ecology (Russ 1985, 1989; Licuanan 1991). However, trophic interactions within the coral reef ecosystems have not been studied. It is also not known how and to what degree reefs are interlinked with mangrove and seagrass ecosystems. Studies are in progress on the energy flow within the systems.

About 70% of the coral reefs in the Philippines are in fair to poor condition with less than 50% coral cover (Gomez et al. 1981). Further degradation is evident in surveys conducted in several parts of the country (Gomez et al. 1981; Licuanan 1991; Alcala et al. 1991). The degradation is primarily due to human activities. Most are fringing reefs which are more susceptible to perturbations from land than barrier reefs. Siltation, sedimentation, eutrophication and destructive fishing have caused a reduction of coral cover (Albaladejo and Corpuz 1981; Alcala and Gomez 1979, 1985; Gomez et al. 1981; Yap and Gomez 1981, 1985, 1988; Aliño et al. 1985). Frequent typhoons also cause damage to reefs (Miclat et al. 1991).

There is a growing body of literature on the systematics, biology and ecology of corals in the Philippines. Diversity of corals is high (Hodgson and Ross 1981; Nemenzo and Montecillo 1981; Ross and Hodgson 1981; Sy et al. 1981). Various forms of corals grow slowly, at different rates (Yap and Gomez 1988), depending on physico-chemical factors (Yap and Gomez 1981; Licuanan and Gomez 1988) and coral cover (Licuanan 1991). Consequently, the regeneration of damaged coral reefs either from man-made or natural causes is slow (Alcala et al. 1981; Miclat et al. 1991).

To alleviate this situation, coral transplantations have been made in pilot sites to study the growth and regeneration of corals (Yap and Gomez 1981; Alcala et al. 1981; Yap et al. 1990); artificial reefs of different designs and materials have been deployed; and subsequent recruitment and growth of corals monitored (Alcala 1991). Marine parks have been established (Castañeda and Miclat 1981; Palaganas et al. 1985), and a marine park system is being planned for the whole country, in which sites are being selected on the basis of diversity of corals and percentage coral cover (Palaganas et al. 1985).

The status of coral reef fisheries in the Philippines is unclear although data have been accumulated over many years by the Bureau of Fisheries and Aquatic Resources. However, it is generally accepted that the fish populations in coral reefs are overexploited (Luchavez and Alcala 1988; Russ and Alcala 1989). Estimates of the size of stock or biomass or abundance are few (Carpenter 1977; Alcala 1981; Alcala and Luchavez 1981; Alcala and Gomez 1985; Russ 1989; Alcala and Russ 1990; Luchavez 1991) and biological data on the stocks of fishes are limited (e.g., Pauly and Ingles 1981; Cabanban 1984).

Abundances of coral reef fishes have been correlated with the coral cover or complexity of the substratum (Carpenter et al. 1981; Luchavez 1991), and patterns of distribution and abundance of fishes have been related to wave-exposure, topography and depth (Carpenter et al. 1981; Hilomen and Gomez 1988; Licuanan and Gomez 1988; Hilomen and Yap 1991). In the Tubbataha offshore reef system, the abundance of larval reef fish was found to be high. Alcala and Dolar (1993) hypothesize that these reefs could be the source of recruits for the rich fishing grounds in Palawan.

To alleviate overfishing, artificial reefs and marine parks have been suggested.

Luchavez (1991) estimates a high potential yield for *Pterocaesio pisang* at an artificial reef, and Alcala et al. (1981) estimate that other target fishes (acanthurids, plectorhynchids) may be harvestable after 4-5 months. However, it is not clear whether artificial reefs are fish-aggregating devices or recruitment sites. Marine parks have been shown to maintain high diversity and abundance of fishes (Russ 1985, 1989; Alcala and Russ 1990) but there is no empirical evidence at present to show that marine parks can be sources of larvae for the replenishment of adjacent overexploited fish populations.

Current Research Needs

Gomez (1991) states that research on coral reef should now be directed to answering how, and not why, reefs in the Philippines must be managed or preserved.

Basic research is needed on:

1. *The interconnections between coral reefs and adjacent ecosystems, such as seagrasses and mangroves.* Quantification of energy flows within and between such ecosystems will answer whether conservation or management is by ecosystem or mega-ecosystem.
2. *Effectivity of artificial reefs.* Do artificial reefs provide recruitment sites or are they merely fish-aggregating devices? Do they enhance the productivity of disturbed nearshore waters?
3. *Marine parks.* Hypotheses on the benefits of marine parks, such as increased abundance of corals and fishes within the park and consequent replenishment of nearby reefs, must be tested. The question of optimum size for marine parks must also be investigated (e.g., Dight et al. 1988).
4. *Larval ecology of corals and coral reef fishes.* How far are larvae of corals and coral reef fishes dispersed from protected sites by hydrographic processes? Results of these studies will provide a scientific basis to the notion that protected sites can provide recruits to surrounding and nearby reefs.
5. *Biology and ecology of coral reef fishes.* Information on growth, reproduction, recruitment mortality, identities of stocks and fishery statistics are required to determine trends and formulate management decisions.

Management Options

Because of their proximity to human population, coral reefs must be managed with the involvement of the local people. They must be trained to become local managers (Cabanban and White 1981; Castañeda and Miclat 1981). In some cases, strong enforcement procedures are needed by concerned government agencies such as the Department of Environment and Natural Resources or the Philippine Navy.

Marine parks have been successfully established in the Philippines (Cabanban and White 1981; Castañeda and Miclat 1981) using nonformal education with the cooperation of the local population in Luzon (Mabini, Batangas); Visayas (Apo, Balicasag, Carbin Islands); and Mindanao (Pamilacan Island, Sulu Sea). Parallel but complementary to this is the establishment of a marine park system in the Philippines by government agencies.

The Status of Coral Reef Resource Systems and Current Research Needs in the Eastern Caribbean

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LAYDOO, R.S. 1994. The status of coral reef resource systems and current research needs in the Eastern Caribbean, p. 19-21. *In* J.L. Munro and P.E. Munro (eds.) The management of coral reef resource systems. ICLARM Conf. Proc. 44, 124 p.

The Eastern Caribbean archipelago is located between North and South America in the Western Hemisphere at approximately 10-20° N latitude and 60-70° W longitude (Fig. 1). Some 40 islands are grouped into 20 political entities, of which seven are dependent territories of France, Holland, United Kingdom or the United States of America. The rest are independent countries. The Eastern Caribbean region is composed of English, Spanish, French and Dutch-speaking nations. Geologically, the islands range from continental to oceanic, and from limestone to volcanic, although many are of both limestone and volcanic fractions.

The coastal waters range from estuarine to oceanic. Estuarine conditions are due mainly to the voluminous discharge from South American rivers during the wet season, from June to November, and therefore tend to be characteristic of islands to the south. More northerly island environments are perennially oceanic. The most common and extensive coastal ecosystems in the Eastern Caribbean are fringing coral reefs, seagrass beds and mangrove wetlands.

Coral Reef Resource Status

The islands which comprise the Eastern Caribbean lie in the hurricane belt. Reefs, particularly on windward or eastern coastlines of the islands, are subject almost annually to the impacts of storm seas. Many of the windward reefs are therefore characterized by a rubble framework in the upper forereef zone, with a live coral cover dominated by a few species, notably elkhorn coral (*Acropora palmata*), brain coral (*Diploria labyrinthyformis*, *D. strigosa*, *Colpophyllia natans*) and star coral (*Montastrea annularis*, *M. cavernosa*). Species diversity and colony size are generally greater on reefs at leeward or western localities.

Mass mortality events have occurred in elkhorn coral (*A. palmata*), seafan

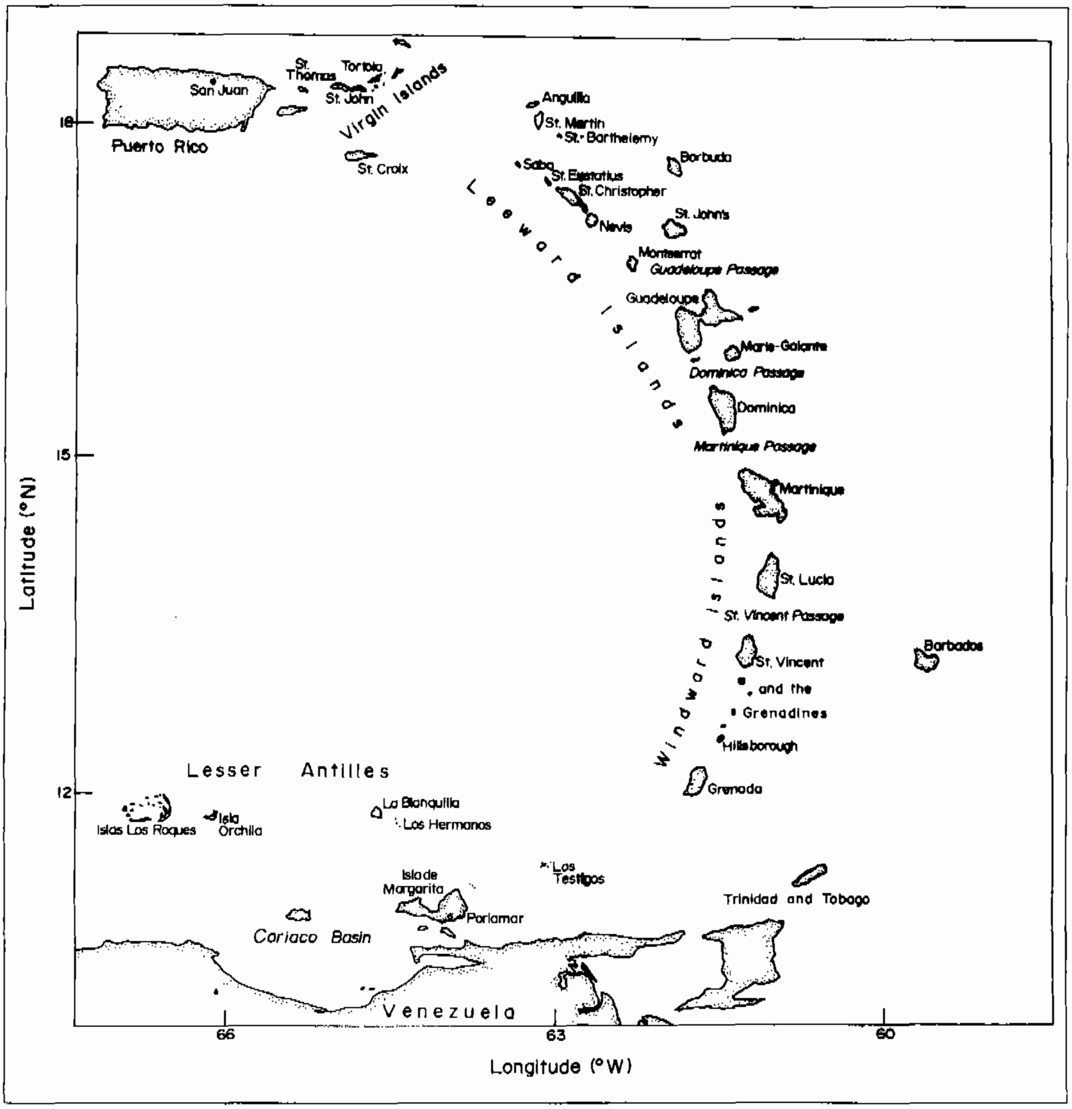

Fig. 1. The Islands of the Eastern Caribbean Sea, showing place names mentioned in the text.

(*Gorgonia ventalina*) and sea urchin (*Diadema antillarum*) populations in the region. Coral mortality, particularly in northern localities, is also associated with coral "bleaching" events.

Degradation and destruction of reefs and their associated marine life, as a result of human activities, are more localized and are of greater significance to the long-term sustainability of the reef resources in the region. Tourism is the only growth sector in the region. Expansion in it results in new and increased impacts on the coastal ecosystems. Ironically, these natural resources constitute a major attraction to visitors.

The impacts of human activities on the coral reef resources in the Eastern Caribbean are diverse. Many reef localities are subjected to direct impacts from tourism such as anchoring, trampling, diver damage and coral collection. Reef fish populations are threatened, or in some areas, overfished by both artisanal and recreational fishing methods. Pollution of the reef environment from shore-based development has resulted in reduction of water quality, particularly with respect to increased turbidity from siltation and nutrient loading from waste disposal (OAS 1988).

In an attempt to control the degradation and destruction common to many Eastern Caribbean reefs, about 40 legally protected marine areas have been designated. However, the actual level of protection in many of these areas is minimal. This is due to a combination of factors, including lack of data on the resource and its environment, ineffective or unimple-mentable laws, lack of management capability with respect to public education, surveillance, research and monitoring; all of which are affected by the lack of sustained funding (OAS 1988; IUCN 1992).

Current Research Needs

The major constraint to the implementation of strategies to reduce or eliminate current threats to the reef resources of the Eastern Caribbean is the shortage of suitably trained personnel in many of the islands. However, there exists a pool of relevant expertise within the region and in the wider Caribbean. While it is unrealistic for each island-state to invest in the development of similar expertise, a realistic solution lies in recognizing the cadre of professionals in the region and sharing the limited expertise in the region through networking.

In terms of the resource, and given the nature and range of impacts on coral reef systems, specific areas of investigation are identified. These are as follows :

- species inventory, habitat mapping and quantitative baseline surveys;
- hydrographic surveys (currents, bathymetry, physical and chemical parameters);
- assessment of management needs;
- identification of critical habitats for commercially important species;
- identification of appropriate mitigatory measures for impacts from shore-based development;
- public education and resource interpretation strategies; and
- forcing factors and sustainability of the resource.

A regional (wider Caribbean and Latin America) project on monitoring productivity at coral reef, seagrass and mangrove sites (CARICOMP) is to begin in 1992.

The Status of Coral Reef Resource Systems and Current Research Needs in East Africa

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MOHAMMED, S.M. 1994. The status of coral reef resource systems and current research needs in East Africa, p. 22-25. *In* J.L. Munro and P.E. Munro (eds.) The management of coral reef resource systems. ICLARM Conf. Proc. 44, 124 p.

This paper examines the status of coral reefs and associated resources in the coastal and marine environments of the East African region. The geographic location of this area is shown in Fig.2. The area falls within the jurisdiction of Tanzania, Kenya, Somalia, Mozambique and the island states of Seychelles, Comoros, Mauritius and La Reunion (France). The East African coast is characterized by a very narrow continental shelf averaging only 15-25 km in width in most areas.

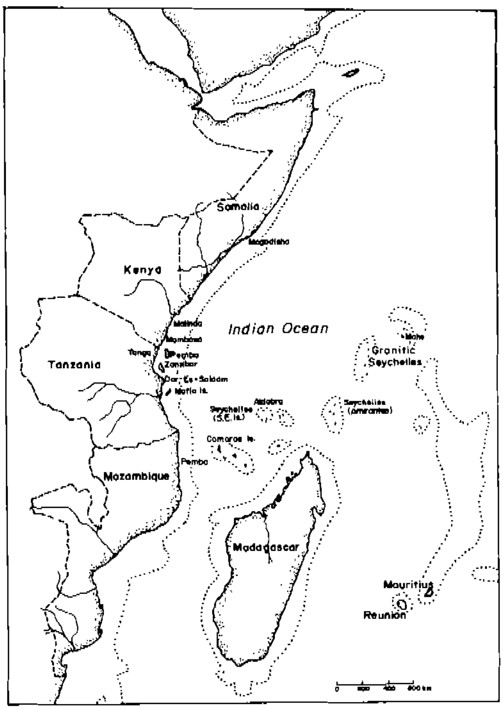

Fig. 2. The East African region, showing place names mentioned in the text.

Occurrence and Extent of Coral Reef Systems

Coral reefs are among the most important habitats of the East African region, with fringing reefs being the most dominant reef formation on the mainland. The island groups, however, display a somewhat wider variety of reefs.

The Somali coast is generally devoid of coral reefs and where corals occur, around Socotra for example, the reefs are poorly developed mainly due to the seasonal cool water upwelling. Some patch reefs occur in the Mogadishu area (IUCN/UNEP 1985).

The reefs of Tanzania are close inshore. Fringing reefs occur all along the coast and are broken only in areas where large rivers discharge into the sea. These reefs are most extensive where the continental shelf broadens around islands such as those of Unguja, Pemba and Mafia (Bwathondi 1980). Patch reefs occur on most parts of the continental shelf away from river mouths.

Coral reefs in Kenya and Mozambique are similarly restricted to areas near the coast. In Mozambique, a fringing reef extends discontinuously from the border with Tanzania south to Inhaca Island, which is the southernmost reef in Africa.

Madagascan reefs are extensive and provide examples of all main reef types. The main reef formations are on the west coast with well-developed fringing reefs along the mainland coast and around offshore islands. On the southwest coast, fringing reefs, barrier reefs and other types of reef formations are well represented (Pichon 1972; IUCN/UNEP 1985).

Three main types of reefs are found around Mauritius. These have been described by Salm (1976) as lagoonal coral patches, peripheral fringing reefs and sheltered fringing reefs. A barrier reef of some 400-600 m wide and 9 km long is about 4 km offshore at Mahebourg.

In the Comoros, fringing reefs are found in the northern islands. An extensive barrier reef (about 140 km long) lies 3-5 km off Mayotte. Fringing reefs are also found adjoining the island (IUCN/UNEP 1984).

The Seychelles have varying reef developments. Many of the granitic islands of the Seychelles, including Mahe and adjacent islands, have no coral reefs and others have only dead patches. By contrast, the islands of Birds and Denis have extensive reef systems and the westerly group of islands, the Aldabras, have spectacular reef formations. In the southeast of the Seychelles Bank, there is a cluster of atolls.

Human and Economic Impacts on Reef Systems

Reefs are a major source of food for the inhabitants of the East African region and of major economic value in terms of commercial exploitation. Table 3 shows details of fish catches in some areas of the region. Artisanal fisheries predominate and as a consequence of the inherently limited mobility of the fishers and the closeness of reefs, fishing activities concentrate near or on coral reefs. This is borne out by catch statistics which show a large percentage of coral reef fish. Overexploitation of reef stocks has occurred in many places.

Overfishing and associated reef degradation has been reported (McClanahan 1987; McClanahan and Muthiga 1988). Overexploitation of fishery resources has also been reported in Tanzania and Mauritius.

The coral reefs of Kenya, Tanzania and Mauritius also suffer damage from destructive fishing practices such as poisoning and use of dynamite (UNEP 1990b). The extensive and continued practice of dynamite fishing has reduced much of the substrate into unconsolidated rubble, thus rendering it unsuitable for recolonization.

Coral reefs also provide other food resources such as crabs, lobsters, bivalves and octopus for home consumption. However, fishers who walk on reefs and tidal flats searching for these have contributed to reef damage.

Table 3. Statistics related to fisheries in the East African region (UNEP 1990b).

Country	Length of coastline (km)	Continental shelf area (km^2)	Mangrove area (km^2)	Fish catch (t)	P. cap. fish consumption ($kg \cdot year^{-1}$)
Comoros	350	900	negative	4,000	12.4
Kenya	500	6,500	587	5,400	3.3
Madagascar	4,000	135,000	3,207	12,000	0.0
Mauritius	200	1,600	negative	5,300	17.7
Mozambique	2,500	120,000	850	31,700	3.5
Seychelles	600	48,000	negative	5,000	82.0
Somalia	3,000	32,500	negative	11,000	0.6
Tanzania	800	30,000	820	49,200	10.0

In many countries of the region, coral reefs are regarded as important in the development of coastal tourism. Tourists are attracted by sandy beaches and coral reefs. However, the destruction of reefs, either directly or through depletion of resources such as shells, has markedly reduced their value in some countries. Furthermore, inadvertent trampling of reefs by tourists, coupled with damage from boats, has been a source of concern.

In many countries of the region, coral and coral sand are mined for construction and lime production purposes. The practice is common in Mafia (Tanzania), Comoros, Mauritius and Madagascar and has caused extensive damage to reefs in the area. The problem is especially severe in the Comoros and Mauritius. Over 500,000 t of coral sand are excavated annually in Mauritius while in the Comoros very few beaches have escaped sand mining (IUCN/UNEP 1985).

In Madagascar, the bivalve *Maleaguing margaritifera* and the gastropods *Turbo marmorata* and *T. imperiales* are collected for export to Europe for button-making. In 1974, over 250 t of shells and corals were exported from Tanzania (IUCN/UNEP 1982). In mainland Tanzania and Kenya, collection of shells and coral has been so extensive that the resources have been severely depleted. Collection has now moved to the offshore islands of Zanzibar and Mafia.

Throughout the region, reefs are under threat from increased sediment loads in the water, caused by destructive agricultural practices. The problem is severe in the Comoros where siltation of reefs has reportedly led to lowering of fish production. Erosion and dredging activities for landfill in Seychelles have affected the coral reefs (IUCN/UNEP 1985). Dredging for port expansion has affected reefs in the Seychelles, Dar es Salaam and Zanzibar. The removal of sand to facilitate ship entry at Moheli in the Comoros has been reported to have exacerbated the problem of sedimentation of reef in that area. Eutrophication is choking reefs in Port Louise (Mauritius), Dar es Salaam and Zanzibar (Tanzania).

Conservation Status

In general, the conservation status of coral reefs in the East African region is good, even though conservation efforts are somewhat inhibited by such problems as lack of clear national policies and institutional responsibilities. The region is in dire need of trained personnel to plan and implement conservation programs for the marine and coastal environments (IUCN/UNEP 1984). Most countries have opted for marine parks and reserves as a means of protecting coral reef areas.

A number of marine areas were designated as reserves in Tanzania in 1981. These include areas around Dar es Salaam, Mafia and Tanga. Reserves have also been proposed for Zanzibar. However, none of these have been implemented and efforts have recently been made to revitalize conservation efforts and to establish functioning marine reserves at Mafia and Zanzibar.

Marine reserves in Mozambique include Bazaruto National Park in the central region and Inhaca Island Marine Reserve in the south.

Several areas on Mahe and on the adjacent smaller islands have been declared as marine protected areas. These include Marine National Park at Saint Anne, Port Launay, Baie Ternay and Curieuse. Aldabra atoll is a World Heritage Site (IUCN/UNEP 1985).

There are five marine parks and reserves in Kenya. These include the 1,600 ha marine national park and the 21,309 ha marine national reserve Malindi/Watamu Marine National Parks and Reserves which were established in 1968 together with a biosphere reserve (19,600 ha) in 1979. Others are Kisite/Mpunguti Marine National Park

(2,300 ha), Kiunga Marine National Reserve (resource reserve and biosphere reserve, 25,000 ha) and Mombasa Marine Park.

Several areas of the coast of Mauritius have been recommended for protected status. These include Blue Bay/Le Chaland, the Flat Island/Gabriel reef complex, Round Island Nature Reserve and Coin de Mire Nature Reserve. Flacq Fishing Reserve and Black River Fishing Reserve also have some reefs under protection.

Research Needs

Coral reef-related research in the East African region has, mostly, been sporadic and conducted on a short-term basis. Moreover, there are few people in the region who are conversant with coral reef research. Consequently, knowledge of the distribution, extent and status of coral reefs is lacking, and their conservation needs are poorly understood.

Given this paucity of information, research needs to concentrate on ecological and biological inventories of coastal ecosystems, including coral reefs. Mapping of critical coastal habitats should also be considered.

In conclusion, coral reef systems and their associated resources are under threat from various sources, and some of the reefs have been destroyed. Given the importance of coral reef resources to the inhabitants of the East African region, there is a strong desire to maintain the economic and ecological viability of the reef systems. This, however, requires a thorough knowledge of the systems, including their associated flora and fauna. This information is lacking in many areas of the region.

The Status of Coral Reef Resource Systems and Current Research Needs in the Maldives

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MANIKU, M.H. 1994. The status of coral reef resource systems and current research needs in the Maldives, p. 25-27. *In* J.L. Munro and P.E. Munro (eds.) The management of coral reef resource systems. ICLARM Conf. Proc. 44, 124 p.

The Maldives is made up of an atoll system on the spine of the Laccadives-Chagos Ridge, which extends southwards from India to the center of the Indian Ocean. There are 23 natural atolls grouped into 19 administrative units, also known as atolls. Being a true atoll system, all islands are sand cays and are devoid of any mountains.

Although the territorial area is over 90,000 km^2 only a relatively small proportion (about 300 km^2) is dry land. Of the 1,302 islands, 201 are inhabited, with a total population of 214,000 (1990). At present, a quarter of the population is based on the 2.5 km^2 capital island, Malé.

Early studies of the Maldive reefs included the notable works of Agassiz, Gardiner and Sewell. Their descriptive work was followed by two major expeditions - the Xarifa Expedition of 1957/58 and the British Expedition to Addu Atoll in 1964.

The Maldivians have always depended on their marine resources for food, building materials and, more recently, foreign exchange earnings. But the reefs have recently achieved major economic significance. The tourist industry has grown at an explosive rate since the early 1970s from a mere 3,000 visitors per year, to over 200,000 visitors per year at present. The tourist industry caters for SCUBA divers attracted by the high diversity and the ideal diving conditions of the Maldive reefs.

Concomitant with population growth and increased wealth from the tourism industry, there has been a steadily increasing demand for building materials in the form of coral nodules and coral sand. Of particular concern is not only the apparent failure of mined reef flats to recover, and the consequent loss of both coral and associated reef resources to the economy, but the loss of potential sea defenses in a period of predicted sea-level rise.

Overfishing

Until the recent past, the local population depended on tuna and tuna-like species, caught with pole-and-line or by trolling, for home consumption as well as for exports. Even today, 80% of the catch is made up of tuna and tuna-like species. However, motorized transport and the demand for exotic seafood by the tourist industry as well as the international markets, have had serious effects on coastal reef-associated resources.

Turtle populations have declined tremendously, particularly hawksbill and green. Existing legislation limits fishing for turtles and a proposal has been submitted to the government to establish a moratorium on all turtle species.

Fishing for bêche-de-mer, which was initiated by the private sector in 1987, started showing a decline in stock. Management measures have now been introduced to reduce overexploitation. The giant clam fishery, which was started in mid-1990, was completely banned in 1991, due to the damage caused to reefs by fishers, as well as the complete depletion of the stock in those areas where they have been fished. Introduction of a culture program is being discussed.

Shark fishing has expanded and the shark populations are also under stress. The catch and average size has declined and an assessment survey is being planned for the second quarter of 1992.

Owing to the lack of an extensive shelf, the reef system in the Maldives is limited, and there is an urgent need to assess the economically important stocks in order to establish management measures.

Coral Mining

This is the most significant threat to reefs as well as islands. In recent years, shallow submerged reefs throughout the Maldives have suffered various degrees of mining. At some of the mined sites, coral cover is only 1% and diversity is greatly reduced.

Coral mining reduces the topographical complexity of the submerged reef thus affecting the numbers and biomass of resident reef stock. This also reduces the active growth of reef flats thus lowering their effectiveness as barriers against erosion and wave action. At present, management measures are being implemented. In addition to mining, there are localized ecological impacts as a result of tourism, sewage outfalls, dredging, reclamation and aquarium fish collection.

Since the islands of the Maldives are sand cays and the two major elements (tourism and fishing) in the economy are marine-based, it is important to identify the limits of the reef environment and the extent of its degradation. Clearly, there are limits to growth. Determining these limits, and managing resources accordingly, is a difficult task when the country has a fast-growing population and its resource base is so sensitive. Thus the fundamental framework for identifying and carrying out coral reef research in the Maldives rests on identifying these limits and managing the resource accordingly.

Recent Initiatives

In 1984, the Ministry of Fisheries established the Marine Research Section (MRS), with five fishery officers. Lacking the personnel necessary to run the section, the approach has been to provide training to those who will make up its future staff. Six people have been sent abroad for higher studies and some are currently studying diverse aspects of reef sciences, while others have returned and are involved in various programs that are underway.

MRS is carrying out research on tuna and reef-associated fisheries, coral reef ecology and degradation, and crown-of-thorns infestation. Experimental remote sensing projects have been made along with a reef fish resources survey. In 1990, a Coral Reef Research Unit (CRRU) was established within MRS, but the agency still lacks a functional staff structure and a well-integrated and coordinated program addressing specific developmental and management needs.

With the establishment of a National Environment Action Plan, which was endorsed by the National Environment Council in 1989, MRS has taken a lead role in establishing a longer-term perspective in its research activities.

Conservation Issues

The greatest threats come from the rapid establishment of the tourist industry, its high growth rate and the introduction of mechanized craft. The high rate of population growth, with an annual rate of increase of 2.8%, is placing nonpelagic marine resources under heavy pressure.

The Status of Coral Reef Resource Systems and Current Research Needs in Thailand

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SUDARA, S. 1994. The status of coral reef resource systems and current research needs in Thailand, p. 28-29. *In* J.L. Munro and P.E. Munro (eds.) The management of coral reef resource systems. ICLARM Conf. Proc. 44, 124 p.

Knowledge of the status of coral reef resource systems in Thailand is based mainly on the Living Coastal Resources Project which has been supported since 1983 under the ASEAN-Australia Economic Cooperative Program on Marine Science. The coastline is composed of the eastern, northern and western parts of Thailand and the Andaman coast (Fig. 3).

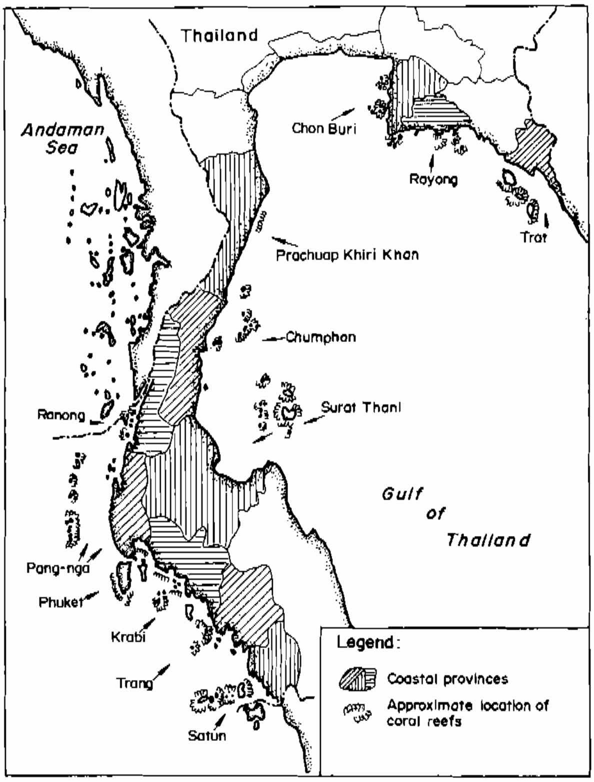

Fig. 3. Reef distribution in Thailand, showing place names mentioned in the text.

In the northern part of the Gulf of Thailand, the corals do not form substantive reefs. This results from the freshwater runoff from the mainland, the high volume of sediment transported into the area or the tremendous abundance of sea urchins, which graze on the coral heads. The coral communities within the Pattaya area have deteriorated due to pressure from tourism. Efforts to convince tourists to preserve the natural conditions have been launched. Some awareness activities have been developed, such as picking up rubbish from underwater by local students and volunteer divers. Further south of the area, at Sataheep, which is a naval restricted area, coverage of live corals is much better. However, some degree of anthropogenic effects can be observed.

Coral reefs are well-developed on the east coast of the Gulf of Thailand particularly at Trat. The coral reef at Rayong is in a fair condition while that of Trat is good. However, tourism pressure in this area is increasing considerably.

On the west coast of the Gulf of Thailand, coral reefs are to be found from Prachup Khiri Khan to Surat Thani. Conditions are variable and most coral reefs are in fair to good condition. A few coral reefs are still very good. In addition to illegal dynamite fishing, tourism has increased remarkably. At some islands, such as Ko Tao, the deterioration of coral reefs as a result of tourism was found to be about 20% annually, and it is expected that tourist activities in this area may increase.

On the Andaman Coast, the coral reefs of Surin Islands, Similan Islands and the coastal islands of Krabi Province are still in good condition. The coral reefs of Phi Phi Islands and Adang Rawi Islands are in fair and poor conditions, respectively, and those of Phuket Island are in worst condition. The coral reefs appear to recover gradually, judging from numerous young coral colonies growing on the destroyed reefs. The major causes of coral reef degradation are *Acanthaster planci* outbreaks, storm damage, dynamite blasting, damage from anchors and recreational activities, and sedimentation.

Data from coral reef surveys and monitoring by the Living Coastal Resources Project in Thailand were used to prepare a management plan which has been accepted by the Cabinet. Sites were categorized as preservation, conservation or development, according to the conditions of the coral reefs. A national marine park was also proposed.

A mooring buoy project to reduce anchor damage on the coral reefs has commenced in certain areas such as Chumphon Province, Koh Tan and Ko Tao. The central government has provided funds for constructing anchor buoys to conserve the corals of Surat Thani Province.

The current research needs for coral reefs in Thai waters are focused on the replenishment of corals and other coral reef populations. To achieve this goal, studies should be carried out on the following:

- the population biology of certain corals and other components of the reef community, such as fishes, including studies of sexual reproduction of corals, patterns of coral recruitment, growth and survival rates of the most important corals, including juvenile corals, and coral fragments;
- the roles of macroalgae on coral communities;
- long-term dynamics of coral reef communities, including recovery rates after natural and anthropogenic disturbances, and techniques for coral transplantation;
- calcium carbonate budget of selected coral communities;
- role of seagrass and soft bottom communities in coral reefs; and
- multispecies modeling of coral reefs and applications for conservation and management.

The Status of Coral Reef Resource Systems and Current Research Needs in Indonesia

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SUHARSONO. 1994. The status of coral reef resource systems and current research needs in Indonesia, p. 30-32. *In* J.L. Munro and P.E. Munro (eds.) The management of coral reef resource systems. ICLARM Conf. Proc. 44, 124 p.

Indonesia is one of the largest archipelagic states in terms of area, natural resources and population. Total Indonesian territory amounts to an area of 8.5 million km^2, of which 75% is covered by sea, harboring some 17,000 islands with an extensive coastline of approximately 81,000 km. About 87% of the total territorial waters are sheltered by islands, while only 13% face the open oceans. Recent population statistics indicate that the population exceeds 186 million.

Coral reefs and associated habitats are important resources to support traditional lifestyles in communities throughout the Indonesian archipelago. The rich and diversified resources include fishes, crustaceans, molluscs and seaweeds. The shallow coastal areas, such as mangrove forests, lagoons and coral reefs, are the most productive habitats, contributing to the protection and stabilization of the vulnerable coastline. Our challenge is to use these marine resources fully and wisely in the coming decades to meet the increasing demand for food and raw materials, and to maintain the environmental quality of the country as a whole.

Reef Condition

The extensive coastline of the 17,000 islands of Indonesia is mostly protected by coral reefs and support a diversity of reef types. Five structural types of coral reefs are present: fringing reefs, barrier reefs, atolls, apron reefs and patch reefs. These reefs have highly diverse assemblages of reef fauna. Approximately 350 scleractinian coral species belonging to 75 genera have been recorded (Best et al. 1989). The three most important reef-building coral genera in Indonesia are *Porites, Acropora* and *Montipora*. Branching *Acropora* mostly occupy the upper reef slope, massive and branching *Porites* occur in the outer reef flat, and branching *Montipora* occupy the reef flat. Calcareous algae, soft corals and gorgonians provide a significant contribution to reef growth and development. In assessing the present status of coral reefs in Indonesia, transect line methods were used. In this paper, only the percentage of living coral cover is presented. Table 4 and Fig. 4 show the living coral cover from 233 stations, including 22 different areas; less than 6% of the reef areas were in excellent condition, 24.5% in good condition, 29.2% in fair condition and 41.2% in poor condition. To manage the coral reef resource systems and to avoid further degradation, there is an urgent need for research and monitoring.

Problems

Coral reef communities have a remarkable natural resilience with respect to natural perturbations such as tropical storms and cyclones. On the other hand, coral reefs are sometimes very sensitive to environmental impacts associated with anthropogenic activities and produce secondary effects which are difficult to predict. Major sources of coral reef degradation in Indonesia can be grouped into natural factors and human impacts.

Table 4. Status of coral reefs in Indonesia.

No.	Location	No. of stations	Excellent cover	Good cover	Fair cover	Poor cover
	West Indonesia					
1.	Sunda Strait	16	0	1	6	9
2.	Seribu Islands	40	0	4	8	28
3.	Belitung Islands	7	0	2	3	2
4.	Natuna Islands*	11	2	5	3	1
5.	Nusakambangan Islands	3	0	0	1	2
6.	Karimun Jawa Islands	16	2	4	6	4
7.	Bali Island	14	0	0	2	12
8.	Kangean Islands*	7	0	4	3	0
9.	West Lombok*	2	0	1	0	1
	Central Indonesia					
10.	Sumbawa Islands	3	0	3	0	0
11.	Komodo Islands	6	2	2	1	1
12.	Selayar Islands	5	0	2	3	0
13.	Taka Bone Rate Islands	5	1	0	4	0
14.	Tukang Besi Islands	5	0	0	3	2
15.	Banggai Islands	14	1	6	5	2
	East Indonesia					
16.	Tobelo Islands	14	0	4	2	8
17.	Morotai Islands	14	0	0	1	13
18.	Ambon Bay*	10	1	5	2	2
19.	West Seram*	4	0	3	1	0
20.	Banda Islands	7	1	5	1	0
21.	Kai Islands*	17	2	3	7	5
22.	Padaido Islands	13	0	3	6	4
	Total	233	12	57	68	96
	Percentage		5.1	24.5	29.2	41.2

Excellent - living coral cover 75 - 100%.
Good - living coral cover 50 - 75%.
Fair - living coral cover 25 - 50%.
Poor - living coral cover 0 - 25%.
* - data were not taken by the author.

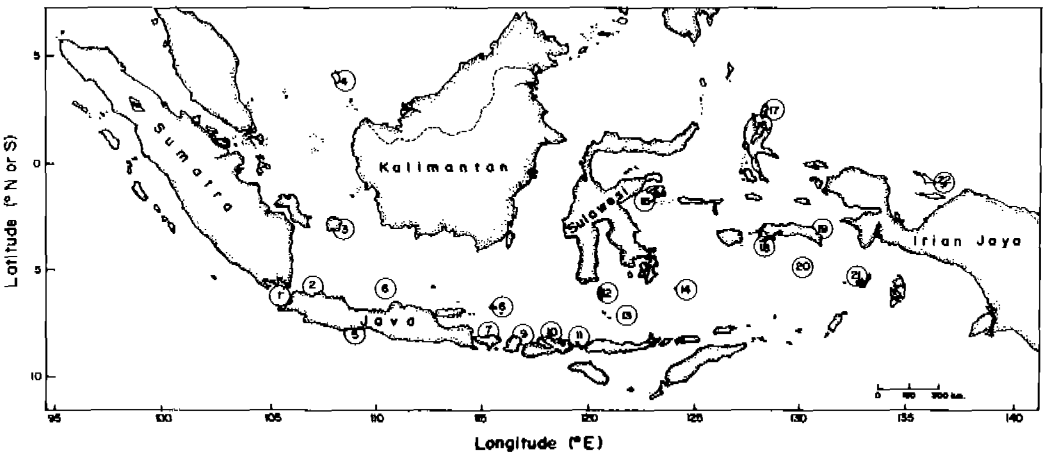

Fig. 4. Reef areas in Indonesia assessed for living coral cover (see Table 4 for place names).

Conditions in Indonesia seem to be conducive to ecological specialization of marine forms. Indonesia's relatively enclosed seas are not subject to physical catastrophes such as hurricanes and tropical storms. However, in 1983, seawater temperature surrounding Seribu Islands increased by 2-4°C above ambient for three months. As a result, corals bleached and subsequently died. The living coral cover, number of species and number of colonies were drastically reduced by 70-90% (Suharsono 1990).

The major forms of human impacts upon coral reefs include sedimentation, coral mining, discharge of industrial wastes, sewage discharge, destructive fishing practices, collection of corals and shells, collection of aquarium fishes, tourism and recreational activities, and oil pollution.

Many coral reefs in Indonesia are situated in or near intensive economic development areas. For example, Seribu Islands are situated offshore of Jakarta, which is a heavily populated and industrialized city. Due to increasing population and rapid development, the coral reefs have come under heavy pressure. High sediment loads of the Citarum, Cisadane and Angke Rivers not only bring sediment but also industrial wastes and sewage discharge. Heavy sediment loads combined with sewage pollution may be lethal or inhibit growth and decrease coral cover. Some of the islands in the Seribu Islands were subjected to dredging of coral reef blocks and sand mining, primarily for the construction of the runway of the Soekarno-Hatta Airport. Tar balls have been noted in some islands of the Seribu Islands (Sukardjo and Toro 1989).

Most destructive fishing practices are confined to the shallow water areas. Consequently, coral reefs are affected. Destructive fishing practices, such as dynamiting, muro-ami and the use of chemicals have caused serious damage to coral reefs. The muro-ami technique is often practised by fishers of the Seribu Islands and Riau. Swimmers drive fish into nets by banging the bottom subtrate with metal rings to scare the fish from their hiding places. Dynamiting is practised throughout Indonesian seas. Cyanide is often used to catch ornamental fishes in Seribu Islands, Bali Island, Biak and Ambon Island.

Coral reefs are also very valuable as tourist attractions and in generating foreign exchange. However, tourist activities such as walking over the reef flat and dropping and hauling anchors damage the corals. Construction of commercial and recreational facilities, such as jetties, sea wall defences and tourist resorts alter current patterns and sediment distribution.

Research Needs

Specific factors that cause reef degradation are not well-known. Comprehensive long-term studies incorporating field surveys, field experiments and laboratory experiments are needed to understand the relative importance of sedimentation, industrial pollution and sewage, and also to assess their additive, antagonistic and synergistic effects.

Comparative studies on the economic valuation of the resources are needed. These studies should include estimates of the total value of marketable resources such as fishes, invertebrates and algae, and their indirect value for recreation, or the values of reefs as marine reserves and their contribution to adjacent fisheries, as well as the net economic gains or losses through other human uses.

Research is needed to evaluate the physical and ecological impacts of recreational activities on coastal and marine areas and to select the critical abiotic parameters, as well as the most sensitive species for monitoring reef ecosystems.

The Status of Coral Reef Resource Systems and Current Research Needs in French Polynesia

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Political Status

French Polynesia has operated under a "Statut d'Autonomie Interne" since 1984, with its own Leader of Government, Ministers and Assembly. The lagoons, reefs and 200 mile exclusive economic zone are under the control of the Polynesian Government, the budget of which depends exclusively on the local territory budget. The land policy is under the control of the mayor of every island. Funds for land development come from France.

Given this background, it will be recognized that there are sometimes problems related to who is responsible for what. For example, in order to reduce the siltation inside the lagoon we need to discuss the situation both with the local government (Ministry of the Sea) and with the mayors of the islands, as this concerns the land development of the island.

The territory has a population of 189,000, of which 131,000 reside in Tahiti, including 95,000 in the capital city, Papeete. The total area of the territory is 5,500,000 km^2, of which the land area is only 3,521 km^2. Tourist arrivals total around 140,000 per year.

Major Characteristics of the Coral Reefs

There are at least four reasons why the coral reefs of French Polynesia can provide the international scientific community with appealing opportunities for research.

- The 120 islands that make up French Polynesia cover an area of ocean the size of Europe. The islands include examples at all stages of geomorphological development, from volcanic islands without associated reefs, through high islands with fringing reefs and high islands with barrier reefs, to atolls.
- The reefs surrounding most islands are less than 2 km wide. This allows easy access from the shore.
- French Polynesia is isolated in the eastern part of the Indo-Pacific biogeographic province. This means that species diversity of all coral reef taxa is reduced.
- Within each taxon, only a few species are abundant. It may be possible to estimate the biomass and productivity of the whole

Table 5. Biological resources of coral reefs in French Polynesia and the organizations involved.

	Species	Catch (t)	Organization[a]
Lagoon fisheries	Fish	4,600	EPHE
	Crustaceans	10	EVAAM
	Molluscs	100	IFREMER
	Pearl	0.5	LESE
Aquaculture	Crustaceans	40	EVAAM
	Mussels	5	IFREMER

[a]For meanings of acronyms, see p. 35.

Table 6. Annual exports of coral reef resources from French Polynesia.

	Weight (t)	Value (US$000)
Fish	2,752	5,123
Shells	150	1,100
Pearl	0.5	25,000
Others: crustaceans molluscs, corals, etc.	0.5	2
Total	2,903	31,225

group by studying the population dynamics of these dominant species.

Reef Resources

All the data given in this section and in Tables 5 and 6 relate to the year 1988.

It is very difficult to collect statistical data for fishing in French Polynesia because the country is so vast and every Polynesian is a potential fisher. Additionally the local market is poorly organized and sales of fish can take place in any part of the country.

In the lagoon fisheries, the fish are mainly caught by traps, lines, spear guns and nets. About 2,400 t of lagoon fish reach the Tahiti market, of which 69% come from the Tuamotus. The Tuamotu fisheries provide statistical data concerning the arrival of fish transport boats in Papeete, the communal markets, the fishers inside the atolls and the cooperatives in the atolls. However, all these data are very imprecise. The best known fishery at this time is the one on Tikehau atoll (Caillart and Morize 1986; Morize and Caillart 1988).

Crustaceans include lobsters, crabs and mantis shrimp. There is no local market for penaeid shrimp in French Polynesia.

Mother-of-pearl and giant clam (99 t), and lately, *Trochus* and *Turbo* molluscs are fished for jewelry, buttons and the tourist industry. They are exported to Japan, Taiwan and Europe. *Trochus* were introduced to the Tahitian reefs in 1957 and commercial fishing began in 1971. The initial stock was estimated at more than 2,500 t. Fishing is regulated by the three-year revolving reserves, and is also subject to an annual quota system.

Pearl farming started in French Polynesia in 1960 and almost 2,000 people now undertake it. In 1988, the cooperative collected 31,462 pearls with a total value of US$3 million. The pearl industry became the major export industry of the

PART III: PHYSICAL FACTORS INFLUENCING REEFS

Climate Variations and Coral Reefs

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The notion that coral reefs are controlled by climate is more implicit than explicit in the biological literature covering coral reefs, yet the link between climate and reefs is a central aspect of that literature. Reefs are formed within sharply defined climatic limits and reef morphology and reef communities may be modulated by climatic factors. Climate is the average expectation of weather. However, studies of reef response to climate have been mostly restricted to infrequent and destructive events, such as cyclones, unusually high rainfall and unusually high terrestrial runoff. The coral reef literature does not embrace the idea that reefs, reef communities and reef environments must be constantly changing because climate is not static—climate varies on all time scales. Global and regional climate has varied in the past, is varying now and will vary in the future.

The Great Barrier Reef (GBR) extends on a north-south axis for nearly 2,000 km. It encompasses a range of mean meteorological and oceanographic conditions. Superimposed on these mean conditions are seasonal cycles of differing magnitudes between regions, in all biologically important climatic factors. There are also interannual and longer time-scale variations. In particular, the GBR lies in the western Pacific and is strongly influenced by the global El Niño-Southern Oscillation. This brings marked variations in ocean-atmosphere conditions on a two to ten year time-scale. Description and understanding of temporal and geographic climatic variations in the GBR are necessary to understanding growth, Territory in 1983. The allowance of areas for pearl farming is decided by the government. Satellite imaging is used by the authorities and the research organization Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER) to follow the evolution of these areas.

Other Resources

Every year, 140,000 t of sand and rubble are extracted from the seabed for the development of the islands. These extractions do not take place without causing environmental problems.

In 1976, phosphates were discovered inside the lagoon of Mataiva atoll. The deposit has been estimated at 12 million tons, with a possible exploitation time of between 10 and 15 years. Polymetallic nodules are not yet collected.

Present Research

In French Polynesia, two Territorial organizations are in charge of the marine resources. The Service de la Mer et de l'Aquaculture (SMA) is involved in the management of the marine heritage, and the Etablissement pour la Valorisation des Activités Aquacoles et Maritimes (EVAAM) is involved in scientific and applied research. Another organization, Institut de Recherche Louis Malardé (IRLM) is concerned essentially with the health of the inhabitants (e.g., ichthyosarcotoxisms).

Several French organizations cooperate with these territorial organizations on applied and fundamental research programs. These are the Ecole Pratique des Hautes Etudes; Centre de l'Environnement de Moorea (EPHE); Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER); Laboratoire d'Etudes en Sciences de l'Environnement, Commissariatà l'Emergoe Atomique (LESE); Institut Français de Recherche Scientifique pour le Développement en Coopération (ORSTOM) and Université Française du Pacifique.

A research program, directed by EVAAM and with Territory and French funds, is in place for pearl oysters. This program is aimed at understanding the cause of the high mortality rate of oysters.

Research Needs

While international scientific help is always welcome, Territorial and French Institutes have been established to develop a comprehensive understanding of the reef resource systems in French Polynesia. The Territory offices need to be persuaded that the long-term collection of statistical data is the best way to manage, protect and increase the resources.

maintenance and, especially, change in reefs and reef communities. Climatic variations are certainly important in attempts to identify unnatural change amidst the background of natural variability. Reefs help in this regard because they are themselves a record of past environmental conditions.

A research group at the Australian Institute of Marine Science (AIMS) is working towards a detailed understanding of density banding in coral skeletons through work with *Porites* spp. from the GBR. Annual density banding is a characteristic of massive, reef-building corals. Such banding is displayed by X-radiographs of slices cut from a skeletal growth axis. Annual growth is about 10 mm and some colonies may reach several meters in height. These "natural archives" may, therefore, provide a history of coral growth variations extending over several centuries and also represent a source of proxy environmental records for reef environments. Instrumental records of climate variations cover little more than 100 years and detailed observations of reef environments cover little more than 20 years. The records contained in growth bands of massive coral colonies, therefore, provide a means to both retrospectively monitor coral growth and also to extend the global proxy climate database into shallow water tropical oceans.

Impact of Surface Waves on Physical Degradation of Coral Reefs

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MASSEL, S.R 1994. Impact of surface waves on physical degradation of coral reefs, p. 37-39. *In* J.L. Munro and P.E. Munro (eds.) The management of coral reef resource systems. ICLARM Conf. Proc. 44, 124 p.

Although ultimately the morphologic and biologic variability of reefs involves complicated interactions between chemical, biological and physical parameters, wave energy has long been recognized as one of the most important controls of coral growth and subsequent reef development. Wave energy and water turbulence associated with wave motion is responsible for reef zonation and segregation of organisms. Waves which shoal over the reef slope and are transformed on the reef platform impose forces on the organisms that inhabit the zone of wave-swept reef. Moreover, water movement is essential for the development and maintenance of a healthy reef ecosystem for replenishment of the supply of food and oxygen, as well as for removing the products of metabolism (Denny 1988).

Waves in Deep Water and on the Reef Slope

Wind waves are considered to be surface gravity waves which are caused by storm winds or cyclones and propagate under the restoring force of gravity. As waves travel into shallower water on the reef slope, their dynamics are progressively more nonlinear and dissipative. Wave energy is partly reflected from the reef and partly transmitted over the reef flat to the reef lagoon. Part of the energy is dissipated due to wave breaking and bottom friction (Massel 1989).

From a wave dynamics point of view, particular reefs can be considered as isolated underwater or surface-piercing structures, or as mutually sheltering matrices of underwater structures. The local slopes in the vicinity of the coral reefs are very steep in some locations. Therefore, the wave refraction and diffraction effects are not negligible. Special methods are needed to evaluate the general procedure of calculation in which the steep slope and bottom curvature, as well as the energy dissipation due to breaking, are taken into account (Massel, in press).

Wave Forces on Massive Corals

The physical degradation of coral reefs is mostly the result of wave impact on corals. The wave-swept organisms (for example coral heads of the genus *Porites*) are subject to so-called inertia forces due to acceleration of water flow, drag forces due to flow velocity, and lift forces also due to wave velocity. While the inertia component is linear in the local wave height, H, the drag and lift components are quadratic in H (Dean and Dalrymple 1984).

The probability of dislodgement of a coral head of a given characteristic dimension is a function of the limiting wave height and a return period of storm (cyclone) events at a given location.

Turbulence and Mixing

Many aspects of coral biology require the movement of water. Planktonic larvae depend on water flow to disperse any substantial distance. Aquatic organisms need water movement to carry away their waste and to bring in new supplies of oxygen (Denny 1988). Unfortunately, water movements intensify the contamination of coral by pollutants.

Water flow is seldom laminar. Waves are one of the dominant mechanisms generating turbulence and mixing. It is trivial to say that turbulent mixing is important for every aspect of biology that relies on transport by fluids (Csanady 1973). Wave motion is periodic motion, with horizontal and vertical components of orbital velocity. It produces extra advection and mixing in the water column.

The wave-dominated bottom boundary layer on the reef slopes is usually turbulent. The presence of organisms on the substratum contributes to the production of turbulence. The intensity of turbulence is greatest near the top of the substratum. Moreover, on steep slopes, the turbulence associated with breaking reaches the bottom too. Thus organisms living on steep reef slopes are very likely to experience turbulent flow and the consequent large acceleration and forces with every breaking wave.

Moreover, waves breaking on the reef slope and their overtopping produces extra water mass flux towards the reef flat and reef lagoon. During wave breaking, water masses absorb a lot of gases and other substances which are transported to all reef areas. Although the traditional approach to turbulence gives a good prediction in many circumstances, the accurate measurements of water flow and a new theoretical approach (e.g., coherent turbulent structures) are needed for better understanding of the biological effects of turbulence.

Towards an Understanding of the Pattern of Nutrient Delivery from Tropical Rivers to the Coastal Zone

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The question of downstream effects of agriculture, leading to elevated levels of nutrients in river runoff which may impact on the Great Barrier Reef (GBR), is presently the subject of much controversy (Kinsey 1990; Bell 1991; Walker 1991). The best studied example is that of the effects of sewage input on Kaneohe Bay, Hawaii. The present state of our knowledge is inadequate with respect to the overall inputs of nutrients to the coastal shelf and the extent to which the inputs are determined by human activities.

The Biological Oceanography group at AIMS is sampling nutrient and suspended sediment concentrations in the rivers flowing into the central GBR province, from the Burdekin River north to the Barron River. Our area of interest is to be extended to include the Fitzroy River catchment to the south. The catchments include the "wet tropics", an area with Australia's highest rainfall and with diverse land uses, including virgin rainforest, sugarcane culture and dryland cattle grazing. The water samples are analyzed for dissolved inorganic nutrient species (NH_4, NO_2, NO_3, PO_4, $Si(OH)_4$), dissolved organics (DON, DOP) and particulate forms (PN, PP). The objective of our sampling program is to develop empirical discharge-nutrient flux models for these rivers in order to quantify nutrient input to the central and southern GBR.

Preliminary sampling of rivers feeding into the central GBR commenced four years ago, with assistance from a number of governmental agencies. Intensive sampling has been carried out in the South Johnstone and the Herbert Rivers over a two-year period. This period covered floods following the tropical cyclones Ivor (March

1990) and Joy (December 1990). Data, mainly from the South Johnstone River, are used here to illustrate some of the issues in estimating nutrient fluxes. The South Johnstone River is relatively short, but its small catchment is one of the wettest and the coastal plain is extensively farmed with sugarcane. River flow in the South Johnstone is fairly regular, with rainfall occurring throughout the year.

Relatively poor relationships were found between the concentrations of dissolved nutrients (for example, NO_3, PO_4, DON and DOP) and instantaneous flow rate, since these species are variously diluted during high flow periods. However, a high correlation was seen between concentrations of particle-associated nitrogen (PN) and phosphorus (PP) and instantaneous flow rate. This is not surprising, since suspended sediment loads increase with flow, reflecting surface flow erosion and mobilization of stream bed sediments during episodes of high flow.

The relative importance of the different forms of nitrogen varied between the wet and dry seasons. The concentration of dissolved inorganic nitrogen species, chiefly NO_3, was highest in the wet season, decreasing to quite low levels at the end of the 1990 dry season. By contrast, DON concentrations were diluted by high flow episodes, increasing to moderate levels through much of the dry season. Concentrations of particulate N exhibited peaks coinciding with peaks in river flow, at other times maintaining a relatively constant level. Phosphorus species were dominated by particulate P in both wet seasons. Maximum concentrations of PO_4 were also observed during the wet seasons, though, as with NO_3, dilution was seen at some peaks of river flow. DOP concentrations showed a similar seasonality to DON, diluting through the wet season, but recovering to relatively constant, higher levels during the dry season.

Differences were also observed within each wet season. A trend of higher concentrations at the beginning of the wet period was seen for the dissolved inorganic and particulate forms of both N and P. This was particularly evident in the 1990/91 wet season, characterized by a series of similar volume peaks of river flow. Such a trend suggests progressive exhaustion of these nutrients through the course of the wet period. Very high concentrations of NO_3 were observed during the large flow event from rainfall associated with cyclone Joy, immediately following very low concentrations at the end of the dry season. This flood was therefore the first flush of the wet season and the high concentrations likely resulted from mobilization of NO_3 stored in sediment and terrestrial pools.

Since almost all export of nutrients from tropical rivers occurs during brief episodes of high river flow, the relative concentrations of different forms during these flood events are of crucial importance in determining flux rates. The high levels of particle-associated nutrients during high flow periods imply that most N and P is exported as particulate form. This appears to be especially true for phosphorus, for which only 10% is present as PO_4 in high flow events in the South Johnstone River, compared to 30% during low flow periods. Such dominance of particle-P is even greater in other, longer rivers, such as the Fitzroy, Burdekin, Herbert and Barron, which carry considerably higher suspended sediment loads.

However, the distribution patterns of dissolved inorganic N and P also vary longitudinally in rivers. Data from the Herbert River show that the concentration of NO_3 progressively increases downstream, due to leaching and mobilization, until the saltwater intrusion point. Below this point, a steady decline of NO_3 is observed toward the river mouth due to dilution with seawater. The pattern for PO_4 is quite different, with sometimes higher levels observed upstream (for example in the Barron River), than in downstream freshwater sections, followed by a sharp increase again at the saltwater intrusion point. This pattern can be explained by progressive strong absorption of PO_4 as particles of the river water travel downstream, until mixing with seawater results in pH changes and its subsequent release from particles.

The implication of this behavior is that considerably more dissolved PO_4 is exported during floods than is estimated by typical sampling in freshwater sections. Evidence for this contention is given by measurements of the Fitzroy River flood plume of January 1991, in which a third to one-half of the P exported was in the form of dissolved PO_4 (Brodie and Mitchell, in press). While no samples were taken from freshwater sections of the Fitzroy River, its catchment is somewhat similar to that of the Burdekin River in which particle-P dominates fresh, river floodwater.

Another major problem in estimating nutrient flux rates is the very high month-to-month and year-to-year variability in discharge from North Queensland rivers, particularly those with a considerable area of mostly dry land catchment, such as the Fitzroy and Burdekin Rivers. Other problems include the difficulties in estimating streamflow and groundwater discharge below gauging points and that of sediment bedload transport. These two omissions may together account for substantial underestimation of nutrient loads. Also, while it is becoming clear that episodic floods and cyclones are the major input events for the coastal shelf, it is still unclear how such events impact in the long term on the system, as the nutrients and sediments are recycled and redistributed.

Coral Reef Islands in a Period of Global Sea Level Rise

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Concerns about global changes produced by the greenhouse effect during the 1980s quickly focused attention on the effects of sea level rise on particularly vulnerable coastal areas. Statements were made by those who knew very little about coral reef processes, which suggested that some islander nations may disappear altogether, e.g.:

> It is estimated that a 60 cm rise around the Maldives in the Indian Ocean would cover these coral islands and displace 177,000 people. (Falk and Brownlow 1989)

The popular press were quick to take up this doomsday theme. For example, the *Pacific Islands Monthly* had as a feature article a special report entitled "The greenhouse effect - where have all the islands gone?" The report argued that "atoll states are the most helpless of all nations in face of the greenhouse effect" and concluded with the forecast, "some of the most recently populated islands in the world may be depopulated ... and some of its most recently formed islands may disappear forever" [As reported in Roy and Connell (1989) and McLean (1989)]. Not surprisingly there was an immediate political response. For example:

> If the greenhouse effect raises sea levels by 1 m, it will virtually do away with Kiribati ... if what the scientists say now is going to be true, in 50 or 60 years my country will not be there. (President I. Tabai, Kiribati, September 1988)

> The environmental change caused by industrial progress in the developed world may slowly drown this unique paradise in its entirety. (President M. Gayoom, Maldive Islands, 1987)

Subsequently, consultants were employed to assess what measures would be required to save these nations. For example, the Delft Hydraulics Laboratory estimated that 34.3% of the national economy of the Maldives would be required to give adequate protection and 18.8% for Kiribati, 14.4% for Tuvalu and 11.1% for Tokelau (UNEP 1990a).

Unfortunately, many of these reports did not examine the processes involved in the formation of coral islands, two types of which, with completely different origins are recognized:

- coral cays, usually formed on the leeside of reefs and dominated by sand-size sediments - these can be found on all types of reef, including fringing reefs; and
- motus, shingle-based islands found on the windward margins of reefs and most particularly around the outer margins of many atolls.

A process approach to an assessment of the hazards suggests that existence of reef islands will not be the problem within the next century, but that other environmental effects of global change will need consideration and planning. Paradoxically, some of the effects may be beneficial.

Wave Action on Reefs - the Formation of Coral Cays

Hopley and Kinsey (1988) suggest that a rise in sea level in the period of 50-100 years would result in an increase of sediment supply to coral reef cays. They suggest that at the present time there was an overabundance of sediments on reef flats of the Great Barrier Reef (but also elsewhere in the world) which have been at sea level for a period of more than 5,000 years. The major problem is one of transporting the sediment to the cay, a process which can take place only at high tide when there is sufficient wave power passing across the reef flat. They further suggest that a small rise in sea level would see greater productivity of reef flat areas and therefore the potential to supply even more sediment towards the nodal point of wave refraction (see also Kinsey and Hopley 1991 for quantitative estimates). Little work has been carried out on the processes of sediment transport on reef tops, particularly in association with coral cays, but what little there is (e.g., Hopley 1981, 1982; Flood 1986; Gourlay 1990) supports this contention. Studies have shown that even under tradewind conditions of up to 25 knots, waves across reef flats of the Great Barrier Reef may be insufficient to move sediment at low tide. Sediment movement is therefore restricted to less than 50% of the time when water levels are sufficiently deep over the reef flat to allow waves of significant size, and therefore transportational ability, to pass over the reef. This is particularly prominent in areas of significant tidal range, such as the Great Barrier Reef, but is also a factor on mid-oceanic reefs where tidal range is negligible. Many of these reefs have developed reef flats at sea levels higher than present (e.g., Hopley 1987; Nunn 1991). Thus, a rise in sea level of up to 0.5 m may unlock reef flat sediments for longer periods and allow them to be moved towards the coral cay.

Most published observations on both sediment movement on reefs and wave action support this conclusion. For example, Hopley (1982) indicates that the time of maximum sediment movement on reefs of the Great Barrier Reef varies according to tide height, wave height and location on the reef flat. Under normal winter conditions of southeasterly winds of approximately 20 knots, the period of maximum turbidity on reef flats close to coral cays occurred when tidal levels were either flooding to, or ebbing from, a high water position with waves breaking close to the cay. As maximum sediment movement takes place just seaward of the wave breakpoint (King 1972), the point of breaking of the transmitted wave on the reef flat becomes a critical factor in determining sediment mobility. Under the 20 knot southeasterly conditions experienced on the Great Barrier Reef, with deep water wave heights of about 2 m, high water waves break directly on the cay beach, but at lower tidal levels the point of breaking is more distant from the cay. Maximum sediment movement thus occurs in a zone on the reef flat that oscillates about the cay according to the tide height and the height of the reformed waves crossing the reef flat.

As waves move into shallow water, towards their break point, there is an increase in discrepancy between the forward orbital motion under wave crests and the slower return flow beneath troughs. The forward movement is short in duration, but high in velocity and may lead to the selective movement of coarser sediments in the direction of wave propagation, i.e., towards the cay, while finer materials that may also be moved by the slower return currents will readily move almost an equal distance in both directions. For movement of sediment of any particular size, the forward orbital velocity must exceed the required entrainment velocity. Bottom velocity has been shown to be a function of wave height and water depth (Inman and Nassu 1956) and thus on a reef flat will vary at different stages of the tide, hence producing the periodicity in sediment movement.

A higher sea level will thus produce water depths which will cause greater movement of sediment towards a coral cay. Buildup of the cay itself will depend on the nature of the waves which break on the cay beach. The height of the constructed beachberm is dependent upon wave runup. Numerous studies (e.g., CERC 1984) show that runup height varies with the wave height, wave steepness, beach slope, shape of the beach profile, and roughness and permeability of the beach material. Gourlay and Hacker (1991), working on Raine Island on the northern Great

Barrier Reef, found that the relative wave runup height varied in a consistent manner with the ratio of the breaker height to water depth over the reef flat, consistent with the fact that the wave heights are limited by shallow water breaking conditions over the reef flat. Gourlay and Hacker (1991) indicate that the height of the beachberm is determined by the runup height of the dominant wave action. This could be expected to occur at the highest spring tides. Although a beachberm elevation of 4 m could be built by small flat waves of 0.5 m height breaking directly onto the beach at the tide level as low as 2.3 m, they also showed that similar heights could be attained by the maximum breaking waves of 1.6 m, at an extreme tide level of 3 m. Although further work is required, these data suggest that a small rise in sea level without any responding buildup of reef flat level, would result in the attainment of greater berm heights under most weather conditions, i.e., a buildup of the island by an amount which could exceed the amount of increase in water level. For example, in the case of Raine Island quoted above, Gourlay and Hacker (1991) suggest that with a 0.6 m-rise in sea level, the larger 1.6 m-waves would increase berm height by a further 0.8 m and 0.5 m-waves would increase berm height by 1.2 m, i.e., to 4.8 m and 5.2 m, respectively.

Atoll Motus

The coarse detrital materials of atoll motus cannot be moved by normal wind-generated waves of local origin. Major tropical storms are required for their emplacement and although atoll motus are found in low latitudes where tropical cyclones do not generate, such locations can still experience large swells generated by storms at higher latitudes. Whilst knowledge of normal wave action on reefs is limited, not surprisingly, data for high energy extreme events are totally absent. Nonetheless, observations made subsequent to such events and the application of empirical methods confirm these conclusions.

The most spectacular example of island construction by a tropical cyclone is the new rampart formed on Funafuti by hurricane Bebe in 1972 (Maragos et al. 1973; Baines et al. 1974; Baines and McLean 1976). On the southeastern side of this atoll, a ridge 19 km long, 30-40 m wide and up to 4 m high was formed during this single storm from material dredged up from up to 20 m depth on the reef front. On more sheltered areas, discontinuous low rubble tracts formed. Under normal weather conditions since 1972, the Funafuti ridge has altered its original convex profile to a concave one, migrated 10-20 m shoreward and been significantly reduced in height. In some areas, it now remains only as a rubble zone and in its migration has left large coral heads as residual reef blocks. Nonetheless, the long-term result has been a building of Funafuti motus.

Further evidence on the response of reef islands comes from the Holocene record. For example, Bayliss-Smith (1988) suggests that storms during the mid-Holocene in the Solomons were more frequent and intense than at present and that at that time islands increased in size. In the Caribbean where, for isostatic reasons, the Holocene sea level record is one of continuous rise up to the present and therefore continuous upward growth and evolution of reef flats (Hopley 1982), it is also notable that on reef complexes such as the Belize barrier reef, coral cays are more frequent than on many Indo-Pacific reefs; possibly because of the lower level of the reef flats and more continuous sediment movement over them.

A greater risk of inundation from storm surges, associated with cyclone activity on mainland and high island coastlines, is not likely to increase dramatically on open-ocean reef islands where amplification of the surge by shoaling and funnelling effects does not take place. In the open ocean, surges are essentially limited to the inverted barometer effect (1 cm for every hPa of pressure reduction) and to wave setup on the margins of the reef.

The general conclusion is that the temperate coastal erosion theories, such as that proposed by Bruun (1988), are not applicable to coral islands. Their application previously suggesting erosion rates of 1-2 m per year as a result of greenhouse-induced causes (Roy and Connell 1989) is misleading. Those who have worked on reef processes generally agree that in the short term of 50-100 years, reef islands may in fact increase in size, e.g.:

> Thus it is possible that with rising sea level the broad sediment-laden reef flats of Kiribati will see substantial re-working of the surficial sediment which could result in the formation of new islands and expansion, through the accretion of existing islands, at least until the existing sediments surplus is exhausted.
> A new phase of island building is therefore envisaged. This will be aided by the presence of the existing islands and the natural beachrock and conglomerate "seawalls" and "groynes" which will serve to trap and stabilize mobilized sediment (McLean 1989).

and

> At least over the next 50-100 plus years coral islands seem relatively secure even if (or especially if) reef platforms become progressively inundated. Increased tropical cyclonic activity, combined with maximum growth rates and new coral habitats will ensure sediment supply and increased water depths will increase sediment transport efficiency (Parnell 1989).

Existing beachrock, conglomerate and other cemented island deposits such as phosphatic cay sandstone will certainly retard even changes in locations of islands. Moreover, there is sufficient evidence (in the form of very recent artefacts contained within beachrock) to suggest that the cementation processes are so rapid that they will be effectively contemporaneous with the addition of new material to reef islands. Raised tidal levels will result in higher levels of cementation, superimposed over the top of existing beachrocks. Availability of land is, therefore, not the problem for the low-lying island nations over the next century as has previously been suggested.

Other Potential Changes to Coral Reef Islands

GROUNDWATER RESOURCES. Concerns have been expressed for the groundwater resources upon which both island peoples and vegetation depend. In general, such concerns have resulted from the application of the now outmoded Ghyben-Herzberg model. This assumes homogeneous materials and that the outflow, or loss of fresh water, occurs at island margins in, or below, the intertidal zone producing a predominantly horizontal flow. Although some of the fresh water remains above sea level, the majority of it (40 units of depth for every unit of head) will reside below sea level. This model produces a great depletion in the potential for groundwater resources if island size is reduced. Freshwater lenses may not occur on islands that are less than 300 m wide. However, the recently discussed layered aquifer model (Wheatcraft and Buddemeier 1981; Herman et al. 1986; Oberdorfer and Buddemeier 1986; Buddemeier and Oberdorfer 1990) whilst suggesting that the overall freshwater resource may be less than in the Ghyben-Herzberg model, has much greater applicability to real world situations. The model presumes two basic geological layers possessing distinct porosities: a surficial layer, of Holocene age, of low permeability overlying deposits of high permeability, of Pleistocene age; separated by a solution unconformity at relatively shallow depths of 7-25 m. The primary mechanism for loss of fresh water is not outflow at island margins but loss to degradation by downward mixing into the saline water in the Pleistocene deposit below. This creates a broad transition zone of brackish water.

However, this model is far less sensitive to island size, and a threshold island width figure of 120 m has been suggested for retention of the freshwater resource. Moreover, if the island size remains constant, Oberdorfer and Buddemeier (1986) suggest that rising sea level has a counter intuitive effect on total freshwater resource for islands possessing a layered aquifer. An increase in sea level makes available more of the low permeability aquifer for retention of freshwater, increasing the total freshwater resource. However, as Parnell (1989) notes, "under current recharge conditions, the potable freshwater resource is reduced by a small amount. It is possible that recharge rates will decrease with higher temperatures and higher evapotranspiration, but if recharge increases (which is possible given increased rainfall and perhaps better land use practices) the model shows a significant increase in both potable and total freshwater resources."

Thus, a rise in sea level may not be disastrous for island groundwater resources. Indeed, if accompanied by an increase in island size as seems likely, and increases in rainfall as is predicted for some areas of low latitudes, groundwater resources may actually increase.

SOILS AND PLANT GROWTH. By definition, reef island soils are young. Fosberg (1954) identifies three soil series with increasing maturity.

- Shioya soil series found on the youngest sediments, deficient in almost every element essential for plant growth;
- Arno soil series with a more developed "A" horizon and some bonding by organic matter; and
- Jemo soil series found under mature island forests and in which much organic matter is incorporated.

It is these latter soils which provide the basis for most agriculture on reef islands. Unfortunately, even though islands may increase in size during the next 100 years, the soils on the new land area will be of the younger immature type. The major concern is that changes to the shape and orientation of islands, which may result from changes in wind directions, may lead to the erosion of at least part of the older core areas of the islands on which the agricultural soils are found.

Most concern, however, has been for rising saltwater ground tables and salt contamination of low-lying vegetation (e.g., Hughes and McGregor 1990). As indicated above, this may not necessarily be so and the future for sustainable agriculture and maintenance of mature vegetation on reef islands may not be as grim as has been forecast in the past. Indeed, there may be a significant increase in the productivity of many tropical crop species found on reef islands. Crops with a C_3 photosynthetic pathway may have crop yields increasing by as much as 33% due to the CO_2 enrichment of the atmosphere. Cassava, sweet potato, taro, yam, banana, papaya and coconuts amongst the C_3 crops are included (Jacobs 1990). There have also been suggestions that CO_2 enrichment will lead to a reduction in stomatal conductance and transpiration and an increase in water use efficiency by plants. If this takes place, then even in areas where a reduction in total rainfall is predicted, there may be some offsetting for agriculture.

MARINE RESOURCES. Rejuvenation of coral growth as suggested by Hopley and Kinsey (1988) and Kinsey and Hopley (1991) should also bring about the replenishment of many of the natural marine resources, upon which island nations depend. On relatively open atolls, a slight rise in sea level may do much to increase lagoon circulation with beneficial effects. However, on atolls where few hoa (lagoon exits) exist, increasing sedimentation through building up of shingle ridges may completely close off lagoons. Such a situation occurred at Taiaro Atoll in the Tuamotus as described by Salvat et al. (1977). Although partial closure of the lagoon occurred as the result of a slight uplift, complete isolation occurred during the 19th century as the result of blocking of the remaining exit by a boulder rampart, deposited during high seas. Corals were initially killed by the uplift, but subsequently hypersaline conditions (about 43 ppt) have developed and only *Porites lobata* survives, compared to 14 species prior to the lagoon being closed. Other fauna have been similarly restricted.

Deterioration in lagoon and near-reef water quality may also occur if nutrients are released into the marine environment during the period of global change (e.g., see Hallock and Schlager 1986). A release of nutrients can result from rising water tables producing a greater leaching of island soils which can also be aggravated if water table fluctuations reach into septic tanks and rubbish tips. Remobilization of naturally occurring phosphate deposits, produced through the accumulation of guano, may also take place as water tables rise through island soils. A full assessment of these changes to nutrient status, and whether or not eutrophication will occur, needs further investigation.

Conclusion

There is no doubt that reef island environments are precarious and extremely vulnerable to environmental change. However, kneejerk reactions, as have occurred two years ago, with so-called scientific assessments suggesting reactions as drastic as mass resettlement for particular island nations, appear to be severe overreactions (Roy and Connell 1989). Although there will be some local land losses and changes to the ecology of the islands, there may well be as many gains from global change as there are losses. McLean's (1989) survey of Kiribati is an example of a true scientific approach towards assessment of the future risk. Although further work is required, particularly on the sedimentation processes occurring on coral reefs, and also on groundwater hydrology, McLean's (1989) summary for Kiribati is probably pertinent to many other reef island situations:

> On the face of it the low atolls and islands of Kiribati appear particularly vulnerable to any future rise in sea level, and while this is to a large extent true, several factors suggest that the most probable outcomes will not be as substantial nor as devastating as initially envisaged ... And yet, in addition to or regardless of any greenhouse-induced changes the population is likely to have to cope with large natural variations in physical phenomena such as fluctuations in water level, freshwater lens volume,

rainfall incidence and drought for example, which will have a profound effect on land and livelihood in the future. ... It should also be stressed that there is no obvious immediate danger from greenhouse-induced causes; these will take decades to have any major impact on any but the most vulnerable locations (Buddemeier and Oberdorfer 1990). But this does not mean that the government should not capitalize on the international support for greenhouse related environmental matters because there is a very real need to address the questions of long term planning and preparation.

As predictions for sea level rise become more conservative (e.g., no more than 25 cm by the middle of the next century), concerns about the island nations may diminish. However, as McLean has shown, the environmental problems existing on many reef islands already necessitate careful planning and management. Only by maintaining (or in some instances restoring) reef systems to a healthy state will they be able to respond to global change in the positive directions suggested in this paper. Such a policy, requiring economic, demographic and sociological as well as scientific input, is necessary even if global changes to environment were minimal.

PART IV: DATABASES AND ANALYSES

The Global Inventory of Coral Reef Systems

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Coral reefs of the world (IUCN/CMC 1988) was compiled and published in response to growing demand in the 1980s for information on coral reefs and their conservation status. The idea of compiling a directory grew out of work underway through the Coral Reef Working Group of IUCN's Commission on Ecology, which involved the documentation of threats to reefs (Salvat 1987) and the compilation of an inventory of parks and reserves containing coral reefs (preliminary data published in the Group's newsletter). The three volumes of the directory were compiled between 1983 and 1988 at the IUCN Conservation Monitoring Centre (now the World Conservation Monitoring Centre or WCMC) and were published as a joint initiative by the United Nations Environment Programme and the International Union for the Conservation of Nature. Just over 100 countries are covered, including those with coral reefs and also those with what are considered to be significant populations of scleractinian corals (e.g., some of the West African countries).

The format adopted for the directory was based on that used for other IUCN directories, notably those for protected areas and for wetlands. For each country, an introductory section describes the distribution of reefs within the country, their status, relevant conservation issues and legislation. A comprehensive reference list, including scientific monographs and papers, popular books and articles, bibliographies, management plans and unpublished reports is included. This section is followed by detailed accounts for reefs situated in existing protected areas, reefs proposed for protection and reefs recommended by qualified experts as requiring protection or management on the basis of their scientific interest or economic importance. In some cases additional sites are included, such as reefs that have been particularly well studied. It proved difficult to apply firm criteria in the selection of the reefs described in site accounts. Instead the choice tended to be based on the amount of information available for a site, and thus reflects reefs that have been well studied or that happen to occur within protected areas, rather than those of true scientific value and conservation importance.

The site accounts have sections on: geographical location; area, depth, altitude of associated terrestrial ecosystem; land tenure (including information available on marine tenure); physical features; reef structure and corals; noteworthy fauna and flora (i.e., species other than corals); scientific importance and research; economic and social benefits (largely importance of the reefs to tourism and fisheries); disturbances or deficiencies; legal protection; management; and recommendations. It was hoped that the use of standardized paragraphs would facilitate any subsequent attempts to enter the information onto a database.

An introduction at the beginning of each volume provides a general overview of the region concerned in relation to reef ecology, diversity, economic importance and management. Tabulations are provided of damage to reefs from natural events such as hurricanes, coral predators and disease; human impacts of various types; existing and proposed protected areas; and national legislation of relevance to reefs.

The first draft of each section was put together from literature available to the compilers, obtained from a wide variety of sources and including both published and unpublished materials (all of which is cited in the bibliographies). Drafts of country sections and site accounts were subsequently circulated widely to relevant experts and their ensuing comments and additional information were incorporated.

It is important to stress that the accumulation and collation of such a large quantity of information would not have been possible without the assistance of an extensive network of extremely helpful people (over 100 for each volume) who willingly gave their time and data. In several instances, volunteers wrote the first drafts of country sections themselves. The network grew steadily over the course of the project, facilitated by the existence of the IUCN Coral Reef Working Group, the International Society for Reef Studies and other relevant organizations, as well as attendance by the compilers at the international coral reef congresses and the annual meetings of ISRS.

The maps that accompany each country section show reef distribution and the location of existing and proposed protected areas. They were prepared using a variety of sources, including admiralty and other charts and maps, as well as maps in scientific papers. Preliminary sketches were circulated to as many experts as possible, particularly to those who had provided information for, or compiled, the text. Nevertheless, the scale involved and the lack of information for many areas, has meant that for many countries the maps provide only an approximation to actual reef distribution.

Although there was considerable discussion as to how the information collected could be used as a basis for a computerized database, the funding and computer facilities at WCMC over that period were insufficient to initiate such a system. The text is in the form of word processing documents (one document per site account), currently on the World Conservation Monitoring Centre's WANG computer, but shortly to be converted to an IBM-compatible format. There have been ongoing discussions between WCMC and other interested parties on the feasibility and funding required for developing a full-scale computerized coral reef database.

The experience gained in compiling the directories and in attempting to develop a database in the course of the project showed that there are a number of important requirements for success. First, a major limitation of the directory project was that it provided no system for measuring changes on reefs over time or for providing any quantitative information on the rate of deterioration of reefs or the areal extent of reef damage. These requirements can now be taken into account by developing a global coral reef database in association with the global coral reef monitoring program being set up under the auspices of UNEP, the Intergovemmental Oceanographic Commission (IOC), the World Meteorological Organization (WMO) and IUCN.

Second, a computerized mapping component would be an invaluable component, taking advantage of satellite imagery and other recent technologies. This would permit the gathering of better distribution data for reefs and start to give some indication of the size of this ecosystem. The maps from *Coral reefs of the world* could be used to provide an initial overview of reef distribution (they have already been used for a Caribbean coastal resources mapping project carried out for the UNEP Caribbean regional office by James Dobbin Associates), but they should not be used as base maps. The WCMC has pointed out that they have recently initiated a "Biodiversity Map Library" project with a three-year funding package from British Petroleum. This will include the development of a spatial database on coastal ecosystems, such as reefs and mangroves as part of the WCMC GIS, but additional funding (perhaps through a university fellowship) is being sought to provide the necessary technical expertise.

Finally, it will be important to establish a broad network of experts and contributors, with an effective means of communication to ensure that data are gathered in a timely and accurate manner. An important aid to this is good feedback; during the UNEP/IUCN directory project, information on a variety of topics was regularly requested by contributors and a point was made of fulfilling these requests to the fullest extent possible. This was done on a purely informal basis, but with appropriate funding and staffing could be developed as a more formal part of a database project, either using electronic bulletin boards or through a printed newsletter. The number of individuals, institutions, and governmental and nongovernmental conservation organizations involved in reef research and management has increased dramatically over the last ten years (see for example Wells and Price 1991) and provides a ready pool of information and expertise.

ReefBase - a Global Database of Coral Reef Systems and Their Resources[a]

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FROESE, R. 1994. ReefBase-a global database of coral reef systems and their resources, p. 52-54. *In* J.L. Munro and P.E. Munro (eds.) The management of coral reef resource systems. ICLARM Conf. Proc. 44, 124 p.

Coral reefs occur all around the globe. Their contribution to the fish catches of developing countries and to global biodiversity is important. Coral reef resources tended to be studied by different groups of scientists working under paradigms different from those guiding fishery biologists, resulting in the literature on coral reefs being even more scattered than that on marine biology. This might be the reason why a consensus on key aspects of coral reefs as a resource system has, to date, failed to emerge. Such key questions are:

- What reef typology would be appropriate for fishery research and for global comparison of fishery yields and potential?
- What are the (maximum) sustainable yields that can be extracted from different reef types?
- What are the current and potential yields for different species groups?
- What are the yields that are foregone when coral reefs are destroyed, or their productive capacity reduced?

To address these and related questions, ICLARM plans to develop a database (ReefBase) containing all relevant information on reefs in a standardized form. In addition to descriptive information on reefs such as are contained in the three-volume *Coral reefs of the world* (IUCN/CMC 1988), ReefBase will focus on data such as the area of various reef formations by country and on numerical information such as time series data on catch and effort. The areas of different reef types are required by country and globally for researchers to compare and extrapolate their results.

Objectives

The objectives of the ReefBase project can be summarized as follows:

- to classify and structure the heterogeneous information available on coral reefs;
- to design a relational database capable of accommodating the structured information;
- to collaborate with existing databases on national reefs in order to join efforts and to include existing information in ReefBase;
- to set up a network of coral reef researchers contributing to ReefBase;
- to train a team of research assistants for inputting the relevant

[a]ICLARM Contribution No. 1066.

information on reefs into ReefBase;
- to link ReefBase with commercial maps and GIS packages to make use of existing data and analytical routines; and
- to develop analytical routines to be distributed together with ReefBase.

Mode of Operation

ReefBase will be developed at ICLARM Headquarters in close collaboration with national research institutes working on coral reefs. It is expected that this collaboration will lead to a standardized collection of data needed for developing coral reef management systems. It will run on IBM-compatible microcomputers which are now available in many institutes in developing countries. After the development phase, it is planned to distribute ReefBase at nominal cost to national research institutes throughout the tropics. ReefBase will draw on the experience gained from FishBase, a large database on fish biology developed at ICLARM. FishBase complements ReefBase in that it will contain all relevant information available on coral reef fishes such as growth parameters and diet composition.

Proposed Structure for ReefBase

A preliminary design for ReefBase is shown in Fig. 5. The Reef systems table contains general information on reefs by country, such as total area of different reef types. General information on individual reefs, such as locality, tenure and physical features, are contained in the Reefs table. For every reef, time series of data on abundance of key species, per cent live cover, catches and efforts, other reef uses and products, and occurrences of stresses such as storms, diseases and

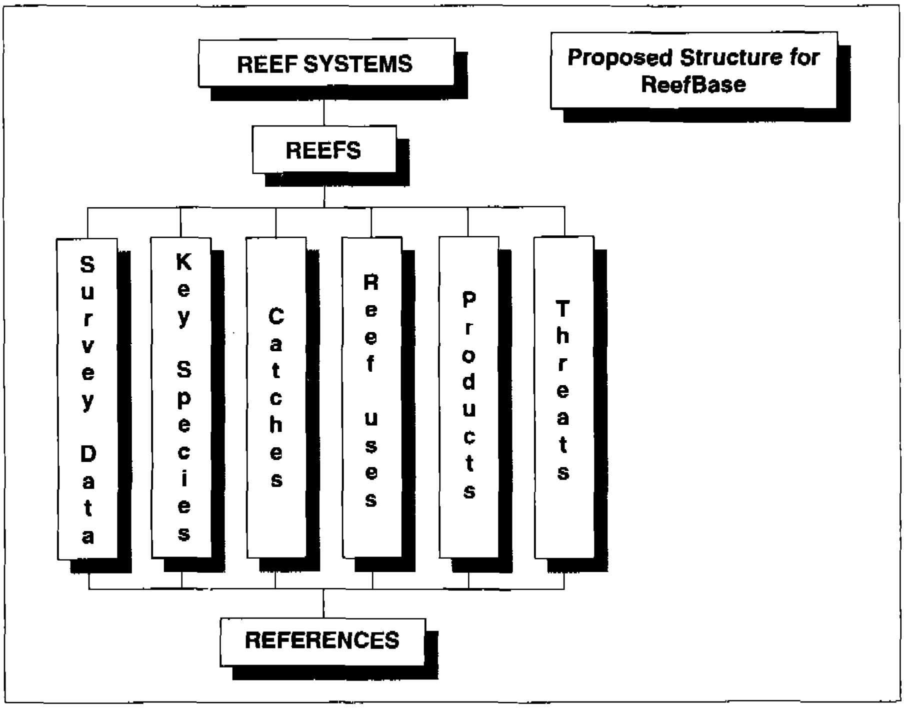

Fig. 5. Proposed structure of ReefBase.

destructive human activities can be accommodated by the respective tables linked to the Reefs table. The sources for the information will be contained in the References table.

Expected Results

ReefBase will help researchers, managers and students by:

- serving as a computerized encyclopedia on coral reefs;
- providing documentation needed for future coral reef research;
- providing data and analytical tools for coral reef research;
- identifying research gaps and avoiding duplication of work;
- encouraging model-driven data collection;
- documenting biodiversity and status of threat;
- preserving information that might otherwise be lost; and
- providing a useful model for similar databases in other fields.

Towards a National Marine GIS for Australia

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Australia is developing national strategies related to the environment. These include a National Strategy for Ecologically Sustainable Development (ESD), a National Strategy for the Conservation of Biological Diversity and recommendations prepared by the Resource Assessment Commission (Bradbury et al. 1991).

National Strategies

ECOLOGICALLY SUSTAINABLE DEVELOPMENT. The Commonwealth Government's ESD strategy reflects growing community recognition that, in pursuing material welfare, insufficient value has often been placed on the environmental factors that also contribute to our quality of life. It also reflects a recognition that economic growth and a well-managed environment are fundamentally linked. Many resource-use decisions do not take sufficient account of these linkages. This has led to unacceptable environmental consequences. The existing approaches to environmental protection have not always been adequate to avoid significant damage.

The task confronting Australia is to

take better care of the environment while ensuring economic growth, both now and in the future. ESD provides a conceptual framework for integrating these economic and environmental objectives, so that products, production processes and services can be developed that are both internationally competitive and more environmentally compatible.

CONSERVATION OF BIOLOGICAL DIVERSITY. The Commonwealth Government has recently established a committee to prepare in consultation with the wider community, a National Strategy for the Conservation of Biological Diversity. The development of the strategy will include assessing the status of and threats to Australia's biological diversity as well as the adequacy of existing mechanisms and legislation. After the adoption of the strategy, the committee will monitor its implementation.

RESOURCE ASSESSMENT COMMISSION. The Resource Assessment Commission is a major initiative on the part of the Government to promote better resource decisions. It has been set up as an independent body with an extremely broad mandate to investigate resource issues referred to it by the Government. It can undertake open, informed evaluation of different aspects of those issues, and has great freedom as to how it makes its assessments. Its guidelines ensure that it focuses on both the environmental and resource development dimensions in its inquiries. As such the Commission is likely to become a major end-user of environmental information.

The Government has referred the Kakadu region of the Northern Territory and Australia's forests and timber resources to the Commission as its first two inquiries, and has announced that the third and fourth inquiries will focus on the coastal zone and the arid zone, respectively.

OTHER NATIONAL STRATEGIES. Australia is also adopting a national approach to other environmental issues. For these too, decisionmakers require effective information. The problems associated with climate variability and change, for example, require cooperative international action as well as a distinct national response. The problems of air, water and land degradation are being explicitly addressed through national programs such as "Save the Bush", Endangered Species Program, Landcare, "One Billion Trees" and the National Soil Conservation Strategy.

For the elaboration of each of these strategies, as for the development of ESD as a viable framework to guide Australia's development, it is clear that governments and other organizations must have access to the highest quality environmental information available, regardless of where that information is held. Acquiring, accessing, managing, integrating, enhancing and visualizing environmental information is critical to the ecologically sustainable development of Australia as well as the world.

The Australian Solution

The establishment of the National Resource Information Centre (NRIC) was announced in the Commonwealth economic statement of May 1988, with the aim of improving the information base for Commonwealth decisionmaking processes relating to natural resource management issues (Johnson and Bradbury 1991). This decision recognized the fact that inadequate information had been a major limitation in the formulation of agreed policies for natural resource management. To help address the problem, NRIC was created to use modern information technology and to draw upon the existing facilities and expertise of the Bureau of Mineral Resources (BMR), the Bureau of Rural

Resources (BRR) and other Commonwealth agencies.

It was further realized that in situations where different options for land use were being evaluated, an agreed, common and accurate information base of the basic natural resource and environmental parameters of the area under discussion would assist both in the commencement of interactions and in defusing some of the potential differences in attitude.

Since its creation, NRIC has made great strides towards its goal of improving the utility and timeliness of the information base for drawing up policy and making decisions about the ecologically sustainable development and management of Australia's natural resources.

It has concentrated on providing integrated solutions for the strategic information base for some of the nation's most pressing environment/development issues:

- southeast forests;
- national forest estate;
- Murray-Darling Basin;
- Shark Bay and Hamelin Pool World Heritage area;
- feral animals on Australia's rangelands;
- decline of productivity in the rural heartlands; and
- coastal zone.

In each of these studies, the Centre:

- has worked with the data custodians to make the fundamental datasets more freely available;
- has taken a national coordinating role in fostering the development of standards for the transfer of the datasets between agencies;
- has acquired, "cleaned up" and assembled the datasets into appropriate analytical structures, usually geographic information systems (GIS), but more and more into decision support systems (DSS);
- has visualized the integrated result with modern visualizing products; and
- worked with policymakers to help them understand the implications of this research.

As part of this work, NRIC has built two new, but critical, tools, described below.

A NATIONAL DIRECTORY OF ENVIRONMENTAL DATASETS. This is a distributed database allowing major users of data to connect with major custodians of data throughout Australia (Johnson et al. 1990a). It will soon be the Australian link in emerging international networks of directories (Johnson et al. 1990b) and it is, uniquely in the world, spatially searchable, which means that spatial coordinates may be used to locate a desired dataset (Johnson and Robey 1990).

A CONTINENTAL SCALE GIS. This system contains, naturally at a fairly coarse scale, the fundamental data layers that will be needed by almost any (especially preliminary) study of a national environment/development issue. It is being built with the close cooperation of the custodians of data layers and made widely available at only the marginal cost of the distribution media.

Australia's Marine Environment

The list of achievements above, while significant, has one gaping hole - the marine environment. There are two reasons for this. The first is that NRIC's limited resources have been fully committed over the last few years servicing major land-based issues. The second is less obvious: there are significant research issues in attacking the marine environment with our current level of informatics.

On the land, we can pretend that we are dealing with basically two-dimensional structures:

- the surface of the land, to a first approximation, is a two-dimensional structure and we can store the bumpiness of mountains, say, as if the bumps were just attributes of the point in two-space;

- at best we are manipulating and displaying a 2.5-dimensioned object.

The sea can never be so simply represented:

- we need a true third dimension to capture the water column;
- we may even need a fourth dimension to capture temporal processes;
- the short characteristic time scales of major ocean phenomena, such as currents and seasonal upwelling, will demand this.

Some scientists will even demand a fifth dimension - the evolution of sedimentary basins cannot be sensibly described in less than five-space.

The problem here is that this will place enormous demands on computing power and storage - already conventional spatial information systems strain even the largest computers. It will also require the invention of new ways to manipulate and visualize these more complicated structures so that policymakers can comprehend them. Nonetheless, it is important to make a start.

An Australian National Marine GIS

NRIC hosted a preliminary meeting in October 1991 of some of the possible major players to discuss ways in which the idea of a national marine GIS could be developed. Natural resource interests, particularly fisheries and offshore minerals and petroleum, were represented by BMR, BRR and relevant policy sections of the Department of Primary Industries and Energy. Environmental interests were represented by the Environmental Resources Information Network of the Australian National Parks and Wildlife Service. The Navy Hydrographer, Commodore Leech, an enthusiastic supporter of the concept, spoke at the meeting and offered his assistance.

It was agreed at the meeting that:

- NRIC would undertake a feasibility study of the problem;
- the model developed for the Australian continental GIS be used as a starting point;
- various agencies would freely contribute national datasets to the development of the system;
- NRIC would develop, coordinate and freely distribute the system;
- the datasets comprising the system would be fully described in the national directory.

In early February 1992, NRIC began the feasibility study with the assistance of BMR. This is a two-month study to evaluate the idea rigorously, concentrating on the availability of datasets, technology and clients. It became immediately clear that, because of the enormity of the problem, the system must be developed on a region by region basis, selecting first those areas of Australia's EEZ of most immediate significance to clients. This approach will gradually "tile" the Australian EEZ with completed sections of the national GIS.

It has also become apparent that the first clients, those with the most immediate needs, are in the offshore exploration industry. They have a good perception of the geological risks and uncertainties associated with exploring a new offshore area, but have a poorly developed appreciation of its "environmental" dimensions. They need urgent assistance in visualizing in an integrated way our present understanding of any offshore region.

The feasibility study, now underway, has already clearly shown that a national marine GIS is feasible with present technology and that the demand is there from client agencies for this system. The major layers that have been identified so far include:

- bathymetry;
- hydrography;
- oceanography;
- jurisdictions including exploration tenements, marine environment protected areas, state and commonwealth boundaries, port authorities;
- surficial geology;
- structural geology from seismic profiles;
- hydrocarbon traces from "sniffer" data;
- fisheries distributions;
- ecosystem regionalizations;
- rare or threatened species;
- oil spill risk surfaces; and
- coastal zone land uses.

Our current plan is to fast-track the development of this system. At the conclusion of the feasibility study, we will initiate a pilot project to build the first "tile" in the system. This will take six months and will be used as a proof-of-concept vehicle for an ongoing study. The likely area for this study will be the South Perth Basin in Western Australia.

Modeling Coral Reef Ecosystems[a]

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The notion of "modeling coral reef ecosystems" may appear sacrilegious to those who believe that the complexity and variability of coral reefs defy modeling, especially modeling of the sort advocated here. Whatever one's view of modeling, one cannot fail to note, however, that lots of coral reef researchers do fieldwork and publish their results based on the (tacit) assumption that their rate and state estimates (e.g., production of some invertebrate, standing stock of some fish) express some aspect of reality, for at least a certain (if generally unstated) period.

This work would greatly improve if one were to apply, to various, well-studied reefs, quantitative approaches through which an assessment can be made of how compatible such published state and rate

[a]ICLARM Contribution No. 1067.

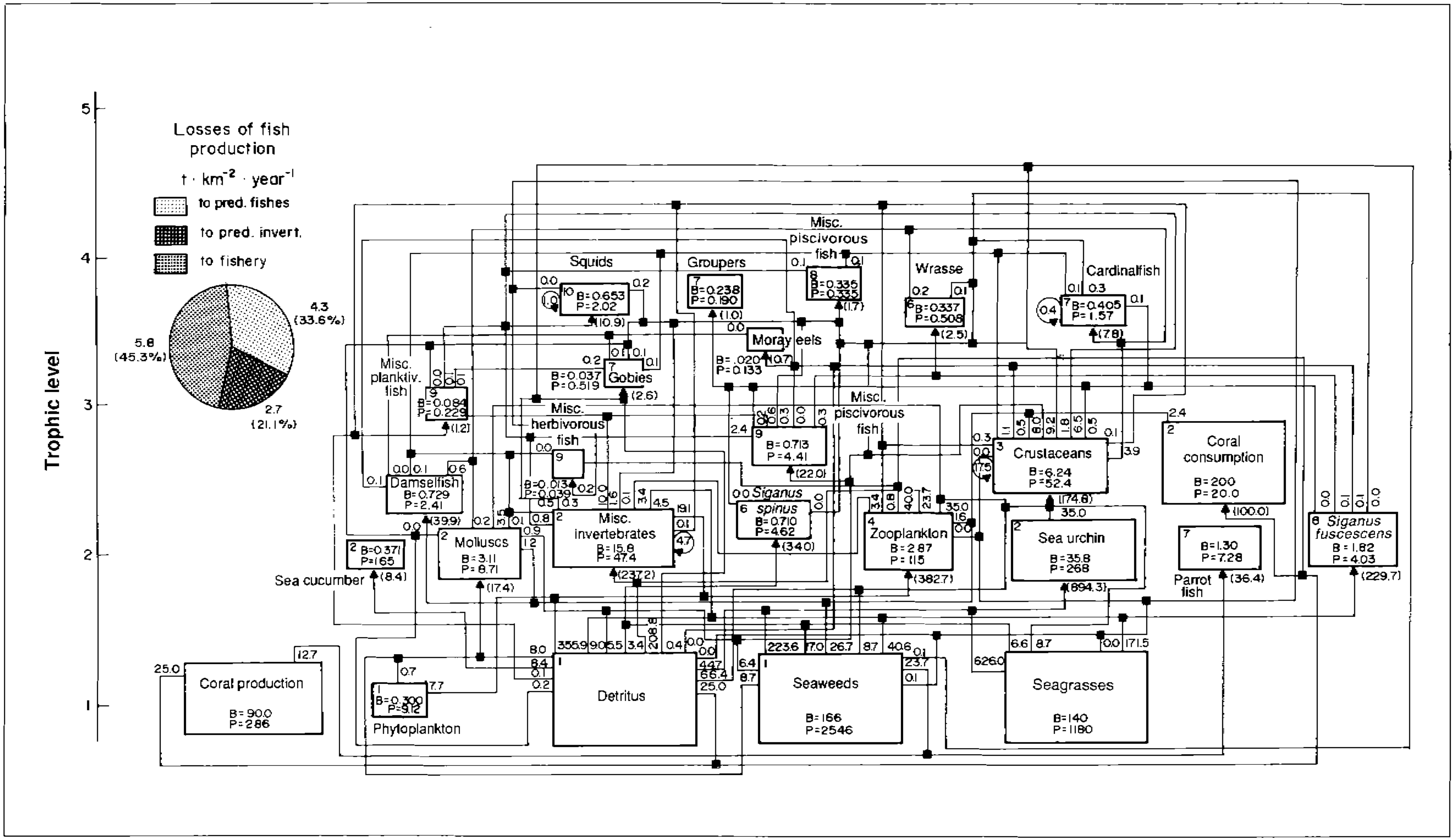

Fig. 6. Trophic model of the seagrass/reef flat area in Bolinao, Philippines, as constructed using the ECOPATH II modeling approach and software.

estimates are, and which can also be used to estimate "missing" values, i.e., fill in the gaps in one's representation of coral reef ecosystems.

Two such approaches are presently being developed at ICLARM:

1. the ECOPATH II software, for construction of steady-state models - this system has been applied to a large number of aquatic ecosystems, including several coral reefs; and
2. a form of length-structured Multispecies Virtual Population Analysis (MSVPA), for application (initially) to the Bolinao reef fishery, Philippines, and which, once tested, will be made available for analysis of coral reefs and other areas.

Numerous documents are available which document the ECOPATH II (2.1) program, its predecessor, J.J. Polovina's ECOPATH, and applications to coral reefs (Polovina and Ow 1983; Polovina 1984; Opitz 1991; Aliño et al. 1993; Christensen and Pauly 1992a, 1992b, 1993) (see Fig. 6 for an example).

The version of length-structured MSVPA presently being developed at ICLARM resembles "Phalanx Analysis" (Pope and Yang 1987), but differs in some major features.

We believe that the application of these two approaches to a number of reefs will help in achieving the following:

1. make use of published rate estimates for major reef organisms, throughout the world (see also documentation on FishBase and ReefBase);
2. identify gaps and compatibility problems in the corpus of literature in (3);
3. provide a formal framework for cooperation between various (groups of) coral reef researchers (to address issues in (2)); and
4. identify and quantify management options for coral reef fisheries (e.g., impact of closed areas, of closed seasons, of mesh size changes, of selective removal of apex predators, of forage fishes, etc.).

We hope that these models will indeed allow for close cooperation between ICLARM and other research groups in developing and developed countries, and also between biologists and social scientists. We anticipate that item (4) could provide a good basis for (bio)economic models and that this modeling effort, along with supportive comparative studies, should help overcome (via ReefBase) the present dearth of global assessment of the role of coral reefs as resource systems.

PART V: MANAGEMENT OF CORAL REEFS

Systems for Selection and Management of Marine Protected Areas

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Marine protected areas (MPAs) have changed conceptually and pragmatically over recent years. From regulation and management of individual marine activities, such as commercial fishing by specialist agencies, through small areas afforded total protection, MPAs have most recently been established as relatively large, multiple-use areas with an integrated management system to provide a variety of levels of protection and use throughout the area (Kelleher and Kenchington 1991). The three key descriptors are large areas, multiple use and integrated management.

In contrast to terrestrial protected areas where relatively confined habitats can be treated as closed systems, the marine environment is not so clearly defined physically or functionally. Currents disperse larval stages of most invertebrate and vertebrate marine animals, as well as propagules of coastal flora, over considerable distances. Protection of small areas in isolation from surrounding exploitation can make a mockery of any conservation effort. In contrast, large area management includes the ability to undertake whole ecosystem management for ecologically sustainable use.

The multiple use concept is based on an appreciation that cooperation of users and adjacent populations is vital to the successful implementation of a protected-areas system. This can only be achieved through recognition of socioeconomic realities, user participation in the selection of MPAs, extension programs, and balancing of all interests and legitimate extractive activities with the overriding conservation purpose.

The integrated approach has the

advantage that coordination of regulation of different human activities can be automatically achieved where the overriding responsibility for management is vested in one agency. Coordination and complementary management by relevant agencies is essential given the high connectivity within the water medium, as well as between marine environments and adjacent land masses in coastal areas (Van Dyke 1991)

Systems for the selection and management of MPAs rely on the underlying goals and objectives in such a system (Ivanovici 1986). Because of the continuity of marine areas, these are most productively viewed in a global, rather than local or regional perspective.

Goals and Objectives

Recognizing the serious threats confronting marine areas around the world, the 4th World Wilderness Congress in 1987 passed a resolution which established a policy framework for marine conservation. A similar resolution was passed by the 17th General Assembly of the International Union for the Conservation of Nature in February 1988. The primary goal envisaged by both bodies was "to provide for the protection, restoration, wise use, understanding and enjoyment of the marine heritage of the world in perpetuity through the creation of a global, representative system of marine protected areas and through the management in accordance with the principles of the World Conservation Strategy of human activities that use or affect the marine environment."

At the recent 4th World Congress on National Parks and Protected Areas, recommendations centered on the key role of MPAs to provide for the protection of biological diversity and ecologically sustainable use. Achievement of these primary goals was envisaged through the establishment of national systems of large MPAs over complete ecosystems, integrated management with complementary management of adjacent land areas; the provision of power, resources and responsibility to a single management agency; balancing access to and protection of resources; involvement of all user groups in planning and management; and the establishment of multidisciplinary research and monitoring to support planning and management activities.

Selection

Several countries have made significant progress in establishing "national representative systems of Marine Protected Areas" in accordance with the IUCN resolution (Kelleher and Kenchington 1991). The typical approach is founded on the construction of a biogeographic classification system incorporating climate, chemical and physical oceanography, flora, fauna and dimensions, with a view to establishing a national marine park within each region so that all marine parks together represent the whole. Defining such marine regions is not a trivial task, especially given the generally low level of knowledge of marine systems, short- and long-term variation in boundaries, migration and current transport of dispersal stages. In Canada, for example, classification of marine regions has been debated over nearly 20 years.

Kelleher and Kenchington (1991) note factors or criteria that can be used in defining whether an area should be included in an MPA or in determining boundaries for an MPA. These include biogeographic, ecological, economic, social, scientific, international or national importance, naturalness, as well as practicality and feasibility.

Management

Management regimes must address and be founded on a range of desirable key elements to achieve the goal and objectives of MPAs. These include: clearly defined and compatible roles of all agencies responsible for human activities in and adjacent to an MPA that are likely to jeopardize the attainment of the goal and objectives of the MPA; umbrella legislation to provide for conservational management over large areas; provision for a number of levels of access and extraction in different zones within a large area; provision for continuing sustainable harvest of food and materials in the majority of a country's marine areas; legislative arrangements, where possible, to grow from existing institutions unless there is overwhelming support for new administrative agencies; inclusion of adequate enforcement powers; cooperation at regional, national and international levels to take into account the migration patterns and larval/propagule transport mechanisms of marine flora and fauna over large distances; and public participation through a provision of opportunities for the public to be involved in the process of preparing management for MPAs with a view to initial and ongoing support for the declaration (Craik 1993).

The Great Barrier Reef Marine Park

The Great Barrier Reef Marine Park (GBRMP) is a multiple-use marine protected area covering around 344,000 km^2, extending from low water mark along most of the Queensland coast out to the Coral Sea. Key features of the park regarded as being responsible for the success of this MPA include its primary conservation objective (rather than resource optimization); a whole ecosystem approach facilitated by its large area; involvement of all stakeholders in planning and management; complementary management of marine and some adjacent land areas as well as between Federal and State agencies; integrated management with other relevant agencies (e.g., fisheries); balancing of protection and legitimate sustainable extractive activities; education and extension activities; flexibility in management strategies; environmental impact assessment of specific uses and strong legislative basis.

Disadvantages of the GBRMP system include the involvement of a multiplicity of agencies in the region; a lack of control over coastal land use; the significant amount of resources required to effectively manage such a large area and, at times, excessive consumption of limited resources through appeal processes. Overall, the balance is strongly in favor of the advantages and the GBRMP is regarded as a good working model of regional planning of MPAs.

Conclusion

Conservation, protection and management of marine and estuarine areas are being addressed by a diversity of legislative and management approaches around the world. This paper has outlined some of the guidelines generally proven to be successful when applied to natural resource management and in particular MPAs. Because of backgrounds it is unlikely that any single model will work in all locations. Application in specific situations will need to take into account the individuality of the region concerned.

Maintenance of Biodiversity of Coral Reef Systems through Management for Resilience of Populations

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Currently, the most important criteria for the selection of marine areas as reserves to protect biotic diversity include high species diversity, density and endemism, complexity of ecosystems, uniqueness in species composition and geographical variation of the species richness (White and Alcala 1988). This approach seeks to preserve biodiversity at all levels of organization: biogeographic regions; reef types within a region (both reef morphology and biotic communities); meta-populations (genetic diversity among populations). Moreover, the interconnectedness of the biota of coral reefs through adult migration of pelagic species and larval dispersal of benthic and demersal species can extend the effect of such protective management well beyond the boundaries of the protected areas.

However, it may be difficult to find such areas in practice, particularly in heavily populated parts of developing countries where there has been long over-utilization of reef resources. A proportion of reefs are always in a state of degradation as a result of disturbances, such as cyclones (Done 1992a, Done 1992b) and crown-of-thorns starfish (Moran 1986). Management for biodiversity should therefore incorporate the concept of various states of degradation and health, the transitions between them, and system resilience. A resilient reef community is one which, when temporarily degraded, will recover in due course as a result of natural recruitment to depleted populations (Done 1992c).

Management actions are required which preserve both good conditions for survival of cohorts inhabiting disturbed reefs during periods of recovery from disturbance, and maximization of the likelihood that there will always be suitably located source reefs. The former depends on action such as limiting access to, or exploitation of reefs, and/or mitigation of pollution or sediment influx onto reefs. The latter depends on the siting of protected reefs to fulfill roles as both sources and sinks of planktonic larvae. Given that many unmanageable disturbances (e.g., cyclones, crown-of-thorns starfish) have patch sizes much greater than the size of most individual reefs, optimizing the numbers and siting of reefs for preservation as sources of species and genotypic diversity is desirable.

Kenchington (1988) notes that current approaches to management for conservation all recognize the interconnectedness of reef populations through migration and larval dispersal, and the desirability of preserving a network of reefs. Rudimentary tools and empirical bases for optimization of reef selection are becoming available for the Great Barrier Reef. These include a hydrodynamic model to estimate connectivity between source and sink reefs tens to hundreds of kilometers apart (Dight et al. 1988, 1992); rate of spread of major *Acanthaster* impact over hundreds of kilometers (Reichelt et al. 1990); empirical relationships between cyclone characteristics and the damage caused to corals and reefs (Done 1992b). Thus, having evaluated the biological attributes of potential sites for some form of protective management, the Great Barrier Reef planner may soon be able to factor hydrodynamics, *Acanthaster* and cyclone data into the process of deciding among reefs for different levels of protective management.

In developed and developing countries alike, the results of such optimization exercises could be used in culturally appropriate educational material to influence communities to forego exploitation of some areas in the interests of achieving longer-term sustainable yields of fished-down resources. With its links to both institutions and communities, ICLARM would appear to be uniquely placed in implementing such an approach in developing countries.

The Caribbean Coastal Marine Productivity Project

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Within the greater Caribbean region, there is a general consensus that in many localities, the coastal ecosystems are changing for the worse. Apparently, the principal causes of the decline are anthropogenically driven, ultimately as a result of explosive human population growth in the coastal zones. Many direct and indirect negative interactions between man's activities and the coastal zone ecosystems have been identified in the Caribbean and elsewhere, ranging from mangrove forests being cut down for lumber, to the suspected effects of global warming.

On the other hand, as our knowledge and experience of tropical coastal ecosystems increase, an image of natural and dynamic changes is also emerging. The situation becomes even more complex when considering the different degrees of ecosystem development and interaction that result from the diverse local settings within the region.

Therefore, urgent action is required to better understand the extent of natural and man-induced changes. Hopefully, with this knowledge, man will be able to adequately harvest the resources of the coastal zone, and also protect the coastal ecosystem for the benefit of future generations.

In the Caribbean region, this difficult task is made more so by the complexity of the socioeconomic environment. It is estimated that some 20 different countries support a population of over 100 million in the coastal zone. Different cultural backgrounds, and limited economic and technical capabilities, are the common traits in the region. Furthermore, many of these states are land-oriented and thus have relatively poor traditional links with the sea.

Notwithstanding that, most Caribbean countries have recognized the need for conservation and restoration, although the development of sound management strategies is crippled by an insufficient understanding of how coastal ecosystems function. Most importantly, perhaps, there is not enough understanding, at the decisionmaking levels, of how to use that knowledge if it became available.

It is with the purpose of contributing to the solution of these problems that the Caribbean Coastal Marine Productivity Project (CARICOMP) was created. Two main goals were perceived:

- to increase our understanding of the natural and man-influenced dynamics of the dominant coastal zone ecosystems of the region (mangroves, seagrasses and coral reefs); and
- to generate the capacity to share that information, together with the experience and knowledge required to apply it properly to local conditions, thereby creating the conditions for a multinational scientific cooperative network with a single objective, the conservation and proper management of coastal ecosystems.

These main CARICOMP goals, like the project itself, originated from two workshops on Caribbean coastal ecosystems' interaction and productivity, in which more than 40 scientists from 16 Caribbean countries participated. In the 1985 workshop, a multinational CARICOMP Steering Committee was nominated. The responsibilities of the Steering Committee were defined by the recommendations of the workshop:

- to draft the CARICOMP;
- to establish the necessary network of marine laboratories; and
- to seek funding for the implementation of the program.

CARICOMP is composed of four complementary sections, covering research, education and training, information and data exchange, and research applications.

Research

The CARICOMP program will operate through a network of collaborating laboratories (22 at the moment, covering the whole Caribbean region), making simultaneous and identical measurements of a suite of important ecological and environmental parameters, on the three main coastal ecosystems (mangroves, seagrasses and coral reefs). The long-term effort will provide an ample database that may strongly help in identifying the dominant factors that regulate coastal productivity, both on the regional and local scale.

A first effort in this direction was to develop a CARICOMP Methods Manual, consisting of a collection of easily implemented physical, chemical and ecological monitoring methods, together with the sampling protocols. The manual was first compiled by recognized experts in pertinent fields, reviewed by the CARICOMP Steering Committee, and further reviewed by the representatives of all participating laboratories, at a special CARICOMP Methods workshop in December 1991.

Education and Training

One problem recognized by all Caribbean countries is the lack of trained and experienced personnel at both senior and technical levels. Since the goals of CARICOMP depend on both types of personnel at each participating laboratory, it is essential to provide educational opportunities and advanced training at all appropriate levels. Among the initiatives are upgrading of equipment, conduct of technical and advanced workshops, and collaboration on formal education.

Data Management and Communication

The other main goal of the program is to establish a Data Management Center (DMC) at the University of West Indies, in Jamaica, where the CARICOMP database will be checked, compiled and maintained. The DMC will issue standard reports of the information obtained, on a bimonthly basis, to all participating laboratories and a comprehensive annual report. The other main function of the DMC is to maintain an efficient communication link for all CARICOMP participants, thus facilitating the exchange of ideas, information, advice and literature. Thus, one of the main problems in the region, lack of proper communication among scientists, will be addressed.

A CARICOMP literature compilation has been produced. It consists of two elements: First, an ample literature search (including grey literature) to provide every participating laboratory with an updated reference list on Caribbean coastal ecosystems. Second, a selection of key papers on the main topics to be provided to each participating laboratory to have initially a uniform set of critical scientific papers.

Application of Research to Management

The main goal of CARICOMP is to provide an understanding of how mangroves, seagrasses and coral reefs function and interact, at the regional and local level in the Caribbean. But the ultimate purpose of CARICOMP is to contribute effectively to the rational management and conservation of Caribbean coastal ecosystems. However, adequate scientific knowledge alone, although indispensable, is not enough to utilize rationally and protect the coastal systems.

Recognizing that rational utilization and conservation of natural resources ultimately means legislation, information should be provided to managers and decisionmakers at different levels. In this sense, CARICOMP envisages linking the scientific knowledge and capacities developed by the project, with the wisdom of traditional uses of the coastal zone, and the needs and ways of modern society in the Caribbean. This approach, to be implemented once the first phase of the project operates, requires the incorporation of a socioeconomc analysis capacity and governmental participation.

The Steering Committee has been able to secure enough funding to start the program on a basic operational level, sometime in April-May 1992. The funding has been provided by the COMAR program of UNESCO, the National Science Foundation (USA) and the MacArthur Foundation (USA).

Suggestions for Future Philippine-Australian Coral Reef Research[a]

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One major approach to the promotion of coral reef management and conservation is the implementation of collaborative international research programs. Because the current workshop has been convened, in part, to set new priorities for future efforts of this type, it would be fruitful to evaluate briefly the need for such research, and some of the factors which should be considered in the design of multilateral research efforts. I will concentrate on the specific example of potential Philippine-Australian research, but many of the points raised would be applicable to programs involving other countries in Southeast Asia and elsewhere.

The paper will focus on: (1) factors which currently delay the implementation of effective reef management programs in the Philippines; (2) research areas which could improve reef management; (3) factors which currently delay research in the Philippines; (4) aspects concerning the design of co-equal collaborative projects; and (5) an example of a research topic, coral reef recruitment, which would make effective use of available expertise and study sites in both countries to improve reef management capabilities internationally.

The approach of the paper will be one of broad overview and initial prioritization. For the sake of brevity, the paper will consist of a series of outlines and short discussions where necessary.

Factors Delaying Philippine Coral Reef Management

1. Human population growth rate (del Norte et al. 1989)
2. Lack of alternative livelihoods (Smith 1979)
3. Training and fielding of community organizers (McManus et al. 1988)
4. Implementation of supportive educational programs (Castañeda and Miclat 1981)
5. Development of controlled small-scale tourism (McManus et al. 1992)
6. Social barriers related to clan structure (Ferrer 1989)
7. Public attitude toward destructive

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fishing (Galvez 1989)

8. Deforestation producing excess siltation (Hodgson and Dixon 1988)
9. Other sources of silt and pollution (McManus 1988)
10. Inadequate ecological evaluations (Gomez et al. 1981)

Ecological evaluations have been critical in the last few years in the identification of reef management problems, and in providing some general guidelines for alleviating them (Gomez et al. 1981). Currently, a high priority must be placed on the implementation of management strategies, and on social research to find better means of implementation (McManus et al. 1988). However, concurrent research on several ecological problems would improve the accuracy and precision with which effective management guidelines can be formulated.

Research Areas which would Improve Coral Reef Management

1. Motivation and persuasion theory (Cofer 1986)
   Improvement of group dynamics and information approaches to:
   - developing interclan cooperation;
   - enhancing adoption of new livelihoods;
   - conversion to better eating habits (more vegetables, etc.); and
   - altering attitudes toward destructive fishing.
2. Reef-flat gathering (McManus 1989)
   - gender and age dynamics;
   - importance in home consumption;
   - market research and development;
   - ecological evaluations of target species;
   - ecological impacts and resource use conflicts; and
   - traditional rights.
3. Resource predictability (Nañola et al. 1990)
   - how much of what species are where?
   - variations with changes in environment and exploitation
   - sociological and economic consequences of such changes
4. Resource exploitation guidelines (McManus et al. 1992)
   What combinations of these would provide for optimal long-term benefit to economically disadvantaged harvesters?
   - number of harvesters;
   - spectra of gear usage;
   - effort levels;
   - areas of the reef for harvest; and
   - harvest seasons.
5. Marine reserves (White 1987; Alcala and Russ 1990)
   What are the optimal sizes, shapes, locations and densities?
6. Better utility of resources (Santos 1988)
   - reduction of postharvest losses and diseases from improper handling;
   - localization of processing to maximize local benefits;
   - harvest of a broader range of organisms; and
   - broadening the range of products from the organisms.
7. Ecologically sound development (Pauly and Chua 1988)
   - mariculture research to produce alternative livelihood and protein sources;
   - small-scale waste treatment and recycling of wastes; and
   - guidelines for coastal industries and structures.

Factors Delaying Progress in Coral Reef Research

Some immediate impediments to research include the following:

- extremely inadequate library system;
- inadequate research salaries (A$200-$400/month);
- lack of funds for overseas Ph.D. training;
- lack of funds for local M.S. training;
- inadequate local research funds (typically $5,000/year/project); and
- inadequate local control over external research funds.

Co-equal Project Development

LEVELS OF HOST COUNTRY INVOLVEMENT. Many international research programs are offered to the host countries as essentially subcontracts for previously designed tasks. This impedes the development of coherent lines of research among host-country scientists directed toward the long-term needs of their countries. A preferable approach would involve the participation of host-country scientists in all phases of the planned research, including:

- setting research priorities;
- planning and submitting proposals;
- proposal acceptance procedures;
- all aspects of field and laboratory work;
- data analysis and publication; and
- project evaluation (periodic and terminal).

HOST-COUNTRY INPUTS. There is often a misconception that the bulk of the cost of a bilateral project in a host country is borne by the so-called "donor" country. Often, the developed country supplies primarily operational funds. Much of the personnel and facility costs come from the host country. In general, these are worth more to the economy of the host country than they would to that of the developed country, because they represent scarce and critical resources. However, even when host-country inputs are evaluated in terms of equivalent costs in developed countries, they generally exceed the operational costs of the project. A cursory analysis of the Philippine subprojects of the ongoing Australian-ASEAN Living Coastal Resources Program at Australian personnel and facility costs might serve as an example. A typical annual input of A$40,000 in operational cost for a subproject (including $20,000 in administrative and coordinating costs) might be matched by roughly $53,000 in personnel and $40,000 in facility costs. Thus, the host-country input is about 70% of the total cost (analysis based on midpoints of high-low estimations).

DEVELOPED COUNTRY BENEFITS. To understand the Earth, one must study Mars. To understand Australian reefs, one must study other reef systems. Some Australian researchers have been criticized for spending too much time working on non-Australian coral reefs. Some of the concern could be reduced with the implementation of properly planned bilateral and multilateral programs. A comprehensive understanding of processes affecting Australian reefs implies that the underlying mechanisms be fully understood. In many cases, progress toward elucidating these mechanisms can be enhanced through comparative research involving areas with substantial differences in climate, hydrology, geomorphology and other ecologically significant factors. Thus, a well-designed international program should be readily justifiable in terms of national concerns.

Example of a Bilaterally Beneficial Research Topic: Recruitment

1. Management implications of recruitment studies. Recruitment studies can improve:
   - resource assessment;
   - harvest guidelines;
   - reserve design; and
   - predictions about global warming.
2. Understanding recruitment implies being able to predict the effects (Sinclair 1988) of:
   - seasonal upwelling;
   - local entrainment features;
   - changes in habitats;
   - changes in harvest spectra; and
   - changes in nutrient levels.

In each case, there is a greater difference in reef conditions between Australia and the Philippines than there is within either country. Parallel studies in both areas could provide a better basis than currently exists for predicting such things as the effect on fish composition of increased fishing on the Great Barrier Reef, or the effects of alterations in hydrology related to climate change on the recruitment of important reef fish stocks in the Philippines.

Summary

1. The greatest impediments to coral reef conservation in the Philippines are related to problems in implementation of programs, and information gaps requiring further research in the social sciences.
2. However, there are many areas in which further ecological research would improve the management of Philippine coral reefs, especially with respect to the design of marine reserves and the development of programs aimed at optimizing the spectra of harvest effort on reefs.
3. Inadequate libraries, salaries, funds and project coordination currently inhibit progress in coral reef research in the Philippines.
4. Comparative international research programs can be directed toward alleviating some of these difficulties, while at the same time producing management information useful to all collaborating countries.

The Use of Refugia for Fishery Resource Management on Coral Reefs

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Refugia from fishing mortality (F) exist and have existed in virtually all fisheries. A uniform fishing mortality throughout a stock is the exception rather than the rule. Traditionally, temporal refugia such as seasonal weather conditions and spatial refugia such as habitats not accessible to fishing gears have ensured non-uniform distribution of F. Short-term refugia, such as closed seasons, are a traditional form of fisheries management but long-term spatial refuges such as marine fishery reserves are not used as commonly in fisheries management. This is despite the fact that the potential effects of spatial refugia were recognized in the early development of yield models of exploited fish populations (Beverton and Holt 1957). The concepts developed to adjust yield estimates in partially fished stocks sprung from a situation where 10% of the North Sea was untrawlable for plaice and dealt with potential fluxes of adult fish between fished and unfished areas. There seems little reason why such concepts cannot be extended to situations where refugia are imposed as a management measure and fluxes of both adult and larval fishes are included in the models. A great opportunity exists to blend into a management approach some existing, if preliminary, fisheries theory with the current enthusiasm for establishing marine parks. These ideas will be expanded upon briefly here in the context of management of coral reef resource systems.

The effects of long-term spatial refuges on fisheries yield from coral reefs will depend upon the nature and extent of interchange of fish between fished and unfished areas. Such interchange may occur as fluxes of adult or juvenile fish and/or pelagic larval fishes. The specific benefits or disadvantages will depend, among other things, upon life history characteristics of the exploited organisms (e.g., longevity, growth rates, mortality rates, lifetime fecundity, recruitment, dispersal characteristics) and the spatial extent and arrangement of the refugia. Various advantages and disadvantages of the use of long-term spatial closures to fishing in the management of coral reef fisheries are summarized in Table 7.

The remainder of this discussion paper will expand upon two potential advantages of long-term spatial refuges in the management of coral reef fisheries:

1. maintenance or possible enhancement of fisheries yield to areas adjacent to the closed areas via adult fluxes; and
2. potential long-term maintenance or even enhancement of fisheries

yield to broad regional areas by larval dispersal.

Table 7. Potential advantages and disadvantages of the use of long-term spatial closures to fishing in the management of coral reef fisheries (adapted and modified from PDT 1990).

Advantages

1. Reduction of chance of recruitment overfishing by maintaining a critical spawning stock biomass.
2. Potential long-term maintenance or even enhancement of fisheries yield to broad regional areas by larval dispersal.
3. Provision of undisturbed spawning/breeding grounds for fishes.
4. Maintenance of intraspecific genetic diversity.
5. Provision of unfished populations for scientific research.
6. Maintenance or possible enhancement of fisheries yield to areas adjacent to the closed areas via adult fluxes.
7. Protection of community/ecosystem structure and thus maintenance of interspecific genetic diversity.
8. Data collection needs for management are reduced and management occurs without complete information and understanding of population parameters of every species, nor of interactions between species.
9. Direct economic benefits through tourism.
10. The concept is easily understandable by the general public and more easily accepted than some other management strategies.
11. Surveillance and enforcement are simplified.
12. Reduction of temptation of fishers to violate laws.
13. Protection of fish habitat.
14. Provision of areas for educational use.
15. Populations in closed areas may be used as sources of broodstock in mariculture and for possible restocking of depleted areas.

Disadvantages

1. Concentrates fishing effort on a smaller portion of the stock.
2. Less of the stock is available to fishers, possibly reducing short-term fisheries yield.
3. Any benefits to the fisheries may manifest themselves only in the long term.
4. Closed areas create an increased incentive for deliberate poaching.
5. Increased need for intensive surveillance and enforcement.
6. Strong local resistance is likely in those specific areas where closures are proposed.
7. Uncertainty concerning size, location and number of spatial closures necessary to ensure persistence of reef fisheries.
8. Long-term and detailed research required to justify spatial closures.
9. Unlikely to be useful for highly migratory species.
10. Resistance of fisheries managers to "new approaches".
11. Closed areas should ideally include all habitats necessary for maintenance of all life history stages.

Adult Fluxes across Boundaries of Refugia

Closed areas may provide a "growth refuge" where fish under F=0 survive, grow and perhaps later move into fished areas. Movement to fished areas can be either directed (emigration to fished areas) or random across boundaries between closed and open areas. Both types of movement may enhance yield per recruit and total yield under high levels of F in fished areas (Beverton and Holt 1957). Predictions of potential yield from fished areas require very detailed knowledge of directions and rates of movement of fish between fished and unfished areas.

Alcala and Russ (1990) report that the presence of a marine reserve at Sumilon Island, central Philippines, enhanced total fishery yield from the 0.5 km^2 coral reef. The evidence for this was based on a natural experiment. Twenty-five per cent of the coral reef was protected for almost ten years (1974-1984), permitting the buildup in the reserve of a large standing stock of fishes of the type which constituted the majority of the yield from the island (caesionids). This biomass was pulse-fished for 18 months (1984-1985) reducing the standing stock by more than half in the reserve. Catch per unit effort and total yield were both higher when the reserve existed than when it did not. Alcala and Russ (1990) suggest that active migration of fishes from the unfished to fished area could account for the result. Subsequently, simulations using *assumed* levels of random movement between fished and unfished areas have demonstrated that the presence of the reserve could theoretically enhance yield per recruit (at high levels of F) of a dominant caesionid in the yield (Russ et al. 1992). It is not suggested here that the model used was the best or even a totally appropriate one. Nevertheless, the concepts may form a theoretical framework for development of models which, given detailed knowledge of movements, growth and mortality, may allow managers of the marine coastal zone to make predictions of the effect of marine reserves on fisheries yields.

Larval Fluxes across Boundaries of Refugia

Refugia may reduce the chance of recruitment overfishing by maintaining a critical spawning stock biomass. A residual spawning stock in areas closed to fishing potentially can supply fished areas with recruits because larvae of reef fishes can disperse over large distances (tens to hundreds of kilometers - Doherty and Williams 1988). Refugia may help to ensure recruitment supply even if other areas are exploited heavily. Furthermore, areas closed to fishing allow individuals to live longer, grow larger and become more fecund. Such increases in fecundity may enhance recruitment to fished areas and thus compensate for the reduced area available for fishing. Closed areas should provide a ready source of supply of larvae to fished areas downstream. Such benefits are possible in areas such as the Great Barrier Reef Marine Park, where 5-10% of the area of the park is closed to line fishing.

Based upon detailed biological and fisheries knowledge of *Lutjanus campechanus* (red snapper) and other reef fishes on the southeastern shelf of the USA, a team of fisheries biologists from the US National Marine Fisheries Service has proposed a reef fish management plan which has long-term, large-scale spatial closures to fishing as its central theme (Plan Development Team (PDT) 1990). Very high levels of fishing mortality in this reef fishery in the 1960s, 1970s and 1980s have reduced the spawning stock biomass of many species to dangerously low levels. For example, the spawning stock biomass per recruit of the red snapper was estimated to be between 1.5 and 1.8% of the unfished level. It was estimated that under high fishing pressure, total fecundity was only 5% of that at low fishing pressure (PDT 1990). However, by protecting 20% of the stock, it was estimated that total fecundity would increase fivefold over that under heavy fishing pressure. The team has proposed creating marine fishery reserves on 20% of the southeastern continental shelf of the US.

In terms of basic demographic information on target species, such as growth, mortality and recruitment, this is probably the best studied (in a fisheries context) reef fishery in the world. Relatively sophisticated analyses such as yield per recruit and egg per recruit have been carried out on many of the important species (PDT 1990). However, regulators have been unable to control fishing effort and fishing mortality by conventional fisheries management strategies and this team has opted for long-term, large-scale spatial closures as the best means to conserve stocks. If such a situation can arise in a developed country such as the United States, the message has even greater gravity for developing countries where rates of human population increase and pressure on reefs is generally much greater. A recent Asian Development Bank-funded fisheries management plan for the Philippines has establishment of marine reserves as a major strategy (White and Lopez 1990).

Conclusion

Detailed research on patterns of reef fish growth, mortality and adult movement will have to be carried out before any marine park is established which is of appropriate size, shape and location to allow an explicit statement of its effect on a reef fishery. Furthermore, effects are most likely to be site- and species-specific. The more substantial and longer-term benefits of refugia are likely to be their potential for maintenance or even enhancement of fisheries yield to broad regional areas by larval dispersal. Given the critical levels of overexploitation of coral reef resources in many parts of the world, they may be the *only* viable option available to maintain levels of spawning stock biomass necessary to sustain reef fisheries.

Facilitating Changes in Artisanal Fishery Practice at Discovery Bay, Jamaica

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Coral reef fishing in Jamaica is largely artisanal, carried out by one to five men in dugout, plank-built, or fiberglass canoes. It is important on the south coast, from which there is access to a wide island shelf and offshore banks. On the north coast, it is less important, because the island shelf is very narrow (less than 1 km wide), and the local economy is better developed. The impact of fishing, as of other terrestrial influences, is especially acute on the narrow northern shelf, where access to the fishery is so easy. Moreover, that impact is concentrated into a small area.

The Fisheries Improvement Project, funded by the Canadian International Development Agency (CIDA), is a collaborative enterprise between the Department of Biology of Trent University and the Discovery Bay Marine Laboratory of the University of the West Indies. Its aims are to assess the status of the fishery, and to work with the fishers of Discovery Bay to help them introduce management measures.

Discovery Bay Fishery

Discovery Bay is a small north coast town where most employment is in the bauxite industry, tourism, service industries or agriculture. There is not a homogeneous fishing community, although some coherence is imposed by the use of two fishing beaches at which most of the boats are based. Some of these men have no other source of income, some have regular paid employment and some have occasional jobs or do a little farming. The major gear types are stick-framed wire-mesh fish traps, spears, hook-and-line and gillnets. Spearfishing was almost unknown 20 years ago, but is important today.

Fish stocks at Discovery Bay are over-exploited. Fishes readily trapped, hooked or speared (e.g., snappers, larger groupers and barracuda) are scarce in visual censuses (Miller et al., in press) and in catches, which are dominated by the less desirable parrotfishes and surgeonfishes (Picou-Gill et al., in press).

General Problem

People exploiting an already overexploited fishery can increase their catches in two ways: they can increase fishing effort, for short-term gains, or they can reduce fishing effort, for long-term gains. Ultimately, the former approach will fail as stocks of fish become further reduced. It is preferable for the community (if not for the individual) to reduce fishing effort and allow fish stocks to recover to levels that can sustain higher yields. Recommended ways of doing this include gear changes, fish sanctuaries and limited entry to the fishery (Munro and Williams 1985). All of these management measures require individuals to forego income. Further, they require some organization and cooperation within the fishing community.

Jamaican Situation

ECONOMIC PRESSURE. Dominant among the social and economic factors influencing the behavior of fishers in Jamaica (Allison 1992) is the country's low economic status. It is relatively poor, heavily in debt to the International Monetary Fund, and cannot afford extensive social services; there is no unemployment support, although there is high unemployment (perhaps 25%) and underemployment. For most people, times have always been hard; in 1991, they became much harder, as the Jamaican dollar devalued by 60% and the cost of living rose in response. Even employed people feel the need to supplement their income somehow.

INAPPROPRIATE BELIEFS. It is a common belief that fishing pressure cannot affect the abundance of fish ("Fish can't done!"); that it is sacrilegious to presume otherwise ("If fish in my trap, is God put it there!") and that other factors are responsible for the decline in catches.

LITTLE CO-OPERATIVE ORGANIZATION. There is no tradition of cooperative fishery management in Jamaica, such as has evolved in some Pacific territories. Jamaican fisheries developed as an individual pursuit, along with peasant farming, when people moved away from the plantations after the abolition of slavery in 1838. Only in recent decades has the overexploitation of fish resources become acutely evident (Munro 1983; Aiken and Haughton 1991), consequent on the introduction of more efficient gear, on an increasing population and on the deteriorating economy. Moreover, there have always been alternative sources of protein and income to bypass the feedback loop of natural selection.

MUTUAL DISTRUST. Because of the frequency of theft, distrust is prevalent. At Discovery Bay, trap fishers do not trust each other; especially those from the other beach. They do not trust spearfishers and each group blames the other for the decline in the fishery. Previous attempts to start cooperatives have failed, either because nothing was done, or because the Treasurer absconded with the funds. Not fertile ground for the growth of cooperative management!

Promotion of Cooperative Action

EDUCATION. The Fishery Improvement Project is working to increase fishers' knowledge about fishery management (Van Barneveld et al., in press). Notice-boards have been set up at each beach and slide and video shows are given. Every opportunity is taken for informal discussion; for instance, when collecting fishery data. Our hope is that increased knowledge will be followed by changes in attitudes and behavior.

THE TWO-FOR-ONE MESH EXCHANGE. It has long been recognized that the wire mesh commonly used for fish traps in Jamaica is of too small a gauge. The "one inch" and even the "inch and a quarter" mesh retain such small individuals of economically important species that fish of more valuable size become scarce, and the reproductive potential of the stock could be reduced. Munro (1983) recommends an increase to "two inch". The Fisheries Division of the Ministry of Agriculture encouraged a progressive increase in mesh size; "one inch" mesh is no longer available from the Jamaica Co-operative Union, the principal source of fishing gear. However, it is necessary for chicken farmers and can still be bought in hardware stores.

The Fisheries Improvement Project had budgeted funds to supply larger gauge wire mesh to fishers (who normally build their own traps), and selected "inch and a half" since it was readily available and was not too big an increase (50% over 1", 20% over 1¼"). But how to issue it, and to whom? The strategy adopted was as follows (Sary et al., in press).

The larger gauge wire mesh was offered in exchange for fish traps, in working order, made of small-gauge wire. Further, we offered sufficient wire to build two traps, for each one that we took in. Thus we proposed: (1) to remove the "fine-mesh" trap from the fishery; (2) replace it with larger-mesh gear; and (3) compensate the fishers for potential loss of income (due to the escape of small fish) by increasing the number of fishers' traps.

Acceptance of our offer (made in March 1991) was slow; it was a month before any trap was turned in. But by the end of the year, 44 of 47 active trap fishers had brought in 213 small mesh traps. Of the other three, two already used the larger mesh exclusively; only one old man has refused to change. We had issued 90 50-yard rolls of wire, costing CAN$12,250.00. Further, after dismantling the traps, the old wire mesh was given to women in the community who wanted to raise chickens; another developmentally valuable action and, in explaining how we got it, an opportunity for further fishery education.

The exercise shows that a well-designed incentive can bring about simultaneous action. Most individuals are glad to have changed; some perceive better catches. But it is too early for our data to show increased recruitment to larger size classes.

CREATION OF FISH SANCTUARIES. We are promoting discussion among fishers, and in the wider community, about the creation of protected areas. This was the most generally favored management measure in a questionnaire given to fishers because it would apply to everybody (Vatcher, in press). But any proposed area would be the habitual fishing ground of a few individuals, to whom some kind of compensation might be appropriate.

FORMATION OF A COOPERATIVE. If community-based management is to become a reality at Discovery Bay, a fishers' organization must be established. First, there must be a shared perception of mutual benefit. But the more successful persons have no wish to share the benefits of their skill. The less successful might band together in desperation, having only a vague idea of the benefits. But we were pleased (and surprised) when asked by a group of fishers to help them form a cooperative. It remains small, but may be the only hope for the improvement of the fishery at Discovery Bay (Van Barneveld et al., in press).

Management Options for Small-scale Fisheries[a]

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In addition to their unique biological characteristics, "coral reef fisheries have a feature which separates them from all other 'marine systems'; the presence of coral outcrops makes the use of trawls and other modern industrial fishing gears unfeasible. Coral reef systems are, therefore, the domain of the small-scale fisher. The sheltered waters created by the coral reef systems, combined with the high productivity of the system, have been an inducement to human settlement". Until recently, the exploitation of coral reefs has been tempered by traditional tenures and taboos. Population pressures in developing countries are now leading to degradation and overexploitation of many coral reef systems, and consequently threatening the productive base on which many of the coastal communities were founded. In many areas, traditional management practices have been discarded. This process will continue until new ways are found to protect and manage coral reefs.

Small-scale Coral Reef Fisheries Sector

Who are small-scale fishers? A dualistic structure often underlies the marine fisheries sector in most developing countries of the world. A traditional, small-scale fishery usually exists side by side with a modern, large-scale industrial fishery. The coral reef fishery exploited by small-scale fishers is

[a]ICLARM Contribution No. 1064.

multispecies, exhibiting high productivity and strong interspecies relationships. The fishers generally utilize multiple fishing gears, which may be highly specialized and designed for a specific location, to target a variety of fish species available either throughout or at specific times of the year. Multigear coral reef fisheries in the tropics are characterized by multigear competition, which results in variable income distribution.

It is important to emphasize that small-scale fishers in developing countries who exploit coral reef fisheries are very different from their industrial fishery sector counterparts in both developed and developing countries. These social, cultural, economic, institutional and political differences must be documented and understood before effective management can proceed. The "problems" of the fishery must be examined in the context of the economies of which they are a part. Most often, solutions will lie outside the fishery. This may often require site-specific analysis of coral reef systems and of the fishers and fishing communities which exploit the resource, since different locations have unique problems and opportunities.

The small-scale fishers can serve as a primary source of information for understanding the coral reef system. Their input should be solicited from the beginning of any coral reef management activity and their active participation in management will provide greater chances for success. The fishers' attitudes and perceptions toward the resource must be understood, for these are largely influenced by economics and a sense of dependence on the survival and sustainability of other resource bases. The traditional institutions and systems for management should be documented. This reasoning is rooted in the communality of the resource and use patterns that are often based on traditional rights and territories (Ruddle and Johannes 1990).

Human Impacts on Coral Reef Systems

Human impacts on coral reefs can be broadly defined as overexploitation, physical damage, changes in the deposition/erosion environment and chemical pollution. Fish stocks, though providing a flow resource, are finite. Underlying all concerns about coral reef management is the growing indication that many of the coral reef fishery resources upon which small-scale fishers depend are biologically and economically overfished. This is in part due to the "open-access" nature of the coral reef resource. A characteristic of all open-access capture fisheries is that in the long run effective fishing effort will expand far beyond the level which maximizes either economic benefits or sustainable catch, to the point where costs become so high and catch so low that no net economic benefit (or resource rent) is being derived. While the individual fisher, especially one who faces a daily problem of survival, may not see "open-access" and the resulting overexploitation as a problem, it is certainly felt in terms of low productivity and fishing income (Smith 1979). An example is the fisher who attempts to increase short-term income by using blast fishing which destroys the reef itself.

A variety of destructive activities impact upon the coral reef system. Coral reefs are commonly destroyed by siltation and sedimentation. The combination of deforestation (both legal and illegal logging) and poor land use practices (such as slash-and-burn agriculture) have reportedly depleted at least 60% of the reefs of Southern Asia. Other sources of increased sedimentation include the dumping of mine tailings and offshore oil drilling. The impacts of sedimentation are often irreversible.

Another major destructive activity is intense and destructive fishing methods such as blasting, use of cyanide, "muro-ami", trawling, gleaning and spearing.

Although commonly referred to as "dynamiting", blast fishing involves a vast array of commercial, military and homemade explosive devices. The impacts of blast fishing may destroy coral for a radius of at least 2 m. Cyanide is used to stun high-value, aquarium coral reef fish. The "spraying" of cyanide on fish hidden in coral recesses often kills the coral itself. Muro-ami (a method to drive fish into nets using weights on scare lines) and kayakas (a similar method using sticks) result in breaking of corals. Excessive collection of marine organisms through gleaning has been found to be a major destructive force in many areas.

Other destructive activities include boat anchorages of all kinds, pollution from urban and industrial areas, and tourism from heavily frequented areas. The rate and causes of disturbance to coral reefs are well documented by, among others, Yap and Gomez (1985); Salvat (1987); and White (1987).

The degradation of coral reefs has led to a number of serious economic and social costs. These include the lost value of fish production, lost jobs and income, malnutrition and undernourishment, loss of tourism income, and an overall reduction in the quality of life.

Thus, any coral reef management strategy must take into account these many and widespread destructive activities. Solutions to these destructive activities, while being fishery-centered, may lie outside the fishery sector, for example, in the forestry or agriculture sectors to reduce siltation. A management strategy must be aware of and take into account these intersectoral linkages to be successful.

Management Approaches

A variety of alternative coral reef management strategies are in use or have been suggested. These approaches have had varying degrees of success, although some isolated successes can provide information for future planning. It should be emphasized that the objectives which are expected to be obtained from management and the strategies used will vary from country to country and between areas within a country. Also, conservation of the reef environment is an essential prerequisite to managing the fishery (McManus 1988).

Many coastal fishing societies possess systems of customary marine tenure (sometimes referred to as traditional fishing rights or territorial use rights in fisheries (TURFs)) (Christy 1982; Ruddle and Johannes 1990). The ability of customary marine tenure owners to protect their marine resources through the exclusion of outsiders provides them with an incentive to harvest in moderation.

Various types of formal fishery regulatory techniques exist to cause the fishery to change from the open-access harvest time pattern to a more desirable pattern. The majority of these techniques were designed for developed-country situations where adequate administration and enforcement resources exist. However, if carefully designed and implemented, several have potential for coral reef management in developing countries. These include restricted harvests (size limit, closed season and protection of gravid females), gear restrictions, closed areas and limited entry (annual or permanent licensing and exclusive access) (Munro and Williams 1985).

Although fishing regulations have rarely led to noticeable changes in reef management in developing countries, it is likely that if the regulations did not exist, the undesirable practices would be far more widespread than they are today. Therefore, although the laws do not lead to a halt to an undesirable practice, they may serve to limit its proliferation. As with any fishing regulation, implementation and compliance are a result of the resources which are put into enforcement. Most developing countries do not have adequate resources for administration and enforcement of regulations from centralized agencies. Even vigorous enforcement (if all feasible or attainable) may not work given the marginal existence prevalent in many fishing communities.

Several countries around the world, with assistance from international donor and research organizations, have initiated work in coastal zone management, including coral reef resources. A major effort in this direction is the ASEAN-US Coastal Resources Management Project (CRMP). This program involves interdisciplinary studies of model coastlines in each ASEAN country. The CRMP uses a "bottom-up" approach, based on sociological, economic and environmental studies at the village level, which leads to recommendations for local control of the resources, where feasible. This approach is particularly applicable in the management of the vast range of coral reef resources (White 1991).

The most direct attempts at coral reef management have involved the establishment of marine parks and reserves. Many regions around the world have gained experience with this approach. A marine reserve constitutes a defined space to which some form of management and limited entry is applied.

Of the nearly 100 marine parks and reserves set up in Southeast Asia, the handful which appear to have been most successful have been those established utilizing a community-based or village-level management approach. Community-based management is a decentralized management system incorporating resource-user participation and holistic development approaches in the implementation of management efforts. Community-based management acknowledges the existence of local variability, local knowledge and skills, and local accountability and uses these factors to manage the resource. It should be understood, however, that the vast majority of community-based management programs will not be truly "local". Some form of co-management with a government agency will be required and will often entail the restructuring of institutions to allow the new management system to operate (Korten 1986).

One of the least costly coral reef management tools is education. There is often a low awareness, as well as a poor understanding, of conservation and resource management issues among most coastal communities. There is a need to promote resource management awareness through education. This in return will raise the acceptance of the community of the management process and activities.

In addition to the above management approaches, other strategies for coral reef management may include the development of alternative livelihood activities to reduce fishing effort (i.e., nondestructive mariculture projects); training in alternative fishing practices (i.e., the use of nets versus cyanide to collect reef aquarium fish); the use of ecological manipulations, such as artificial reefs and supplemental stocking, for habitat enhancement; the development of new and/or alternative fisheries and price and marketing strategies to reduce or expand effort for particular species or fisheries.

The key to success appears to revolve around resource-user participation, understanding local variability and needs, and being innovative in developing management methods and techniques. The institutions which manage coral reef fisheries, both traditional and modern, must be understood.

Community-Based Management of Coral Reef Resource Systems: South Pacific Experiences

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The management of any resource system, those of coral reefs included, involves the management of human activity. The day-to-day utilization of resources and long-term transformation of resource stocks by human populations are integral parameters of coral reef management, far more so than the usual status of these activities as external "socioeconomic" contexts would indicate. An integrated approach to these problems is in fact taken in a great variety of community-based management systems, devised and operated through generations by the local people who engage in the direct utilization of coral reef resources. These systems are increasingly documented from locations throughout the tropics and beyond (Ruddle and Akimichi 1984; Gray and Zann 1988; Cordell 1989). An extraordinarily large and varied number of such systems of customary marine tenure ("CMT", cf. Hviding 1991) are found in the island societies of the South Pacific (Ruddle and Johannes 1990). Customary marine tenure systems which regulate access to and use of marine resources in reef and lagoon environments, function as fisheries management systems and may, under certain circumstances, ensure long-term conservation (Johannes 1978). In many Pacific Island nations, CMT systems play an important role in the contemporary development and management of inshore marine resources. The customary control over reefs by the people who live by them and from them acts both as a constraint on large-scale development, and as an opportunity for decentralized enforcement of locally appropriate resource use regulations. This is the case particularly in those countries where customary law and its associated rights and privileges are given formal legislative recognition, as is the case in a number of Pacific island nations (Hviding and Ruddle 1991).

CMT systems in the South Pacific are based on property rights usually inalienable, over inshore reefs and seaspace and the living and nonliving resources found within sets of recognized boundaries. These rights are usually held as communal property by groups of people bound together by common kinship and residence and are usually recognized by neighboring groups (for detailed analysis of a CMT system in Solomon Islands, see Hviding 1988). CMT systems are actually complex sets of mechanisms for the regulation of highly multispecies, multigear fisheries. They contain management measures such as gear restrictions, protection of species, quotas, seasonal closures, and de facto licensing of fisheries through limited entry by the exclusion of outsiders.

Recent research shows that these measures often operate in an overlapping fashion, with multiple levels of fishing-related rights held by individuals and groups, with commercial activities being more strictly regulated than subsistence fisheries, and with prescribed procedures for obtaining resource use permissions on a temporary or permanent basis. Furthermore, inshore seas and reefs thus managed by local communities are in many cases subject to zonation, where different regulations apply to different subsections of reefs, often according to different seasons. One example is that of spawning grounds of important food fishes subject to closures for the duration of the spawning season. Also, certain easily depleted species such as trochus shell, bêche-de-mer or turtles may be temporarily protected in part of or throughout the reefs held by a specific group, whereas less stringent regulations apply to less vulnerable resources in the same areas.

This brief listing of management measures applied by Pacific Islanders may strike a familiar note with many coral reef managers working from a Western scientific point of view (Johannes 1978). Indeed, a comparison of customary marine tenure systems with formal, elaborately written management plans such as those developed by the Great Barrier Reef Marine Park Authority shows striking similarities in fields like multiple-level restrictions, zonation, limited entry, licensing requirements and the consideration of interdependencies among the ecosystems and economic activities of both sea and land. From the perspective of Pacific Islanders, the modern management plans for the Great Barrier Reef could actually be interpreted as approximations of their own traditional systems.

In the Pacific Islands, the assertion of community-level rights over coral reef resources nowadays frequently meet commercial challenges from outside (cf. Hviding 1988). A brief survey of contemporary issues in the South Pacific indicates that CMT systems in various ways shape the course of externally initiated activities such as industrial tuna bait fishing, the cultivation of seaweed, pearl oysters and giant clams, diving-based tourism, the poaching of giant clams by Asian vessels and even land-based developments of logging and mining, through protests from reef-holding groups against river-carried sedimentation from soil erosion. The traditional resource managers of the Pacific Islands thus obtain experiences from fields that range far beyond their coastal villages. Though "community-based" through having communally held property as their foundation, CMT systems today have a scope that far transcends the local community and its co-equal neighbors.

The fact that ecological processes in coral reef and lagoon systems are influenced by terrestrial, inland developments, is well recognized, not least by the women, who exploit the inner coastal zone intensively for the gathering of shellfish and crabs from mangroves. Thus, the "coral reef resource system" perceived by local people includes far more than just reef finfish, extends spatially and ecologically far beyond the "home reef" and embraces habitats like mangroves and estuaries. Also, through fishers' intimate knowledge of fish migrations and spawning aggregations (cf. Johannes 1981), ecological interrelations between distant, but connected reefs are often recognized. If, then, we consider a resource system in terms of its boundaries, the systems perceived and managed by Pacific Islanders involve activities and ecological links of a decidedly nonlocal nature and we are actually looking at very large linkages of events involving resource appropriation, usage and transformation.

During the last decade, the growing

interest in community-based management systems and their associated environmental knowledge has evolved in tandem with a recognition that standard western biological and economic models are inadequate for the management of tropical inshore, multispecies fisheries (Hviding and Ruddle 1991). On this background, the question may be asked whether CMT systems as they are found in the South Pacific region can form the basis for effective inshore fisheries management elsewhere, under similar ecological conditions. A direct transfer of management systems from the South Pacific, in the form of blueprint models, is hardly feasible. CMT is inextricably linked with the wider social and cultural contexts from which it emerges. Also, the direct applicability of such systems is also contingent on a form of government characteristic of the small island nations of the South Pacific, involving a mixture of local-level autonomy, devolution of power and national recognition of customary laws, which is not found everywhere in the tropical world. However, there is every reason to believe that the community-based management systems associated with coral reefs in the South Pacific have a lot to contribute throughout the tropics, indeed worldwide, to innovative thinking about inshore fisheries management. These systems contain a great number of potentially valuable lessons and practical tools for handling important challenges of resource assessment and local-level enforcement and compliance, and in approaching the complexities of multispecies, multigear fisheries and integrated coastal zone management.

Monitoring and Enhancement of Coral Reef Resource Systems

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This paper presents a short summary of some recent resources research and conclusions relative to the areas of monitoring and enhancement of coral reef resource systems.

Monitoring of Coral Reef Resource Systems

In 1990, the Hawaiian lobster fishery experienced a major failure in recruitment at banks in the northwestern half of the fishing grounds. Research since then has produced evidence indicating that this regional failure was not due to overfishing but to a change in oceanography which impacted larval retention and survival. Further, based on regional and global sea level data, it appears that large-scale ENSO (El Niño-Southern Oscillation) events are responsible for the regional recruitment failure. We hypothesize that meso-scale fronts are responsible for the retention and survival of lobster larvae near some areas of the archipelago and that ENSO events can change the position and strength of these fronts and hence subsequent recruitment to the fishery (Polovina and Mitchum 1994). Sea level data correlate very well with regional recruitment and may be useful to management as a four-year forecast of the exploitable population (Fig. 7). Other components of the ecosystem, specifically reef fishes, sea birds and monk seals, have shown substantial fluctuations which may be linked to oceanographic changes resulting from ENSO events.

It is therefore concluded that:

1. large-scale environmental change can have different impacts within an archipelago;
2. regional comparisons of environmental or biological parameters between areas within an archipelago, or even between archipelagoes, can offer a powerful experimental design;
3. sea level is widely measured throughout the Pacific and may be an excellent environmental index;
4. sea bird diet and breeding success rates may respond to changes in the marine ecosystem and are relatively easy to monitor; and
5. ENSO versus non-ENSO periods may provide the greatest environmental contrasts for Pacific marine ecosystems.

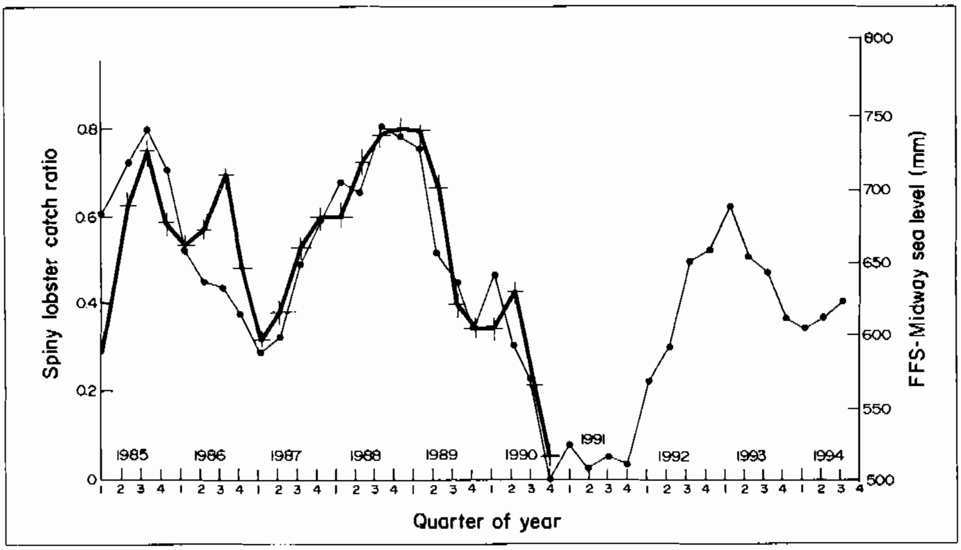

Fig. 7. Three-quarter moving average of the ratio of quarterly landings of spiny lobster at Maro Reef to quarterly landings at Maro Reef and Necker Island (+) overlaid with the three-quarter moving average of sea level at French Frigate Shoals (FFS) - midway advanced by four years (•).

Enhancement of Reef Resources with Hatchery Releases

Mathematical models, such as the yield-per-recruit, dynamic surplus production, and age-structured models can offer some insight into the benefits from juvenile stocking based on various life history and environmental characteristics (Polovina 1990, 1991). The yield-per-recruit model indicates that the contributions of hatchery releases to a fishery are sensitive to two population parameter ratios: the ratio of natural mortality to growth (M/K), and the ratio of fishing mortality to natural mortality (F/M). The fishery yield-per-hatchery juvenile increases as F/M increases and as M/K decreases (Fig. 8). Thus even for a slow-growing rockfish, hatchery releases may contribute substantially to fishery yields because the magnitude of the contribution does not depend on the actual values of M or K but on their relative values defined by the ratio M/K. A dynamic age-structured model was used to simulate the contribution of hatchery releases to rebuild an overfished population of Pacific ocean perch, *Sebastes alutus* (Polovina 1991). A variety of rebuilding and fishing strategies were simulated and the results suggest that hatchery releases may be an economically beneficial tool to rebuild depleted populations (Fig. 9).

The Oceanic Institute conducted field trials to evaluate the impact of releases of hatchery-reared striped mullet, *Mugil cephalus*, in select nearshore fishing areas in Hawaii (Oceanic Institute 1991). They experienced the greatest recapture of hatchery fish in Hilo Bay, Island of Hawaii. In August and October 1990, a total of 30,000 tagged juvenile mullet 45-130 mm were released in two areas of Hilo Bay. It was subsequently estimated that 15.7% of the mullet captured by the recreational

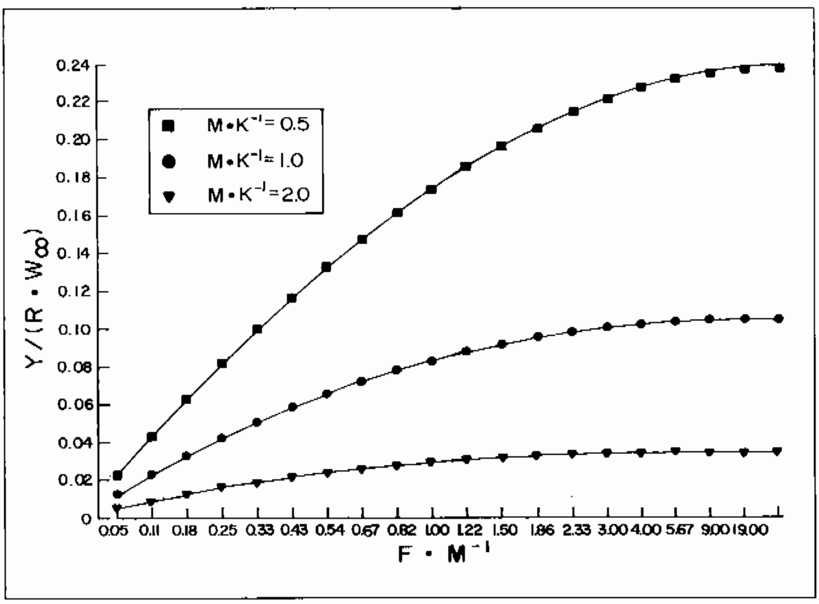

Fig. 8. Beverton and Holt yield-per-recruit as a fraction of asymptotic weight at optimum size at entry to the fishery as a function of F/M for three levels of M/K.

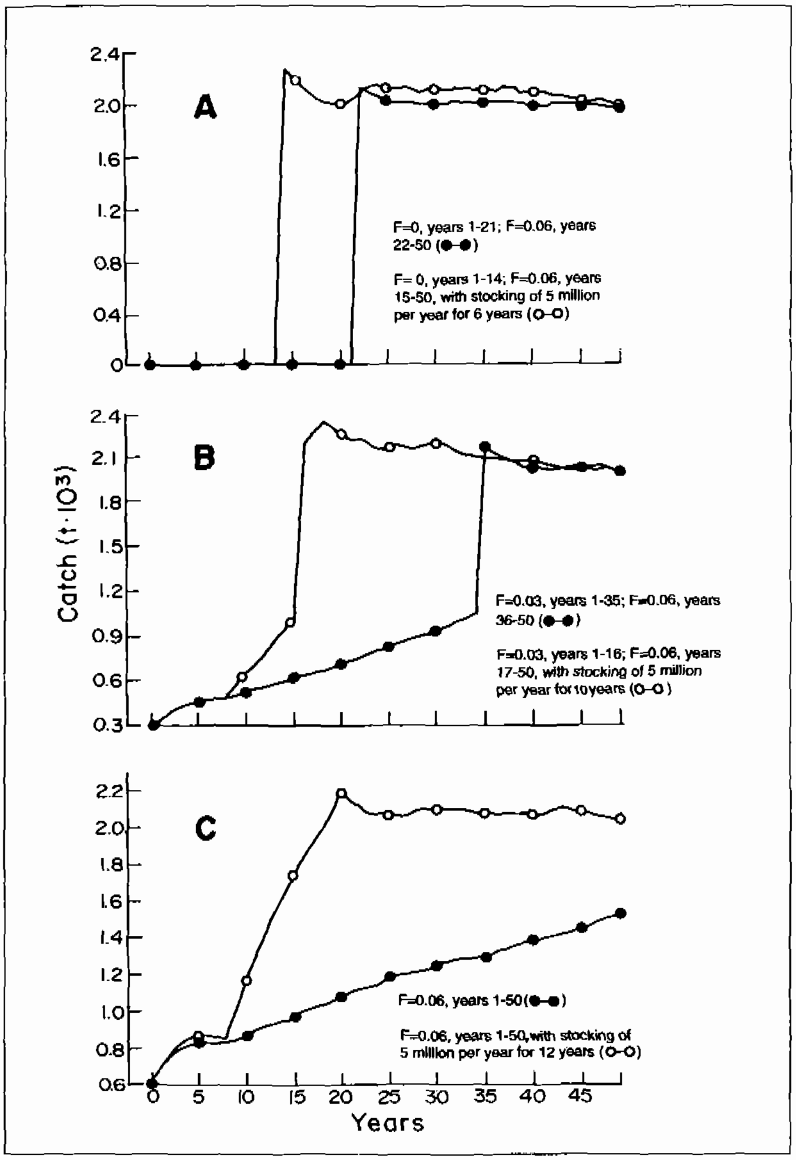

Fig. 9. Simulated annual catches of Pacific ocean perch, with and without hatchery releases, for three management strategies.

fishery were hatchery fish (Oceanic Institute 1991).

Tropical hatchery release programs should be aware of the current controversy over the use of hatcheries for salmon fishery enhancement. There appears to be a decline in the success of hatcheries to enhance salmon fisheries as well as concerns about the loss of genetic diversity (Hilborn 1992).

Enhancement of Pacific Island Invertebrate Fisheries by Restocking

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In a number of Pacific Island countries, stocks of several inshore marine species of subsistence or commercial importance have been reduced or completely eliminated, mainly by fishing activities. This is particularly true of sessile or slow-moving invertebrates, including giant clams, pearl oysters, trochus, green snail, coconut crabs and others. Where these stocks are still intact, growing levels of fishing pressure threaten to reduce them in a similar way. Other resources, such as sea cucumbers (or bêche-de-mer), are also increasingly threatened because of their relative ease of harvesting and the increasing profitability of collecting them.

In recent years, the concept of re-establishing these populations through the use of aquaculture or "ocean ranching" has been widely discussed, and it is gaining currency in the region. Aquaculture programs have been conceived and, in some cases, established with the specific aim of producing juveniles or adults for use in restocking programs. Hatcheries have been established for giant clams and trochus specifically to produce animals - either adults or juveniles - for release into wild populations. Attempts are underway to develop similar facilities for other species, such as bêche-de-mer. Interest in this type of ranching or restocking is being fuelled by increasing levels of commercial exploitation of vulnerable inshore species. However, restocking may also be considered as a means of mitigating environmental degradation, or simply of improving the productivity of natural populations, especially those that may be recruitment-limited.

Restocking is taken here to refer to a group of related techniques for the enhancement of natural populations of selected marine resources by the conduct of aquaculture and associated activities. The term, which might be better expressed as "aquacultural resource enhancement" (ARE), embraces all activities which involve:

- the deliberate placement, transplantation or restocking of juvenile animals that are produced in hatcheries; or collected from natural habitats, and protected from predation for some part of their life cycle;
- the enhancement of natural recruitment by augmenting, concentrating or protecting broodstock;
- increasing spat or juvenile settlement by providing artificial substrates (spat collectors, etc);
- reducing natural mortality by creating artificial habitats, shelters, or other forms of protection.

There is considerable overlap of these categories of ARE with each other and with more intensive forms of aquaculture, often with no clear boundaries. In some cases it is clear that ARE will only be warranted if it is supplemented by additional measures such as fishery regulation or management, or pollution control.

In 1988, the SPC Inshore Fisheries Research Project (IFRP) and the FAO South Pacific Aquaculture Development Programme (SPADP) jointly presented a short working paper (WP9) to the 20th SPC Regional Technical Meeting on Fisheries (RTMF) that discussed issues relating to reef resource enhancement through aquaculture. The paper, and the ensuing discussion of the topic during the meeting, revealed that there was a high level of interest in the use of aquaculture techniques (and especially juvenile-release programs) as a means of enhancing stocks of depleted fishery resources. However, it was also agreed that the information available to evaluate the potential usefulness of restocking (with juveniles or adults) as an enhancement tool in any given fishery situation was inadequate. There was a general concern that most present efforts were focused principally on the development of aquaculture technology, especially that for the production of juveniles, while the basic biological issues that control whether restocking of any given species might be successful were receiving less attention than they should. This led to two risks: one, that effort and funding would be expended on aquaculture activities that might not be rewarded by real enhancements to fishery stocks; and two, that fishery management practices or philosophies might be modified in the expectation that fishery restocking programs would be successful before this had been demonstrated to be the case.

The meeting agreed on the need for improved information on the role that aquaculture might play in resource enhancement in the region, and recommended that IFRP and SPADP collaborate in a two-phase project to elucidate some aspects of this debate.

Phase 1 of this collaborative activity was to involve the collection and dissemination of pertinent biological information on Pacific Island species for which restocking might be considered, and on reef ranching experiences elsewhere. This was to take place by consultation with specialists in the field, a literature review and the preparation of a report of the initial study findings. The concept of a technical workshop on reef resource enhancement issues was considered as a possible means of both acquiring and disseminating more detailed information in this field, but no firm commitment has so far been made to organizing such a workshop.

Phase 2 of the project was to be planned in more detail following the findings of phase 1, but it was anticipated that it would be field-oriented, would be carried out in conjunction with in-country restocking experiments or activities, and would include one or more studies or groups of experiments aimed particularly at evaluating the results of juvenile release trials.

Review of Restocking Activities

In response to this recommendation, IFRP and SPADP staff collaborated on the production of a report, but this was less comprehensive than originally envisaged because it was discovered that literature on this topic is not abundant and tends to be scattered, peripheral to the subject and unfocused. The topic of restocking and reseeding is not easily amenable to automated keyword-indexed searches through bibliographic databases. The review was thus, by necessity, compiled mainly using sources already known to the authors or found through cross-referencing. The process of information-gathering is not yet complete and it is planned to expand the review further, especially by adding more details of restocking programs carried out elsewhere, with the ultimate aim of circulating it more widely as a technical paper.

The paper principally considers the biological and other characteristics that will affect the potential for restocking of several key species groups that are presently subject to overexploitation in some parts of the region. These include giant clams, pearl oysters, trochus, green snail, spiny lobsters, mangrove crabs, coconut crabs and sea cucumbers. In particular, relevant knowledge of basic reproductive and larval biology is reviewed in each case in an attempt to understand whether restocking is likely to be effective.

Some information is also presented on restocking experiences outside the region, especially in Japan. This experience suggests very strongly that the benefits of restocking are not automatic, nor are they easy to actually quantify. Restocking on its own will not solve problems that have arisen because of a need for fishery management. Rather, restocking needs to be considered as one of a group of fishery management tools available for improving fishery yields.

Specific issues that emerge from the review include the following:

1. Restocking needs to be considered as part of an overall management approach and not as an alternative to management. Experience elsewhere all underlines the fact that simply releasing large numbers of juveniles into the fishery will not produce population increases unless the fishery is also subject to some form of management that allows the released juveniles to reproduce and thus make a contribution to population growth. Restocking should be viewed as one of a set of management tools, and not as an easy way out of management.
2. The reproductive and larval biology of the species will be major determinants of whether restocking is likely to have biologically significant results. Restocking is likely to be of most benefit to populations in which recruitment is a limiting factor. The limitation may arise because the population has been so reduced that reproductive success has been impaired (giant clams, pearl oysters, possibly trochus), or because specialized habitat requirements or larval life history characteristics impose a "filter" on the number of juveniles that are able to recruit to the adult fishery (tropical spiny lobster, possibly trochus).
3. Restocking is likely to be of greatest economic value in species that achieve large sizes (or high values) relatively quickly, and which have low mortality rates. Slow-growing species, those that have a high ratio of mortality to growth, or those that do not achieve a large size or high value, will be less viable candidates for restocking from an economic viewpoint. Most organisms show higher rates of both growth and mortality early in their lives, and these drop in different ways as the animals age. In most cases, the economics of restocking will be determined by the cost of raising the animals to the point where the ratio of mortality to growth falls to an acceptable level.
4. The contribution of restocking programs to wild populations can be extremely difficult to assess. This has been demonstrated in well-funded, high-technology juvenile release programs in Japan, as well as in experiments with trochus carried out within the region. In many cases, there has been no demonstrable effect on yields from wild fisheries despite releases being carried out over many years and

the expenditure of large amounts of effort and funding.

The paper concludes that restocking has the potential to be of benefit to Pacific Island fisheries in certain circumstances, but that these circumstances need to be evaluated very carefully in the light of country-specific information, as well as knowledge of the biology of the species in question and the economic value of the fishery. Terms of evaluation will include the importance of recruitment as a limiting factor in population growth and the ratio of growth to mortality at different stages in the life history of the species in question. The benefits of restocking are by no means assured or automatic, and unless properly evaluated, restocking programs can absorb a great deal of research and development effort (and funding) without delivering observable benefits.

Juvenile Release Experiments

The conduct of one or more field studies on restocking activities was envisaged as part of phase 2 of the joint IFRP/SPADP project. The first of these has now taken place with the release of 1,400 juvenile trochus onto Erakor reef in Vanuatu in May 1991. The animals, of 10-28 mm basal shell diameter, were individually marked with numbered tags. Vanuatu Fisheries Department is conducting a multiple-recapture experiment in which those tagged shells that can be found are measured and re-released at approximately two-monthly intervals. More details and a progress report are given by Amos (1990). A preliminary examination of results will be made after one year in order to estimate growth and mortality, while monitoring will be continued until such time as the animals recruit to the fishery (two to three years). Further experiments of this type will be carried out in Aitutaki in the Cook Islands during 1992 (again using trochus), and as other opportunities present themselves.

Future Activities

There is still a need to generate a greater awareness of these issues among technical and managerial fishery staff involved in activities related to restocking. To achieve this, there is a need to look objectively at experience elsewhere (especially in Japan) and to examine more closely specific aspects of the biology and life histories of the key species involved in order to realistically understand the contribution that aquaculture might be able to make to resource enhancement. This topic area might be addressed by the convening of a specialized technical workshop as originally envisaged, or by some other means.

There are areas of research in this field that could usefully be addressed by universities and other research bodies from both within and outside the South Pacific region. The detailed investigations into aspects of reproductive and larval biology that will be necessary in the development of hatchery technology for key species are beyond the capacity of most national and regional fisheries agencies to address. However, these could possibly form the basis of university studies that met the requirements of academic research projects and at the same time contributed towards fisheries development goals in the region. There thus appears to be merit in Pacific Island countries encouraging and supporting research bodies interested in developing such research programs.

A Potential Role for Light-traps in Enhancement of Coral Reef Fisheries

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Light-traps are automated samplers that use light attraction to collect live pelagic juvenile fish. These devices have now been extensively tested on the Great Barrier Reef with deployments of >20,000 trap hours over eight seasons at depths ranging from the surface to 100 m.

Although catches are strongly influenced by spatial factors (such as depth, distance across the continental shelf, proximity to reef), the general pattern is for highest catches around the new moon. On the GBR, greatest catches of reef fishes are obtained around midsummer, although certain commercially valuable targets are most abundant during winter/spring months. In addition to this seasonality, sampling of fixed sites has shown substantial interannual variability at all taxonomic levels; both results are consistent with the results of previous recruitment surveys.

Notwithstanding these sources of variability, light-traps have been found to capture a wide range of pelagic and demersal fishes, including reef and nonreef, commercial and noncommercial, taxa. Commercially valuable groups include lethrinids, lutjanids, scombrids, serranids and siganids. In the case of small noncommercial reef fish, we have shown that light-traps provide alternatives to visual surveys for monitoring the replenishment of these stocks. In the case of high-value species, which often have mobile or cryptic juveniles, light-traps may offer the only cost-effective estimates of initial replenishment.

In addition to their use as monitoring tools, light-traps have potential to be applied to certain mariculture propositions, including experimental restocking of natural populations. This is because light-traps are size-selective, mainly capturing advanced pelagic juveniles which are generally inaccessible to conventional techniques. Furthermore, because these fish are merely trapped, not killed, they can be removed from the trap for controlled growout or released back into the environment.

In the long run, it would generally not be cost-effective, nor perhaps sustainable, to constantly harvest large numbers of wild juveniles for any form of mariculture. My proposal is that light-traps may offer a relatively cheap way of determining the feasibility of reef enhancement. In their current form, each trap represents a capital investment of approximately A$1,500 with running costs of around A$20 per month. At these levels and because of their automation, it is possible for a small operation to service quite a large array of traps. Catches of target organisms from individual traps have been as high as hundreds or thousands in a single night.

Lethrinids and siganids are two taxa that seem particularly suitable for the proposed trials. Both share the following characteristics:

- reliable and abundant supply;
- robust to handling;
- easy to maintain in culture so that the effect of size at release could be easily manipulated;
- feed low or relatively low on the food chain and hence have minimal impacts on species at high trophic levels;
- fast postsettlement growth, especially in the case of siganids; and
- appropriate habitat and ecological requirements, i.e., lagoonal species which offer some prospect for containment of the additional increment of productivity.

Positive results from this stage may provide the justification required for the more expensive proposition of closing the life cycles of suitable species in the laboratory, for the sustainable supply of juveniles.

Cultivation of Benthic Marine Algae in Reef and Lagoonal Systems, with Special Reference to the Tropical South Pacific

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The benthic marine macroalgae or seaweeds of the reef and lagoonal systems of the tropical South Pacific region are poorly known, and their potential as a resource has been scarcely exploited. Tropical seaweeds have long been utilized by man as food, medicines, ceremonial objects and for ornaments. Throughout the region, human consumption of seaweeds is widespread, although few detailed statistics are available on the quantities harvested. The value of these edible species may be considerable. The potential for cultivating edible species has been scarcely exploited in tropical regions, with the crop being obtained by subsistence seaweed gatherers. The future use of edible seaweeds in the South Pacific should be examined.

The tropical South Pacific's extensive coral reefs and lagoons, characterized by slow to moderate currents, clear water and sandy or coralline bottoms, provide ideal habitats for seaweed farming. During the past 20 years, the cultivation of *Eucheuma* spp. (Rhodophyceae, Gigartinales) has become a significant activity in a number of Pacific Island countries. This development is part of a worldwide trend to commercially cultivate seaweeds for their valuable extracts (gum or phycocolloids). The industry is concentrated in, although not exclusive to, the Philippines, Malaysia, Indonesia, China and Japan. There is also a small industry based in East Africa. *Eucheuma* spp. are an ideal source of the phycocolloid carrageenan, which is a high-molecular-weight polymer of simple sugars (polysaccharides). Eighty per cent of the world's production of carrageenan is now derived from aquaculture, principally in the Philippines.

Farming of *Eucheuma* is favored in the Pacific Islands, partly because it requires a low level of technology and investment and is adaptable as a family activity, but also because it is not destructive to the environment and is normally compatible with traditional fishing and other subsistence uses of the inshore marine environment. In some countries, such as Fiji, it has been seen as an important source of income and employment in the rural areas by government.

In the Philippines, *Eucheuma* cultivation industry was first established in the late 1960s, and has since become one of the most important marine exports of that country. Unlike the Philippines, South Pacific countries have experienced great difficulties in their attempts to successfully cultivate *Eucheuma* in commercial quantities. Trials or actual cultivation of *Eucheuma* have been conducted in Fiji, Tonga, Kiribati, Solomon Islands, Federated States of Micronesia and Tuvalu, and of these countries, only Fiji and Kiribati have been able to establish any kind of success. The first (unsuccessful) trials, using Philippine seed stock, were in Fiji in the 1970s. In 1977, the first trials were held at Christmas Island, Kiribati, using Hawaiian seed stock originally derived from the Philippines. Trials commenced in Tonga in 1982 and a new program was established in Fiji in 1984, using seed stock from Tonga. Steps are currently being taken to expand a commercial *Eucheuma* growing program in Pohnpei State, with possible expansion to Yap and Kosrae.

Methods of farming *Eucheuma* have been well documented and the industry provides detailed information on methods and costs to potential growers. *Eucheuma* is a large, rapidly growing seaweed that, under farming conditions, is easily propagated vegetatively (sexual reproduction is rare in farm conditions); in suitable conditions crops can be harvested every 6-12 weeks. There are various color varieties of *Eucheuma* species, the most common being green and brown.

The conditions required for successful growth of *Eucheuma* are:

- water temperature ranging from 25 to 30°C;
- salinity at 28 ppt or more;
- a white sandy bottom with a limited amount of natural seaweed;
- moderate water movement, with an exchange of ocean water;
- clear water with good light penetration;
- 0.5 m depth water at spring tide;
- absence of pollution; and
- absence of fish grazing.

There are three principal farming methods now employed in the South Pacific: off-bottom (fixed monofilament lines between posts driven into the substratum), floating rafts or floating long lines. The off-bottom method is most suitable for protected, shallow water sites with good movement and a lack of grazers, and requires clean water with little siltation. The floating raft method requires protection from heavy waves and needs good anchorage. It is more suitable for sites with poor water movement and can be used in deeper water. An advantage is that it avoids space usage conflicts with tourism and other fishers. The longline method can be used in exposed areas and where the water is over 30 m deep (e.g., outside fringing reefs). Problems may be experienced with stinging hydroids wrapping themselves around the lines in some seasons.

Any future success of *Eucheuma* farming in the tropical South Pacific will heavily depend on world market prices and trends and the cost of freight. Although farming is technically feasible and the quality of South Pacific *Eucheuma* is high, there is little prospect of the industry becoming fully commercialized in the South Pacific. *Eucheuma* farming does, however, have the continuing prospect of remaining as a valuable income supplement in the subsistence sector, providing a number of basic requirements can be met.

Until fairly recently there were two principal companies manufacturing carrageenans: the Marine Colloids Division of the FMC Corporation (USA) and the Copenhagen Pectin Factory. These manufacturers, until the 1960s, relied on raw materials (hand-gathered *Chondrus* and *Gigartina*), through a cottage industry-style system. Currently other manufacturers are involved in purchase and processing of seaweeds for carrageenan, to a total of 80,000 t annually.

The volatility of the seaweed industry is such, however, that by 1990 there was a significant turnaround in world prices and demand for carrageenan, with the price more than doubling in a relatively short period of time. New uses for carrageenan, combined with the entry of new markets (such as that of China) and poor productivity in the Philippines owing to weather conditions, led to a shortage of raw material and an increase in price. There is every indication that this trend will continue for several more years. Overall, however, caution is recommended in the development of any seaweed industry in the region, with particular reference to the need for design of strategies for penetrating the existing markets.

Production of *Eucheuma* is 51,000 $t \cdot year^{-1}$ in the Philippines, and 14,000 $t \cdot year^{-1}$ in Indonesia. Pacific countries can expect to be only minor producers in the short- to medium-term future. They will, however, be able to market a good product in light of the fact that there is presently an annual shortfall in carrageenan production worldwide. Factors that should be considered by Pacific Island countries when examining the feasibility of *Eucheuma* cultivation include the following:

- the minimum income that a seaweed farmer will accept;
- the local costs of establishing a seaweed farm;
- domestic costs (e.g., transport, quality control);
- costs for the exporter (e.g., inspection, sorting, baling, shrinkage losses, overheads, financing costs, etc.); and
- world prices and currency exchange fluctuations.

The above factors cannot be generalized, but must be calculated for each country. Pilot farms are important and the need for farmers to diversify their income to reduce the risk of failures cannot be overstressed.

Gracilaria has considerable potential as an aquaculture species and, in addition to its food value, is a valuable source of the phycocolloid agar. It is surprising that, considering the price of dried *Gracilaria* (more than US$600 per t) and the world shortage of agar, no large-scale farming has been undertaken. A review of *Gracilaria* cultivation in the Caribbean would be worth evaluating from a Pacific Islands standpoint.

The edible seaweed resource in Pacific Island countries should be determined through a comprehensive survey. The extent of the resource and its market value is unknown, the effect of seaweed gathering on the environment has not been assessed, and the potential for developing the edible seaweed resource in a sustainable manner has not been evaluated. Certainly, edible green algae such as *Caulerpa* are successfully cultivated in Southeast Asia. Given its popularity in some Pacific Island countries (such as Fiji) and its comparative ease of cultivation, the feasibility of growing this species commercially could be further investigated.

Like any other successful aquaculture enterprise, a secret to success is the provision of an appropriate research and development program as a support to the industry. Presently, there is no center in the South Pacific region devoted to the seaweed aquaculture industry, and there is no opportunity for Pacific Island nationals to gain training in this area. Attempts are being made by the University of the South Pacific, with the assistance of the International Centre for Ocean Development, Canada, to assess research and development priorities in support of the seaweed aquaculture industry in the region, and in particular to review the possibility of establishing a program in association with the University of the South Pacific's Atoll Research Program in Tarawa, Kiribati.

As a concluding note, the importance of benthic marine macroalgae in the coral reef ecosystem must not be overlooked. Their importance in reef-building, as primary producers, as indicators of reef disturbance and pollution, their role in the food web and their scarcely realized potential as sources of pharmaceutical products and other substances of commercial value must not be underestimated.

Lastly, there is an urgent need to document the poorly known floras of most tropical regions of the world, but especially of the tropical South Pacific, and to train a cadre of young scientists in the field of algal systematics, ecology and physiology, since at present there is less than a handful of such experts in the region. The result is that, more by default than design, the importance and role of benthic macroalgae in the ecology of coral reefs and their potential roles as a future resource, tend to be overlooked. The inclusion of algae as a topic for consideration in this important workshop is most welcome and will, I hope, lead to a more comprehensive approach to coral reef resource management, and an enlightened approach to future investigations of coral reef ecosystems.

Prospects for Aquaculture in Coral Reef Environments[a]

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The scope for increasing the biological productivity of coral reef systems through the development of aquaculture and fisheries enhancement systems warrants close examination. In many developing countries, coral reef lagoons are foci of human settlement, often by landless peasants, and consequently are intensively exploited.

Successful aquaculture in coral reef environments in the tropical Indo-Pacific is currently confined to the cultivation of the red algae (*Eucheuma* sp.) and pearl oysters (*Pinctada margaritifera* and *P. maxima*). These activities can still be described as marginal in some areas, depending very much on scale, access of markets and level of technology. The Philippines, Indonesia and Fiji are the only countries producing *Eucheuma* on a consistent basis, although there are development trials in progress elsewhere (see South, this vol.).

In the Caribbean, there has been much interest in the cultivation of the queen conch (*Strombus gigas*) and of the spider crab (*Mithrax spinosissimus*) and much progress has been made in hatchery technology. However, no commercially viable systems have yet emerged.

Current biotechnical advances in giant clam cultivation are leading towards development of effective farming systems. Farming systems suited to local ecological conditions, particularly the tidal regimes, have been developed in Australia, Palau, the Philippines and the Solomon Islands, and small hatcheries have been set up in a number of developing countries. Given favorable bioeconomic assessments, additional research on enhancement of giant clam germplasm will be warranted.

Pearl oysters currently support a pearl culture industry in developing countries of the Indo-Pacific Region (excluding Australia) which is valued at over US$60 million per year. However, pearl oyster cultivation is confined to several atolls in French Polynesia, one atoll in the Cook Islands, small commercial ventures in the Philippines and Fiji, and to a limited area in the Sudan (Gervis and Sims 1992). The industry is primarily directed towards the cultivation of cultured pearls, with the pearl shell being an important secondary product. Almost all of the current production of blacklip pearl oyster (*Pinctada margaritifera*) occurs in oceanic atolls, where natural spatfall is sufficient for extensive aquaculture systems based on the deployment of spat collectors. Elsewhere, spat collectors have not been successfully deployed and the industry is

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dependent upon the gathering of wild stocks or, in a few countries, upon hatchery-reared stocks. However, the hatchery technology is sequestered in the hands of powerful commercial interests and the technology needs to be redeveloped and disseminated before development of village-based production systems for spat becomes feasible. This will enable coastal villagers, in areas which do not receive natural spatfall, to participate in the lucrative spat rearing, shell production and live pearl oyster industries.

In Southeast Asia, grouper cultivation occurs in Thailand, Malaysia and Singapore, and some of this is done within coral reef lagoons (Tucker et al. 1991; Powell and Tucker 1992; Toledo et al. 1993).

There have been numerous attempts at developing various forms of fish and invertebrate culture in coral reef systems in the past but few have come to fruition. Most past efforts have been based on the introductions of familiar species such as oysters and mussels and none have been a commercial success, although remnants of introduced stocks survive in many areas.

There has been some interest in the production of sponges, and some progress in their vegetative propagation has been reported in Pohnpei, FSM. Within the Indo-Pacific region, research is currently underway or planned on cultivation of sea cucumbers, sea urchins, crabs, spiny lobsters, topshell, green snails and various species of reef fishes.

Some threats to the coral reef environment appear to be posed by the prospects of cage or pen cultivation of desirable species in coral reef lagoons. The technology for cultivation of high-value predatory species such as snappers, groupers, barramundi and oceanic dolphin fish is currently available, and constraints lie in hatchery production techniques, nutrition and marketing. Countries of Oceania with canneries or processing plants for skipjack and yellowfin tuna are capable of producing relatively low-cost fish meal and hence there is a possibility of low-cost pelletized feeds.

For many of the species under consideration, such as sea urchins, sea cucumbers, gastropods (particularly *Trochus niloticus* and species of reef-bound reef fishes, effort is likely to be directed towards the reef or lagoon ranching concept) where selected desirable species of reef organisms will be propagated and stocked into reef and lagoon habitats, isolated from other reef habitats by tracts of deep water or soft bottom habitats. This is analogous to stocking a lake or reservoir. The species stocked are expected to survive to be harvested in due course. The only difference between this concept and the much older concept of restocking marine systems, as practiced in Japan and with many salmonids elsewhere, is that where level bottom marine habitats are stocked the habitat is often limitless and, as in the Japanese experience, beneficial effects are difficult to detect (Cowan 1981; Sproul and Tominaga 1992). The big difference in coral reef systems is that it appears that for the most part such restricted ecosystems are recruitment-limited, and thus could support far greater numbers of organisms than are commonly encountered on the reef.

Genetics in Marine Science

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There is increasing pressure for the development of marine resources, but a limited database on which to plan for their sustained utilization. Genetic methods (protein and DNA markers) offer a rapid means of assessing the structure and degree of genetic diversity of biological resources that may be impacted by developments. They also offer a means of identifying resources, such as the occurrence of different strains of species with aquaculture potential, which may improve development of the resource.

Many marine species are being brought into culture as a source of food or other products. The speed with which these can be domesticated can be increased by the appropriate application of selective breeding techniques. Genetic marking can be used to monitor the spread of cultured animals in the wild. It also has an important role to play in monitoring restocking programs, and appropriate attention to the design of the genetic constitution of the restocked population is required to achieve effective restocking of wild populations.

The value of genetic approaches is not limited directly to biological material. Information on the gene flow occurring in wild populations can also provide clues to oceanographic patterns on a variety of spatial and temporal scales.

Particularly where natural resources have been little studied (and this relates to most marine organisms), the use of genetic markers to define genetically different groups is perhaps the most rapid method of assessing whether cryptic species occur, or whether relatively isolated stocks occur within a species. Surveys from a relatively small number of samples from a single time collection can provide useful first-order information. Establishing the extent of gene flow or exchange between populations and the patterns of dispersal among populations demands more care and may require multiple sampling on a variety of spatial and temporal scales. Nevertheless, the time periods for first-order genetic work of two to three years compares well with the investment required for tagging work (decades). Almost all work to date has been obtaining first-order data and there is a need to develop longer-term approaches, integrated with other fisheries and aquaculture work, to better define dispersal dynamics and monitor changing stock structures.

It is already clear that even widespread species with planktonic larval phases are genetically structured. For example, giant clam populations in different parts of the Pacific are genetically different, suggesting unique resources may be available in some places and that considerable care be taken in transferring stocks throughout the region (Benzie, unpubl. data).

The need to increase food production from the sea in the face of declining fisheries yield, demands the rapid development of aquaculture. The rapid domestication of these organisms is the goal and genetics, through quantitative breeding programs, can speed the adaptation of organisms to culture. In addition, selective breeding is an established technique that has increased the efficiency and production of agriculture and allowed the development of products tailored to market demand.

Uncontrolled reproduction in cultured populations can lead to marked losses in productivity through inbreeding and there are already unfortunate examples in aquaculture (e.g., in salmonids, prawns and other finfish) that demonstrate this effect (Benzie 1992).

There is a considerable interest in restocking fisheries or reefs using aquaculture to provide large numbers of young (e.g., trochus, giant clams). However, batches of young produced by hatcheries often show reduced genetic diversity and considerable shifts in gene frequency from the natural populations from which their parents were derived. Potential resource loss can result from introducing genetically different animals from elsewhere but it is important to note that providing locally derived material for restocking may also affect the natural local resource.

There is a need for close genetic monitoring of restocking and for the development of strategies to control the genetic constitution of the restocked population. It is easier to identify genetic differences between populations and to use genetically distinctive animals from one area to stock another and so trace the success of the stocking procedure. However, given the concerns about transfers from one genetically differentiated stock to another, it would be better to establish rare variants within a locality and breed these up in sufficient numbers for release. Effective hatchery procedures and sophisticated DNA markers are required to achieve this.

Protein electrophoresis is a well-established technique that can provide rapid processing of samples (hundreds per day) and the presence of genetic variation within and among wild populations has been demonstrated in many fish and molluscs. Protein variants have been used to estimate wild fisheries stock structure, estimate population size in mark-recapture experiments and identify the source and impact of hatchery-released fish (Ryman and Utter 1986; Seeb et al. 1986).

Several recent advances in technique (such as PCR, RAPD and oligonucleotide dot blots) have made DNA methods more useful for screening work, increasing the speed and range of analysis and decreasing unit cost of analysis (hundreds per day)(Erlich 1989). There are already scattered reports of genetic variation at the DNA level for fish, molluscs and crustaceans, indicating higher levels of genetic variation are detectable using DNA than protein variants, but none yet for these groups for RAPDs or using oligonucleotide dot blots. By mixing and matching PCR, RAPD, sequencing and dot blotting, powerful, sensitive and rapid methods of assaying variation are feasible. The DNA methods are likely to be able to identify rare variants or rare combinations of variants within local populations to a greater extent than protein variants.

All these techniques demand a sample or tissue be obtained (usually frozen) and tested in the laboratory to detect the genetic mark. The need to define the diversity of natural resources is great. It is upon this genetic diversity that the biosphere depends for its continued ability to adapt to changes and from which new biotechnologies can be developed. Equally important is the urgent need to monitor deliberate manipulations like restocking, both to assess their economic effectiveness and their impact on the natural resource. The tools to achieve this are available.

The use of genetic markers needs to be integrated with other development work, but is unlikely to be cost-effective within developing countries. This sophisticated technology can be supplied from specialist centers within developed countries. There is also a need to maximize the development of suitable aquaculture resources and this can be achieved through improved yields obtained by selective breeding. This is something that can be achieved within developing countries although expert assistance in developing breeding programs and effective local extension services would be required.

Coral Reef Resources and Research for Management

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A Difficult System for Resource Managers?

Coral reefs have the reputation for being complex and diverse but is special treatment warranted with regard to resource management? Some of the features of coral reef systems are not unique to reefs: for example, most ecosystems are complicated, other tropical ecosystems display processes occurring at multiple scales and have diverse species assemblages of interacting species with some being used for commercial gain.

The aim of this paper is to suggest that research for tropical marine resource managers may benefit from less effort on documenting the complexity of the system and more effort on discovering simplifying procedures to allow the resource managers to specify and then achieve their goals.

Statement of Objectives from Resource Managers

In planning research for fisheries resources management, it is sometimes difficult to obtain a clear statement of objectives from the resource managers. There are a number of possible reasons for this. The resources may be so poorly described that the manager cannot define the objectives of the research. Also, the users of the resources may be so factionalised that the manager can produce only the most general statement of objectives. When an objective is very general, then it is difficult to measure management performance in relation to that objective.

Australian fisheries, at the Commonwealth level, have defined their objectives as follows (but paraphrased):

- to conserve the fisheries resources and the ecosystem on which those resources depend;
- to ensure the resources are used in the most economically efficient way; and
- to ensure that the Australian community receives some return for granting some people the right to use the "common property" of all Australians.

These objectives are fairly broad. For management of any particular fishery, they are often refined for operational use such as, for example, the detailed management objectives for the Torres Strait lobster and prawn fisheries produced by the Bureau of Rural Resources.

In the past, a wide range of general biological research has been classified as research for management, but the recent trend towards controlling total catch (through quota schemes) rather than fishing effort has brought the scientific assessments under very intense scrutiny.

The goal of fishery research has evolved from estimation of maximum sustainable yield, to estimation of sustainable yields under a range of management control options, to description of resource dynamics and a risk analysis of the likely outcomes under particular management controls.

Not all fishery managers realize that this change in emphasis has occurred; the change towards increasingly specific descriptions of resource dynamics puts increasing onus on the resource manager to specify the management objectives more precisely. A consequence of this change is the increasing importance of collecting validated information on fishing activities.

The point of this example is that resource managers can achieve only limited objectives if researchers cannot make predictions about resource dynamics and phrase their advice in useful terms and that research advice is considerably less useful if the work is done by scientists who are unaware of management objectives.

Involvement of Resource Managers In Setting Research Objectives

An emerging trend in Australian fisheries is the increased involvement of fishery managers and the fishing industry in setting research objectives. This approach has worked successfully for many years in some fisheries, such as the Northern Prawn fishery where CSIRO and industry cooperate closely, and is being introduced in other fisheries, such as the southern shark fishery.

In management of coral reef resources, fishery management is only one of a range of responsibilities. The resources are diverse and the establishment of precise management objectives is difficult; lack of information on the present status of the resources remains one of the greatest obstacles in many countries.

In order to reduce the problems to manageable proportions, one approach may be to use the large body of information documenting the complexity of coral reef systems to produce some *simplifying statements* about these systems (e.g., regarding threats to the system and control of the threats; improving productivity of the resources for economic benefit; or the conservation value of the system).

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Allowing resource managers to specify their objectives for the system in these simpler terms and hence, allowing for the differences between coral reef regions, will enable the different sets of management principles applying to each region to be clearly understood by scientists aiming to design monitoring programs and to do research for predicting the behavior of those systems. This can be done only by cooperation between researchers and resource managers (e.g., government regulators, park managers, etc.) at the early stage of defining resource management objectives.

Conclusions

Many countries, including Australia, urgently need improved monitoring systems to describe their marine resources and the changes over time in order to ensure the information is available for setting management objectives and monitoring performance of management actions in achieving those goals.

Simple statements of practical management objectives are needed, such as those described for Thailand, where conservation, economic and human values are integrated to ensure that those involved in international efforts (such as the present initiative of the Australian International Development Assistance Bureau) are speaking the same language even though objectives will vary from region to region. This is particularly important if education and training is being done by scientists from widely varying cultures and regions.

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APPENDICES

Appendix 1

Welcoming Address[a]

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The opportunity for this international workshop arose from two events. First was the announcement by the then Australian Prime Minister Bob Hawke in September 1991, at the Commonwealth Heads of Government Meeting in Zimbabwe, of an Australian initiative supporting management of tropical marine ecosystems. Second was the development of a new strategy for international research by ICLARM which included a coral reef program as a major element.

Since the Australian initiative is to be an international one, the Australian International Development Assistance Bureau (AIDAB) is handling the project. AIDAB also provides support to ICLARM. It was natural then that AIDAB asked ICLARM to help. At the same time, ICLARM was seeking a mechanism to consult with researchers to develop in more detail a coral reef research agenda. This workshop is the logical outcome.

At this meeting we have a unique chance for dialogue. Researchers are here from the major areas of the world where coral reefs are important and represent a broad range of disciplines ranging from social science to physical oceanography. We are here not to present scientific theories but to discuss future activities.

We will hear shortly from Mr. Casson of AIDAB who will give more information on the Australian initiative in tropical marine ecosystem management and request your feedback.

There are, however, other equally important reasons why we are here. The problems of the conservation and management of tropical marine ecosystems are enormous.

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The initiatives of ICLARM and of the Government of Australia will be modest efforts. We must cooperate and pool our resources to solve these problems. In addition, there are a number of other initiatives here in Australia, in the Caribbean and in the Indian Ocean, that could be linked. Finally, in June 1992, the Earth Summit, the United Nations Conference on Environment and Development (UNCED) will convene in Brazil to consider the combination of conservation and development and set the agenda for the rest of this decade. Much will be said on coral reefs. Let us hope we can help carry out the agenda.

ICLARM's mandate is global but we have a firmer base in Asia and the Pacific than elsewhere. We are to carry out research on management of living aquatic resources at the international level for the benefit of the poor. We are also very concerned about issues of sustainability and equity.

ICLARM's view of a coral reef is one of a resource system with four interlocking components: the organisms; the ecosystem; the fishery or human interactions; and the ecoregional or the broader context. We can and must study each of the components but in order to solve the management questions we must be able to put all of the components together.

The following are some of the critical areas where ICLARM could play a role.

Organisms

There has been considerable research on coral reef organisms but ICLARM can play a role in helping make the information more available: for example, through databases such as FishBase. Aquaculture and fisheries enhancement can play a substantial role in reef management by returning endangered species, increasing the incomes of coastal communities and increasing the incentive to conserve reefs. In order to realize this potential there will be a need for increased effort on the biology of potential species. Building on the experience of the Giant Clam Mariculture Project, ICLARM plans to expand its effort in this area.

Ecosystems

While much important work has been done recently, this area needs considerably more effort. Initially a computer database might be useful to follow up the work done by Susan Wells on the global status of reefs. In addition, there is a need for more work on modeling reef systems and determining the implications for management of various interventions. Comparative research on reef reserves and their effect on fisheries would be important.

Fisheries

There has been very little research on the users of the reef resources and their impacts. It is virtually impossible to even obtain adequate data on fisheries catches from reefs, let alone the gleaning and collecting by women and children. ICLARM is hoping to assist in improving our knowledge of the utilization and management of coral reef resources by coastal communities through coordinating case studies on utilization, knowledge and management of the resource. A particular area of interest will be community management of coral reef resource systems.

Ecoregional

In many cases, the problems of management can only be solved outside the reef system. This will involve wider issues on coastal systems management which ICLARM will address in a separate program that will deal with intersectoral linkages, policies, resource economics and institutional constraints to management.

In conclusion let me say that I hope we can leave here with plans for specific action that will be our own agenda for the 1990s. This should not only be implementable but also reflect collaboration between our various institutions and interests. ICLARM can help in this process by coordinating, catalyzing and filling the gaps.

Welcome to this meeting. We hope that it will help tropical developing countries solve serious problems of managing their very valuable coral reef resource systems.

Appendix 2

Opening Address: The Australian Initiative in Tropical Marine Ecosystems Management

M.R. CASSON
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Many of you will be aware that the former Australian Prime Minister, Mr. Bob Hawke, announced at the Commonwealth Heads of Government Meeting in Harare in October last year, a range of measures aimed at addressing the need to develop cooperative solutions to the world's environmental problems.

Included in these measures was a new initiative to make available Australian expertise in managing tropical marine environments. Australia will provide A$500,000 over two years to assist Commonwealth and other tropical and subtropical developing countries to better manage their tropical marine ecosystems. The initiative will be developed in the context of the United Nations Conference on Environment and Development (UNCED).

The initiative arises from the realization that over a number of years, Australia has developed a considerable capability in training, research and management in the tropical marine ecosystem field. In recent years, aspects of this resource have been made available to a number of countries in this region. They have involved the provision of project assistance, training awards and technical assistance to national and regional institutions, particularly in the countries of the Association of Southeast Asian Nations (ASEAN).

The initiative was formulated following recognition that there is scope to better program this assistance. For many governments and peoples, particularly developing countries in this region, marine resources play an important role in economic terms (tourism, fishing), in nutritional terms and in cultural terms. The better management of marine ecosystems could result in marine resources making a more significant sustainable contribution to national development objectives.

Without sound management practices being put in place, the sustainability of tropical marine ecosystems is jeopardized and in a number of cases, we are seeing evidence of marine resources coming under increasingly severe pressure from environmental damage and unsustainable exploitation and usage.

Considerable interest, both internationally and in Australia, has been shown in the initiative and several scenarios have been suggested. The three main options are:

- the establishment of an International Tropical Marine Resource Centre (INTROMARC) as proposed by the heads of marine agencies in Australia (HOMA);
- a program of technical cooperation with an emphasis on training awards, but also including provision of technical cooperation and research; and
- collaborative activities between Australia and a relevant international institution such as UNEP's Oceans and Coastal Areas Program Activity Centre (OCA/PAC) or the International Center for Living Aquatic Resources Management (ICLARM).

A number of countries and international institutions have been consulted on the initiative and the possible options and feedback have been most positive. There is a general view that Australia possesses recognized expertise in research and management of tropical marine ecosystems, and the offer to make this expertise available internationally is welcomed. The Townsville location is seen as an appropriate center for coordinating the assistance, being the site of the well-established and highly regarded institutions of the Australian Institute of Marine Science (AIMS), the Great Barrier Reef Marine Park Authority (GBRMPA) and James Cook University (JCU).

There is also general agreement that training and, to a lesser extent, research should be the focus of the initiative, within a framework of coordination and cooperation between existing Australian and international institutions.

ICLARM has suggested using some of the funds for the collaborative development of a global database on coral reefs. The database could act as a repository for information gathered by various reef monitoring programs. Similar databases have been developed in the biology of tropical fish and coastal management research in ASEAN countries.

Offers of collaborative programs from a number of sources have been received, including a research and development study on the rehabilitation of oil-damaged mangrove sites and an existing regional seas program.

A Southeast Asian country suggested linking Townsville-based expertise into a network of associated centers in several countries.

In order to take the initiative one step further, and with an eye on the financial and timing constraints of the initiative, the Australian International Development Assistance Bureau (AIDAB) engaged a consultant, Dr. David Gwyther of Dames and Moore, with environmental expertise in the marine area. The objective set for this was to identify areas of Australian expertise and to match these with the identified needs of developing countries. He was asked to take into account the views of countries and institutions canvassed and those of Australian institutions.

The consultant found that nonsustainable practices are exerting considerable pressure on tropical marine ecosystems. Such practices include overexploitation, destructive fishing methods, coral and shell collection, aquarium fish trade and habitat degradation activities, such as coastal wetlands and mangrove destruction, siltation, urban and agriculture pollution.

The situation is compounded by an inadequate institutional infrastructure in many countries. In addition, poor interdepartmental and cross-sectoral coordination, a lack of skilled personnel, rigidities caused by traditional land and fishing rights, and inadequate enforcement of regulations are inhibiting integration of coastal zone management.

The consultant identified developing-country needs as being in four major areas:

- coastal zone management: the definition of principles for sustainable development, village level education, user planning and regulation, and linkages between catchment land use and catchment management;
- environment impact assessment: understanding and application of assessment techniques, including likely areas of impacts, assessment of critical habitats, issues, constraints and opportunities, monitoring techniques and definition of indicators;
- resource economics: application of cost-benefit analysis to the need to understand and to know how to apply economic comparisons of alternative coastal resource uses; and
- inshore/coastal fisheries: effective coastal management requiring understanding of the roles of ecosystems in fish production, techniques for assessing sustainable yields, reef or lagoon aquaculture and fisheries enhancement, and coastal fishery databases.

In summary, developing-country needs are for:

- making decisions and implementing management plans on the basis of existing knowledge, rather than undertaking additional research (i.e., it is a question of education and extension rather than new research);
- the provision of technical competence through education and training in overseas countries;
- the transfer of skills and techniques in assessment of ecological and economic impacts of coastal resource use practices; and
- expertise in translating these skills in the local context, at the village, administrative and political level.

How then can Australia assist in satisfying these needs? The consultant concluded that Australia's strengths lie in coastal zone management and environment impact assessment (and to a lesser extent in reef and reef fish management). Our environmental resource economics capability was seen to be held by relatively few people. In general:

- Australia has a great comparative advantage in providing education and training across a wide range of conditions. The focal point of this training is seen as being in Townsville, at James Cook University and, to a lesser extent at the Great Barrier Reef Marine Park Authority (GBRMPA) and the universities of New England, Northern Rivers, Northern Territory and Western Australia in selected fields.
- Australia also possesses well-developed practical methods of research and assessment of tropical ecosystems in areas such as reef/mangrove monitoring (AIMS); in impact of tourism on reefs (GBRMPA); in tropical marine coastal management, tropical fisheries research, marine environment research, natural resource management and assessment (CSIRO); in management of coastal wetlands, tropical estuaries, mangroves and coastal commercial and recreational fisheries (State Government Departments of Fisheries and Environment).
- Australia possesses a potentially high capacity for "packaging" our capabilities in programs of extension and education

which can be used, at the local level, to enable villagers to see the benefits of following sustainable practices. However, expertise in this area was held by a relatively few people.

In drawing together these findings, the consultant did not specify the mechanism for implementation other than to suggest that:

- education and training in defined areas based in Townsville was a high priority;
- programs for the in-country transfer of skills, knowledge and application of sustainable management practices were urgently needed;
- development and testing of an extension manual were urgently needed to arrest destructive coastal practices in Southeast Asia and to a lesser extent in the South Pacific; and
- to achieve maximum impact, an integrated approach to the above measures was needed, or the limited funds could be applied to one area only.

We in AIDAB have reached the point where there is now a need to decide how best we can implement this initiative. It would seem that training activities based around Townsville will be a major component of the program, but would include, perhaps, one or two other activities such as ICLARM's proposed reef database, or collaboration in a program with another international organization such as the UNEP Oceans and Coastal Areas Program Activity Centre.

Some progress has been made on design. Discussions over the past few weeks with interested parties have suggested that one way to proceed might be the establishment of a fully self-funding center.

The readiness of the Townsville institutes to work together to meet the needs, such as were identified by the consultant, is encouraging. I understand that they have agreed to proceed with the establishment of INTROMARC along the lines proposed by HOMA. Through this center, they would provide their resources jointly in coordinated programs. Of course the legal and institutional arrangements for the new center will take some time to finalize, but a program funded from the Australian initiative funds could form an initial activity for the new center. This would follow one or more of the options in the consultant's report. After using the Australian initiative funds of A$500,000 during the two years for which they have been pledged, other international and Australian financing would be needed to implement continuing international activities.

Once the Centre is operational, it may be possible, for example, for Australian regional and bilateral aid program funds to be directed towards specific activities to be run by the Centre. This would be, of course, subject to recipient countries' priorities.

It is encouraging to note that, already, organizations such as ICLARM itself, the UNEP Oceans and Coastal Program Activities Centre and the International Maritime Organization have each expressed an interest in collaborative ventures with the proposed center. AIDAB believes that there is potential for major funding agencies such as UNDP, the Commonwealth Fund for Technical Cooperation and, possibly, the multilateral banks, to also sponsor activities which the Townsville Centre could undertake.

With these preliminary thoughts, Mr. Chairman, I would like to invite consideration by participants of the means by which Australia can effectively contribute to tropical-country needs through Australia's initiative in tropical marine ecosystem management.

In particular, we would be interested in participants' views on five matters:

- What are the most pressing needs of developing countries?
- What type of programs do you see the initiative funds are being used for?
- What are the best mechanisms or structures that could be used for the

delivery of the program?

- What geographic focus should there be for the program?
- What are the possibilities of networking with existing institutions in both developing and developed countries?

I regret that other obligations, including a parliamentary committee of enquiry, do not allow me to stay on for this most interesting and timely set of discussion topics. However, my two colleagues Peter Buckley (Development Cooperation Specialist) and Peter Hayward (Environment Specialist) will be happy to participate in your discussions.

Appendix 3

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Appendix 4

Workshop Program

Workshop on Coral Reef Resource Systems
Australian Institute of Marine Science
Townsville, Australia
3-5 March 1992

Tuesday, 3 March

Opening ceremonies

Dr. K.T. MacKay. Welcoming address

Mr. R. Casson. Opening address: The Australian initiative in tropical marine ecosystems management

Dr. J.L. Munro. Definition, scope and purpose of the workshop

Monitoring

Dr. D. Kinsey. Monitoring effects of global climatic and environmental change on coral reef ecosystems

Dr. J. Lough. Climate variations and coral reefs

Dr. S. Massel. Impact of surface waves on physical degradation of coral reefs

Tea break

Dr. A. Mitchell. Towards an understanding of the pattern of nutrient delivery from tropical rivers to the coastal zone

Biodiversity and protected areas

Dr. B. Lassig and Mr. S. Woodley. Systems for selection and management of protected areas

Dr. T. Done. Maintenance of biodiversity of coral reef systems through management of resilience of populations

Regional reports on the status of coral reef resource systems and current research needs

Ms. A. Cabanban	Philippines
Mr. R. Laydoo	Eastern Caribbean
Mr. S.M. Mohammed	East Africa
Mr. M.H. Maniku	Maldives
Dr. S. Sudara	Thailand
Dr. Suharsono	Indonesia
Dr. R. Galzin	French Polynesia

Dr. E. Jordan-Dahlgren. The Caribbean Coastal Marine Productivity Project (CARICOMP)
Dr. J. McManus. Suggestions for future Philippine-Australia coral reef research

General discussion

Lunch

Management of coral reef resource systems
Dr. H. Choat. Demographic and life history features and their importance in tropical fisheries
Dr. G. Russ. The use of refugia for fishery resource management on coral reefs
Dr. I. Poiner. Managing tropical fisheries under threat of climatic change impacts - predicting ecological response to climate change
Dr. J. Woodley. Facilitating change in artisanal fishery practices at Discovery Bay, Jamaica
Dr. R. Pomeroy. Management options for small-scale fisheries
Dr. E. Hviding. Community-based management of coral reef resource systems: South Pacific experiences
Dr. J.J. Polovina. Monitoring and enhancement of coral reef resource systems

Fisheries enhancement and aquaculture
Mr. G. Preston. The potential of aquaculture as a tool for inshore invertebrate resource enhancement and management

Tea break

Dr. P. Doherty. A potential role for light traps in coral reef resource enhancement
Prof. R. South. Cultivation of benthic marine algae in reef and lagoonal systems, with special reference to the tropical South Pacific
Dr. J.L. Munro. Cultivation of fishes and invertebrates in coral reef environments
Dr. J. Benzie. Genetics in marine science

Database development and modeling of coral reef systems
Ms. S. Wells. The global inventory of coral reef systems
Dr. D. Hopley. Coral reef islands in a period of global sea level rise
Dr. R. Froese. ReefBase: a global database on coral reefs
Dr. R. Bradbury. Towards a national marine GIS for Australia
Dr. R. Reichelt. Coral reef resources and research for management
Dr. D. Pauly and Dr. V. Christensen. Modeling coral reef ecosystems

Close
Dinner

Wednesday, 4 March

Working Groups on:
1. Conservation of reef systems and their biodiversity (House 2)

Dr. D. Kinsey	*Dr. J. Lough*
Dr. J. Jordan-Dahlgren	*Dr. S. Massel*

Dr. A. Mitchell	*Dr. Suharsono*
Dr. T. Ward	*Dr. B. Lassig*
Dr. S. Sudara	*Dr. T. Done*

2. Management of coral reef resource systems, particularly fisheries (House 3)

Dr. H. Choat	*Dr. G. Russ*
Dr. I. Polner	*Dr. J. Woodley*
Dr. R. Pomeroy	*Dr. E. Hviding*
Dr. J.J. Polovina	*Mr. S.M. Mohammed*
Dr. R. Galzin	*Dr. K. MacKay*

3. Increasing sustainable yields from coral reef resource systems by aquaculture and fisheries enhancement (House 4)

Mr. G. Preston	*Dr. P. Doherty*
Prof. R. South	*Dr. J.L. Munro*
Dr. J. Benzie	*Mr. R. Laydoo*
Mr. H. Maniku	*Ms. A. Cabanban*
Dr. J. Polovina	*Mr. S. Woodley*

4. Database development and modeling of coral reef ecosystems (House 5)

Ms. S. Wells	*Dr. J. McManus*
Dr. D. Hopley	*Dr. R. Froese*
Dr. R. Bradbury	*Dr. R. Reichelt*
Dr. D. Pauly	

Thursday, 5 March

Plenary presentation and discussion of reports from Working Groups

Working Group 1

Tea break

Working Group 2
Working Group 3
Working Group 4

Lunch

Recommendations of the workshop

Close
Dinner