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Aspects of coastal and marine areas management in the Pacific

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CONTENTS

PREFACE

This volume is the fifth in a series that provides a record of meetings sponsored by the United Nations Environment Programme (UNEP) for the purpose of encouraging inter-regional cooperation and communication among scientists and administrators concerned with the three Regional Seas Programmes and their Action Plans in or adjoining the tropical and southern Pacific (South Pacific, South-East Pacific, and East Asian Seas). The first of these meetings was held at the XV Pacific Science Congress in Dunedin, New Zealand, in 1983 (UNEP 1985); the second at the XVI Pacific Science Congress in Seoul, Korea, 1987 (UNEP 1988); the third at the VI Inter-Congress of the Pacific Science Association in Viña del Mar, Chile, 1989 (UNEP 1991); and the fourth at XVII Pacific Science Congress in Honolulu, 1991 (UNEP 1992).

The UNEP Inter-Regional Regional Seas meeting that forms the basis of this volume was held at the VII Pacific Science Inter-Congress, which met in Okinawa, Japan, from 27 June to 3 July, 1993. The meeting in Okinawa was co-chaired by Margarita Astrálaga of UNEP's Oceans and Coastal Areas Programme Activity Centre (OCA/PAC) and William C. Clarke, who also served as editor of the volume.

The focus of attention at the Okinawa meeting was proposed to be "Integrated Coastal Zone Management", which, under the name "Integrated Coastal and Marine Areas Management" (ICAM), is presently one of the central concerns of OCA/PAC and the Regional Seas programmes around the world (see Astrálaga, this volume). Within that general focus on coastal and marine areas management the ten papers that make up the volume divide into the four topic areas listed below:

1. INSTITUTIONAL APPROACHES TO COASTAL AND MARINE AREAS MANAGEMENT

The first four papers all reflect, at various levels, the growing recognition by governments of the importance of and necessity for integrated management of coastal and marine areas. Astrálaga's paper provides an overview of UNEP's Regional Seas Programme and of some of the particular programmes and their action plans, using the Mediterranean Action Plan to illustrate the development of Integrated Coastal and Marine Areas Management (ICAM). Smith's paper examines in more detail a single regional seas programme and action plan as these are now developing within the South Pacific region, where the mandate to assist member countries to maintain the quality and productivity of coastal and marine environments is held by the South Pacific Regional Environment Programme (SPREP). The South Pacific's regional integrated coastal management project is described and its objectives, strategies, and components are specified. Helgenberger's paper carries the discussion to the national level in an archetypical Pacific country of low coral islands and atolls, the Republic of the Marshall Islands. Within the framework of the country's recently prepared National Environmental Management Strategy (NEMS), Helgenberger describes the environmental challenges facing the country's coastal zone (which essentially includes the entire terrestrial environment of the Marshall Islands) and the current responses to those challenges. Considering a vastly greater scale – with regard to population, land area, biodiversity, and variety of environments – Baines looks at the purpose and functioning of Indonesia's Marine Resource Evaluation and Planning Project.

Explicit in all four of these papers is the recognition that coastal and marine management is only beginning to establish the mechanisms whereby effective results toward sustainable development of coastal and marine areas might be achieved. The process is slow in that it requires setting out clearer and firmer policies, which must then be backed up with legal, planning, scientific, and administrative apparatus. The bright side of the situation is that now not only governments but also bilateral and multilateral aid agencies recognize that sustainable development will require integrated environmental planning and management and, further, that support should be given not only to the usual economic sectors but also to public awareness of environmental issues and to building each nation's capacity for environmental management.

2. BIO-PHYSICAL RESEARCH

As is underscored in the four institutionally focused papers, an essential requirement of good management is the acquisition of information about and understanding of the processes and problems of coastal and marine environments. In the three research papers in this section, three different aspects of those environments are examined. Using past analogues from the Pacific, Ellison reviews the ways
in which mangroves – a coastal bulwark of vegetation – can be expected to respond to different rates of sea-level rise. She then discusses the parameters of the long-term global monitoring of mangroves now underway. Based on observations of re-colonization that occurred on the floors of artificial lagoons near Singapore, Chou discusses responses of coral reefs to rising sea level. Eldredge turns attention to the (mainly) intentional introductions of aquaculture animals to the Pacific Islands, a matter of growing significance as natural stocks of fish and shellfish everywhere decline.

3. HEALTH AND POLLUTION

Both papers in this section contain concern for *measuring* pollution or toxicity as well as for *controlling* pollution's threats to the environment and human health. In Kwiecinski's paper the worldwide coastal necessity, present in industrial and in less developed countries alike, to plan effective and safe sewage disposal is examined with reference to one particular place, the Bay of Panama. Santos-Mendigo considers, with reference to the Philippines, the responses of government agencies to recurrent episodes of "red tides" and shellfish toxicity.

4. A LONG-TERM VIEW OF COASTAL MANAGEMENT

In the final paper, John Bardach, a senior marine scientist with long experience in the Pacific, reflects on the recent downgrading of forecasts for sea-level rise and on the continuing interactions between coastal environmental changes and the rapid increase in economic development and human population along the world's coasts. He further speculates as to which sorts of responses are most appropriate to a variety of coastal environmental changes, in the light of the frequency of recurrence of natural phenomena and the difference in time scales between natural and social environments.

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The Regional Seas Programme: Current Activities in Integrated Coastal and Marine Areas Management (ICAM)

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ABSTRACT

The Regional Seas Programme of the United Nations Environment Programme (UNEP) is briefly described, with a particular focus on the recent development of **Integrated Coastal and Marine Areas Management** (ICAM).

INTRODUCTION

The Regional Seas Programme of the United Nations Environment Programme (UNEP), launched in 1974, at present includes twelve regions and has over 140 coastal states participating in it. It is conceived as an action-oriented programme having concern not only for the consequences but also the causes of environmental degradation in coastal and marine areas. It encompasses an approach to combating degradation by means of more comprehensive management. Each regional action plan is formulated according to the needs of the region as perceived by the Governments concerned and is designed to link assessment of the quality of the marine environment and the causes of its deterioration with activities for the management and development of the marine and coastal environment. The action plans promote the parallel development of regional legal agreements and of action-oriented programme activities.

The programme is coordinated by the Oceans and Coastal Areas Programme Activity Centre (OCA/PAC) of UNEP, but its success critically depends on the work of specialized organisations and centres dealing either with specific regions covered by the programme or with specific subjects common to most or all of the regions.

The substantive aspect of any regional programme is outlined in an "action plan", which is formally adopted by an intergovernmental meeting of the Governments of a particular region before the programme enters its operational phase. In the preparatory phase leading to the adoption of the action plan, Governments are consulted through a series of meetings and missions about the scope and substance of an action plan suitable for their region. In addition, with the cooperation of appropriate global and regional organisations, reviews on the specific environmental problems of the region are prepared in order to assist Governments to identify the most urgent problems in their region and to assign corresponding priorities to the various activities outlined in the action plan. UNEP coordinates directly, or in some regions indirectly through existing regional organisations, the preparations leading to the adoption of the plan.

An action plan usually includes components on both *environmental assessment* and *environmental management*. *Environmental assessment* is intended to provide for the assessment and evaluation of the causes of various forms of environmental degradation as well as their magnitudes and impacts on the region. Emphasis is given to such activities as baseline studies; research and monitoring of the sources, levels, and effects of marine pollutants; ecosystem studies; studies of coastal and marine activities and of social and economic factors that may influence, or be influenced by, environmental degradation; and a survey of national environmental legislation. Environmental assessment is undertaken to enable national policy makers to manage their natural resources more effectively and sustainably and to provide information on the effectiveness of legal/administrative measures taken to improve the quality of the environment. *Environmental management* includes activities such as: co-operative regional projects on training in environmental impact assessment; management of coastal lagoons, estuaries, and mangrove ecosystems; control of industrial, agricultural, and domestic wastes; and formulation of contingency plans for dealing with pollution emergencies.

Taking the above into account, UNEP proposed to the Mediterranean and Caribbean States in 1987 that the programme be refocused toward environmentally sound integrated planning and management of coastal zones in order to give greater prominence to the management of coastal areas and, thus, integrate more closely the various components of the action plan, taking into consideration their environmental dimension.

INTEGRATED COASTAL AND MARINE AREAS MANAGEMENT (ICAM)

Integrated Coastal and Marine Areas Management (ICAM) is one of the most important activities of the Mediterranean Action Plan (MAP) and certainly the most important one for MAP's Priority Actions Programme (PAP). The basis of ICAM was developed within the respective priority action, resulting in the preparation of the PAP/RAC document (1988) *A Common Methodological Framework for Integrated Planning and Management in the Mediterranean Coastal Areas*. A wider implementation of ICAM started in 1988 through Country Projects, which were later transformed into MAP Coastal Area Management Programmes (CAMPs).

The activities of PAP were directed to the implementation of ICAM through:

- preparation of planning and management documents in selected small Mediterranean areas, in cooperation with the local and national experts;
- development and application of tools and techniques of ICAM;
- organisation of training for national and local experts on the preparation of integrated plans and studies, and on environmental management of coastal areas; and
- improvement, updating, and expansion of the methodological basis for ICAM

The approach to ICAM was tested through the preparation of management documents within CAMPs. The PAP resources allowed only for the preparation of documents at the level of studies and programmes enabling the identification of problems of coastal areas, definitions of development options, proposals of models of resource utilisation at a sustainable basis, identification of appropriate institutional structures for environmental management, and proposals of immediately applicable measures for resolving environmental problems. Such documents have been prepared for the Syrian coastal region (both a study and a management plan for coastal resources) and the island of Rhodes in Greece, and are in preparation for the city of Izmir in Turkey. In cooperation with the Blue Plan (UNEP/MAP/BP 1988; Grenon and Batisse 1989), development-environment scenarios have been prepared for the area of Kastela Bay (Croatia), which was the most important input for the preparation of an integrated project undertaken by the national authorities.

To meet the requirements of Mediterranean developing countries, PAP has adapted a number of tools and techniques for ICAM, such as: Geographical Information System (GIS), in cooperation with UNEP-GRID and UNITAR; Carrying Capacity Assessment for tourism (CCA); Hazard Assessment and Risk Management (HARM); and multi-criterial analysis for environmentally sound siting of development projects.

Most of these tools and techniques have been applied in practice at a number of sites in the Mediterranean, mostly through CAMPs. For example, GIS has been applied in Kastela Bay, the Bay of Izmir, the Syrian coastal region, and the island of Rhodes; CCA for tourism in the islands of Vis and Brijuni (Croatia), and the island of Rhodes; HARM in Kastela Bay; and the multi-criterial analysis for finding a suitable site for a thermal-power plant on the Adriatic coast. The application of these tools and techniques at selected sites is first implemented in order to resolve environmental problems, especially within CAMPs. Each application has been the subject of a report, which presents the results and benefits of each activity carried out.

The experience gained over four years showed that the methodological framework of ICAM should be revised. In cooperation with OCA/PAC, PAP/RAC prepared the document entitled *Guidelines for Integrated Management of Coastal and Marine Areas* (UNEP 1995), which offers practical advice on how to prepare planning and management documents for coastal areas. In addition, a number of issues of emerging importance to environmental management in Mediterranean countries have been studied more thoroughly (institutional structure, economic instruments, environmental statistics), an activity that will result in practical procedures to be implemented in interested Mediterranean countries.

In the period 1994-95, the PAP activities related to ICAM will be focused on the practical application and testing of the Guidelines for ICAM (prepared in cooperation with OCA/PAC). Apart from the preparation of suitable documents, an intensive training activity is envisaged, both through regional workshops and national training courses. Special attention will be paid to testing the results of the analysis of specific management issues (economic instruments, institutional management). The countries will be offered specific procedures and assistance in their implementation.

Besides continuing the application of the well established tools and techniques, such as GIS and CCA, especially within the existing CAMPs – and the new CAMPs planned in Albania, Egypt, and Tunisia – additional tools and techniques will be developed and tested in the Mediterranean region. Special attention will be given to ones such as remote sensing and its linkage to GIS, and conflict-resolution techniques for use in environmental management.

Since 1989, the South-East Pacific Action Plan has been refocused to address coastal zone management issues. Direct support was given to national institutions of Colombia, Chile, Ecuador, Panama, and Peru for the preparation of case studies on coastal zone management plans for specific sites. Training on the application of GIS in the development of coastal zone management plans was provided to fifteen professionals of the South-East Pacific region in late 1993.

In the case of the Eastern African region, a project on coastal zone management has been launched and is being implemented by FAO in cooperation with the Intergovernmental Oceanographic Commission (IOC) and the World Conservation Union (IUCN). Training has been provided in the use of GIS, and, during the latter part of 1993, professionals of the Eastern African region were trained in the methodologies used for undertaking integrated coastal zone management. After the training has been provided, States from the Eastern African region are expected to carry out pilot case studies in selected sites.

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Integrated Coastal Zone Management in the Pacific Island Region: SPREP's Responsibilities and Initiatives

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ABSTRACT

The South Pacific Regional Environment Programme (SPREP) is mandated to assist its member countries to manage and plan for the multiple-use, ecologically sustainable development and conservation of coastal areas, habitats, and resources. To this purpose, SPREP has initiated a regional Integrated Coastal Zone Management (ICZM) project. ICZM is a comprehensive, multi-sectoral, integrated approach to the planning and management of coastal areas. Although only in its early development, the project proposes to include the following components:

1. ICZM approach to development for the Pacific islands;
2. coastal management and planning for priority areas (urgent response projects);
3. coastal hazards management;
4. national integrated coastal zone management programme development;
5. ICZM education and awareness programme; and
6. regional coordination of integrated coastal zone management activities.

INTRODUCTION

It is impossible to overstate the importance of coastal areas to the Pacific island peoples, cultures, and economies. The coastal areas of Pacific islands are where most island people live, and where most subsistence and commercial agriculture, fishing, and economic development take place. Increasingly, this combination of increased settlement and activity results in the degradation of coastal habitats, the over-exploitation of natural resources, and an increase in conflicts over resource use, especially around the Pacific's rapidly growing urban centres.

Coastal areas of the Pacific are also subject to the damaging effects of natural hazards. Extreme events such as cyclones (typhoons, hurricanes), high storm waves, and abnormally high tides cause extensive damage and destruction. Low-elevation islands and the low-lying coastal areas of the larger, higher Pacific islands are particularly at risk. Global warming now threatens to exacerbate these hazards through accelerated sea-level change, increased frequency and intensity of storms, and other changes to climatic and oceanographic conditions.

These problems of coastal management are widespread in the region and in some areas require urgent attention. The potential for sustainable development of coastal areas and resources is being permanently lost or compromised. Coastal management needs are particularly pressing in the very small islands, especially low-elevation islands, and the coastal urban areas of the Pacific. However, much of the degradation of coastal habitats, depletion of resources, and destruction of coastal areas could be avoided, reduced, or mitigated through integrated coastal zone management and planning.

This paper will provide an overview of the South Pacific Regional Environment Programme (SPREP) and its mandates concerning coastal management; outline the need, constraints, and opportunities for coastal management in the region; and discuss SPREP's initiatives for Integrated Coastal Zone Management (ICZM).

THE SOUTH PACIFIC REGIONAL ENVIRONMENT PROGRAMME

The South Pacific Regional Environment Programme (SPREP) is a regional organisation established by the governments of 22 Pacific island countries and territories (American Samoa, Cook Islands, Federated States of Micronesia, Fiji, French Polynesia, Guam, Kiribati, Marshall Islands, Nauru, New Caledonia, Niue, Northern Marianas Islands, Palau, Papua New Guinea, Pitcairn, Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu, Wallis and Futuna and Western Samoa); and four developed countries (Australia, France, New Zealand and the United States).

SPREP began as a programme within the South Pacific Commission, based in Noumea, New Caledonia, in 1978. SPREP's office and staff moved from Noumea to Apia, Western Samoa, early 1992. In June, 1993, the agreement establishing SPREP as an autonomous intergovernmental organisation was signed.

AIM

SPREP's mission is to assist Pacific island countries and territories protect and improve their shared environment, and to manage their resources to enhance the quality of life for present and future generations.

OBJECTIVES

The Action Plan (SPREP 1993a) sets out the mandate for SPREP's activities and provides a framework for environmentally sound planning and management for the region. The 1991-95 Action Plan is a regional strategy, identifying many aspects of environmental assessment, management, and law. SPREP is responsible to its member governments and administrations for overall technical coordination and supervision in implementing the Plan, which aims to:

- further assess the Pacific environment, especially where humans influence ecosystems, including effects on their own environments;
- strengthen national and regional capabilities, links, and funding to carry out the Action Plan;
- provide integrated legal, planning, and management methods to protect and use natural resources in an ecologically sound way;
- provide more training, education, and public awareness for improving the environment;
- encourage development that maintains or improves the environment;
- protect ecosystems of both land and sea, and their component species that need special attention or help;
- reduce pollution on land, in fresh and sea water, and in the air; and
- encourage the use of Environmental Impact Assessment (EIA) and other methods to stop or lessen the adverse effects of humans on the environment.

PROGRAMMES

SPREP's Work Programme deals with the following major areas:

Conserving Biological Diversity
Global Climate Change and Sea-Level Rise
Environmental Planning and Management

Coastal Management and Planning
Managing Pollution and Pollution Emergencies
Environmental Information, Education and Training
Regional Environmental Concerns

BASIS FOR ACTION

The goal of the Coastal Management and Planning component of the SPREP Action Plan instructs SPREP to assist member governments ". . . to manage and plan for the multiple-use, ecologically sustainable development and conservation of coastal areas habitats and resources" (SPREP 1993a: 15). Additionally, the goal of the Global Change component of the SPREP Action Plan mandates SPREP ". . . to develop and implement a regional programme to assist members to understand and avoid or mitigate the potential adverse impacts of climate change" (SPREP 1993a: 11). The more detailed SPREP Climate Change Work Programme, formulated by the Second SPREP Meeting on Climate Change and Sea Level Rise in the South Pacific Region, instructs SPREP to develop and implement integrated coastal zone management programmes and plans in all Pacific Island countries, with particular emphasis on very small and vulnerable islands.

Developing and implementing an Integrated Coastal Zone Management Project for the Pacific islands region would be a major step towards fulfilling the national, regional, and global requirements to address issues of the coastal environment and development in Pacific island countries. At the national level, a multi-nation regional project would support the sustainable development of the coastal zone, as called for in the various National Environmental Management Strategies (NEMS) and national development plans. Regionally, the mandate of the SPREP Action Plan and the major elements of the SPREP Work Programmes on Coastal Management and Planning and Climate Change would be addressed. Internationally, a regional-wide coastal zone management project would implement portions of Chapter 17 in UNCED's Agenda 21, the Climate Change Convention, and the Inter-Governmental Panel on Climate Change recommendations.

CONSTRAINTS AND OPPORTUNITIES

The general issues of environment and development and the constraints to sustainable development in the Pacific island region were clearly identified in *The Pacific Way* (SPREP 1992), the report prepared for the United Nations Conference on the Environment and Development (UNCED). They have been further elaborated in Thistlethwaite and Votaw (1992) and in preparatory documents for the Global Conference on the Sustainable Development of Small Island Developing States to be held in 1994 *(e. g.*, SPREP 1993b). Many of the constraints and opportunities also relate to implementing national integrated coastal zone management programmes. The key constraints and opportunities relevant to the implementation of integrated coastal zone management are outlined in this section, based on material in *The Pacific Way* (SPREP 1992: 13-32).

ENVIRONMENT

The small size and narrow resource base of many Pacific islands make them particularly vulnerable to inappropriate development and mismanagement, the effects of which are usually manifested in the coastal areas. For some countries, the ocean is a major part of their resource base, with very high ratios of sea to land (Kiribati has a ratio of over 4,000:1). Similarly, the ratio of coastline to land area is extremely high. With the exception of the larger Melanesian islands, the Pacific islands are almost entirely dominated by their coastal character.

The dispersed archipelagic nature of the Pacific islands is both a blessing and a cause of difficulty. The broad distribution of the islands through the world's largest ocean has endowed many Pacific island countries with large Exclusive Economic Zones (EEZ) and access to the resources within them. However, the great distances within and between countries places a considerable cost burden on transportation. This cost explains, for instance, the concentration of most coastal-related management and training activities in the easily accessible centres.

The generally small size of Pacific islands means that the natural disasters (cyclones, floods, droughts) have a relatively great impact on the environment; and the tremendous distances involved places heavy burdens on disaster management and response.

POPULATION

Many of the coastal management concerns can be traced to high population densities and the continuing high rate of population growth, coupled with poor management and planning of expanding settlements. The net population growth of the region is high with natural rates of population increase well over two per cent, and in some countries over three per cent or even regularly approaching or slightly exceeding four per cent – close the world's highest rates of increase. These rates of increase mean that in many Pacific countries the population can be expected to double within the next 30 years, and in a few countries to double over the next 20 years or even less.

Coastal management problems are often associated with urbanisation and growth in established population centres. In the capitals of atoll nations, population density is phenomenally high – that of Tarawa in Kiribati rivalling the density of Hong Kong, and Ebeye Island in the Marshall Islands having a population density of 23,200 per square kilometre. Throughout the region there is a movement of people into the urban areas. Apart from the social effects of this movement, the environmental effects are considerable – amplified by the limited land areas. There is often a loss of valuable agricultural land to housing developments; the disposal of liquid and solid wastes poses an almost insurmountable problem; coastal regions are overfished. All these processes combine to degrade the coastal areas.

Only in those smaller countries – such as American Samoa, Cook Islands, Niue, and Tokelau – where emigration arrangements with metropolitan countries allow, are some of these problems avoided or mitigated. However, for a few countries, the loss of population through emigration has been so substantial that they have experienced a negative rate of growth and suffer a severe human-resource shortage because it is the skilled and highly qualified workers who have been enticed away.

EDUCATION

There are many concerns about the quality of formal education and a frequently expressed need for greatly increased effort in vocational training, apprenticeship programmes, and other on-the-job, skill-learning opportunities. Environmental education is one facet of the broader education process and throughout the region there is some emphasis on education on environmental issues, both within the formal education system and for the general public. For example, there is growing awareness via mass media (TV, radio, and print) of environmental issues. However, the subject still remains a relatively low priority.

ECONOMIES

The economic characteristics of the Pacific island countries vary largely according to resource endowments, consumption patterns, and the institutional capacity to support such development. Compared with the rest of the region, the Melanesian countries are resource-rich; Papua New Guinea, when compared with the other Melanesian countries, is particularly fortunate in its marine resources, mineral wealth, and large areas of fertile upland soils.

At the other extreme, the atoll nations are poor in natural resources, their sole major economic development opportunity being the marine resources of their EEZs. In some instances, economic prospects may be brightened by an increase in tourism, but the difficulty and high cost of access to most of the atolls for international tourists may limit this prospect.

Pacific island economies, like their physical environments, are extremely fragile and vulnerable to external and domestic factors, most of which are beyond their control. This vulnerability stems, in part, from their narrowly-based economies. They rely upon a narrow range of commodities, the prices of which fluctuate widely in world markets. The level of consumption is high, domestic savings are low or negative, and domestic expenditures typically exceed GDP by wide margins, so that there are large current account deficits in the balance of payments, which are financed largely through aid and, in a number of cases, remittances.

LOCAL KNOWLEDGE OF RESOURCES AND THEIR MANAGEMENT

Within the past few years awareness of the importance of local knowledge and management systems has grown rapidly within international development and conservation agencies. The potential for these systems to be applied to the management of coastal areas in the region is great. The value of management systems based on local knowledge and the interest expressed by islanders and their governments in having the knowledge recorded and used in the management of natural resources is, unfortunately, not reflected in the attention being given to the matter by natural-resource professionals and management advisers in the region. There has also been some interest in building traditional customs and management controls into modern legislation to reconcile legal precision with customary practice.

Local knowledge is eroding at an accelerating rate as a consequence of westernisation, industrialisation, urbanisation, and the accompanying alienation of the young from their traditions. The educated elite whose formal education is often obtained far from their own communities frequently know little about local subjects. It is these very people who will be most responsible for influencing patterns of natural resource use and management in their communities in future years. Their technical and political sophistication cannot be put to best use without consideration of the traditional knowledge and practices of their elders.

COASTAL MANAGEMENT

A number of constraints limit the effectiveness of coastal management in the Pacific region. The key structural impediment is the current *ad hoc,* sectoral approach by most governments in the region to activities that bear on coastal management. Rarely is there a single or lead agency responsible for overseeing coastal management. Where there is, the agency's scope of responsibilities is usually quite limited, or narrowly defined.

Communication or coordination between departments on government-initiated projects is minimal or cursory at best. For example, how often would a Public Works Department consult or coordinate its activities with the Fisheries Department and/or Environment Unit when initiating work adjacent to the shoreline? This problem is being partly addressed by the slow adoption by governments of Environmental Impact Assessment (EIA) procedures for development projects.

There is often a failure to recognise the interconnectedness of island ecosystems, resulting in the non-recognition of problems, causes, and effects. The limited number of qualified personnel with experience in coastal management and related areas is a major problem throughout the region. This is exacerbated by a lack of financial support and an overload of work. One of the negative effects of this situation is that what coastal management related activities do occur tend to be centralised on the main islands (political/government centres) and rarely extend to the outlying areas and islands.

On the positive side, the opportunity to implement national integrated coastal zone management programmes has never been better. There has been a considerable change in attitude by leaders in the region concerning the need to ensure that development activities are sustainable, and that sound environmental practices and policies need to be incorporated into national strategic plans. The United Nations Conference on Environment and Development (UNCED) in 1992 not only illuminated the problems of small islands on the international stage, but also raised the level of awareness within the region. That the political will in support of environmentalist actions is now there is indicated by the current development of National Environment Management Strategies in the independent Pacific island countries (for instance, see Helgenberger, this volume). What is needed for coastal management is positive action to support that developing political will.

INTEGRATED COASTAL ZONE MANAGEMENT IN THE PACIFIC REGION

REGIONAL APPROACH

The particular combination and linkage of geographical, social, cultural, and economic conditions found in the Pacific islands region necessitates a fresh approach to integrated coastal zone management. Integrated coastal management guidelines and programmes that have been prepared or have been enacted around the world, are either too general in nature, or are inappropriate for the conditions found in our region. It is therefore essential that appropriate approaches for integrated coastal zone management be developed for the Pacific islands region, while taking into account the experiences of other regions of the world.

DEFINITIONS

Integrated Coastal Zone Management (ICZM) is a comprehensive, multi-sectoral, integrated approach to the planning and management of coastal areas. It encompasses a process of planning and management for the sustainable development, multiple use, and conservation of coastal areas, resources, and ecosystems. Natural hazards preparedness and response planning in coastal areas are also important parts of ICZM, which now must be expanded to include planning for the impacts of climate change – especially warming-induced sea-level rise – in the coastal zone.

The meaning of "coastal zone" is often interpreted differently by planners, resource managers, lawyers, decision makers, and the general public. For the purposes of this paper the following description of the coastal zone is used.

The coastal zone is a region of indeterminate and variable width. It extends from and includes, the wholly marine (*i.e.*, the sea bed, the overlying waters, and their resources) to the wholly terrestrial (*i.e.*, beyond the limits of marine incursion and the reach of salt-spray). Linking these two environments is the tidal area, which forms a transition between the land and the sea. The coastal zone, so described, is characterised by a steep ecological and environmental gradient (from the wholly marine to the wholly terrestrial) and is consequently rich and diverse in natural resources. Because of this, the coastal zone is the focus of subsistence and commercial agriculture, fisheries activity, and the location of intense economic development and settlement.

The environments of the land and sea are strongly linked at the coast. Events on land are reflected in coastal waters while storm events also have a substantial impact on coastal lands and seas. The extent of such linkages and their effects vary seasonally, year-by-year, and in response to occasional catastrophic events. Superimposed on this physical and biological base is human activity. Managing coastal activities is normally approached sector by sector (*i.e.*, fisheries, agriculture, transport) and area by area, which is inappropriate. Rarely is the coastal zone viewed, much less managed, as an integrated entity; the challenge of integrated coastal zone management is to do so.

SPREP'S REGIONAL ICZM PROJECT

Project Development

In 1992, SPREP prepared a concept document on "Integrated Coastal Zone Management in the South Pacific Region" in response to increasing pressures being placed on coastal areas in the region. The concept document was circulated for comment and received positive feedback. As a result it was decided to seek funds to hold a technical working group meeting to further develop the concept.

The technical working group meeting was held in late May, 1993. Participants included professionals with experience in different disciplines related to coastal management (*e.g.*, in marine resources, geoscience, social science, policy, planning, and others) so as to ensure that a multi-sectoral perspective was obtained. The working group participants were drawn from regional institutions/ agencies, universities, governments, and an NGO. The concept document formed the basis for discussions.

The following information is largely based on the recommendations of that working group. The project proposal is presently undergoing extensive review, which will include a review meeting by SPREP member governments. Following these reviews the final project proposal will be drafted for distribution and submission to potential donors.

Statement of Purpose for the ICZM Project Proposal

To promote the sustainability of coastal areas and resources for Pacific islands through Integrated Coastal Zone Management, by integrating all human activities and natural processes that affect coastal systems and recognising that these do not conform to administrative boundaries.

Principles

The following principles have been based upon those declared by the regional leaders in *The Pacific Way* (SPREP 1992: 34) as being important in guiding sustainable development in the region. SPREP believes it is important that the linkages between the regionally identified principles for sustainable development and those for integrated coastal zone management be made. The principles upon which the integrated coastal zone management project proposal is based, are:

- The needs of present generations must be met without compromising the ability of future generations to meet their own needs.
- Equity in participation must be promoted in sustainable development.
- Adverse environmental impacts of economic development must be minimised.
- The precautionary principle must be taken into account.
- Resource use and development planning policies must integrate environmental considerations with economic and sectoral planning and policies.
- International responsibilities in the Pacific islands region must be met.

Goals

Integrated Coastal Zone Management for the Pacific islands region should:

1. Sustain natural systems by ensuring sustainability of coastal resources, protecting critical systems and biodiversity, and recognising the inter-relationships between natural, social, economic, and cultural systems.
2. Be determined by locally identified needs and be appropriate to local social, cultural, political, and economic systems.
3. Balance local, provincial, regional, and national goals.
4. Provide for the economic and social needs and aspirations of communities.

5. Encourage integrated coastal management and strategies at appropriate levels of decision-making.

6. Incorporate measures for capacity building, including training and education at all levels in order to strengthen institutional capacity, improve information and data bases, and enhance the exchange of information, experience and expertise.

Specific Objectives

The specific objectives of the regional integrated coastal zone management project are:

1. To develop approaches to integrated coastal zone management appropriate to the Pacific islands region.

2. To develop the capacity to conduct short-term, issue-targeted projects to address urgent coastal management problems that require attention sooner than it could be available through standard funding and programme-development cycles.

3. To minimise or mitigate the impacts of coastal hazards (including accelerated sea-level changes) in the coastal zone in both the long-term and short-term, by bringing the practices of disaster preparedness, planning and management into line as a component of ICZM plans.

4. To establish national integrated coastal zone management programmes in Pacific island countries.

5. To generate awareness in the Pacific of the needs and benefits of integrated coastal zone management, both the general public and, particularly, the decision makers. To develop specialised ICZM training for national coastal zone managers.

6. To develop greater coordination and cooperation between regional organisations and also between Pacific island governments with regard to issues of coastal management and problems.

Strategies

This project proposes to adopt strategies which encompass a "bottom-up" approach to management. The success or failure of any national integrated coastal zone management programmes in the region will depend upon how involved the local communities are in any decision making. This is particularly important in the Pacific islands due to the degree to which customary practices are presently involved in the decision-making process. Even at the government level a very high value has been placed on the traditional process of cooperation and the achievement of consensus in problem resolution. In integrating coastal management activities, SPREP and its member governments also place a high priority on ensuring the inclusion of Non-Governmental Organisations (NGOs), particularly women's groups, in any decision-making process.

All of the independent countries of the Pacific island region are developing National Environmental Management Strategies (NEMS). These provide a broad national institutional framework for integrated environmental management and planning, within which can be incorporated the development and implementation of integrated coastal zone management. The NEMS that have already been developed have identified the need for ICZM and set out priority areas for ICZM action. Wherever possible, this project will utilise the NEMS task forces already set up in countries to facilitate the implementation of ICZM programmes. In countries that do not have NEMS task forces or Sustainable Development Commissions, a similar multi-sectoral mechanism will be suggested as the preferred means to initiate the ICZM process.

This ICZM project is structured in such a way as to allow both the short-term and long-term issues and needs of coastal management in the Pacific islands region to be addressed. In addition, it encourages the use of preventative methods and processes rather than remedial ones.

Because of the constraints currently affecting coastal management within the region, and because the project is regionally based, there will be considerable emphasis on coordinating activities within the region, especially on sharing information and, where possible, personnel between countries and between the countries and the regional agencies involved.

Project Components

The six proposed project components correspond directly to the specific objectives noted above. They are:

1. Integrated Coastal Zone Management Approach Development for Pacific Islands.

   To provide a critical review of coastal zone management needs and develop a support tool which will enable appropriate regional approaches to be developed and implemented. This component is seen as underlying much of the other work.

2. Coastal Management and Planning for Priority Areas – Urgent Response Projects.

   To address issues which require responses on a time scale which is not possible within normal programme development cycles, and which cannot wait until fully integrated national coastal management planning is developed.

3. Coastal Hazards Management.

   To address the management of extreme events arising from climatic, oceanographic, and tectonic events, which have major physical, social, or ecological impacts. This includes accelerated sea-level rise as it represents a coastal hazard, albeit on a longer time frame.

4. National Integrated Coastal Zone Management Programme Development.

   The long-term goal of this project is to establish effective national integrated coastal zone management programmes within the countries of the Pacific islands region.

5. Integrated Coastal Zone Management – Education and Awareness Programme.

   For ICZM to be successfully implemented in this region, it will be essential that the decision makers – at the national as well as the village level – understand the need for and benefits of integrated coastal management. This will only be achieved through extensive education and awareness programmes. This component will also include a specific training sub-component for coastal managers. This whole component is inextricably linked with the other components.

6. Regional Coordination of Integrated Coastal Zone Management Activities.

   The large number of countries, the limited expertise and the urgent need to resolve coastal management issues will necessitate greater regional coordination. This will include sharing of experiences and expertise within the region, information networking, and greater coordination of regional and international agencies active in coastal related activities.

CONCLUSION

The project proposal for ICZM is still in its development stages and so the information presented here, although based on input from member countries and the technical working group, may differ from the final project document. The final shape of the project will be determined by the results of the detailed review by SPREP member governments' representatives (who met in September, 1993), combined with comments from external reviewers.

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Managing Marine and Coastal Resources for Sustainability in the Republic of the Marshall Islands

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ABSTRACT

The Republic of the Marshall Islands (RMI) consists entirely of low coral islands and atolls. With only a small area of land and quite limited freshwater resources and agricultural potential, the country must rely on its abundant coastal and ocean resources for economic growth and sustainable development. Yet the coastal resources are fragile and are suffering several sorts of degradation because of development and rapid population growth, particularly in the urban centres of Majuro and Ebeye. In 1991–92, with assistance from the Asian Development Bank, the RMI prepared a National Environmental Management Strategy (NEMS), which identified the major environmental challenges facing the country and put forward a set of environmental action strategies, several of which relate to coastal resources. This paper briefly describes the environmental challenges to the coastal zone and reviews the current responses to the challenges, the implementation of the action strategies, and the future priorities for strengthening the nation's environmental-management capabilities.

INTRODUCTION

The Republic of the Marshall Islands includes 29 atolls and five low-elevation islands located in the north-central Pacific Ocean (Figure 1). Twenty-two of the atolls and four of the islands are inhabited. Scattered in an archipelago consisting of two roughly parallel island chains – the western Ralik ("sunset") and eastern Ratak ("sunrise") chains – the atolls and islands extend about 1130 km (700 miles) north to south and about 1290 km (800 miles) east to west. With a total land area of just under 181 square kilometres (70 square miles), a mean height above sea level of two metres, and an Exclusive Economic Zone of over a million square kilometres, the country is largely marine, and the small area of land is wholly dominated by its coastal zone. Expectably, the country's major natural resources are also concentrated in the reefs, lagoons, ocean waters, and, potentially, the deep-sea floor. Comparatively, the terrestrial resources are impoverished. With few exceptions, the soils in the Marshall Islands are nutrient-poor and shallow. Moreover, they are subject to continual exposure to salt spray, high rates of evaporation, and high average wind speeds – all of which contribute to high surface salinity, a further impediment to the healthy growth of many plants. For the most part, natural freshwater resources are limited to the sub-surface Ghyben-Herzberg lenses, which where present can usually be accessed by digging down only a metre or two. Because the lenses are not uniformly present (generally being located only on larger islets) and are subject to contamination, most of the inhabited islands rely heavily on rainwater catchment systems to help meet freshwater needs (Republic of the Marshall Islands 1992a: 1-6).

ENVIRONMENTAL CHALLENGES

The major environmental challenges presently facing the Republic of the Marshall Islands have been identified and fully described in the two-part report that presents the country's National Environmental Management Strategy (NEMS) (Republic of the Marshall Islands 1992a; 1992b). The

NEMS document represents the first government-wide effort to evaluate the state of the environment in the Marshall Islands, to assess environmental-management needs, and to establish future priorities for improving management capabilities. It is the product of a lengthy consultative process between government officials (the National Task Force on Environmental Management and Sustainable Development) facilitated by technical assistance from the Regional Environment Technical Assistance (RETA) Project. Funding for the RETA Project was provided by the Asian Development Bank, and technical assistance and further funding were provided by the South Pacific Regional Environment Programme (SPREP), the World Conservation Union (IUCN), and the United Nations Environment Programme (UNEP). The full discussion and description presented in the NEMS document provide the basis for the briefer details in this paper, which will particularly focus on issues of environment and its management that relate to the coastal zone of the Marshall Islands.

CLIMATE CHANGE AND SEA-LEVEL RISE

The most threatening environmental challenge seen to be facing the Marshall Islands is global climatic change and the accompanying potential for a rise in average sea level, a process that would impinge drastically upon the Marshall Islands by destroying precious arable land, by diminishing and contaminating the freshwater lenses, and by damaging coastal property. In the worst-case scenario, the nation's atolls and islands could be rendered uninhabitable.

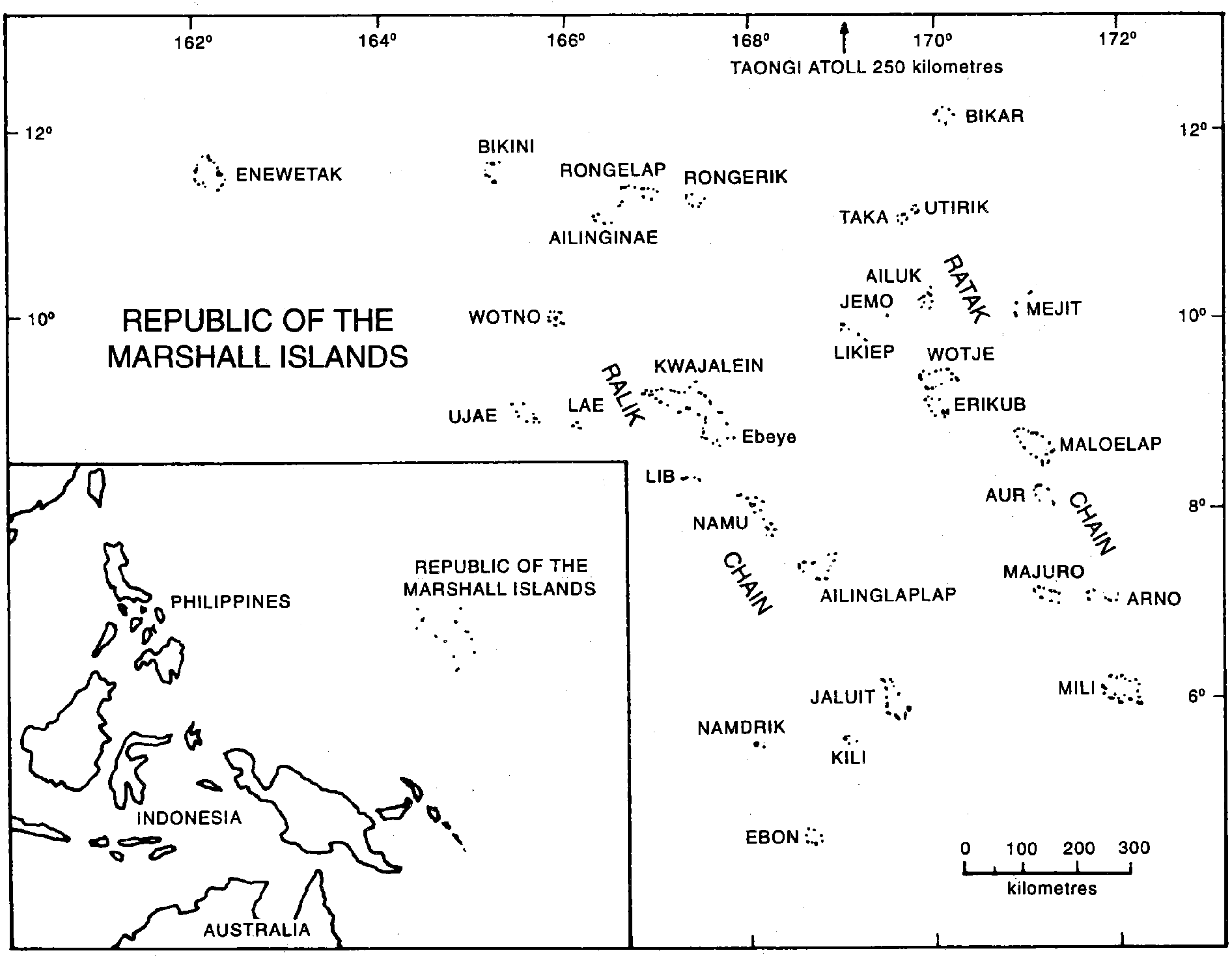

Figure 1: Map of the Republic of the Marshall Islands

SOLID WASTE ACCUMULATION AND DISPOSAL

Today, the typical household in the Marshall Islands generates significant quantities of nonbiodegradable solid waste, which accumulates on land and in adjacent waters at ecologically damaging levels. Particularly in the two urban areas, with their high population densities (11,500 persons per square kilometre in urban Majuro and 23,000 persons per square kilometre in Ebeye), people have become heavily dependent on imported packaged goods, and the buildup of solid waste both on land and in the tidal zone now threatens marine life, spreads vector-borne diseases, and contaminates freshwater sources. Because collection of solid waste is erratic on Majuro, piles of trash often remain near residences for days, attracting flies and inviting animals to rummage through and disperse the waste on the ground. To avoid this, some residents have reverted to the traditional practice of throwing waste into the ocean or lagoon. When waste is collected by the municipal authority, it is taken to the public landfill located on the oceanside reef of the atoll where it is dumped behind a gabion seawall. Although permit restrictions stipulate that the landfill is to be compacted and covered with a layer of fill material daily, this procedure is not always carried out because of equipment failures and insufficient quantities of fill. At high tide, ocean water inundates the fill, and – although the gabions generally stop the solid waste from drifting away – leachate freely seeps onto the adjacent reef flats so that the surrounding ocean waters consistently fail to meet the water-quality standards of the Environmental Protection Authority. On Ebeye, the trash-collection system has improved over the past several years, but, as on Majuro, the disposal methods remain inadequate and threaten the health of both people and the reef.

Rural areas also have their problems of solid-waste disposal. With garbage pits the most common mode of disposal in rural areas, pollution of nearby wells from seepage through the porous limestone earth is common. Open garbage pits also provide breeding grounds for flies and other disease-carrying pests. The magnification of the waste steam and the nonbiodegradable character of much of its content now render the traditional disposal method of throwing trash into the intertidal zone highly undesirable, particularly in the light of the heightened emphasis on artisanal fisheries as part of rural development and the associated importance of maintaining healthy, clean reefs.

HAZARDOUS WASTE ACCUMULATION AND DISPOSAL

The hazardous materials accumulating in the Republic originate as materials left there by various agencies or as byproducts of modern life. For instance, electrical transformers containing PCB-contaminated oil date back to the US Trust Territory Administration. Large metal drums containing a road-repair emulsifier, with carcinogenic potential, were donated to the Republic by a foreign contractor in 1986, but the material has remained unused until recently, and the remaining drums have become rusty and leaky in the humid, salt-rich atmosphere. A Taiwanese technical mission left behind enough pesticides (labelled only in Taiwanese) to fill a small warehouse. Also, small amounts of hazardous waste are generated daily by the laboratories of the College of the Marshall Islands, the two hospitals, a few industries, cars, boats, and airplanes. It bears mention, as well, that on several occasions foreign interests have solicited the government to allow the dumping of various types of solid wastes within the domain of the Marshall Islands; to date, these offers have been considered but not accepted.

In summary, the disposal of hazardous waste is an unmet challenge in the Republic. There are regulations that prohibit the dumping of hazardous wastes, but no alternative legal method for their disposal has been defined. A portion of the hazardous medical waste is burned, but the incinerators used at both health centres are faulty and emit noxious fumes; and storage facilities for existing hazardous substances are insufficient. Not surprisingly, illicit dumping occurs. It is recognized in the Republic that a higher priority must be assigned to developing a comprehensive system for the routine disposal of waste safely and efficiently.

EUTROPHICATION AND POLLUTION OF COASTAL WATERS

Signs of eutrophication and pollution are readily evident on reefs adjacent to settlements, particularly in urban areas. Algal blooms occur along the coastline at Majuro and Ebeye, and are especially apparent on the lagoon side adjacent to households lacking toilet facilities. In Majuro, lagoonal waters adjacent to urban areas are plagued with "red tide", a proliferation of dinoflagellates, which may threaten marine life by lowering dissolved oxygen levels in the water, and may also render some types of seafood toxic to humans. Eutrophication of Majuro lagoon has been intensified by the construction of a system of land-filled causeways between islets. These enclose over 65 per cent of the circumference of the lagoon, preventing the natural flushing of lagoonal waters.

Today, most eutrophication results from inadequate disposal of sewage and household waste, with industrial waste being only a minor contributor. In the two urban centres, the sewage is expelled untreated via outfalls located in 8–14 m of water. Although serious damage to the surrounding ecosystem is not reported now, the outfalls may require extension if the volume of waste increases, whether through further population growth or industrialization or both.

Sewerage facilities are inadequate in many households and schools. The 1988 Census of Population and Housing indicated that, of households with toilet facilities, the majority in urban areas had flush toilets, while the majority in rural areas had pit latrines. Roughly 10 per cent of all urban households and over 60 per cent of rural households have no toilet facilities, a lack also found in some schools. In the absence of toilet facilities, people follow the traditional practice of defecation in the intertidal zone, contributing to eutrophication and to the spread of various diseases.

DESTRUCTION OF CORAL REEFS

Although many activities contribute to the physical destruction of coral reefs, three particularly destructive ones are dredging, channel blasting, and boat anchoring. Primarily on Majuro and Kwajalein, sand and gravel for construction are extracted from the lagoonal intertidal and nearshore zones by suction and bucket dredging. Both types of dredging destroy reefs at the dredging site; the suction dredging also heavily affects adjacent reefs because the large volume of sand displaced during dredging is carried down-current where it is deposited on reefs, leading to their gradual death.

Channel passages into the lagoons of many atolls have been widened and deepened to accommodate the four government ships that service the outer atolls. Shallow passes have also been created to allow the passage of small motor boats. Any dynamite blasting and dredging carried out to create these channels must necessarily destroy portions of reef, but some methods are more destructive than others. The present technique involves simply placing the dynamite in a natural recess of the reef and detonating the charge, without drilling a charge hole or locating the charge in such a way as to minimize incidental damage to adjacent reefs. Consequently, many organisms are killed in the vicinity of the blast, and adjacent reefs may take years to recover. Also, tidal flats shoreward of the reef sometimes suffer habitat destruction from channel blasting because flats that once remained submerged during low tide become permanently exposed to air.

Boat anchorages often damage coral reefs, as on the reefs of Majuro and Kwajalein, where anchorage scars can readily be seen. The sections of reef torn away by anchors can take several years to recover. Although the increasing popularity of Majuro lagoon as a yacht anchorage has made this an issue of increasing concern in recent years, no formal studies quantifying the aggregate damage have been carried out. Nor are there any permanent mooring sites for pleasure craft, even though there are typically 15 to 20 yachts anchored in the Majuro lagoon at any time.

COASTAL EROSION

Although no accurate measurement of the natural rate of erosion is available, many landowners believe that erosion has significantly increased in recent years, especially in urban areas, where construction activity has been concentrated. Dredging, sandmining, development of the coastal zone, and the construction of inter-island causeways can all contribute to coastal erosion. Development of the coastal zone is largely uncontrolled. Enforcement of existing Environmental Impact Assessment requirements and earthmoving-permit requirements has been poor because of inadequate human resources, resistance from landowners, and underdeveloped EIA requirements. Efforts to control the recent proliferation of unmonitored construction in the coastal zone have been further hampered by the absence of a comprehensive coastal zone management plan, with defined Environmental Impact Assessment procedures (see p. 21).

OVER-EXPLOITATION OF RENEWABLE MARINE RESOURCES

Under the nation's Second Five Year Development Plan 1992–1996, the marine-resources sector is expected to take the lead in revenue production, helping to reduce the trade imbalance and to increase national self-sufficiency. Pelagic fisheries are expected to make the largest contribution to the increased revenue, while artisanal fisheries and mariculture programmes are intended to lessen the current rate of urbanisation and to enhance local self-sufficiency. This encouragement of the exploitation of marine resources in a setting of rapid population growth and inadequate regulations with regard to conservation is an invitation to over-exploitation.

The four main targets of current marine resource exploitation are pelagic fisheries, artisanal fisheries, aquarium fish, and cultivated invertebrates. The pelagic fishery in Marshallese waters is mainly exploited by foreign interests, using long-line and pole-and-line techniques. Pelagic drift-net fishing is prohibited by national legislation. Registry of foreign vessels and the granting of permission to fish under bilateral and multilateral agreements produce a significant source of revenue, which has been lessened in the past by an unknown amount of poaching. Surveillance of the EEZ improved greatly during 1991–1992, resulting in the apprehension of several poachers.

Artisanal fisheries development projects are being implemented on rural atolls, with Japanese assistance. Some environmental controls are in place but a comprehensive conservation system is not yet implemented. Aquarium fish have been commercially harvested from reefs in Majuro for over a decade by one company, which has followed a well defined reef-rotation scheme, harvesting fish from different areas each day, and giving exploited reefs time to recuperate. It is estimated that in 1991 at least 3000 fish per month were exported from Majuro for sale in Hawaii, California, and Japan. This trade is expected to grow over the next several years, with new companies joining the enterprise, which makes essential the development of regulations to monitor and protect the resource.

Other renewable resources include the giant clam, coconut crabs, and marine turtles, all of which are threatened by over-exploitation. The five species of marine turtles believed to swim in Marshallese waters are considered endangered because of over-exploitation worldwide. Anecdotal evidence from outer atolls suggests that sizes of coconut crabs and giant clams collected for food have decreased over the past five years, but without formal stock-assessment studies it is difficult to quantify current depletion rates and patterns. Several mariculture projects are being developed to increase stocks of threatened invertebrates, including giant clams.

RAPID POPULATION GROWTH AND URBANISATION

Although rapid population growth and urbanisation are not environmental challenges in the sense that coastal erosion or eutrophication of lagoonal waters are, they relate directly or indirectly to all the environmental issues described here. According to the Census of Population and Housing, the national population of the Republic was 43,380 in 1988, a figure which represents an increase of 40 per cent since the 1980 Census, which in turn yields an average annual rate of increase of 4.2 per cent – one of the world's highest. During the previous intercensal period (1973–1980), the annual population growth rate was 3.5 per cent. Projections based on a slowly decreasing growth rate show an increase of 48 per cent in the population during the 1990s, which would bring the population to 68,500 in the year 2000. Aside from the strains put on healthcare and educational resources by the increasingly high ratio of dependency (the ratio of dependants, ages 0–14, to working-age individuals, ages 15–64) brought by the extremely high rate of population growth in the Republic, resources available for environmental protection measures will also be strained, especially if a national prioritisation of needs should place health or education above environmental protection. Thus, the long-term success of environmental management programmes will depend to a large extent on the success of family planning programmes.

Approximately two-thirds of the nation's population lives in one of the two urban centres – 45 per cent on Majuro and 21 per cent on Ebeye. The combined land area of the two urban centres is 11.4 per cent of the total national land area. The combination of rapid population growth with in-migration has resulted in the extremely high urban population densities already mentioned in the section on Solid Waste Accumulation and Disposal (p. 17). As is clear from the discussion of environmental challenges, this concentration of people on small atoll islets has already placed severe strains on the natural-resource base as well as on sanitation and waste-disposal systems and environmental-management capabilities generally.

RESPONSES TO THE ENVIRONMENTAL CHALLENGES

The country's current and past responses to environmental challenges are described in Part A of the National Environmental Management Strategy (Republic of the Marshall Islands 1992a: Chapter 4). These include such actions as the formation of the Environmental Protection Authority in 1984 and its continued growth since then so that it is presently able to operate several programmes, such as those having to do with water-quality monitoring, environmental sanitation; solid waste disposal monitoring, earthmoving monitoring, and public environmental education. Another agency concerned with the environment, the Marine Resources Authority, was established in 1988, with the mission to develop, maintain, and protect the country's biological and physical marine resources. Other projects and programmes outside of these two agencies have been concerned with rural sanitation, freshwater supply from a water lens on Majuro atoll, and a case study designed to evaluate the vulnerability of Majuro atoll to potential sea level rise. Various pieces of environmental legislation have also been developed over the past decade, and there have been actions to develop human resources. In 1990 a National Population Policy was passed, and in 1991 a special Population and Development Unit was established to monitor the implementation of the Population Policy during the period of the Second Five Year Development Plan (1992–1996).

FUTURE PRIORITIES

During the discussions and debates held by the Task Force on Environmental Management and Sustainable Development to formulate the National Environmental Management Strategy (see pp. 15–16), future priorities for strengthening environmental management capabilities were established (Republic of the Marshall Islands 1992a: Chapter 5). These general priorities, which fall into the five programme areas listed below, served as the basis for the formulation of more specific strategies and programmes.

- **Maintaining clean water, land, and air**
- **Conserving renewable resources** (including the provision of accurate and timely information regarding the condition of the resources)
- **Ensuring environmentally sensitive decision making** (including the fostering of a partnership between development and environment sectors, developing environmental management capabilities, and increasing community awareness of environmental issues)
- **Protecting special spaces and species** (including the establishment of a national nature park system, conserving biodiversity, and preserving the nation's cultural identity)
- **Minimising the impact of environmental emergencies** (including support for initiatives to stabilise and eventually reduce greenhouse-gas emissions, and ensuring that responses have been prepared for environmental emergencies such as major oil spills)

STRATEGIES FOR IMPLEMENTATION

Growing out of these general programme areas and priorities, twelve specific strategies were formulated for implementation in the Marshall Islands (Republic of the Marshall Islands 1992b: Chapter

2). Because of the geography of the Marshall Islands, most of the strategies relate to at least some degree to the coastal zone or the larger marine realm. Those strategies that are directly related to the management of coasts and ocean are listed below, together with some of their associated programmes for implementation (in italics):

- **Anticipating sea-level rise**

  (*Establish a centre for the study of climate change*)
  (*Plan for sea-level rise*)

- **Improving sewage disposal and management**

  (*Expand sewerage capital works*)
  (*Improve sewerage outfall design*)

- **Managing marine and coastal resources for sustainability**

  (*Establish a marine resource management information system – MARIS*)
  (*Develop regulations for marine resource conservation*)
  (*Improve causeway design in urban areas*)
  (*Establish a coastal zone management plan*)
  (*Develop a marine biodiversity conservation programme*)
  (*Promote the mariculture of giant clams and trochus shells*)

- **Anticipating environmental emergencies**

  (*Train technicians in oil-spill response*)
  (*Acquire equipment necessary to respond to oil spills*)

Now that environmental priorities and action strategies have been formally set out in the National Environmental Management Strategy, it is recognised in the Republic that institutional strengthening and capacity building are required in the Environmental Protection Authority and the Marine Resources Authority, the two agencies with primary responsibility for environmental management. The environmental planning and management capabilities of both agencies are severely constrained by inadequate funding and too few – even though dedicated – environmental specialists. The Republic is presently embarking on the strengthening of the agencies and the implementation of the action strategies, with further assistance from the Asian Development Bank. In early 1993, international consultants in environmental and coastal engineering and in ecology began working to strengthen the Environmental Protection Authority. The Authority's capabilities in environmental impact assessment, monitoring, enforcement, public awareness, information management, and environmental planning have all been reviewed. Plans are underway to develop a comprehensive training programme for the Authority's staff and other staff, with some training already underway in early 1993. In addition, the Asian Development Bank will sponsor consultants in environmental law, chemistry, and education to strengthen regulatory instruments, monitoring capabilities, public education, and modern technologies for organising and analysing environmental data. A computerised, map-based system for managing environmental data is also proposed.

Critical to the success of strengthening the Environmental Protection Authority and related agencies, such as the Marine Resources Authority, will be the revision of existing environmental impact assessment and regulatory procedures. In particular, long-range planning and management of the coastal zone and its resources are essential. Efforts are now underway to develop subsidiary regulations to implement the Coast Conservation Act, which was passed in 1988 and required the submission of a comprehensive coastal zone management (CZM) plan within three years. Although the deadline has passed and the CZM plan has not yet been developed, its development has been established as a high priority for the Environmental Protection Authority's Five Year Plan 1992–1996.

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An Initiative in Marine-Area Planning for Sustainable Development in Indonesia

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ABSTRACT

Indonesia, an island nation with vast and diverse coastal and marine resources, faces the prospect of a continuing decline in the quality of its marine estate because of inadequately controlled economic development and the expansion of population.

Consistent with the growing understanding by development banks that sustainable development requires well planned foundations, the Asian Development Bank has loaned the Government of Indonesia funds to assist in the development of a capability in planning for the rational use of coastal and marine resources. The approach to, and results arising from, Indonesia's Marine Resource Evaluation and Planning Project (MREP) have considerable relevance for other maritime tropical countries.

INTRODUCTION

A RICH MARINE ESTATE

Indonesia has an extensive coastline of over 54,000 km – more than twice the length of that of any other Asian nation. Its Exclusive Economic Zone is correspondingly huge – almost five and a half million square kilometres. The country is richly endowed with tropical marine ecosystems – estuarine, mangrove, seagrass, coral reefs, and plankton-based ecosystems of the sea. These form an important base for national development and also have natural values of significance for Indonesia and the world. Together with neighbouring Philippines, Indonesia is a major global centre of biodiversity. Eastwards and westwards from these island nations the numbers of coral and other marine species decline.

Indonesian seas are rich in fish stocks, and its seabed has significant petroleum reservoirs (World Resources Institute 1992). Over the period 1987-89 the annual average commercial fish catch (marine and freshwater) was 1,971,000 tonnes, an increase of 60 per cent since the 1977-79 period. This expansion continues. Marine food and shell resources now constitute the fifth largest non-oil export – with 70 per cent of these exports of living marine resources made up of shrimp. In 1989 penaeiad shrimp exports amounted to 77,000 tonnes, over half being harvested from coastal fish ponds, most of which were established by extensive clearance of mangroves.

With offshore oil production in 1990 amounting to almost 23 million tonnes, managing the petroleum industry so as not to pollute the marine environment is a sizeable challenge. A high-quality marine environment is required not only to maintain the habitat of the living marine resources but also because it is an important component of the tourism industry – another big earner of foreign exchange.

Coral reefs are a major tourist attraction. They also serve as an important ecological base for fisheries, and as sturdy geological structures protecting many parts of the coast from storm-wave erosion. A recent report on the status of the world's coral reef ecosystems (Wilkinson 1992) states that "the reefs at greatest risk are those at the centres of coral biodiversity in the two ocean systems; the island archipelagoes of Indonesia and the Philippines, and the Atlantic centre (of biodiversity) in the Caribbean." Virtually all of Indonesia's reefs are reported to be in the "critical" and "threatened" categories. "Critical" reefs are defined as being "severely damaged and in imminent threat of collapse", while "threatened" reefs are those which show signs of stress and which are likely to collapse if human populations and development pressures continue to increase. The major human-induced stresses on coral reefs appear to be those arising from (1) nutrient enrichment (mostly from sewage and from drainage of fertilizer residues from agricultural land), (2) sediment, and (3) the removal of excessive numbers of fish and other coral reef species.

An already weakened coral reef is more vulnerable to additional stresses such as might be imposed by, for instance, petroleum hydrocarbons drifting shorewards from oil spills. This can mean that the added damage of even low levels of oil and other forms of pollution on those reef areas of Indonesia already categorised as "critical" and "endangered" could tip the ecological balance towards destruction. This precarious condition of Indonesia's coral reef ecosystems is a potent argument for better planning of coastal and marine resources development.

PLANNING FOR RESOURCE USE ALONG COASTS AND IN THE OPEN SEA

Bearing in mind how vital are coastal and marine areas for Indonesia's present and future development, it is a matter of growing concern that pollution of coastal waters is increasing, that considerable destruction of fisheries habitat continues, and that the large volume of shipping traffic along international sea lanes is so inadequately controlled. Large numbers of oil-carrying tankers operate in Indonesian waters. Major tanker routes between the Indian and the Pacific oceans are the Malacca and Makassar-Lombok straits.

Industrial pollution in some of the larger rivers is now being addressed through a "Clean River Programme", referred to by its acronym "PROKASIH". Gradually, bathymetric surveys are being extended, navigational aids improved, and traffic-separation schemes for shipping introduced. Yet valuable mangrove habitat continues to be destroyed at an alarming rate. The south coast of Sulawesi, for instance, is estimated to have lost 71 per cent of its original mangroves in the short period between 1982 and 1991!

Nothing more clearly illustrates the difficulty of achieving the objectives of sustainable development in Indonesia than the current rush to destroy mangroves and replace them with brackish water ponds for shrimp culture (*tambaks*). Because of the close ecological association of mangroves with fisheries stocks in adjacent waters, there is inevitably a loss of natural fisheries diversity and production. Where pond production levels are high, under capital-intensive production systems, an economic case can be argued in favour of *tambaks*. Yet the sad reality is that only a very few *tambaks* are in this class. Many of those that are not have been abandoned – though in a condition that prevents natural regeneration of mangroves. So significant has been the loss of mangrove habitat that Indonesian authorities recently applied to the Asian Development Bank for a loan to fund a programme of rehabilitation of degraded mangrove areas in Sulawesi.

At the time Indonesia achieved political independence in 1945, the country faced an imperative to address an urgent development problem of poverty. As elsewhere in the world at that time there was poor understanding of the environmental limits beyond which economic development was not sustainable. Now there is a growing awareness of these limits, and of the need to shift to a pattern of sustainable development. Yet much of the unsustainable approach of the past continues.

WEAKNESSES IN PLANNING AND CONTROL

Among other things, sustainable development requires a rational allocation of areas and resources, which implies a need for comprehensive planning for the allocation of space and resources. There are, however, major weaknesses in arrangements for the allocation of marine areas and resources. Though the nation is made up of 27 provinces, each with its own government, provincial authorities do not have control over development activities in the seas which lap their shores. It has long been said that a certain level of authority over marine areas is to be devolved to provinces, but no timetable for this has been set; nor has the seaward extent of provincial jurisdiction been decided.

The long-awaited legislation to provide a basis for provincial responsibility in spatial planning was enacted at the end of 1992 but it is not consistent with principles of good planning in that it sets lengthy plan periods (25 years at a national level, 15 years for provincial spatial plans) but contains no provision for periodic review and amendment of spatial plans as circumstances change. Provincial planning authority in, and jurisdiction over, coastal seas and other marine areas are not addressed by the new legislation. In the context of such uncertainty, marine area planning for sustainable development is that much more difficult to achieve.

TOWARDS RATIONAL PLANNING OF THE MARINE ESTATE

DEVELOPMENT BANK SUPPORT

The perspective of the development banks has recently broadened to encompass an appreciation that truly sustainable development requires, among other things, better and integrated planning and management. Banks now consider it appropriate to lend money in support of such capacity building, which is outside the usual economic sectors that they have traditionally funded.

Indonesia approached the Asian Development Bank (ADB) for assistance towards rational planning of development activities in coastal and marine areas. In 1991 the Bank funded a feasibility study to develop ideas for a cross-disciplinary, interagency project in integrated coastal zone management (Robertson Group PLC 1992). A "Marine Resources Evaluation and Planning Project" (MREP) was subsequently formulated.[1] MREP addresses Indonesia's need to plan for, and manage, the marine and coastal environment and resources in order to meet the objectives of sustainable development. The full scope of such planning and management in an archipelagic state of almost 14,000 islands is vast; but the project does not attempt to deal with the whole country. Rather, it focuses on several areas which embrace the spectrum of development scenarios and coastal types. Though this project provides for planning and management only in specific areas, and those provinces involved are to gain the greatest planning benefits, the subject areas are also regarded as a range of examples from which experience and information are to be drawn for application to other provinces of Indonesia and, indeed, to other countries of Southeast Asia.

The management and planning needs of ten Coastal Marine Management Areas (CMMAs) in as many provinces are to be addressed, and three Special Marine Areas (SMAs). CMMA planning is set in the context of provincial spatial planning, and matched to complementary land area planning.

SMAs are primarily a national interest, located in open-sea areas beyond Provincial jurisdiction (the straits of Makassar and Lombok, and the "Timor Gap" area of the Timor Sea). SMA activities are to provide a focus for the development of a national approach to open-sea planning, which is needed so as to meet the broader objective of sustainable management of the Indonesian marine environment and its resources, to the outer extent of national responsibilities – the Exclusive Economic Zone.

Planning and management activities are underpinned by provisions for the acquisition, compilation, and interpretation of data, and the strengthening of Indonesian institutions to process and apply the data. MREP is part of an effort to establish integrated coastal resource management throughout the Republic of Indonesia. The experience in developing ten provincial and three open-sea planning regimes will be vital in developing the skills and planning models needed for eventual nationwide coverage by coastal-resource management plans.

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[1] The author of this paper participated in the Asian Development Bank Fact-Finding and Appraisal Missions which led to this project being approved in late 1992 for an expected commencement in late 1993.

The project draws on the considerable scientific and technical resources available within Indonesia, complemented by skills, information, and understanding from other tropical marine areas. In this respect, the MREP documents make particular reference to INTROMARC, Australia's International Tropical Marine Resource Centre, as an organisation with experience relevant to Indonesia's training needs in marine area planning. INTROMARC is a grouping of Australia's major tropical marine institutions – James Cook University of North Queensland, Australian Institute of Marine Science, and the Great Barrier Reef Marine Park Authority.

SCOPE OF THE MREP PROJECT

MREP is a complex project. Its scope is wide, addressing both sea areas and the land-sea interface of the coast. It embraces technical, ecological, institutional, legal, and social issues – and it involves no fewer than eleven different agencies of national government, in addition to ten provinces. Project management has been facilitated by presenting the project as four distinct "packages", namely:

1. Marine and coastal management and planning

This package encompasses the preparation of marine- and coastal-area physical plans, management regimes for Special Marine Areas of the open sea, environmental monitoring, planning for marine conservation areas, and a legal and institutional framework for marine and coastal areas.

2. Marine and coastal information systems

New imagery is to be obtained, coastal- and marine-area base maps prepared, and a database and information system are to be established for marine and coastal (GIS-based) areas. Terminals to access these data are to be provided for a number of national government agencies, the ten provincial development planning agencies involved in the project, and participating university environmental study centres.

3. Marine and coastal ecological systems and processes

Under this component there is to be an assessment of fisheries resources in the 13 planning areas and the carrying out of hydrographic surveys in their shallow waters. A marine and coastal geodynamics database is to be established, and a marine and coastal ecosystems database.

4. Project management and coordination

THE ROLE OF ENVIRONMENTAL STUDY CENTRES IN MREP

Indonesia's Pusat Studi Lingkungan (PSL), or "Environmental Study Centres", have considerable potential to contribute to the planning process at the provincial level – in particular by conducting the social, economic, and environmental research and surveys needed to provide data for comprehensive development planning. A number of PSLs, of which all state universities have one, provide technical services, including environmental assessments, to central and local government agencies. They could become an important element in Indonesia's emerging institutional framework for sustainable development, fitting well with the universities' mandate to provide service in the public interest as well as to engage in teaching and research.

In the design of MREP close attention was paid to the idea of providing the environmental study centres of universities in the provinces involved in the project with a substantial role as providers of data and guidance to provincial development planning agencies in the preparation of coastal marine management plans. The extent of their involvement is expected to vary from province to province, depending on the extent to which each province is prepared to devolve this role to a centre, and on the capacity of a centre to carry out this vital role competently. Where circumstances permit, it could be possible for a province to delegate to an environmental study centre full responsibility for data collection and analysis, and for the preparation of coastal marine management plans. A continuing close involvement of provincial planning staff would, of course, be expected.

An important reason for seeking to involve these centres in this way is to help to build capacity and competence in coastal marine planning and management, which can subsequently be applied elsewhere in Indonesia. This will also stimulate research for marine area management and feed back topical information into teaching programmes.

EXPECTATIONS FOR THE MREP PROJECT

The Marine Resources Evaluation and Planning Project has been designed in the expectation that it will:

- strengthen Indonesia's capacity to allocate coastal marine resources wisely and to protect their environment;
- afford greater protection for Indonesia's rich marine biodiversity;
- result in improved knowledge of the environment and ecological processes fundamental to sustainable production of living marine resources;
- lead to a rationalisation of arrangements for administration of coastal- and marine-area activities, and improved legislation in this respect;
- help develop Indonesia's capacity to meet its obligations for managing its marine environment and resources under the Law of the Sea Convention and various multilateral and bilateral agreements;
- strengthen capabilities in the collection, processing, and application of data related to marine environment and resources;
- provide better information on harvests of fish and other living marine resources, and improved methods for the collection and presentation of this information for purposes of planning and management;
- integrate a marine-data system with a complementary land-data system to facilitate the integration of land and sea planning and the management of Indonesia's natural resources;
- assist the development of a national capability in oil-spill contingency planning through research and skills development, focussed on the straits of Makassar and Lombok;
- establish environmental and social reference points against which change in coastal and marine areas can be measured, trends can be monitored, and a determination can be made as to whether this approach to marine area management is truly sustainable; and
- result in a range of "model" marine management areas from which information, experience, and skills can be applied throughout the country.

The ideal of sustainable development is not easily achieved. Some of the difficulties to be faced in the implementation of this project are that:

- long-established narrow sectoral attitudes to planning, reflected in administrative arrangements, and in legislation, may hinder the development of a truly integrated, multiple-use management approach to the marine estate;

- the capabilities of the staff of provincial planning agencies may not be adequate to the complex task of integrated marine and coastal area planning;

- cooperation and coordination between executing agencies may not be as effective as anticipated;

- a slow pace in the rationalisation of administrative arrangements for marine areas, and the enactment of relevant legislation will hinder the effectiveness of the planning component of the project;

- the skills and experience of some of the University Environmental Study Centres may not be up to expectations;

- actions of the ships of other nations in international waterways near to Indonesian coasts may frustrate efforts to protect the marine environment;

- the absence of early action to devolve a fair measure of planning control to provinces results in an uncertainty in the provincial planning process, which can be exploited to the advantage of unscrupulous resource users; and

- meaningful public participation in project activities may not be achieved.

OTHER CONTRIBUTING ACTIVITIES

Indonesia's declared determination to address marine area and resource management issues has drawn interested responses from a number of international agencies and bilateral donors. MREP builds on these initiatives, which are briefly described below.

The **ASEAN-Australia Marine Science Project** actually preceded the current strong official Indonesian interest in marine area management. It has been underway for eight years and is made up of two components: one on **Living Coastal Resources**, which seeks to determine the stability and interdependence of coastal ecosystems such as mangroves, seagrasses, soft benthos, and coral reefs; and the other component entitled **Regional Ocean Dynamics**, which produces tidal data for coastal and maritime applications, and oceanographic data vital to the understanding of global climate change. This project aims to develop an improved understanding of the marine and coastal environment through collection, analysis, and modelling of data, and dissemination of information to industry, government, and the wider community. A considerable amount of data has been collected, and training undertaken. There remains a need to get the data into the management sphere.

An **East Asian Regional Seas Action Programme** has been developed under the auspices of the United Nations Environment Programme. The **International Oceanographic Commission (IOC) WESTPAC Programme** involves international scientific cooperation in the study of physical oceanographic processes in the Western Pacific. Indonesian scientists participate. Both programmes are concerned with, among other things, the prevention and management of marine pollution.

Environmental Management Development in Indonesia (EMDI) is a joint project of the Ministry of Population and Environment (KLH) and the School of Resource and Environmental Studies, Dalhousie University, Canada. EMDI is in its third stage, funded by the Canadian International Development Agency (CIDA) and has engaged in a number of intitiatives designed to foster awareness, policy development, and action in marine area management.

The Asian Development Bank has funded a project through which **marine science education** at six Indonesian universities is being upgraded. Also, a UNDP **Marine Pollution Monitoring and Training Programme** is underway. Among other things, skills in pollution sampling and monitoring are being transferred to the staff of certain environmental study centres.

The World Wide Fund for Nature (WWF) has had a long involvement in efforts to establish marine conservation areas in Indonesia. It continues to be active in this respect, often working together with other organisations, as, for instance, KLH Technical Team for Coral Reef Ecosystem Conservation and Management (1992).

MREP builds on these varied initiatives, with an overall objective of strengthening Indonesia's capacity to plan for and manage coastal marine areas. The project's Special Marine Areas (SMAs) are Makassar Strait, Lombok Strait, and the Timor Gap. Within these areas BAPEDAL, Indonesia's national Environmental Impact Assessment Agency, is to have a coordinating role with respect to efforts to prepare sensitivity maps and to develop contingency plans for oil spills.

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Pacific-Island Mangrove Swamps: Monitoring Their Responses to Sea-Level Rise

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ABSTRACT

There are two main environmental settings for mangroves of the Pacific, deltaic and estuarine mangroves of high islands, and embayment, lagoon, and reef flat mangroves of low islands. Past analogues show that their close relationship with sea-level height renders mangrove swamps particularly vulnerable to disruption by sea-level rise. Stratigraphic records of Pacific island mangrove ecosystems during sea-level changes of the Holocene show that low-island mangroves could keep up with a sea-level rise of up to 12 cm/100 years, as is shown by paleoecological reconstruction of mangrove response to sea-level rise in Tonga. Mangroves of high islands can keep up with rates of sea-level rates of up to 45 cm/100 years, according to the supply of fluvial allochthonous sediment input, as is shown by paleoecological reconstruction of mangrove response to sea-level rise in Samoa.

Sea-level rise may cause low cliff erosion of mangrove sediments at the seaward edge, sheet erosion of surface sediments and litter, and widening of creek banks and estuary mouths. Increased inundation and salinity may cause stress symptoms in mangrove species, such as reduced growth, reduced litter production, and reduced resistance to pests and storms.

Monitoring for these impacts should be carried out, including substrate elevation relative to the tidal prism, sedimentation, litter fall, and surface retention, as well as changes in growth and spatial extent of different species. This is the aim of the UNEP-IOC-WMO-IUCN long-term global monitoring system of mangroves, which is presently being established as part of the Global Ocean Observing System (GOOS).

INTRODUCTION

The term "mangrove" is used to describe a taxonomically diverse group of tree species that grow in the upper intertidal zone of sheltered shores in the tropics. The extent of their cover has been estimated by the International Tropical Timber Organization to be 20 million hectares. Adaptations developed for their saline wetland environment such as aerial roots, halophytic strategies, and vivipary distinguish mangrove trees as a specialized minority within their families (Hadac 1976). There are 34 true mangrove species in 9 families, each with a limited geographical distribution around two centres of diversity, Indo-Malaya and Central America (Tomlinson 1986). Mangrove species of the Pacific are of the Indo-Malayan assemblage, and decline in diversity from west to east across the Pacific, reaching a limit at Samoa. To the east of Samoa there are no non-introduced mangroves, owing to isolation. The Pacific islands in Table 1 are listed, generally, from west to east, and the area of mangroves and number of species indicates this trend.

The importance of mangrove ecosystems is well established. They serve as: (1) sediment traps promoting aggradation and maintaining the quality of coastal waters, (2) natural breakwaters protecting coastlines from erosion during storms, (3) a natural resource base for silviculture and a large range of economic products, (4) habitats for rare fauna, and (5) nurseries for commercially valuable fish and crustacean species. They also have educational and tourism uses. These many benefits are described in detail by Chapman (1976), Hamilton and Snedaker (1984) and Tomlinson (1986).

Large mangrove ecosystems develop on sedimentary shorelines of gentle gradient, between mean sea level (MSL) and the level of mean high water spring tides (Lear and Turner 1977; Belperio 1979). Growing in the upper half of the tidal range, their close relationship with sea-level position renders mangrove swamps particularly vulnerable to disruption by sea-level rise. With most Pacific islands having a tidal range of less than 1 m, mangrove ecosystems will be disrupted by a sea-level rise of 0.3 m, and will retreat landwards with a sea-level rise of 1 m. However, factors such as physiographic location, tidal range, species assemblage, and sediment supply contribute to heterogeneity in mangrove response to rising sea-level.

Research to investigate the impacts of sea-level rise on mangroves falls into two areas. First, sea- level effects on an ecosystem can be reconstructed from the past, from analysis of stratigraphy, provided the evidence is available from proxy indicators. This technique has the advantage of indicating long-term complex system response, though detail of short-term individual responses of species can usually only be speculated. Second, case studies carried out at present can be considered, such as in areas of the world where sea-level rise is occurring, or in areas where flooding of mangroves has been carried out for mosquito control. From these approaches, monitoring programmes can be developed for identification of changes in the mangrove ecosystem resulting from climate change and sea-level rise.

PAST RECORDS OF MANGROVE RESPONSE TO SEA-LEVEL RISE

Within the intertidal habitat of mangroves, species have different preferences of elevation, salinity, and frequency of inundation, resulting in species zones. Substrate elevation can be increased under mangroves, by accumulation of vegetative detritus to form a mangrove peat or mud, which may also contain matter brought in by the tides and by rivers. If the sedimentation rate keeps pace with rising sea-level, then the preferences of mangrove species zones for a particular salinity and frequency of inundation will remain largely unaffected. If the rate of sea-level rise exceeds the rate of sedimentation, then mangrove species zones will migrate inland to their preferred elevation, and seaward margins will die back. As the accumulation of sediment under mangroves gives some ability to keep up with rising sea-level, vulnerability can be assessed by establishing the rate of sedimentation from studies of Holocene stratigraphy.

Stratigraphy of Pacific island mangroves indicates that mangroves have only become established in expansive swamps since the middle of the Holocene, about 6500 years before present. Before this time they were limited by the interactive factors of rapid sea-level rise and lack of sedimentary shorelines. Mangroves probably survived this period as individual trees, as seen today on shorelines with too steep a gradient or that are too exposed for expansive development of swamps.

There are two major environmental settings for mangroves of the Pacific, deltaic and estuarine mangroves of high islands, and embayment, lagoon, and reef flat mangroves of low islands. These are assessed below for relative vulnerability to sea-level rise.

DELTAIC AND ESTUARINE MANGROVES OF HIGH ISLANDS

Deltaic and estuarine mangroves occur on islands sufficiently high to develop a river system, which delivers significant quantities of sediment to the coastal zone. These areas are the most extensive mangroves of the Pacific islands, for example the Rewa delta on Viti Levu (Fiji), the Dumbéa delta in New Caledonia, and the estuaries of Palau and Pohnpei (Ponape). The mangrove areas not only receive terrigenous sediment from the island, but also accumulate vegetative debris to form a mud.

Table 1

Pacific mangroves

Country or region *Island*	Mangrove area km^2	Physiography	Number of mangrove species
Australia	11617[b]	continental	28
Papua New Guinea	6000[b]	continental	30[f]
Palau	47[d]	high	10[f]
Micronesia	86[d]	high	
Guam			7[f]
Saipan			2[f]
Chuuk			7[f]
Pohnpei			7[f]
Kosrae			7[f]
Solomon Islands	642[c]	high	19[f]
Vanuatu		high	11[f]
New Caledonia	200[c]	high	11[f]
Nauru	0.02[c]	high	1[f]
New Zealand	198[b]	continental	1[f]
Marshall Islands		low	4[f]
Kiribati		low	4[f]
Gilberts			
Tuvalu		low	2[f]
Fiji	197[b]	high	7[f]
Viti Levu			
Vanua Levu			
Tonga	10[c]	low	7[f]
Tongatapu			
Vava'u			
Western Samoa		high	7[f]
American Samoa	0.5[e]	high	7[f]
Tutuila			
Kermadec	0		0
Niue	0		0
Hawaii		high	2[a]
Cook Islands	0	high	0
Tokelau	0		0
Phoenix	0		0
French Polynesia			1[a]
Tahiti			
Moorea			
Bora Bora			

Notes: a. Introduced

Sources: b. World Resources Institute 1990; c. World Resources Institute 1986; d. Miyagi and Fujimoto 1989; e. Whistler 1976; f. Woodroffe 1987.

These environments are demonstrated by mangroves of Tutuila, American Samoa (Figure 1). Tutuila is 32 km in length, 2–9 km wide, with steep and rugged terrain descending from a largely continuous central ridge of over 300 m, with maximum elevation of 524 m. Samoa marks the eastern boundary of mangroves in the Pacific, with two common species, *Rhizophora samoensis*, which forms the seaward zone just above mean sea-level, and *Bruguiera gymnorrhiza*, which forms the landward zone that approaches high tide mark. Such habitats cover only a small aggregate area in American Samoa (Whistler, 1976), but they consistently occur at the base of each river valley.

The mangrove swamps all have a stratigraphy of shallow mangrove mud, a mixture of peat and basaltic or calcareous sand, with 10–30 per cent organic matter. Radiocarbon dates on organic mud samples indicate the mean rates of sedimentation (Table 2), ranging from 14.5 cm/100 years at Nu'uli (Pala Lagoon) to 45.2 cm/100 years at Masefau. The high rates on Tutuila probably reflect the steep gradients of this relatively young volcanic island, with resultant high rates of slope-wash. This is shown by the low organic matter of mangrove muds.

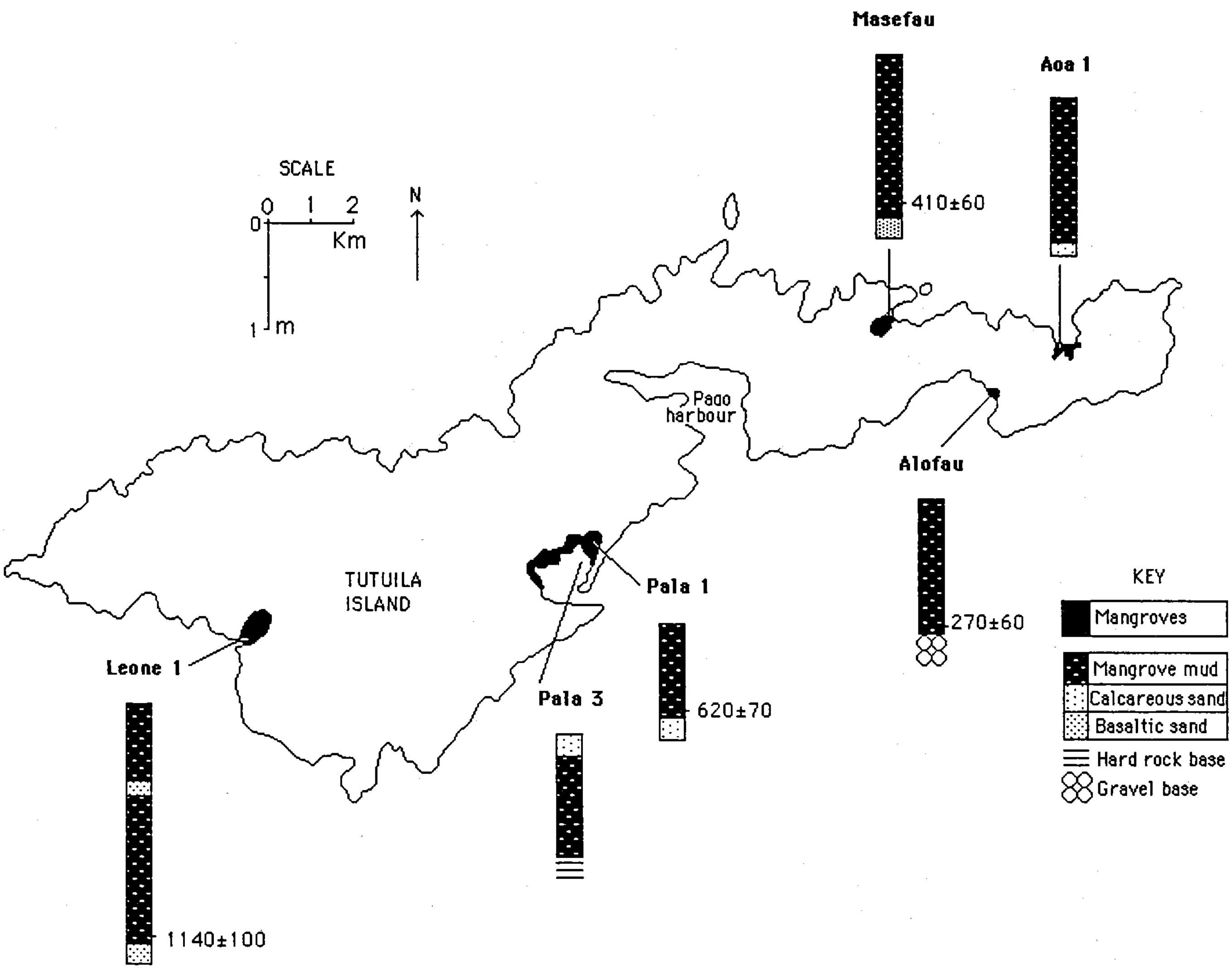

Figure 1: Coastal stratigraphy of Tutuila, American Samoa.

(Core depths indicate rapid sedimentation on this high island)

Table 2

C^{14} dates from mangrove stratigraphy, American Samoa

Sample number	Beta lab. number	Depth (cm)	Depth rel. to MSL (cm)	C^{14} age yrs. BP	Sedimentation rate (cm/100 yrs.)
AN1-1	54276	355–370	272	3080±70	11.8
MA1-2	54278	135–150	118±25	410±60	34.6
AF1-1	54271	115–130	98±25	270±60	45.2
NU6-1	54280	80–100	65±25	620±60	14.5
LE1-1	54277	220–230	200±25	1140±100	19.7

EMBAYMENT, HARBOUR, AND LAGOON MANGROVES OF LOW ISLANDS

Embayment, harbour, and lagoon mangroves can be extensive where fine sediment accumulates to form a broad intertidal slope. Low-island mangroves do not have an external supply of sediment, and build up their substrate by accumulation of vegetative detritus to form a highly organic peat.

In Tonga, the island of Tongatapu has an area of 245 km^2, its longest diameter being around 35 km from east to west. The island is limestone without rivers, the highest point in the south-east is around 65 m. Mangroves occur on the sheltered, leeward northern coast, and around the central Fanga 'Uta lagoon. Stratigraphy of these mangrove areas showed sediment depths of 1-4 m (Figure 2). At Folaha, the largest mangrove area in the western arm of the Fanga 'Uta lagoon, a mangrove peat occurs between depths of 1.3–2.3 m below present MSL (Ellison 1989; Ellison 1991). This peat unit underlies all of a one-kilometre transect across the modern swamp, and continues at lower levels beneath the lagoon. The peat in Folaha core 1 formed between 6870±90 and 5650±80 years BP, giving a rate of peat accumulation in this period of 7.7 cm/100 years. Mangrove assemblages contributing to formation of peat at the levels dated were identified by pollen analysis, and the present elevation of these assemblages has been used to determine past MSL. This shows that MSL was 3.2 m below present at 6870±90 BP, and 1.7 m below present MSL 5650±80 years BP (Ellison 1989). The rate of sea-level rise through the lower peat unit was 12.2 cm/100 years.

During this period of slowly rising sea level, the mangrove ecosystem was able to persist because peat formation raised substrate levels at a roughly quivalent rate, but the ecosystem was drowned out by more rapid sea-level rise, shown stratigraphically by transition from mangrove peat to overlying lagoonal sediment. This is the earliest Holocene peat-buiding mangrove ecosystem in the Pacific, developing before other locations owing to the protected location of this part of the lagoon.

Mangrove stratigraphy from low-island mangrove ecosystems indicates rates of accumulation of up to 12 cm/100 years. The rate from Tongatapu is similar to rates of peat accumulation from other low islands, for example, Grand Cayman (Woodroffe 1981) and Bermuda (Ellison 1993). This reflects the rate of authochthonous production by the mangrove trees, there being few sources of inorganic sediment in these environments.

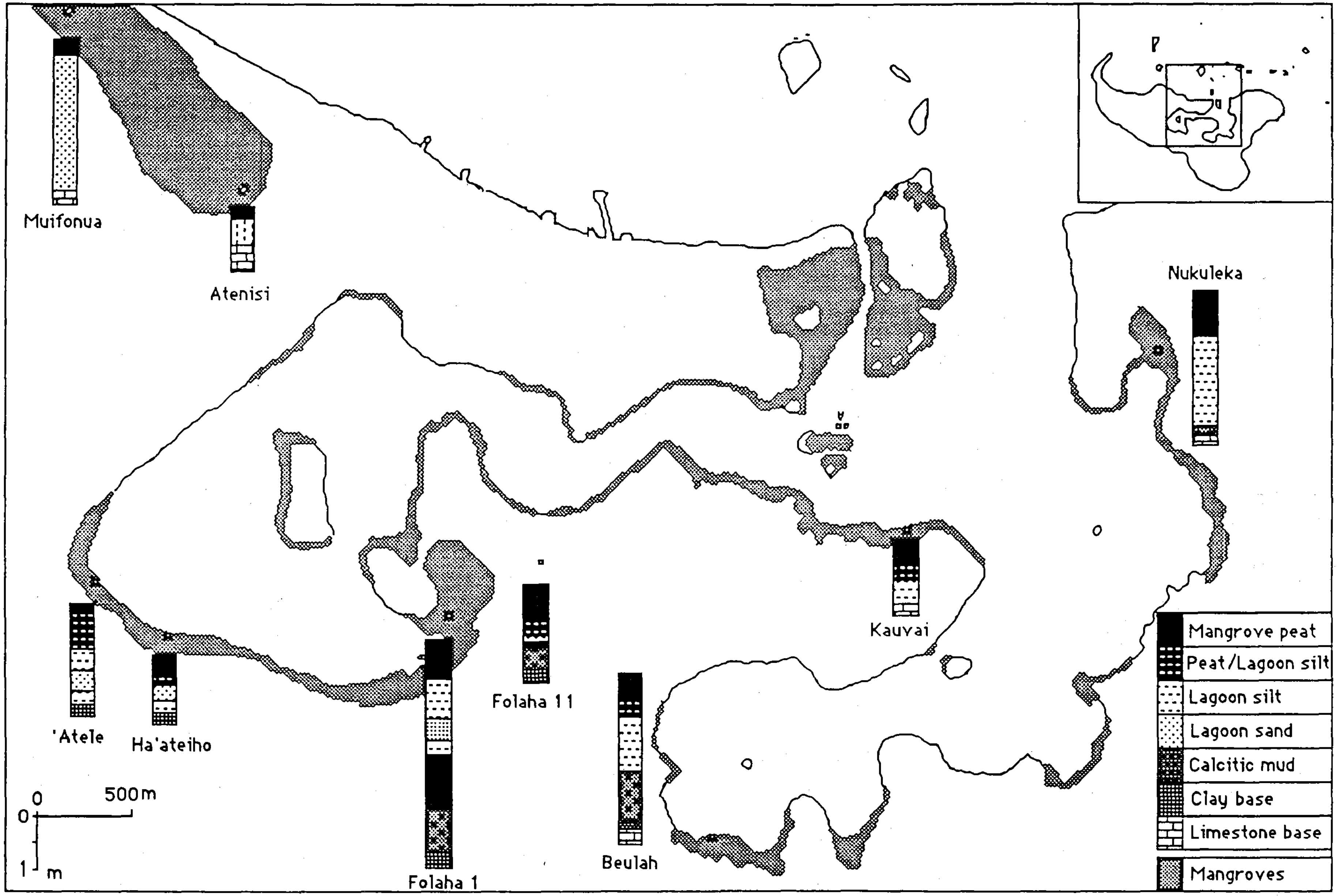

Figure 2: Coastal stratigraphy of central Tongatapu, Tonga.

(Core depths indicate low sedimentation on this low island)

ANALYSIS

Comparison of mangrove stratigraphy from Samoa and Tonga shows that low-island mangroves are more susceptible to disruption by rising sea level because of the relatively low rates of sediment accumulation. Stratigraphy from high islands and continental coastlines, which have more sediment coming off the land into intertidal areas from rivers and longshore drift, indicates that mangrove ecosystems in such environments will be better able to keep pace with sea-level rise. Low-island mangroves could keep up with sea-level rise of up to 12 cm/100 years. High-island mangroves could keep up with rates of 45 cm/100 years, provided the sediment supply is not restricted by constructions such as dams on rivers leading to mangrove deltas. These differences are clearly illustrated by Figures 1 and 2, with deeper Holocene stratigraphy on Tutuila than on Tongatapu.

These rates must be compared with those of IPCC projections of sea-level rise. In the last 100 years there has been a rise of about 10 cm in eustatic sea-level; and a projected eustatic sea-level rise of 0.3–0.5 m by 2050, and 1 m by 2100 (IPCC 1990). These projections mean rates of rise of 50-90 cm/100 years over the period, which indicates that high-island mangroves will experience serious problems with rising sea-level in the next 50 years, and low-island mangroves could already be under stress.

SEA-LEVEL TRENDS IN THE PACIFIC REGION

Owing to interactions between Late Pleistocene deglaciation and hydro-isostatic adjustment, it has been modelled that the south-central Pacific experienced a stand of sea level higher than present during the mid-Holocene (Clark *et al.* 1978; Clark and Lingle 1979). This higher level is modelled to have peaked around 5000 BP, and declined in magnitude from +1.7 m at 40°S, through +0.8 m at 22°S to +0.2 at the equator.

There is a growing consensus of evidence in support of this regional highstand, especially within the latitudes of 10-30°S. In north Queensland Chappell *et al.* (1983) show sea-level fall from +1.0 m since 6000 BP. In New Caledonia Bourrouilh-Le Jan (1985) shows sea level to be +2.5 m 3500 BP, and Coudray and Delibrias (I972) show sea-level to be + 2.1 m 2200 BP. In Fiji, Nunn (1990) analysed sea-level records to show that the Holocene transgressive maximum reached 1–2 m above present MSL some 3000 to 2000 years BP. In the southern Cook Islands, Spencer *et al.* (1988) show from Mangaia that sea-level stood at +1.3 m 5000 BP and +1.7 m 3.400 B.P., and in the northern Cook Islands Scoffin *et al.* (1985) show from Suwarrow atoll that sea level stood at +0.5 m 4700 to 2400 BP. In French Polynesia, Pirazzoli and Montaggioni (1988) analysed raised reefs and notches to show MSL +0.8 to +1.0 between 5000 and 1200 BP, and a short-lived sea-level peak at +1.0 m was identified between 2000 and 1000 BP.

This widespread record of a higher sea-level in the Pacific islands in the last 6000 years is of significance in consideration of longer term impacts of sea-level rise on coastal systems in the Pacific relative to the Caribbean or the Indian Oceans. On most Pacific-island relic shorelines 1-2 m above the present sea level there are erosional benches or depositional sedimentary levels or fossil reefs, recorded in the research reviewed above. While the levels exist for mangrove establishment at a higher sea level, these are also the land areas favoured by human settlement, hence mangrove migration onto these levels may be restricted.

The highstand record is not synchronous, partially owing to the heterogeneous tectonic movements of Pacific islands. Like any coastal locations, subsiding areas will have a greater problem with sea-level rise than emerging areas. In the Pacific islands, S. Tonga, N.E. Fiji, the Philippines and Micronesia are shown to be rising (Ellison 1989; Nunn 1990; Emery and Aubrey 1991: 139; Tracey *et al.* 1954: 60). The south shore of Viti Levu and the southern islands of Fiji are shown to be subsiding (Nunn I990), and it is believed that Samoa is also subsiding (Green and Richards 1975). However, generally the rates of tectonic change are minimal relative to the rates of sea-level rise predicted to occur with climate change.

The longest tide gauge record from the Pacific islands is from Pago Pago in American Samoa, with records since 1948, shown in Figure 3, giving a rate of rise of 18 cm/ 100 years (Emery and Aubrey 1991: 143). Using two different methods of analysis for 231 tide guage stations (excluding Fennoscandia), Gornitz and Lebedeff (1987) find a global average sea-level rise of 12 and 10 cm/100 years. The record of sea-level rise in Samoa is above average, consistent with the record of subsidence. It is apparent that lower sea-level during ENSO events (1983) reduces the rate of rise from the Samoan record.

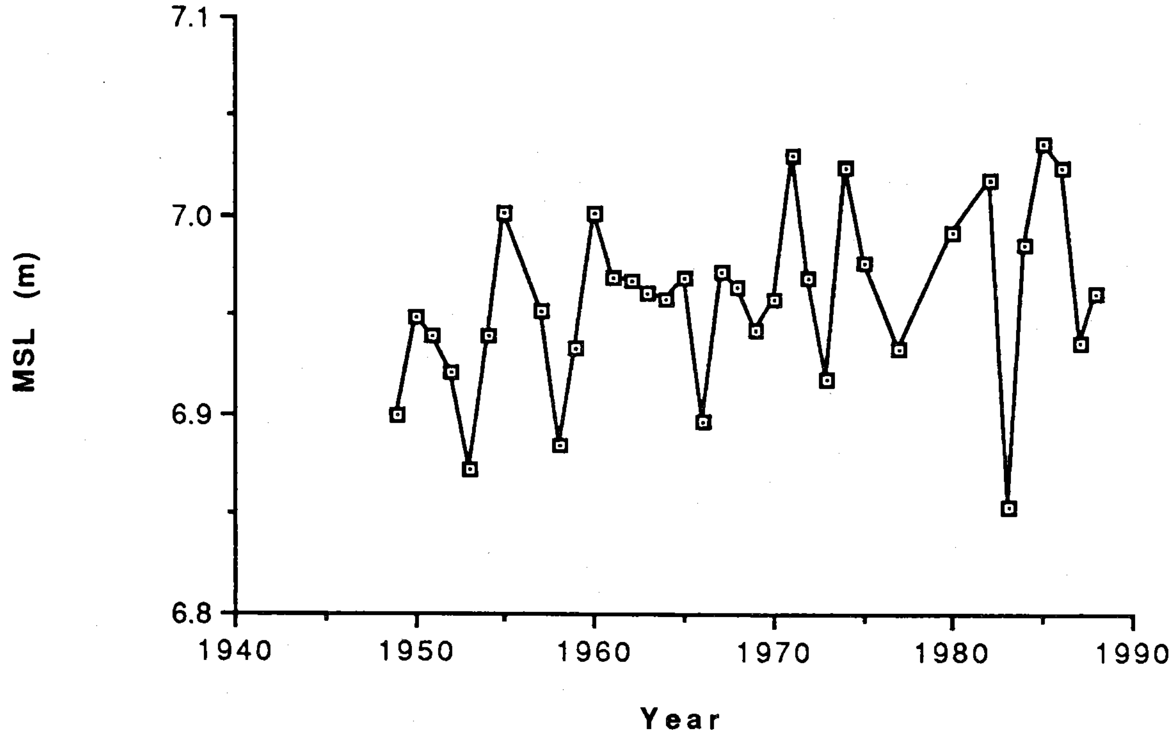

Figure 3: Tide gauge record for Pago Pago, American Samoa

MANGROVE PROBLEMS WITH SEA-LEVEL RISE

Having identified from the stratigraphic record that mangroves can only keep up with slower rates of sea-level rise, it is now necessary to consider the possible responses of mangroves if the rate of sea-level rise exceeds the rate of sedimentation.

EROSION

With rising sea-level, sediment from the upper part of the tidal range is eroded and deposited sub-tidally, as shown in modelling of beach erosion (Bruun 1962; Schwartz 1967). Because mangrove swamps occur from mean tide to high tide, if sedimentation does not keep pace with rising sea level, erosion of the substrate can be expected - and should develop before problems are apparent in adjacent beach areas as the sediment of mangrove swamps are finer than beach material.

The sediment at the seaward edge may erode, undercutting mangrove roots and leading to windthrows. Loss of the seaward zone leads to truncated zonation and narrower fringes. Erosion of tidal creek banks may also occur owing to a greater volume of tidal water and more active currents.

This would lead to slumping of banks and loss of trees. Management responses could be stabilization and protection from further erosion by use of friction matting placed on the sediment surface, or more natural fibrous material, such as woven palm fronds. Once sediment built up against the eroding edge is stabilized, it could be replanted with mangrove propagules. Mangrove management authorities should monitor sedimentation rates within the mangrove ecosystem.

The understanding and prediction of global sea-level trends is only possible through a coordinated system of tide gauges, such as the Intergovernmental Oceanographic Commission (of UNESCO) Global Sea Level Observing System (GLOSS), or the National Oceanic and Atmospheric Administration (NOAA) network. The installation of such tide gauges in areas with mangroves should be supported as it will identify trends of sea level that may cause problems to mangrove ecosystems.

For identification of problems related to rising sea level, the elevation of the mangrove substrate in different zones should be surveyed with respect to tide gauge information. Such surveys will indicate the preferred elevations of different mangrove species, data which will be of use should replanting become necessary with sea-level rise. Also, the surveys could identify areas low in the tidal spectrum that may already be experiencing problems with erosion. Surveys over time should indicate this better, combined with monitoring of sedimentation rates by means of calibrated stakes. To enable comparison between different surveys, a permanent benchmark should be established close to each mangrove area.

INUNDATION STRESS

Impoundment of mangroves for mosquito control provides an analogy for effects of increased inundation. Harrington and Harrington (1982) recorded extensive death of *Avicennia germinans* and *Rhizophora mangle* at India River, E. Florida, following four months of 30-45 cm depth of flooding of an impoundment. Naidoo (1983) found that prolonged flooding resulted in reduced rates of photosynthesis in *Bruguiera gymnorrhiza*, and Lahmann (1988) found that rates of litterfall reduced during flooded months of an impounded *Rhizophora mangle* forest in Florida. When lenticels of aerial roots become inundated, oxygen concentrations in the plant fall dramatically (Scholander 1955). If inundation is sustained, anoxic conditions and mortalities follow. This is thought to have been the cause of widespread mortality of *Avicennia germinans* stands in Puerto Rico recorded by Jimenez *et al.* (1985), following permanent flooding as a consequence of adjacent dredging.

It is possible that increased inundation with sea-level rise may cause stress in this manner, resulting in reduced net primary production. Mangrove managers can expect the consequences to be reduced growth, reduced litter fall, and reduced production of propagules. Variable tolerances of species to inundation would promote landward migration of species zones by death of older trees and successful seedling establishment in higher zones in a landward direction. The soil depth of anoxic conditions can be monitored over time, by observation of the oxidised level on an iron stake inserted in the sediment. Changes over time in community composition can be monitored by vegetation surveys.

INCREASED SALINITY

Increase in salinity in mangroves leading to salt stress can result from a number of factors: sea-level rise, groundwater depletion owing to reduced hydraulic gradient, groundwater extraction, and reduced rainfall. Two major physiological adaptations enable mangrove survival in saline ocean water (Scholander *et al.* 1962), salt exclusion in species of *Rhizophora* and *Laguncularia*, and salt excretion in species of *Aegialitis* and *Aegiceras*. Salt excluders not only operate ultrafiltration, but also cease or diminish transpiration and photosynthesis when exposed to saline water. Salt secretors can continue photosynthesis utilizing ocean water in transpiration, owing to salt glands in the leaves.

A number of experiments have shown reduced seedling survival and growth, and decreased photosynthetic capacity with increase of salinity (Stern & Voight 1959; Ball and Farquhar 1984). Mangrove managers can expect some mangrove species to suffer salinity stress , indicated by reduced growth, reduced litter production, and death. Successful seedling establishment may occur more to landward than previously, resulting in retreat of species zones. Limitation of groundwater extraction in the catchment or promotion of sedimentation within the mangroves could mitigate this impact.

Mangrove areas should be mapped and remapped periodically, to show the location of different mangrove zones, and of seaward and landward fringes of the mangrove area. Older records from the mangrove area should be compiled into a database. Large-scale colour air photographs should be taken. Information on the history of sites should be compiled from climate records, previous studies, and records of logging or other activities. This would allow identification of community changes resulting from increased inundation frequency or salinity.

MONITORING STRATEGIES

Certain identification of climate change and the effects of sea-level rise requires long-term monitoring of biological and physical parameters in mangrove swamps at many different locations. This is the intention of the UNEP-IOC-WMO-IUCN (1991) Long-term global monitoring system of mangroves, established as part of the Global Ocean Observing System. The key parameters selected for measurement are listed below.

PARAMETERS

Measurements of biological indicators and certain physical parameters should be made along a transect across the intertidal slope, as close to the centre of the area as possible. Sampling frequency along this transect will be site dependent according to the scale and characteristics of the site. Further to the systematic study specified below, resurvey should be made immediately following an extreme event such as a severe cyclone.

Minimum Biological Requirements

The following biological indicators are the minimum necessary to assess the impact of possible climate change and sea-level rise on mangrove ecosystems.

Parameter	Minimum Frequency	Methodology
Forest structure	5 years	ASEAN-Australia Manual or USM Manual
Tree size	5 years	ASEAN-Australia Manual or USM Manual
Density	5 years	ASEAN-Australia Manual or USM Manual
Tree growth	5 years	DBH increment (USM Manual)
Leaf-area index	5 years	Light attenuation (ASEAN-Australia Manual, with modifications)
Interstitial macrofauna	2 years	Holme and McIntyre 1971; Hulings and Gray 1971
Species composition of macrofauna	1 year	Burrow density

Minimum Physical Requirements

Because of the diversity of mangrove environments and in order to distinguish the effects of climate change from anthropogenic and other non-climatic impacts, the following physical parameters are the minimum required.

Parameter	Minimum Frequency	Methodology
Relative sea-level change	Continuous	GLOSS or tide gauge at met. station
Topography	5 years	EDM survey, relative to datum
Stratigraphy	Baseline	Coring and radiometric dating
Sedimentation rate	5 years	Inserted stakes, remain *in situ*
Meteorological data:	Continuous	Automatic met. station to WMO standards
Total radiation		
Air temperature		
Rainfall		
Wind speed & direction		
Relative humidity		
Atmospheric pressure		
Evaporation		Evaporimeter, WMO standards

Additional Indicators

Further to these minimal requirements, it would be desirable where possible to monitor the following biological and physical indicators, to allow assessment and interpretation of biological responses to climate change and sea-level rise.

Additional Indicators	Minimum Frequency	Methodology
Biological indicators:		
Analysis of leaf pigments and tannins	5 years	Tannin analysis of treetop leaves
Height of pneumatophores	5 years	Ruler with EDM survey
Physical indicators:		
Sediment particle size	5 years	Sieve cascade, ASEAN-Australia manual
Redox potential	5 years	Inserted iron stakes, removed
Soil salinity	Seasonal	Squeeze cored sediment
Surface water temperature	Seasonal	Maximum/minimum recorder

Further Additional Indicators for More Complete Analysis

For a more complete analysis the following parameters could also be examined and would assist in interpretation of biological responses.

Indicators	Minimum Frequency	Methodology
Biological Indicators:		
Age distribution of macrofauna	5 years	ASEAN-Australia model
Pre-dawn water potential	5 years	Scholander bomb
Physical indicators:		
Wave conditions		Derive from meterological data
Water circulation		GCNSMS Activity 2
Sediment ash free dry weight	5 years	Loss on ignition
Trace metals	5 years	To international standards
Pesticides	5 years	To international standards
Root flora	1 year	Qualitative observation
Carbon partitioning	5 years	to be determined
Rate of turnover biomass	5 years	to be determined
Litter breakdown	5 years	to be determined

This long-term monitoring will identify responses of mangroves to climate change and sea-level rise, with site comparison acting to eliminate concurrent response to some other forcing factor.

ACKNOWLEDGEMENTS

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Natural Colonization of Man-Made Lagoons by Reef Communities: A Model for Assessing Reef Response to Sea-Level Rise

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ABSTRACT

There is a growing interest in the response of coral reefs to the sea-level rise that may accompany global climatic change. One question asked is whether reef communities will be able to colonize shore habitats newly submerged by rising sea level. A model suitable for investigating this question is found in man-made coastal lagoons created within the reef habitat. In the southern offshore islands of Singapore, several man-made lagoons, constructed at different times, enable spatial as well as temporal analysis of colonization by reef communities. A study of a lagoon constructed in 1975 showed minimal colonization by hard corals (less than one per cent areal cover). Although the areal extent of algae, sponges, and soft corals was greater than that of hard corals, the combined cover did not exceed twenty per cent of the transect that showed the best colonization response. Different zones in the lagoon were observed to display different rates of colonization.

INTRODUCTION

Many of Singapore's southern offshore islands with fringing reefs have had their reef flats reclaimed. One such reclamation was carried out at the island of Pulau Hantu in order to enhance its recreational potential. The island, located 8 km south of the main island of Singapore at 1° 13.6′ N and 103° 45.5′ E, originally consisted of two small adjacent islands, Pulau Hantu Besar (2 ha) and Pulau Hantu Kechil (0.4 ha), surrounded by fringing reefs and sharing a common reef flat in between them. Under a massive land reclamation programme between March 1974 and April 1975, 0.4 million m^3 of sand were used to increase the land area of the two islands to 12.2 ha (Figure 1). The reclamation covered most of the reef flat up to an average distance of 15 m from the reef edge, with a rock bund holding in the sand. The reef flat in common between the two islands was buried under sand, and its waters transformed into a swimming lagoon.

After the reclamation, the establishment of some coral colonies and other benthic organisms associated with reefs was observed. Because this situation would be similar to that of sand beaches becoming inundated by rising sea level, the colonization of reclaimed lagoons presents a useful model for interpreting the response of reef organisms to shore habitats newly submerged by rising sea level. A preliminary study was undertaken in 1992 to assess the reef community colonizing the lagoonal floor, 17 years after the creation of the lagoon.

MATERIALS AND METHODS

A transect was established at the northern entrance of the lagoon, running perpendicularly from the original reef crest into the lagoon (Figure 1, p. 48). Seven 20 m transects, parallel to each other, were laid out at 10 m intervals along the initial transect; these parallel transects are identified as A to G, with A being the farthest into the lagoon, and G at the entrance. Along each 20 m transect, a 1 m^2 quadrat with a grid of 100 squares of 100 cm^2 each was placed at alternate metre marks, enabling an area of 10 m^2 per parallel transect to be assessed. Within each m^2 quadrat, the areal cover of individual benthic organisms was measured.

RESULTS

The depth profile of the lagoon was constant along the initial transect. There was no exposure, even at very low spring tides. The substratum was mostly sandy with a few small rocks present. Hard corals were usually found associated with these rocks. The total percentage of live cover of all organisms across the transects ranged from 5.6 to 19.9 (Table 1). The trend of increasing abundance from the inner to the outer part of the lagoon reversed abruptly at the outermost transect (G).

Apart from the major life-form groups shown in Table 1, other organisms observed were gastropods, bivalves, hydroids, anemones, zoanthids, and polychaetes as well as more motile forms such as gobies and crustaceans. *Sargassum* was the major macroalgae, and of the two genera of seagrass present, *Halophila* was more abundant than the larger *Enhalus*.

Table 1

Total percentage live cover of all major groups of benthic organisms across the transects

Transect	A	B	C	D	E	F	G
Hard corals	0.02	0.15	0.34	0.1	1.1	0.7	0.3
Soft corals	0.02	-	0.02	-	-	0.3	-
Sponges	1.2	1.6	2.1	3.5	0.6	0.06	0.07
Seagrass	0.5	2.9	1.4	0.8	0.2	0.04	-
Macroalgae	3.4	5.7	5.2	5.7	18	16	2.1
Others	0.46	1.65	1.44	1.9	-	2.1	4.02
TOTAL	5.6	12	10.5	12	19.9	19.2	6.49

Among the living community, the abundance distribution showed macroalgae to be consistently dominant throughout all transects (Table 2). Other well-represented groups were seagrasses and sponges. After macroalgae, tunicates dominated the innermost transect but tapered off sharply in the remaining transects. Although hard corals were not abundant, they were spatially distributed throughout all transects together with two other groups, macroalgae and sponges. Anemones were confined to the outer two transects while seagrasses and zoanthids were absent there. In terms of group diversity, the inner transects supported a larger variety of life forms.

Table 2

Component lifeform percentages based on total living community cover

Transect	A	B	C	D	E	F	G
Hard corals	0.36	1.16	3.67	0.92	5.8	0.6	11.7
Soft corals	0.36	0.01	0.18	0.04	-	2.7	-
Sponges	21.9	12.9	22.5	32	2.8	5.1	2.5
Tunicates	22	2.19	1.6	6.5	1.4	-	-
Zoanthids	4.5	15	-	0.69	-	1.56	-
Anemones	-	-	-	-	-	0.43	3.9
Seagrass	8.3	22.8	14.9	6.72	0.79	-	-
Macroalgae	61	45.8	57.2	53.1	89.2	89.6	81.9

DISCUSSION

A previous study of the original reef crest and slope of the island complex found live coral cover to range from 29.5 per cent to 43.8 per cent at three survey sites (Chou 1988). The site nearest the present transects supported a hard coral cover of 29.5 per cent, dead coral cover of 13.3 per cent, algal cover of 13.5 per cent, and other fauna of 10.8 per cent. The original reef community along the reef crest and slope continues to provide the larval source for the colonization of the lagoon. Colonization by macroalgae and seagrass is faster than it is by the faunal groups. Of the faunal groups, sponges were the fastest and most widespread colonizers. The levels of abundance of macroalgae, seagrass, and sponges were equivalent to other reef flats which were unaffected by any form of reclamation (Chou and Wong 1985).

Colonization response of hard corals was slow. Colonies were mainly small and of the massive growth form such as *Goniopora*, *Porites*, *Favites*, *Favia*, *Goniastrea*, and *Platygyra*. The observation that hard corals grow in association with rocks indicates that a hard substratum is necessary for their colonization, as has also been observed in deeper areas beyond the reef slope (Chou 1986).

This preliminary study gives some indication of how reef communities would respond to sandy habitats inundated by a raised sea level. In discussion of sea-level rise, questions are often asked of its effect on coral reefs. Can, for instance, fringing reefs eventually colonize new habitats submerged by sea-level rise? Answers have not been definite because the problem is complex and compounded by a large number of unknown variables, such as the extent of erosion and sedimentation from increased storminess, the rate of sea-level rise, and the interaction between newly submerged land and sea.

Even in a simplistic scenario without these variables, there is much uncertainty as to whether reefs can colonize such areas. Neither isolated studies on transplantation of coral colonies nor laboratory-based experiments have so far been conclusive and do not give any indication of how an entire reef community will respond. One way to study the process is to look at areas submerged by land subsidence. Another is to examine areas which have been filled by sand but still remain submerged, representing a shallow zone that will typify many such areas when sea level rises. Artificial coastal lagoons are thus ideal for this kind of investigation; the results of such investigations can demonstrate if and how reef communities will colonize such areas, and whether additional management strategies will be required to enhance colonization.

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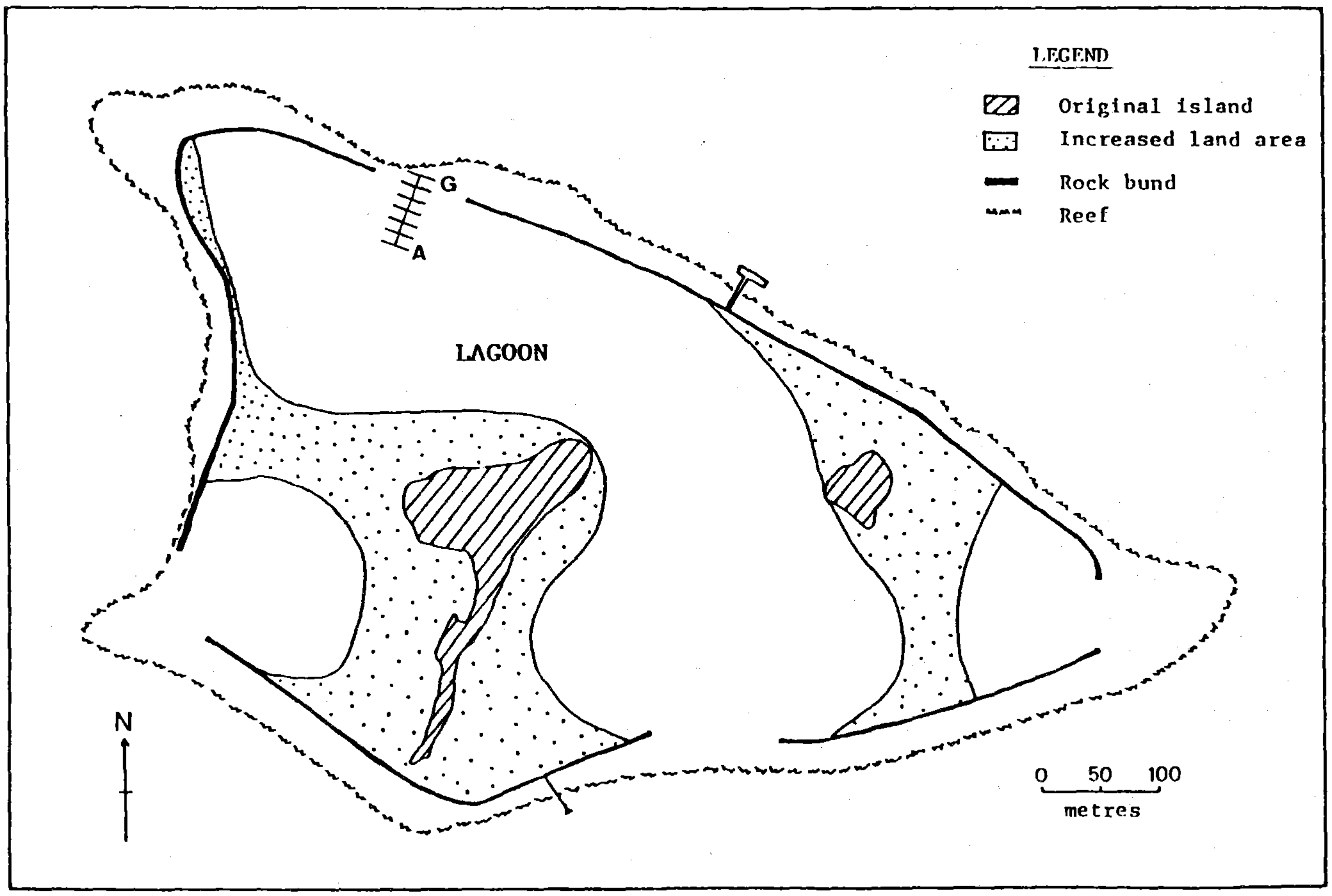

Figure 1: Pulau Hantu, showing reclamation and location of survey transects

The Introduction of Aquaculture Animals to Pacific Islands

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ABSTRACT

Aquatic animals have been transported among the Pacific islands since the beginning of maritime activities. Examples are characterized into six time periods, but most have occurred during the past two decades. The majority of introductions have been for aquaculture purposes, and within the past ten years a substantial number of introductions have occurred through the aquarium and ornamental fish trade. More than 136 species have been introduced to the Pacific islands (not including the Hawaiian Islands). Tabular information is provided for giant clams, oysters, green mussel, pearl oyster, trochus, green snail, and freshwater snails. Additional information is provided on penaeid shrimp and freshwater crustaceans. Fifty-six species of introduced fresh/brackish water fishes are recorded from the Pacific islands; information on seven tilapia species is provided.

INTRODUCTION

Documentation of the introductions of animals to the Pacific islands is for the most part anecdotal. Long-term, quantitative studies have not been conducted as they have in other areas. This review records the animals introduced (primarily intentionally) for aquaculture purposes to the Pacific islands (the area covered by the South Pacific Commission).

Animal introductions, both accidental and intentional, have occurred in the Pacific since the beginnings of island settlement. But during the past two decades, special emphasis has been placed on the development and expansion of marine and freshwater aquaculture, which has accelerated the introduction of aquaculture animals to the Pacific islands.

The first major review of introduced aquatic organisms to mention the Pacific islands was that of Walford and Wicklund (1973), who described a short case-history of the Hawaiian Islands drawn from a review by Brock (1960) which formed the background for most more recent reports. In 1984, Maciolek reviewed the fishes introduced to the Pacific; Randall (1987) added new information on Hawaiian fishes. Also in 1984, Uwate *et al.* conducted a country-by-country review of aquaculture activities in the Pacific region. A wide range of aquatic animals was reported as having been introduced to Fiji (Andrews 1985). For Papua New Guinea, West and Glucksman (1976) described a number of fish introductions; Allen (1991) has brought this information up to date. Introductions to coral reefs were reported by Eldredge (1987). One very important and extensively introduced group – the tilapia – were the topic of a single review (Nelson and Eldredge 1991). More recently, Munro (1993) described aquaculture development and environmental issues in the Pacific, noting that commercial aquaculture is restricted to red alga, black-lip pearl oyster, and penaeid shrimps. Unsuccessful attempts have resulted in the establishment of some wild stocks, but the effects of these are largely unknown.

In his historical review of the introduction of inland aquatic species, Welcomme (1992) reported that 36.1 per cent resulted from aquaculture. He concluded that there was a need for an international code of practice. In the Pacific region, the International Council for the Exploration of the Sea (ICES) code has been slightly modified and adopted by the Indo-Pacific Fisheries Council to aid in formulating national legislation.

The following outline of aquaculture animals introduced to Pacific islands is extracted from the more detailed report ***Introductions of commercially significant organisms to the Pacific islands*** by L. G. Eldredge, forthcoming from the South Pacific Commission (SPC) in conjunction with the South Pacific Regional Environment Programme (SPREP).

GIANT CLAMS (Family Tridacnidae)

Giant clams have played a major role in islander life throughout history. Local overharvesting has reduced stocks and led to local extinctions in several islands. Hatcheries have been established, the larger ones being at Palau [Micronesian Mariculture Demonstration Center (MMDC)], Solomon Islands [Coastal Aquaculture Center of ICLARM (CAC)], and Australia [Orpheus Island Research Station of James Cook University, Townsville]. Hatchery-reared individuals have been transferred to numerous islands to establish populations and to reseed lagoons and coastal areas.

Transport of adults and juveniles allows for the transport of potential diseases, parasites, and predators. The snail predator *Cymatium muricinum* is the most well known (Perron *et al.* 1985) and is thought to have been taken to American Samoa with *T. derasa* from Palau (Itano and Buckley 1988). The pyramidellid snail *Tathrella iredalei* is an ectoparasite on giant clams and arrived at Guam with *T. derasa* from Palau in 1989 (Smith, pers. comm.).

Table 1

Transfers of giant clams among the Pacific islands

Taxon	Island	Source	Date (Remarks)
Tridacna derasa (Smooth giant clam)			
	American Samoa	Palau	1986-1991 (heavy predation; brood stock developed)
	Cook Islands	Palau	1986 (first introduction outside native range)
	FSM: Chuuk	Palau	1991
	Kosrae	Palau	1988-91
	Pohnpei	Palau	1985-90, 1992
	Yap	Palau	1984-87, 1991, 1993 (heavy predation)
		Kosrae	1992
	Fiji	Palau	1985 (first shipment to South Pacific)
	Guam	Palau	1984-89
	Marshall Islands	Palau	1985-1990
	Saipan	Palau	1986-88, 1991
	Tuvalu	Palau	1989 (heavy predation)
	Western Samoa	Palau	?
Tridacna gigas (Giant clam)			
	American Samoa	Palau	1991
	Cook Islands	Australia	1991
	FSM: Chuuk	Palau	1991
	Kosrae	Palau	1991
		Marshall Is.	1991
	Pohnpei	Palau	1990
	Yap	Palau	1991

Fiji	Australia	1986-87, 1990
Guam	Palau	1982 (unsuccessful)
Mariana Islands	Palau	1991
Tonga	Australia	1991
Western Samoa	Australia	1990, 1991
Tridacna squamosa (Fluted clam)		
Guam	Palau	1982 (heavy predation, unsuccessful)
Western Samoa	?	1990
Tridacna tevoroa		
Tonga	Fiji	? (2 per cent mortality)
Hippopus hippopus (Horse's hoof)		
Cook Islands	Australia	1991
FSM: Chuuk	Palau	1991
Kosrae	Palau	1990-91
	Marshall Is.	1992
Yap	Palau	1991
Fiji	Australia	1991
Saipan	Palau	1991
Tonga	Australia	1991
Western Samoa	Australia	1991
	Solomon Is.	1990-92 (all died)

OYSTERS (Family Ostreidae)

Oysters are found worldwide throughout temperate, subtropical, and tropical waters. Many species are harvested for local consumption. Numerous species have been transported throughout the Pacific--most such introductions have been unsuccessful. The biology and culture of tropical oysters have been reviewed (Angell 1986).

Mud-blister worms, *Polydora* spp., are closely associated with oysters. Individual worms bore into mollusk shells, forming a small mud-filled cavity which lowers marketability. *Polydora websteri* was introduced to land-locked oyster runways in Hawaii. The infestation was so extreme that the oyster culture operation eventually ceased operation (Bailey-Brock and Ringwood 1982).

Table 2

Transfers of oysters among the Pacific islands

Taxon Island	Source	Date (Remarks)
Crassostrea belcheri		
Tonga		
	Sabah	1977, 1978 (trials terminated)
Crassostrea echinata [Australian oyster]		
Fiji	Australia	1910
	Tahiti	1981 (high mortality)

French Polynesia	New Caledonia	1972, 1978, 1983
Guam	Palau	1979
New Caledonia	Tahiti	
Crassostrea gigas (Pacific oyster, Japanese oyster)		
Fiji	Japan	1968-70, 1973-74
	California	1971 (hurricane damaged)
	American supplier	1977 (100 per cent mortality)
	Philippines	1976 (cultured, no growth)
French Polynesia	California	1972, 1976 (heavy *Polydora* infestation)
Guam	Taiwan	1973 (unsuccessful)
New Caledonia	Japan	1967, 1970-77
	California	1970-77
	?Australia	1971
	Tahiti	1976-77
Palau	California	1972, 1973, 1975
	Washington	1973
Tonga	Japan	1975
	Tasmania	1975
Vanuatu	California	1972-73
Western Samoa	Northwest USA	?
Crassostrea iredalei (Philippine oyster)		
Fiji	Philippines	1975-76
Tonga	?	1976
Crassostrea virginica (American oyster)		
Fiji	Hawaii	1970
Tonga	California	1973
Ostrea edulis (Flat oyster, European native oyster)		
Fiji	Japan	1977
Tonga	Japan	1975 (high mortality)
	California	1975 (high mortality)
Saccostrea commercialis (Sydney rock oyster)		
Fiji	Australia	1880s, 1968, 1970
	California	1973
New Caledonia	Australia	1971±
Tonga	New Zealand	1973
Saccostrea cuccullata tuberculata (Solomon Is. mangrove oyster)		
Guam	Solomon Is.	1978

GREEN MUSSEL (*Perna viridis*)

Green mussels are marine bivalves which live attached to rocks and hard substrates in shallow waters. The biology and culture of three species of *Perna* have been reviewed by Vakily (1989) – only one species has been transported in the Pacific islands.

Table 3

Transfers of the green mussel *Perna viridis* among the Pacific islands

Island	Source	Date
Cook Islands	Tahiti	1984
Fiji	Philippines	1975, 1976, 1987
French Polynesia	New Caledonia	1978-79, 1990
New Caledonia	Philippines	1972, 1976, 1978-80, 1983
Tonga	Philippines	1975-76
	Singapore	1976
	Sabah	1978
Western Samoa	Tahiti	1982

PEARL OYSTERS (*Pinctada* and *Pteria* spp.)

Three species of the pearl oyster *Pinctada* have been transported and cultivated throughout the Pacific islands since the turn of the century. The biology and culture of pearl oysters have recently been reviewed (Gervis and Sims 1992).

Table 4

Transfers of pearl oysters among the Pacific islands

Taxon Island	Source	Date (Remarks)
Pinctada fucata martensi		
(Japanese pearl oyster)		
Marshall Islands	Japan	1935-36 (abandoned 1942)
Palau	Japan	1935-36 (abandoned 1942)
Tonga	Japan	1975-77
Pinctada maxima		
(Gold-lip pearl oyster)		
Cook Islands	Australia	1904
Kiribati	Australia	1904 (unsuccessful)
Palau	Australia	1935-42 (abandoned 1942)
Tonga	Japan	
Pinctada margaritifera		
(Black-lip pearl oyster)		
Cook Islands	w/in country	1955, 1980s (successful)
French Polynesia	w/in country	ongoing
	Okinawa	1979
Kiribati	Christmas Is.	1977
Tonga	Japan	mid-1970s
Pteria penguin (Winged pearl oyster)		
Tonga	Japan	1975

JAPANESE CLAM (*Tapes japonica*)

About 3000 to 5000 very small Japanese clams were transported to Fiji in 1971 from California along with a shipment of oysters. They arrived in excellent condition and were planted in Bay of Islands near Suva, but their present status is unknown.

TROCHUS (*Trochus niloticus*)

The native range of this large trochus *Trochus niloticus* includes the Andaman Islands in the Indian Ocean to the Pacific islands of Fiji and Wallis, including Palau, Yap, Papua New Guinea, the Solomon Islands, Vanuatu, and New Caledonia, and the north and northeastern coasts of Australia (Bour 1990). Individuals have been introduced to all other islands where they are presently found. Trochus shell has been harvested since the beginning of the century. World production is currently estimated between 3000 and 6000 tons, making this species one of the most valuable gastropods in the world, market both for shell and for meat.

Table 5

Transfers of trochus among the Pacific islands

Region and Island	Source	Date
Micronesia		
Chuuk	Palau	pre-1927-31, 1939
Eaurpik	Yap	1985, 1986
	Ulithi	1992
Ebon, Aur, Maloelap	Marshall Islands	1984
Elato	Yap	1986
	Woleai	1991
Fachaulap	Yap	1984
	Woleai	1992
Fais	Yap	1987
Guam	Saipan	early 1950s
Ifalik	Yap	1985, 1987
Kapingamarangi	Pohnpei	1989
Kili	?	1954
Jaluit	Chuuk	1939
	Palau	1939
Kosrae	Pohnpei	1940s/1950s, 1959
Lamotrek	Yap	1986
	Woleai	1991
Nukuoro	Pohnpei	1989
Pingelap	Guam	1989
Pohnpei	Palau	pre-1927, 1939
	Chuuk	1939
Puluwat	Palau	1937
Saipan	Palau	1938
Satawal	Palau	1939
Sorol	Ulithi	1991, 1992
Ulithi	Yap	1939 or 1940
West Fayu	Yap	1986, 1987
Woleai	Yap	1983, 1984
	Fachaulep	1992
Yap (and other atolls)	Palau	1930

Polynesia		
Aitutaki	Fiji	1957
American Samoa	Fiji	1958
Austral Islands	Tahiti	1968, 1972
BoraBora	Tahiti	1963
Funafuti	Fiji	1985, 1987
Gambier Islands	Tahiti	1968, 1972
Hawaii	Guam	1952, 1963
Manihiki	Aitutaki	1982
Moorea	Tahiti	1963
Niue	Fiji	1992
Northern Cook Islands	Aitutaki	1985, 1986
Palmerston	Aitutaki	1973, 1981, 1982
Rakahanga	Aitutaki	1982
Raiatea	Tahiti	1964
Southern Cook Islands	Aitutaki	1981-83
Suwarrow	Aitutaki	1985, 1987
Tahiti	Vanuatu	1957
	New Caledonia	1958
Tokelau	Fiji	1986
	Aitutaki	1988, 1989
Tonga	Fiji	1992
Tuamotu	Tahiti	1968, 1969, 1972
Tuvalu	Aitutaki	1988, 1989
Western Samoa	Fiji	1990
Melanesia		
Gran Terre	Lifou	1989

GREEN SNAIL (*Turbo marmoratus*)

The green snail is found naturally west of Fiji and is considered to be limited to continental islands, such as Papua New Guinea, Solomon Islands, and Vanuatu (Yamaguchi 1989), but not New Caledonia. The biology of the green snail has been described by Yamaguchi (1988). The success of the transfer to Tahiti led to additional introductions (Yen 1991).

Table 6

Transfers of the green snail among the Pacific islands

Island	Source	Date
Tahiti	Efate, Vanuatu	1967
Moorea, Huahine, Raiatea, Tahaa, BoraBora, Maupiti	Tahiti	1980-81
Tuamotu	Tahiti	1980-81, 1985, 1990
Cook Islands	Tahiti	1981

FRESHWATER GASTROPODS (Family Ampullariidae)

Commonly known as apple snails or golden snails, these species cause much damage to rice and several other plants in Asia and to taro in Hawaii (Acosta and Pullin 1991; Cowie, in press).

Table 7

Transfers of apple snails among the Pacific islands

Taxon Island	Source	Date (Remarks)
Pomacea canaliculata		
Guam	Taiwan	1989 (eradication required; by 1991, dense wild populations)
Pomacea lineata		
Papua New Guinea	Philippines	1991
Pila conica		
Guam	?	1984
Palau	? Guam	1984-85 (eradicated)

PENAEID SHRIMPS [Family Penaeidae]

Penaeid shrimps have for many centuries been considered a good source of food. Most species are found naturally in shallow, inshore tropical and subtropical waters and many have been artificially cultured in ponds. Bailey-Brock and Moss (1992) have reviewed the taxonomy, biology, and biogeography of the commercial species.

Of all the transfers and introductions, apparently only one species – *Penaeus merguiensis* – has become established, this having occurred in an estuarine area of Fiji after its release at the conclusion of experiments (Choy 1983).

Table 8

Transfers of penaeid shrimps among the Pacific islands

Taxon Island	Source	Date
Metapenaeus ensus		
(Greasyback shrimp)		
Tahiti	New Caledonia	1973, 1983
Penaeus aztecus		
(Northern brown shrimp)		
Tahiti	Texas, USA	1973
Penaeus indicus		
(Indian white prawn)		
Fiji	Tahiti	1981
Penaeus japonicus		
(Kuruma prawn)		
Tahiti	Japan	1973
Fiji	Japan	1974
French Polynesia	Japan	1983

Penaeus merguiensis		
(Banana prawn)		
French Polynesia	New Caledonia	1972
Tahiti	New Caledonia	1973
Fiji	Tahiti	1974
Penaeus monodon		
(Giant tiger prawn)		
American Samoa	?	?
Fiji	New Caledonia	1975
	Tahiti	1976-81
	Australia	1990-91
Guam	Taiwan	1978
Solomon Islands	Australia	1987
Western Samoa	Tahiti	1980
Penaeus semisulcatus		
(Green tiger prawn)		
Tahiti	New Caledonia	1973, 1983
Penaeus stylirostris (Blue shrimp)		
Guam	Hawaii	1990+
New Caledonia	Mexico	1980

FRESHWATER CRUSTACEANS (*Macrobrachium* spp.)

These two large species of freshwater prawns belong to the family Palaemonidae. Their distribution is limited – *M. lar* being found in the Indo-Pacific from east Africa to the Ryukyus and the Marquesas (introduced to the Hawaiian Islands); *M. rosenbergii* is more restricted from northwest India and Vietnam to the Philippines, New Guinea, northern Australia, and Palau (Holthuis 1980). Aspects of the biology of *M. rosenbergii* have been detailed by New and Singholka (1985).

Table 9

Transfers of freshwater prawns among the Pacific islands

Taxon Island	Source	Date
Macrobrachium lar		
Hawaii	Guam	1956
	Tahiti	1961
Macrobrachium rosenbergii		
Fiji	Hawaii	1975
Guam	Hawaii	1974
Hawaii	Malaysia	1965
Palau	Hawaii	1974
Rarotonga	Tahiti	1992
Solomon Islands	Tahiti	1983+
Tahiti	Hawaii	1973
Western Samoa	Hawaii	1979

FISHES

Among the islands of the Pacific there are only a few documented reports of introduced marine fishes (Maciolek 1984); however, at least 33 marine species have been introduced into Hawaiian waters (Randall 1987). Live baitfish are needed for the pole-and-line skipjack fishery. Small-scale development projects were initiated at Western Samoa where Mexican mollies (*Poecilia mexicana*) were cultured; however, the results did not prove to be economically sound (Popper 1982). A similar project in American Samoa cultured *P. mexicana* and *P. vittata*.

Mullets (*Mugil cephalus*) were imported to Guam in 1989 from Hawaii to establish a brood stock and have not been released into the wild. A faster growing variety was introduced from Taiwan to Guam in 1991-1992. In June 1990, 10,000 mullet fry were imported to Tonga from Hawaii and released in Lake Ano.

At least 56 species of freshwater fishes have been introduced into Pacific islands, exclusive of the Hawaiian Islands where more than 40 species alone have been reported.

Among the freshwater fishes several species of tilapia have been widely introduced into Pacific islands for a variety of reasons (see Table 10). Negative impacts have been reported, ranging from decreases in waterbird population to disruptions of subsistence and traditional aquaculture practices.

The common carp *Cyprinus carpio* was introduced to Papua New Guinea in the early 1960s and escaped into the Sepik River drainage system. Individuals are spreading about 40 to 60 km per year, both upstream and downstream (Ulaiwi, 1990) where significant fisheries have developed.

Table 10

Transfers of tilapia among the Pacific islands

Taxon Island	Source	Date	Purpose
Oreochromis mossambicus			
(Mozambique tilapia)			
Micronesia			
Fanning Atoll	Hawaii	1958	accidental
Guam	Philippines	1954	culture and weed control
Nauru	?	1960s	mosquito control
Pagan	Saipan	1955	enhance freshwater lakes
Saipan	Philippines	1955	stock enhancement
Tarawa	? Fiji	1963	subsistence aquaculture
Washington Is.	Hawaii	1958	no apparent purpose
Yap	?	1970s	for culture
Polynesia			
American Samoa	Western Samoa	1950s	stock enhancement
Cook Is.	Fiji	1955	for culture
Funafuti	?	?	unknown reasons
Nanumanga Is.	?	?	unknown reasons
Niuafo'ou Is.	? Tongatapu	1982	subsistence enhancement
Niue	?	?	unknown reasons
Niutao Atoll	?	?	unknown reasons
Nomuka Is.	Tongatapu	1970s	mosquito control
Tahiti	?	1950s	unknown reasons
Tongatapu	Fiji	1955	mosquito control
Vava'u Is.	? Tongatapu	?	subsistence fishery

Wallis	?	1966	unknown reasons
Western Samoa	Fiji	1955	small-scale culture
Melanesia			
Efate Is.	New Caledonia	1950s	stock enhancement
Guadalcanal	?	1957	for culture
Malaita	? Guadalcanal	1957+	unknown reasons
New Caledonia	Philippines	1955	for culture
Papua New Guinea	Malaysia	1954	for culture
Rennell Is.	Guadalcanal	1957+	stock enhancement
Santa Ana	? Guadalcanal	1957+	unknown reasons
Tanna Is.	New Caledonia	1950s	stock enhancement
Vanua Levu	Viti Levu	?	for culture
Viti Levu	Malaysia	1954	subsistence culture
Oreochromis niloticus (Nile tilapia)			
Rarotonga	Fiji	1993	for culture
Vanua Levu	Viti Levu	1988-90	for culture
Viti Levu	Israel	1968	subsistence culture
Oreochromis aureus (Blue tilapia)			
Viti Levu	?	1974	for research
Oreochromis urolepis (Wami tilapia)			
Viti Levu	Taiwan	1985	for research
Tilapia macrochir (Longfin tilapia)			
Wallis	?	1967-70	unknown reasons
Tilapia rendali (Redbreast tilapia)			
Wallis	?	1967-70	unknown reasons
Papua New Guinea	U.K.	1991	stock enhancement
Tilapia zilli (Redbelly tilapia)			
Fiji	Hawaii	1957	for culture
Guam	? Hawaii	1956	aquatic weed control
Hybrid tilapia (*O. mossambicus* and *O. niloticus*)			
Guam	Taiwan	1973	for culture

Source: Nelson and Eldredge (1991), with additions

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Sewage-Disposal Management in the Bay of Panama

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ABSTRACT

Nearly half of the population of the Republic of Panama lives in Panama City, and it is estimated that by the end of the century the city will contain more than one million inhabitants. One result of this expansion will be a substantial increase of sewage discharged into the Bay of Panama. At present, domestic wastes are discharged directly into the bay through some 20 outfalls and indirectly via the Matasnillo, Mathias Hernandez, and Juan Díaz rivers. In 1985, the sewage load was already estimated to be 100 million tons/year, contributing to a heavy BOD and high bacterial populations near the shore. Because of the growing magnitude of sewage discharge and the resulting pollution, a study of sewage discharge was conducted to seek effective disposal methods that could maintain the seawater along the shoreline within tolerably safe limits of pollution.

INTRODUCTION

Nearly half of the present population of the Republic of Panama lives in Panama City. Projections indicate that by the end of the century, the city's population will surpass one million people. Among other effects, this urban expansion will bring a substantial increase in the sewage discharged into the Bay of Panama. Domestic wastes are discharged at present directly into the bay through approximately 20 outfalls and indirectly via three rivers, the Matasnillo, Mathias Hernandez, and Juan Díaz. From these sources, the sewage load entering the bay in 1985 was estimated to be approximately 100 million tons/year, which introduced about 10,000 tons BOD/year. In addition, a high concentration of bacterial pollution is found in several places along the shore, with values as high as 160,000 MPN/100ml (Figure 1). Bacterial pollution decreases with distance from the shoreline of Panama City and generally is below 1000 MPN/100ml outside a one-mile (1.61 km) perimeter (IDAAN 1977).

The surface-water circulation in the Bay of Panama follows a counterclockwise eddy (Smayda 1966). According to Bennet (1965), the bay's counterclockwise current system is part of the Colombia Current and follows the isobaths, with maximum current speed of 30 cm/sec occurring during the spring tides, and with a tidal range at the Pacific entrance of the Panama Canal of about 5 metres. Water pollution follows the general pattern of the net current in the bay, being at the same time subject to the effects of dilution and dispersion in the area. While the seawater close to the shore along the northern part of the bay is heavily polluted, the western part of the bay, with an important recreational area in the vicinity of Fort Amador, is at present relatively free of serious pollution.

Because the future trend of Panama City's growth – like the present trend – will be eastward of the city's centre, an ever greater part of the population will discharge their sewage directly into the Juan Díaz River. With the population of the eastern area projected to be over half a million by the year 2020, it is estimated that by that time sewage discharge into the river will reach 200,000 cubic metres/day (IDAAN 1977). As the river's present mean discharge rate is about 64,000 cubic metres/day during the dry season and 470,000 cubic/metres/day during the wet season, sewage discharge into the river by the year 2020 can be projected to be three times greater than the mean discharge during the dry season and close to half the discharge of the wet season (D'Croz and Kwiecinski 1980). As the river is already heavily polluted, the projected magnitude of discharge, if it has no previous treatment, will be well beyond the limits of tolerance.

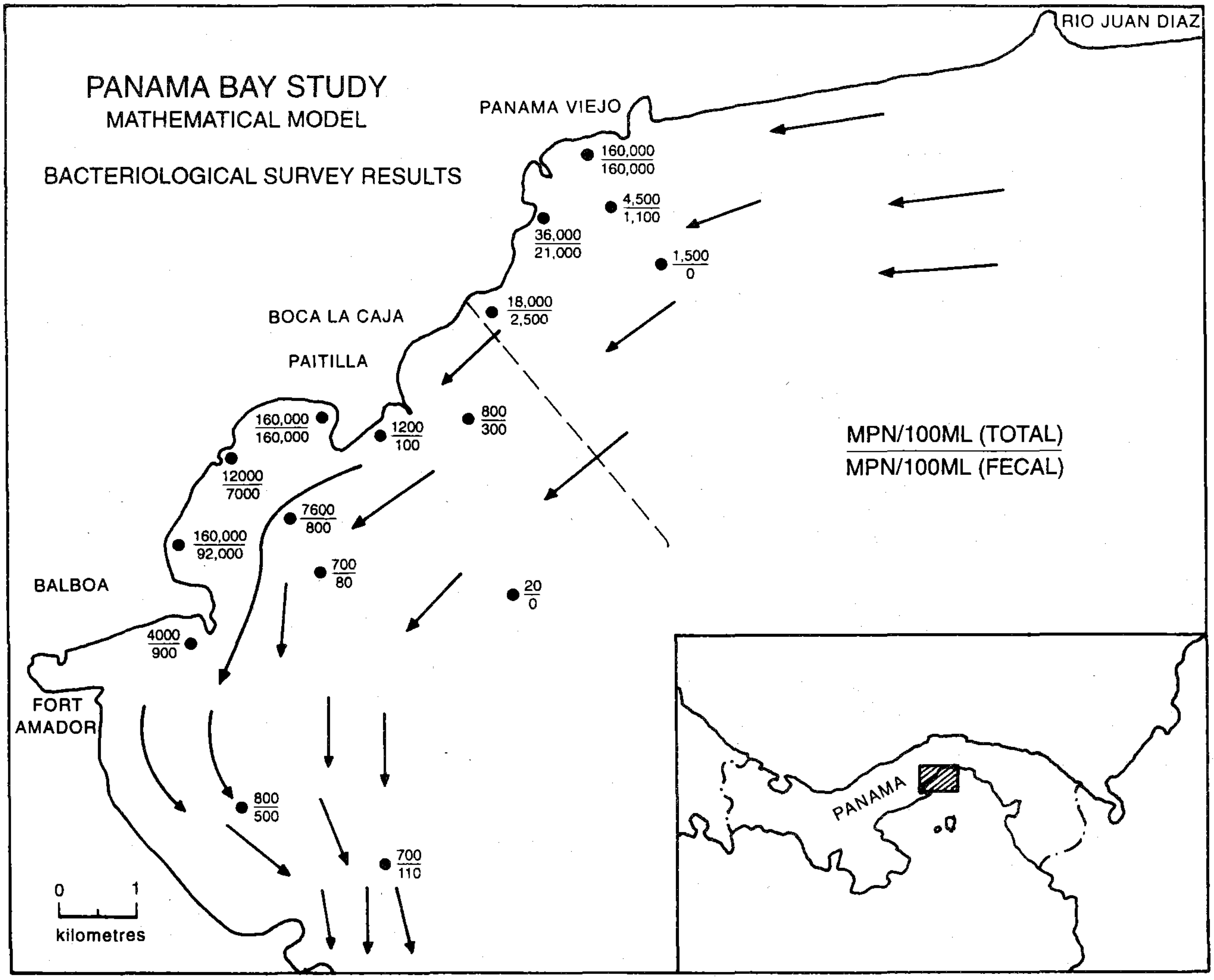

Figure 1: Location map and bacteriological survey results

SEWAGE-DISPOSAL STUDY

Recognizing the significance of the objective to establish a sewage-disposal system that could maintain seawater within tolerably safe pollution limits in the future, the Government of Panama requested that a study of sewage disposal from Panama City and the Juan Díaz area be carried out as a joint-venture project by Technipan of Panama and Hazen-Sawyer of the USA. The study was based on an initial assumption that Panama City's sewage should be collected at one location (Boca la Caja) and disposed of through an underwater pipeline into the bay. Similarly, it was recommended that a single underwater pipeline should carry the sewage from the Juan Díaz area some distance into the bay for discharge. In both cases, the study was intended to answer questions about the optimum length and characteristics of the pipelines and the addition of primary treatment to the sewage before its disposal, taking into account the hydrologic characteristics of the Bay of Panama. These consideration were to include economic as well as environmental implications.

To answer these questions, mathematical modelling and a series of field studies were carried out. Of primary concern were the definitions of the speed and direction of the tidal currents, the net currents, and the dispersion and mortality of bacteria in the seawater of the Bay of Panama. A series of measurements revealed that the direction of the current at incoming tide was 340 degrees while that of outgoing tide was 160 degrees, with the average velocities of the tidal current calculated to be 9–11 cm/sec. The direction of net currents followed the topography of the bay, the flow being directed to the west along the northern part of the bay and to the south at the western part of the bay. The average velocities of the net current was found to be with the range of 3–6 cm/sec, depending on the location within the bay (Figure 2). In addition, an experiment with Rhodamine B was executed, tracing the dye's dispersion by means of periodic aerial photography during one tidal cycle.

The optimum length of the pipeline was defined to be 4 km, with its design such as to provide for about 40:1 initial dilution. It was found that the dispersion pattern from the point of emission of sewage into the seawater would follow the tidal currents and extend to the west. The extension to the east was negligible, as shown by hydrographic modelling of the movement of particles during several tidal cycles once the tidal and net currents were known and the design of the pipeline defined (Figure 3).

Bacterial mortality was determined experimentally. Raw sewage was diluted 40:1 with seawater, and the time of 90 per cent mortality was found to be about five hours.

All pertinent data were introduced into the mathematical model to provide the picture of projected bacterial pollution in the bay and its distribution outside the emission point of the pipe. Finally, the alternatives were proposed of (1) discharge of raw sewage through the four-kilometre pipelines without treatment and (2) the inclusion of primary treatment and disinfection before discharge. These alternative were modelled for the sewage loads of 1990 and the projected loads of 2020 (Figure 4).

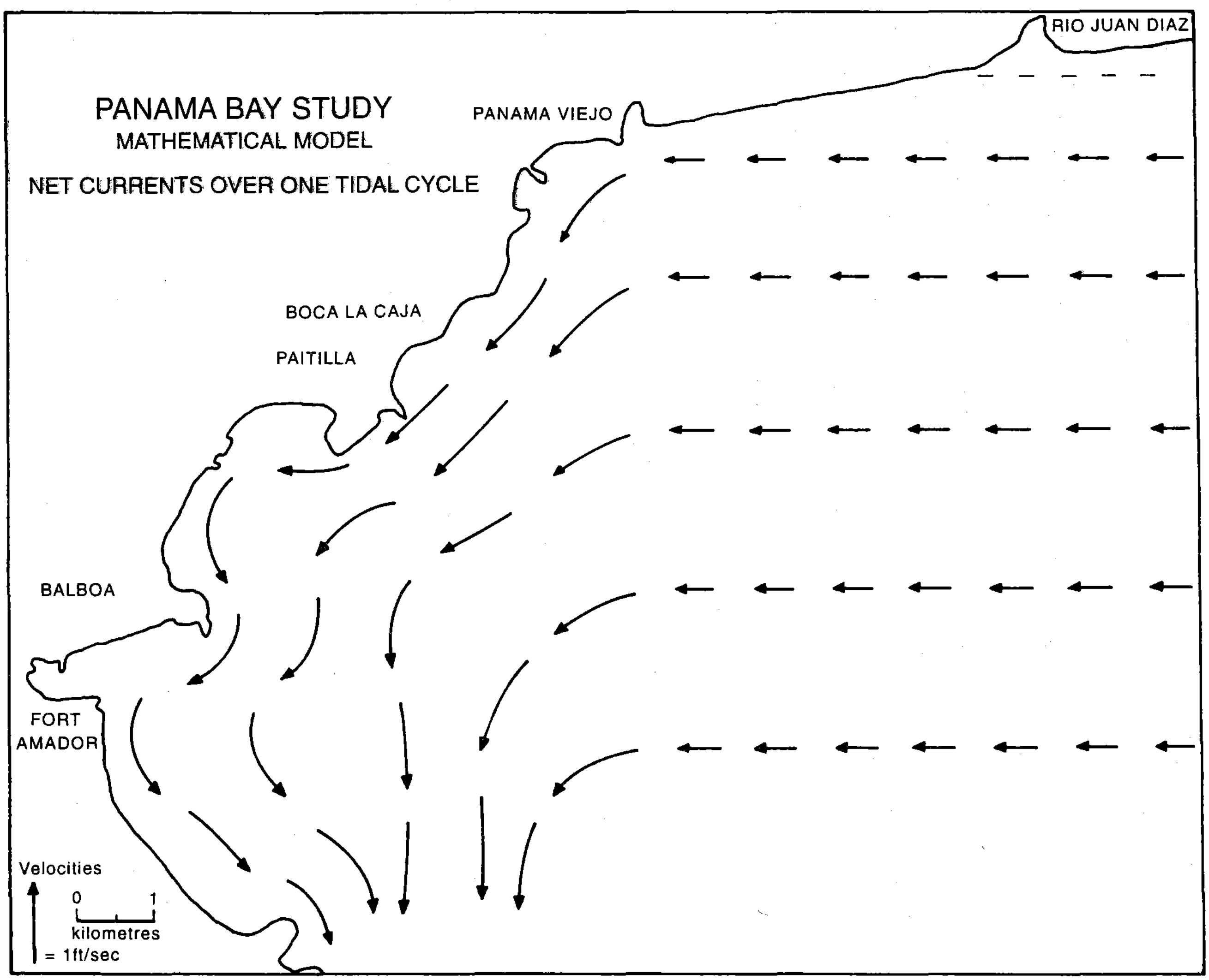

Figure 2: Net currents in Panama Bay over one tidal cycle

These alternatives of sewage disposal, as modelled, seem to be efficient enough to maintain the inshore waters of Panama Bay within internationally recognized safety limits with regard to bacterial pollution. It is difficult to know, however, when the new methods will become fully developed as such action depends largely on external loans and the priorities of the country.

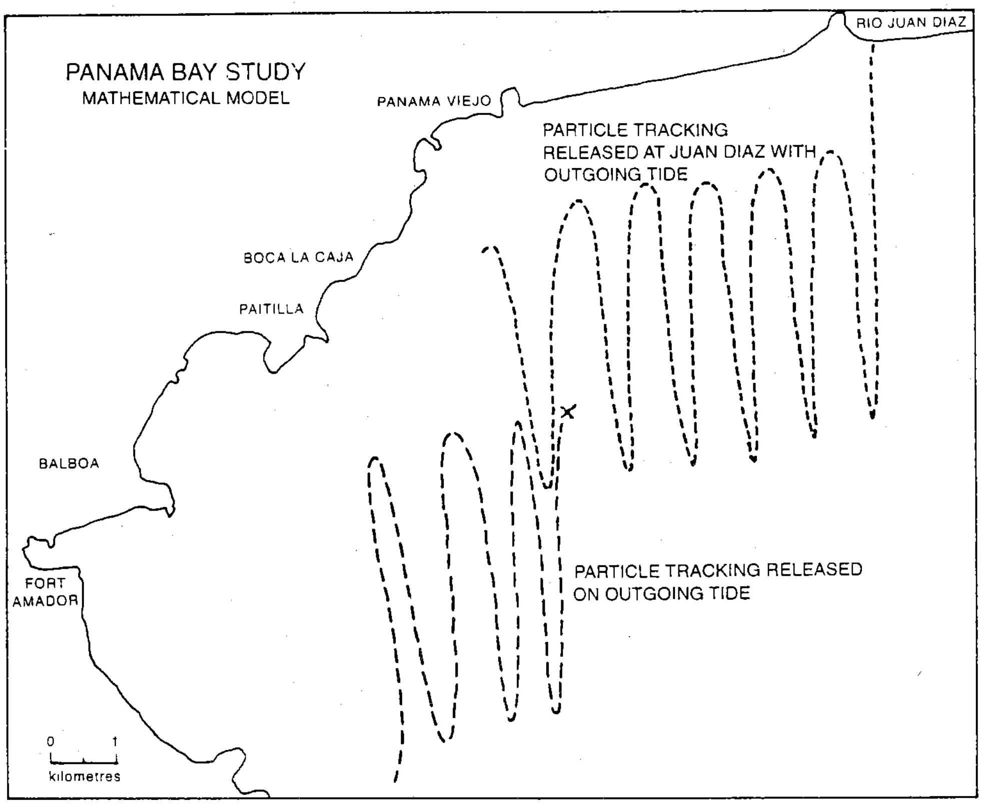

Figure 3: Model tracking of particles released on outgoing tide

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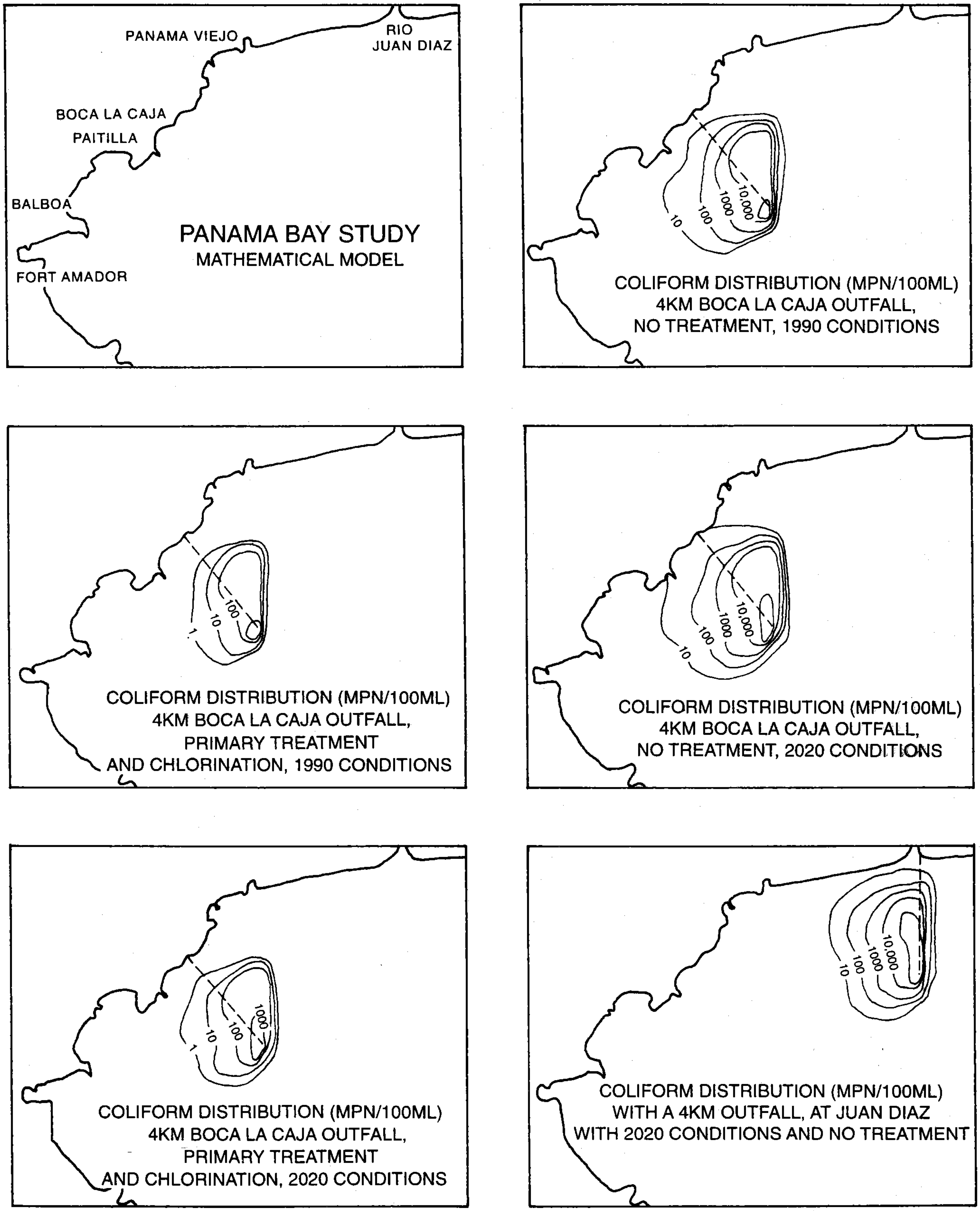

Figure 4: Models of coliform distribution from the two proposed outfalls in 1990 and 2020 under alternative treatments

Pyrodinium Red Tides:
How the Philippines Has Coped with a Recurrent Problem

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ABSTRACT

Periodic blooms ("red tides") of the phytoplankton *Pyrodinium bahamense* var. *compressum* have occurred in the Philippines over the past decade, bringing deaths by "paralytic shellfish poisoning" (PSP) and harming both health and economic welfare in various places in the archipelago. In response, government agencies monitor both shellfish toxicity and the cell count of *Pyrodinium* in sea water and issue bans on contaminated shellfish as appropriate. Despite knowledge of a ban, some people ignore it and fall victim to poisoning – a "psychological factor" that government agencies have to deal with in their efforts to lessen the harmful effeccts of red tides. Research continues in an effort to develop countermeasures against the effects of shellfish toxicity. Measures related to manpower training and education are also underway, as is legislation to enhance management of the problem and to coordinate monitoring and research efforts.

1. INTRODUCTION

The Philippines is an archipelago of 7,150 islands and rocks with a total land area of 0.3 million km^2. It sits in a strategic area of the Pacific basin, straddling sea lanes of communication crucial to commerce and trade in the region. The aggregate coastline is 18,000 km (NAMRIA 1993). The archipelago's waters cover an area seven times that of its land. Of the 2.1 million km^2 of marine waters, 12 per cent are coastal (Marcelo 1993).

The current Filipino population is 63.4 million. Their basic diet is rice and fish. The extensive coastline provides rich areas for fishing and shellfish gathering and the cultivation of marine life that are economically important, such as seaweed, prawns, and bivalves. The green-lipped mussel *Perna viridis*, or *tahong* (Pilipino), has been widely cultured in certain bays, encouraged by the Department of Agriculture through the Bureau of Fisheries and Aquatic Resources (Blanco and Pimentel, n.d.).

Since 1983 periodic blooms of the phytoplankton *Pyrodinium bahamense* var. *compressum* have been reported. The blooms discolor the water with brownish red patches, hence the term "red tide." During red tides, filter-feeding shellfish like *tahong* accumulate the toxic plankton, exhibiting no apparent ill effects themselves, but when ingested quickly paralyze the consumer victims, hence the term "paralytic shellfish poisoning" (PSP).

The most notorious bloom occurred in1988 in Manila Bay. For the first time, red tide struck at the heart of the capital and economically devastated the fishing community there. Most consumers refused to buy any seafood, despite tentative pronouncements that only bivalves and small planktiverous fish were unsafe. It also highlighted the inadequate state of preparedness in various government agencies. It was clear that something had to be done quickly to understand the phenomenon and to assuage its strongly negative impacts on health and economic welfare.

2. MONITORING

From 1983 to early 1993, there have been 1,458 PSP cases resulting in 83 deaths (Table 1) (Corrales and Gomez 1990; Gonzales, BFAR,1993, personal communication; Dayrit *et al.* 1993). The areas affected are shown on the map of Philippines (Figure 1). If the aim of an effective monitoring programme were the prevention of a single human death, then one is tempted to conclude that the Philippine effort has not been effective. However, before one so concludes, one must also consider a peculiar phenomenon, the "psychological factor," and the role it plays in creating victims.

Table 1

Paralytic Shellfish Poisoning (PSP) Cases in the Philippines
(Number of cases/number of deaths)

PLACE	1983	1987	1988	1989	1990	1991	1992	1993
Samar	157/8	211/6	25/1					
Carigara Bay	32/5		45/6					211/11
Capiz	8/1		3/1					
Masbate	27/2					7/1		
Sorsogon	51/2							
Camarines Norte	2/2							
Angeles City	1/1							
Zambales		15/1			1/0			
Manila Bay			125/4			73/8	269/11	45/1
Leyte Gulf/San Pedro			7/1					
Negros Oriental			106/4					
Cebu				24/5				
Camiguin					13/1			

Sources: Gonzales 1993; Dayrit *et al.* 1993

2.1 INTERNATIONAL MONITORING METHODS

A 1990 survey of monitoring methods around the world reveals that mouse bioassay is the method of choice in most countries, where a 1-ml intraperitoneal injection of a sample into a 20-g mouse effects a death time that is correlated to mouse units (van Egmond *et al.* 1992). Mouse units are translated into µg of saxitoxin equivalents according to the AOAC method (Helrich 1990). Toxicity is expressed as µg toxin/100 g shellfish meat. Twenty-one of the 47 countries that responded to the survey had legislation on PSP in fishery products. All but five have allowed tolerable levels of 80 µg/100 g. Austria, Italy, Germany, the Netherlands, and Norway have set the limit to 40 µg/100 g. In the Philippines, the 80-µg limit was lowered on 16 July 1993 to 40 µg during an outbreak in Manila Bay because of reports that although shellfish toxicity levels were below 80 µg, there were still cases of poisoning (Gonzales *et al.* 1993). The DOH is conducting a study to evaluate the safe level for Filipinos considering their average weight and intake of bivalves. Another factor to consider is the observation that toxicity levels may vary widely over a few metres within a single area.

The survey also cites other methods that certain countries employ. Spectrophotometric methods are used by Austria and Germany. The HPLC (high performance liquid chromatography) method is used by France, Ireland, Korea, and the Netherlands. The Philippines is currently setting up HPLC systems for PSP analysis in food at the Bureau of Food and Drugs (BFAD), and in body fluids from PSP victims at the Marine Science Institute, University of the Philippines-Diliman (UP-MSI).

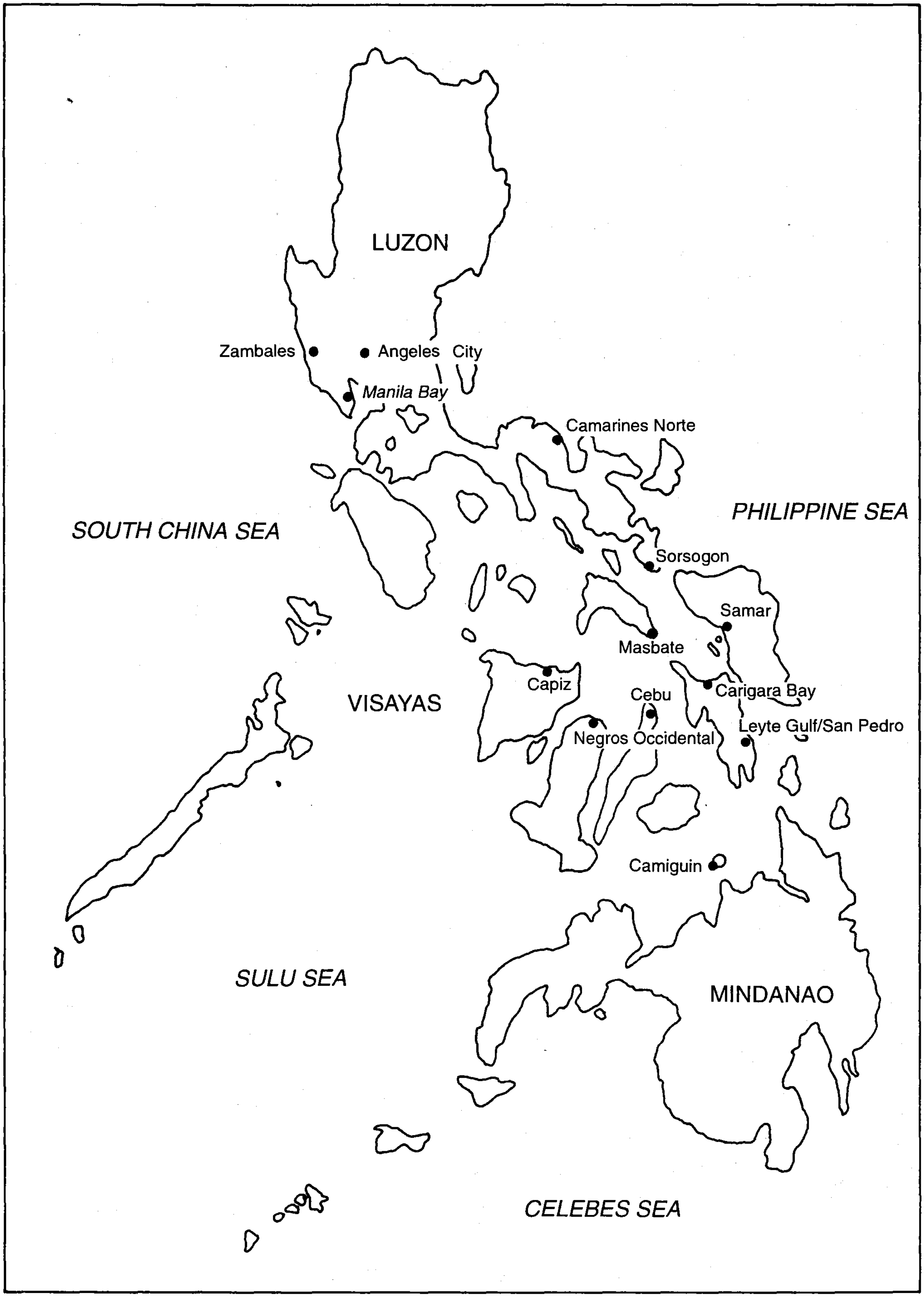

Figure 1: Map of the Philippines showing incidents of PSP

2.2 THE RED TIDE TASK FORCE

The Bureau of Fisheries and Aquatic Resources (BFAR), an agency under the Department of Agriculture, monitors both shellfish toxicity and the cell count of *Pyrodinium* in sea water. Logistics limits the amount of monitoring that can be done. Currently in areas with a history of red tide, BFAR collects shellfish and seawater samples on a regular basis. During the "off-season," cell counts are taken twice or thrice weekly. Shellfish toxicity is determined thrice weekly. When the number of cells in the water gets to 2 per litre, it is taken as a warning that a bloom is imminent. Sampling is increased to every other day, morning and afternoon. A Coast Guard helicopter is made available for an aerial survey of the area of discoloration (Abuso, BFAR, 1993, personal communication). It has been found that during a bloom, there are as many as 50,000 cells in a litre (Sotto and Young 1993).

Results are forwarded to the Red Tide Task Force (RTTF), a group under the Inter-Agency Committee on Environmental Health (IACEH), which was created by Executive Order 489 in 1988 to coordinate government programmes in addressing the problem of red tides. The RTTF has the following composition (Pastor 1993):

RTTF National Level

Dept. of Agriculture BFAR - Chairman
Dept. of Health EHS and BFAD- Member
Dept. of Science and Technology PCHRD and PCAMRD - Member
Dept. of Trade and Industry - Member
Dept. of Interior and Local Government BLD - Member
Philippine Coast Guard - Member
Philippine Information Agency - Member

RTTF Regional Level

Regional Agricultural Office - Chairman
Regional Health Office - Member
Regional Science and Technology Office - Member
Regional Disaster Coordinating Center - Support

RTTF Provincial Level

Provincial Governor - Chairman
Provincial Agriculturist - Member
Provincial Health Officer - Member
Provincial Disaster Coordinator - Support

Members of the RTTF deliberate on the information and give their recommendations to the IACEH on the basis of shellfish-toxicity levels. By law, only the Chairman of the IACEH, who happens to be the Secretary of Health, or his duly appointed representative can impose a ban on the harvesting, transporting, and selling of contaminated shellfish. Three action levels are recommended by the RTTF: no restriction, warning, and banning.

No restriction. (Toxin level is not detectable, *i.e.* no deaths in mice) Harvesting, gathering, transporting, and selling of shellfish is allowed.

Warning. (Toxin level is less than 80 µg*) A message is sent to the fishing community that shellfish from their locality may become toxic soon.

Banning. (Toxin level is 80 µg* or more) The DOH imposes food quarantines in markets within the affected province. The DA withholds Transport Permits for shellfishery products from the affected area. Announcements are made through print, radio, and television informing the public within the province that a ban has been imposed on the harvesting, transporting, and selling of shellfish.

*lowered to 40 µg in July 1993

2.3 EPIDEMIOLOGY

The Department of Health (DOH) monitors the number of PSP cases in hospitals and health centers within the affected areas and their environs. The working definition of a PSP case is any previously healthy individual who suddenly develops any two motor and two sensory abnormalities (Table 2) after ingesting a meal of bivalves. Unfortunately, not too many doctors are trained to check for the classic PSP symptoms, and a checklist of a patient frequently shows only numbness and dizziness as the main complaint (Pastor and Santos-Mendigo, in preparation). A diagnosis of PSP is then made on the basis of these symptoms and the last ingested meal of bivalves.

Table 2

Symptoms of paralytic shellfish poisoning

MOTOR ABNORMALITIES	SENSORY ABNORMALITIES
inability to walk	numbness
weakness	body malaise
difficulty in breathing	dizziness
difficulty in swallowing	lightheadedness
difficulty in talking	headache
paralysis	feeling hot
	short-tongue sensation

Source: Pastor 1993

2.4 THE "PSYCHOLOGICAL FACTOR"

A survey done in July 1993 by members of the Field Epidemiology Training Program of the DOH reveals that a number of PSP victims courted disaster during the 1993 Manila Bay outbreak when they ate *tahong* in defiance of an existing ban (Dayrit *et al*. 1993). Of the 45 confirmed PSP cases from Bataan, 32 were interviewed as to why they ate *tahong* during a ban. Most (72 per cent) said they were aware of the ban but ignored it. All but five had gathered the shellfish themselves. Among the reasons given by the victims were: they did not believe the shellfish were poisonous because their neighbors ate *tahong* and did not get sick, they were not afraid of getting sick (probably a show of misplaced *machismo*), and they wanted to test it on themselves and to prove that the *tahong* were not poisonous (*tahong* commerce is their livelihood and the ban wiped out their income). This defiance in the face of a ban is the "psychological" factor mentioned earlier, contributing to the pool of casualties during red tides. An educational campaign to change this attitude is ongoing.

Many coastal families derive their chief source of protein from shellfish that they gather from the wild . The food is free. Many times it is all they can obtain to eat because they have no money to buy other food. When a ban remains enforced for months, these families will take the risk and eat the forbidden food. People the author has interviewed would take the precaution of keeping a glass of coconut milk nearby, to imbibe as soon as tingling around the mouth was felt. For some, it was effective. For others, friends of those interviewed, it had a tragic end.

2.5 ASEAN-CANADA RED TIDE NETWORK

The ASEAN-Canada Marine Science Program is coordinated in the country by the DOST-PCAMRD. Under this program, a Red Tide Network was established in July 1993 with two components: Red Tide Awareness Network, where member-states inform the network of red tide occurrences in their respective countries, the information to be treated in a confidential manner; and Red Tide Information Network, where historical and other information is disseminated to the responsible parties within the network. The Regional Network Coordinator is Dr. Rhodora Azanza-Corrales of the Marine Science Institute, University of the Philippines (UP-MSI) at Diliman, Quezon City. The National Anchor is Mr. Cielito Gonzales of the Bureau of Fisheries and Aquatic Resources, Quezon City (Azanza-Corrales, 1993, personal communication).

3. RESEARCH

3.1 NATIONAL RED TIDE RESEARCH AND DEVELOPMENT PROGRAM

The Department of Science and Technology, as a member of the IACEH, has led the effort to formulate a National Research and Development Program on Red Tide. At an inter-agency workshop initiated by the Philippine Council for Health Research and Development (PCHRD) in May of 1992, the main areas for research were discussed and outlined (Figure 2). Projects given priority and funded in 1992 were: the establishment of a Red Tide Research and Development Information System, the development of appropriate depuration methods for red-tide-contaminated shellfish, development of fisheries-related alternative livelihoods for mussel farmers affected by the calamity, and the carrying out of oceanographic studies to improve monitoring and prediction methods for red tides (Guerrero 1992).

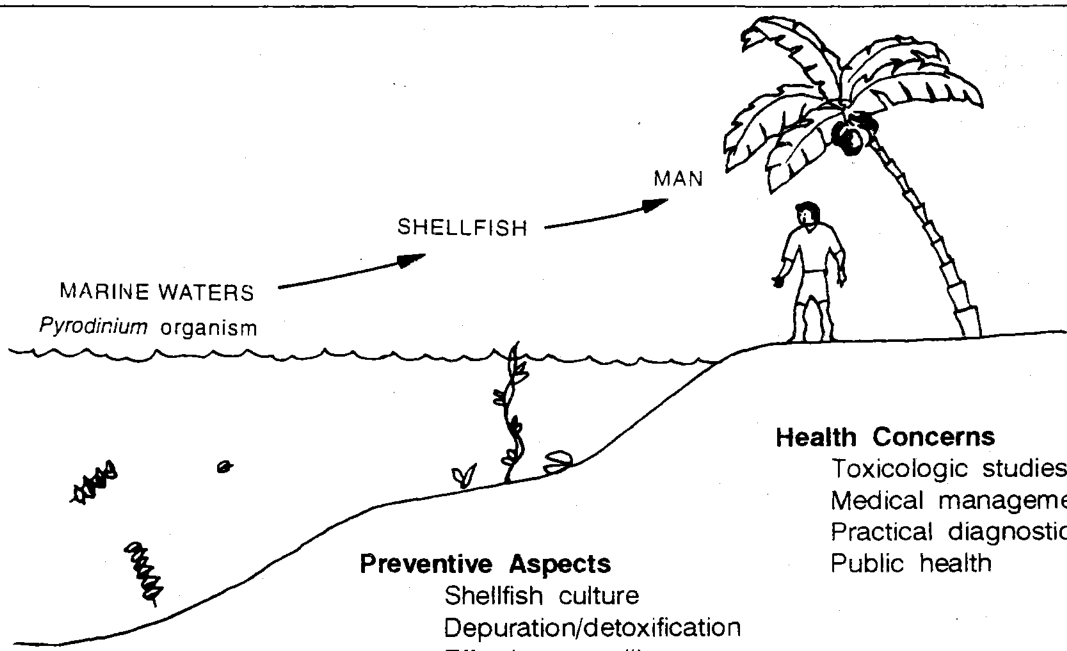

Figure 2: Thrusts of the Red Tide Research & Development Program of the Philippines

3.2 UP-MSI CONCLUDED AND ONGOING PROJECTS

At the UP-MSI, concluded and ongoing projects are the following: development of the blowfly assay as an alternative for PSP monitoring, culture of *Pyrodinium* cells, use of body fluids for diagnosis of PSP, purification of toxins from contaminated mussels for use as standards in PSP monitoring and research, development of antisera against saxitoxin and tetrodotoxin, study of *Pyrodinium* cyst density and viability in selected areas in Manila Bay, and study of hydrographic conditions attendant to red-tide outbreaks in Manila Bay. Several proposals have been submitted and are awaiting approval.

4. MANPOWER DEVELOPMENT

4.1 NATIONWIDE TRAINING ON RED-TIDE MONITORING AND DATA MANAGEMENT

In 1992, the Department of Agriculture awarded a one-year contract to UP-MSI under the Fisheries Sector Program to conduct nationwide training on red-tide monitoring and data management. Most trainees came from government agencies, mostly BFAR and DOH personnel, but some came from universities or other institutions. Supervisors of participants from government agencies were required to sign a Statement of Commitment that they would not reassign trained personnel to other jobs that did not make use of the training gained. (In the Philippines today, devolution is taking place whereby agencies are being transferred from the national government to local governments. Often, local officials have other priorities, and the effort to counteract red tide suffers.)

Each training batch participated in one week of lectures, laboratory exercises, field work and discussions. A total of five batches were trained: two from Luzon, one from Eastern Visayas, one from Western Visayas, and one from Mindanao. An average batch had 15 trainees and 8 observers.

Among the outputs of the UP-MSI effort was a Field and Laboratory Manual on Philippine Red-Tide Monitoring and Data Management that put together standard methods on plankton identification and quantitation, selection and sampling of sentinel species, shellfish toxicity determination, physical and chemical hydrographic measurements, epidemiology, data management and decision-making (Santos-Mendigo and Azanza-Corrales, 1993). The draft manual was extensively used during the training and finalized at the conclusion of the contract period. Another output was a video presentation of the red-tide problem and the efforts undertaken to address it.

An important offshoot of the project was the development of standardized data formats, which were made available to monitoring and research agencies nationwide, with the view of creating a database that would, over the years, yield important information for the prediction of *Pyrodinium* red tides.

4.2 INTRA-AGENCY TRAINING

On its own, BFAR conducts periodic training of its personnel for red tide monitoring. Local and foreign experts are invited to conduct demonstrations and hands-on workshops in various field offices throughout the archipelago.

The DOH has a Field Epidemiology Training Program where medical doctors are trained to conduct investigations on epidemics. During the 1988 outbreak, one FETP member who was principally responsible for recommending the banning of shellfishery products from Manila Bay received a number of death threats from enraged members of the fishing community who claimed that "red tide" was a conspiracy of the DOH and the chicken and meat vendors (Pastor, 1988, personal communication).

5. LEGISLATION

Two pieces of legislation related to red tide have been submitted to Congress for deliberation. One relates to sanitation of the shellfish, the other to control of algal blooms.

5.1 NATIONAL SHELLFISH SANITATION CODE

The bill entitled "An Act Providing for a National Shellfish Sanitation Code of the Philippines" submitted by Representative Dominador G. Nazareno, Jr., seeks to set water quality standards for shellfish-growing areas; require environmental sanitary surveys of shellfish and their growing areas; classify growing areas as approved, closed, restricted, or prohibited; regulate the processing, relaying, depuration, and transport of shellfish; set shellfish sanitary quality standards; regulate the issuance of licenses and permits related to the planting, growing, gathering, harvesting, processing, tranporting, and relaying of shellfish; set penal provisions for violators (Nazareno 1993).

There already exists a Sanitation Code of the Philippines created by Presidential Decree 856. But it is general. The bill seeks more specific measures to regulate the key aspects of the very important economic resource that shellfish are.

5.2 NATIONAL ALGAL BLOOM CONTROL PROGRAM

The bill entitled "An Act Establishing a National Algal Bloom Control Program" submitted by Representative Roy Almoro seeks to coordinate all monitoring and research efforts on both freshwater and marine algal blooms by the establishment of an Algal Bloom Control Commission and a National Algal Bloom Research Center (Almoro 1993).

As of this writing, both bills are undergoing further study through committee hearings.

6. CONCLUSION

The Philippines has responded to a national emergency with a unified effort to address all problems related to the *Pyrodinium* red tide through monitoring, research, information dissemination and education, manpower development, and legislation. It is hoped that in a short time there shall be no more deaths from PSP, and that the mystery surrounding the blooms shall have been solved, making prediction of these red tides possible. Patterns have begun to emerge in Manila Bay, but they need further validation before predictions can be made with confidence.

ACKNOWLEDGEMENTS

The author acknowledges the support of the United Nations Environment Programme, which enabled her to participate in the Pacific Science Inter-Congress held in Okinawa, Japan, June 27 to July 3, 1993, where this paper was presented orally; and the Philippine Council for Health Research and Development for a research grant, the partial results of which were reported in a poster entitled "Use of Human Urine for the Diagnosis of PSP" at the same Inter-Congress. Grateful acknowledgement is also made to Dr. Gil Jacinto and Dr. Rhodora Azanza-Corrales for their critical review of the manuscript, and to Alex Padre for assistance in its preparation.

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APPENDIX: LIST OF ACRONYMS

AOAC	Association of Official Analytical Chemists
ASEAN	Association of South-East Asian Nations
BFAD	Bureau of Food and Drugs
BFAR	Bureau of Fisheries and Aquatic Resources
DOH	Department of Health
DOST	Department of Science and Technology

FETP	Field Epidemiology and Training Program
HPLC	high performance liquid chromatography
IACEH	Inter-Agency Committee on Environmental Health
NAMRIA	National Mapping and Resources Information Authority
PCAMRD	Philippine Council for Aquatic and Marine Research and Development
PCHRD	Philippine Council for Health Research and Development
PSP	Paralytic Shellfish Poisoning
RTTF	Red Tide Task Force
UP-MSI	University of the Philippines, Marine Science Institute

Coastal Change and Coastal Management

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ABSTRACT

Over the last decade, the anticipated extent of a sea-level rise because of climate change over the next century has been downgraded. Nevertheless, various coastal-zone resource uses will be influenced differentially by what rises do occur, especially as these interact with the rapid increases of economic development and human population along coasts. Speculations are made here about the timeliness of anticipatory actions from environmental and economic vantage points. Special attention is given to coastal erosion, mangroves, coastal water quality and fisheries, and coastal management.

INTRODUCTION

Rapidly rising human occupancy of coastal regions with its inherent trend towards urbanisation (Table 1; Figure 1) makes for increasing need to balance societal demands on the coastal zone with changes brought about by natural forces. More and more people on or near coasts cause more and more changes, especially in coastal waters. The interplay of these social and economic influences with geologic and climatic changes poses difficult challenges to coastal zone management. People desire stability, at least in a historic time frame, while certain changes in nature involve longer periods; others occur at shorter intervals or irregularly.

Table 1

Growth of selected cities on Asian/Pacific coasts, 1950–1990

Number of inhabitants, in millions	1950	1960	1970	1980	1990
Karachi	2.0±	2.0±	3.1	5.2	8.2
Bombay	2.9	4.0	5.7	8.5	11.9
Calcutta	4.0	5.5	7.1	9.5	12.6
Bangkok	2.0	2.0±	3.3	4.6	6.5
Manila	2.0±	2.3	3.6	6.0	8.3
Shanghai	10.3	10.7	11.4	11.8	12.0
Tianjin	5.4	6.0	6.9	7.7	8.0
Tokyo/Yokohama	6.7	10.7	14.9	17.0	17.2
Los Angeles	4.1	6.6	8.4	9.5	10.5

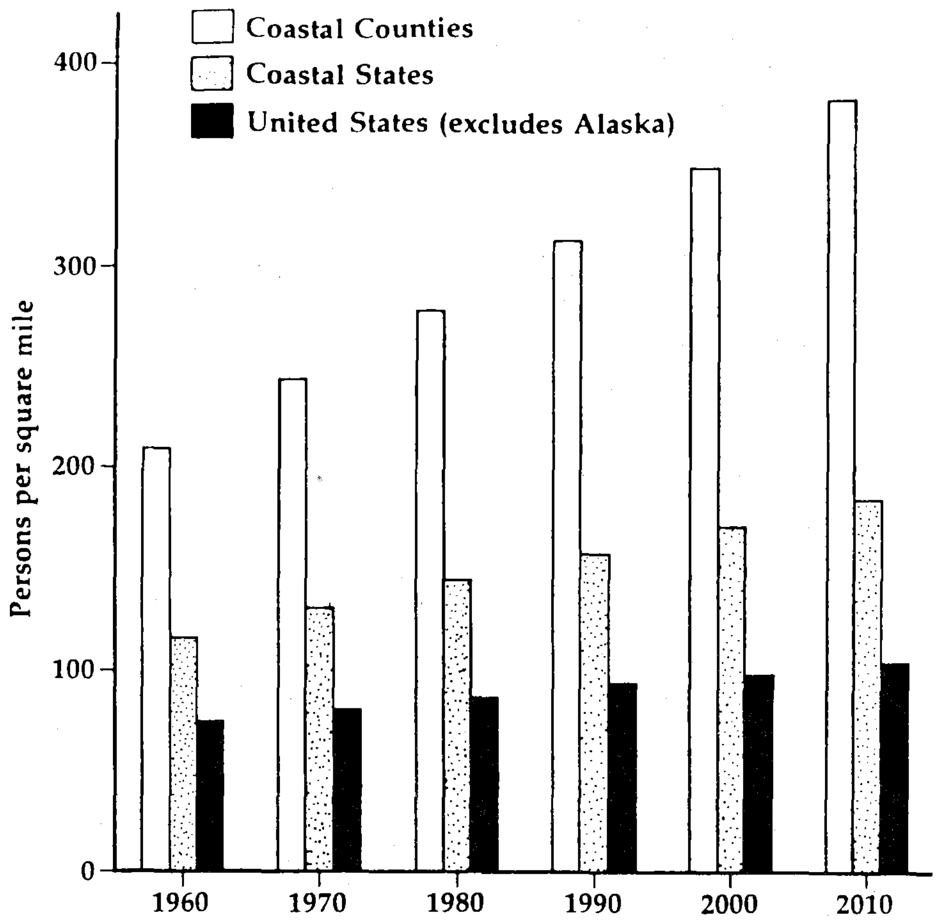

Figure 1: Changes in USA population density, 1960–2010
(Culliton *et al.* 1990)

SEA LEVEL RISE

Changes in climate have occurred throughout the earth's history. They brought with them changes in sea level, but never before were there so many people living close to the sea, potentially influenced in all aspects of their lives by a shoreward advance of the ocean.

Sea level rise due to global warming has been much discussed in scientific circles and the popular press, the latter writing of vanishing isles and inundated cities. But, over the last ten years, estimates have lessened for a eustatic (overall) sea level rise due to global warming over the next century (Fletcher 1992). Recent assessments suggest that the difference between high and low rates of rise would, by 2050, amount to only 5–10 cm. Thus, cries that low-lying coral islands will vanish in 50 to 60 years, such as were made by Presidents of Kiribati and the Maldives, can be seen as political responses to sensational journalism rather than reliable predictions of future occurrences. Population increases are likely to affect the lowland tropics, including islands, far more severely than a rising sea, at least in the next 50–100 years (Wyrtki 1990). We have only limited success with curbing population growth and it is thus not surprising that it seems easier, in a culture where technology counts for much, to call for physical rather than social measures.

True, even a slight elevation of the sea level can exacerbate the effect of a typhoon, and coastal ground-water supplies may experience some sea-water incursion. At the same time, though, at least over the next 50–100 years or so, coral islands do not seem insecure even if, (or especially if) reef platforms become progressively inundated. Increased tropical cyclonic activity, combined with maximum coral growth rates and new coral habitats will ensure sediment supply, and increased water depths will increase sediment transport efficiency (Parnell 1989; Hopley 1993).

Existing beachrock, conglomerate, and other cemented island deposits will retard changes in locations of islands. Moreover, there is sufficient evidence (in the form of very recent artifacts contained within beachrock) to suggest that the sedimentation 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 sedimentation, superimposed over the top of existing beachrocks. Availability of land may, therefore, not be the (prime) problem for the low-lying island nations over the next century as has previously been suggested (Hopley 1993). If sea level rise is sufficiently slow (well within the more conservative estimates), vertical growth of corals may be able to keep pace with sea level. Furthermore, if there should be increased storm activity, the accumulation of coral debris may maintain reefs and low islands in relation to sea level (Buddemeier and Smith 1988; Parnell 1989: 297).

It remains important for those who live on coral islands to work now to maintain and often to improve the health of their coral reefs, to consider setback laws and ordinances as planning tools, and to deal with the presently ongoing human influences on their shorelines. This is best done by making and executing coastal zone management plans. Only long-term structures such as airport runways, low-lying road causeways, and large beach settlements such as resort hotels might have a modest sea level rise factored into their construction. (The State of Hawaii considers this to be 30 cm, for the foreseeable future and with a good margin of safety.)

The case presents itself differently, though, for the subsiding lands of highly populated river deltas in Asia, some in hurricane paths, where the purpose of structures that keep out the sea has been and remains stabilization and contemporary disaster protection, a fight against loss of land year by year. Dykes, polders, and the like would, of course, be included in works for the coastal zone and in coastal zone planning. Equally important, and similar to reef conservation, is the maintenance of mangroves on flat coasts as they are natural bulwarks against the incursion of the sea - and are discussed in a following section.

EROSION

There is a world-wide natural tendency to shoreline erosion; beaches become narrower and dunes and backshore cliffs retreat (Wanless 1989). But coastal advances also occur because sediments are redistributed; some rivers deposit more sediments than they did earlier, and there is uplift on certain coasts, especially those which bore a heavy load of ice during the last glacial period. Human action also increasingly contributes to changes in coastal configuration; longshore drifts are captured and rivers are dammed and/or used for irrigation with the result that both sediment load and water flow are reduced. Land reclamation with dykes and polders occurs in many populated areas.

Rising seas have eroded the land regularly when glaciers receded after the ice ages, as geologic records show, but it is only now that human populations are growing so rapidly, ever increasing the demand for space and coastal amenities, that erosion like one of its causes, the rise in the level of the sea, assumes socio-economic importance. Unfortunately there are only a few systematic attempts to assess the degree and extent of shoreline changes over the last several hundred years. Those related to the re-gaining of land from the sea by the people of the Netherlands during the last hundred years or so are an exception, as are records kept on the deltas of the Yellow river and the Yangtze. Sporadic historical notes also have been kept by the riparian people of the North Sea, but otherwise records of shoreline changes before 1850 are anecdotal, if that (Carter 1988).

One must note that processes of coastal erosion are a persistent natural tendency towards an equilibrium of the shore configuration between waves and the sediments they carry. Actions slowing or halting these processes are courting instability. Yet attempts are being made to stabilize most flat shores. Dams or polders are built to keep out the sea, with or without pumps, as in Holland, China, and Bangladesh, to name only a few prominent such locations. Groynes, which are breakwaters perpendicular to the shore, and breakwaters that occupy strategic locations parallel to the shore can be found on virtually all beaches with the goal of stabilizing or replenishing sand or other coarser beach materials. Their effectiveness is limited in time and degree. It depends to a great extent on the economic development of the shore that is intended to be protected or stabilized and hence on its structural complexity. It also depends on proper understanding of coastal hydrography and on the influence which coastal engineering can have on it. Most such structures do not last longer than 50 years, some stand up for a much shorter time (major dams excluded), and their effectiveness expressed as a percentage can vary between 15 and 95 (Carter 1988).

A decision to resort to one or another protective interference is usually based on cost/benefit considerations to protect the monetary value of property, services, or amenities (if the latter can be so assessed). Estimates of storm recurrence, graded by severity from events that occur about every 50 years to those that occur once in a 1000 years, importantly influence such calculations. Experience in these matters has shown that preparing for the rarest events with intensive preparations and interference is not as cost effective as planning for more likely and more frequently recurring events, especially as the rarer and more intensive ones cannot (yet) be foreseen with adequate certainty. The recent hurricanes Andrew in Florida and Iniki in Kauai could not be anticipated. By the same token they made it clear that proper planning for shore-zone occupancy (setbacks, housing construction) rather than protection by engineering works is a good deal more rational and effective against extreme events that change the shore than extensive seawalls!

Methods to control erosion fall in a specialty domain of shore-zone oceanography and landscape engineering hardly to be detailed here. A good overview of them is given by Carter (1988). However, the region of the world which this paper treats was endowed in places with natural erosion-control mechanisms in the form of mangrove formations, which will receive attention here.

MANGROVES

The mangrove environment comprises about 60 species of trees and shrubs and also provides living space for about 2000 species of a dependent biota of invertebrates, fishes, and epiphytic plants (Hamilton and Snedaker 1984). In tropical Asia and the Pacific Islands mangrove coasts are prevalent, associated with shallow sediment-laden waters at the mouths of rivers and creeks. They can reach many kilometres inland depending on the flow of freshwater and the coastal configuration (*e.g.* Bangladesh). They are bulwarks against the sea, nursery grounds for shrimp and fish, and when wisely harvested they furnish various subsistence products aside from industrial and semi-industrial wood materials. The significance of mangroves to the productivity of fisheries is illustrated in Table 2, which compares the fisheries of the mangrove-rich west coast of peninsular Malaysia with those of the east coast, which has almost no mangroves.

Table 2

Landings and wholesale values of marine fish, Malaysia

	1978	1979	1980	1981	1982
Peninsular West Coast					
Quantity*	411	432	493	433	434
Value*	966	810	779	808	976
Peninsular East Coast					
Quantity	154	139	130	216	133
Value	327	178	199	407	258

*(Quantity in '000 tonnes; value in '000,000 Malaysian $)

Source: Ng 1987: 166.

Options for obtaining goods and services from a mangrove area range from direct, on-site benefits (wood, crabs, honey, *etc.*) to indirect off-site benefits (shrimp and fish catches in adjacent waters, protection from storm damage). To these could be added the value of a certain portion of the mangrove area that could be transformed into another use of the space instead of management of the mangroves proper – for example, semi-intensive, ecologically responsible aquaculture well set back from the shore and with properly spaced ponds for semi-intensive practices.

Advances in shrimp aquaculture have however already led to excessive transformation into ponds of many tens of thousands of hectares of mangrove stands. This occurred even though the trees are difficult to clear, the soils cannot be worked with heavy machinery, and many mangrove soils are acid, which makes the pH of the ponds deleterious to the shrimp. Such acid sulfate soils necessitate frequent liming or initial covering of the pond surface with protective inert material or replacement soils. But the perfection of shrimp hatcheries and the development of shrimp feed has led to very high shrimp yields per unit pond surface. Also in view of the relatively low value set by Governments on mangrove areas, shrimp farms have been established fast and relinquished equally rapidly on many shores. The first developer may leave after 5 to 10 years, and secondary occupants may come in expecting lower yields. After a few years they also give up because further advances in culture led to higher production and lower costs elsewhere. In any case these pond areas are then lost to other uses and it is very difficult if not impossible to re-establish mangroves.

But there are former mangrove areas in which low-intensity, low-input shrimp and milkfish ponds have been established for long periods, as in parts of Java. Channels in the mangroves lend themselves to the positioning of fish cages and of rafts for mollusk culture. Advantage is taken of plankton and detritus production in the mangrove area itself, making importation of food from outside largely unnecessary.

In addition to direct and indirect products and services from mangroves, the trees have been removed to make way for human settlements. No wonder then that worldwide great inroads have been made into mangrove formations, so much so that in certain locations *(e.g.*, Thailand) a significant percentage of the former mangrove area is removed annually. It would be wrong, though, to extrapolate such trends to their complete disappearance, especially since their value is beginning to be recognized, and forestry practices to regenerate their stands are being developed (Hamilton and Snedaker 1984; ISME 1993). An evaluation of various forestry practices (clear-cutting, thinning, *etc.*) suggests that mangrove-area management should be planned with an active horizon of several decades. Though only moderately resilient to a sea level rise, mangroves are renewable forestry resources that can keep up with slow coastal changes even while serving as bulwarks against erosion. The more their rational use can be incorporated into overall coastal-zone management, the greater their contribution to sustainable development will be. It is necessary, therefore, that where mangroves can be preserved, plans to do so must be long-range rather than short-range.

COASTAL WATER QUALITY AND COASTAL MANAGEMENT

It may seem self evident that, through pollution and siltation, patterns of use on the land are direct determinants of the condition of coastal waters, affecting water quality and fisheries. Try as we may, however, success at maintaining and improving coastal water quality has been slow in coming, especially in industrial or industrialising nations. Although portions of the land can be individually owned, and there are well established laws governing their use, it is not so in the sea. Activities affecting the sea must be governed by laws and ordinances not so much involving individuals but a community, be that a township or a larger government unit. In the United States, for instance, Gore (1992: 150) wrote that:

> Though federal law purports to prohibit the dumping of municipal sewage and industrial waste into the oceans by 1991, it is obvious that the increasing volumes being generated and the enormous cost of the steps required to prevent ocean dumping will make that deadline laughably irrelevant. Currently, our coastal waters receive 2.3 trillion gallons of municipal effluent and 4.9 billion gallons of industrial wastewater each year, most of which fails to pass muster under the law. Nor are we the only nation guilty of

this practice. Germany's river system carries huge quantities of waste toward the sea each day. Most rivers throughout Asia and Europe, Africa and Latin America, are treated as open sewers, especially for industrial waste and sewage.

It may be worth stressing that these conditions result from long periods of relative ignorance of the cumulative impact of humans on the biosphere. Technologies such as simple sewage-treatment plants were capable of coping with the loads of fifty or so years ago but increasingly complex activities (industrial as well as those related to higher standards of living) by more and more people require greatly improved technologies. Not only would these have been more costly but they would also have to have been based on long-range, ecological thinking, of a kind that is not yet expected from most of today's engineers and economists, who have not yet been sufficiently challenged to prepare for a century in which development everywhere on earth must be environmentally sound, must include externalities (species loss, acid rain), and must consider long-range effects, many years if not decades away.

For the maintenance of coastal water quality this would mean, as a mere beginning, improvements in methods to deal with organic and inorganic inflow loads at the source or, in any case, before they reach the ocean. In many places this would mean establishment of new facilities and devices. Expensive and therefore doubtful of realization as this may be, changes in certain culturally based habits and practices necessary for the clean-up of coastal waters may be even more difficult to attain.

Water quality is assessed by engineers with chemical tests, but the public judges it by what kind of or how many creatures live in the water and they compare conditions today with those – usually better – of the past. For example, it is estimated that the natural fish population in Hawaii's coastal waters has been depleted in numbers by 85 per cent since the beginning of the 20th century (Shomura, 1987); mullet are among other species are fish that are much less prevalent than earlier in all bays and estuaries and that once furnished much of the catch of both sport and commercial fishermen. Fortunately, their numbers can be replenished.

The Oceanic Institute in Waimanalo, Oahu, and the Hawaii State Division of Aquatic Resources have collaborated in test releases of cultured mullet in several bays (Oceanic Institute 1990; 1991; 1992; 1993). The fish were tagged with a method adapted from that used on salmon, and released in several sizes and in large numbers. The tests were successful, leading, in locations, to contributing greatly to catches from some remaining resident populations indicating that the depletion was most likely due to habitat destruction, competition by non-native species, and overfishing. Such stocks can be replenished to a point, depending also on the quality of the receiving waters. If and where one uses the technique will further depend on the value placed on restoring ecosystems to earlier states and/or on decisions as to how much money should be spent on placing fish in the water, for they do not come free as the former natural populations did.

The method can be adapted to other species and it could serve to test for environmental recovery. There are many impoverished coastal waters where the ability to follow individuals of certain indicator species might become important for the management of water quality, an indicator the reverse of keeping canaries in coal mines to signal through their distress that the atmosphere was becoming unsafe. In the case of the aquatic bio-assay through fish releases, when the fish survive well the water quality has improved. Presently, however, efforts at protective management through tests for water quality with chemical kits or with bio-assays do not match the large scale destruction of the biological infrastructure on which the health and wellbeing of coastal waters rest. In the temperate region that infrastructure consists of sea grass and mussel beds and algal stands, in the tropics it is made up of coral reefs and mangroves; to an important degree that health and wellbeing expresses itself, ultimately, in the status of shore fisheries.

Their management, rather than their biological base, often has a combination of shortcomings: 1) insufficient understanding of the biological principles, particularly those related to population dynamics, upon which fisheries management rests; 2) confused politics and therefore bad decision making by bureaucrats; 3) inadequate perception of the biological aspects of management goals; and 4) inadequate comprehension of the essential function of renewable-resources management with its components in both social and natural realms. In more practical terms these shortcomings reflect a poor appreciation of linkages between environmental processes and the social world.

Ultimately, management of the complex pull between economic, social, and environmental interests requires legislation at several levels. Most simply, it can be divided between a broad approach dealing with the maintenance of environmental quality – that is, certain absolutes of permitted uses and broadly worded development purposes – as opposed to specific laws and ordinances dealing with such details as ambient water quality standards, fishing quotas, building permits, or the designation of areas for parks and protected areas. This latter legislation is often too weak and in many countries does not exist as yet, which is to be expected in that the consequences of pollution may not manifest themselves for years after their inception. More importantly, recognition of a healthy environment as a basis for social wellbeing is only now beginning to make itself felt. It can take many years for laws to be made or changed and it is not surprising, therefore, to read even with regard to higher-income countries that: "Legislation for conservation of coastal resources is insufficient or non-existent in many cases" (Juhasz 1991: 597).

Broadly speaking, community goals and related activities in the coastal zone can be represented in the schema in Figure 2. The goals and activities differ importantly from left to right in the amounts of external energy and materials that are continuously made to flow through the ecosystems that contain them. Generally, there are also far more people involved on the left than on the right side. These simple facts have bearing on the manner in which coastal zones are managed, and environmental vulnerabilities assessed. Individuals singly or in like-minded groups, units of government, business and private economic interests must create mechanisms for evaluating, continuously, their intentions and the effects of their actions on the coastal environment. These instruments – councils, law- and ordinance-making bodies, as well as protecting and enforcing units – must be competent to evaluate the consequences of proposed actions and to exercise checks and balances.

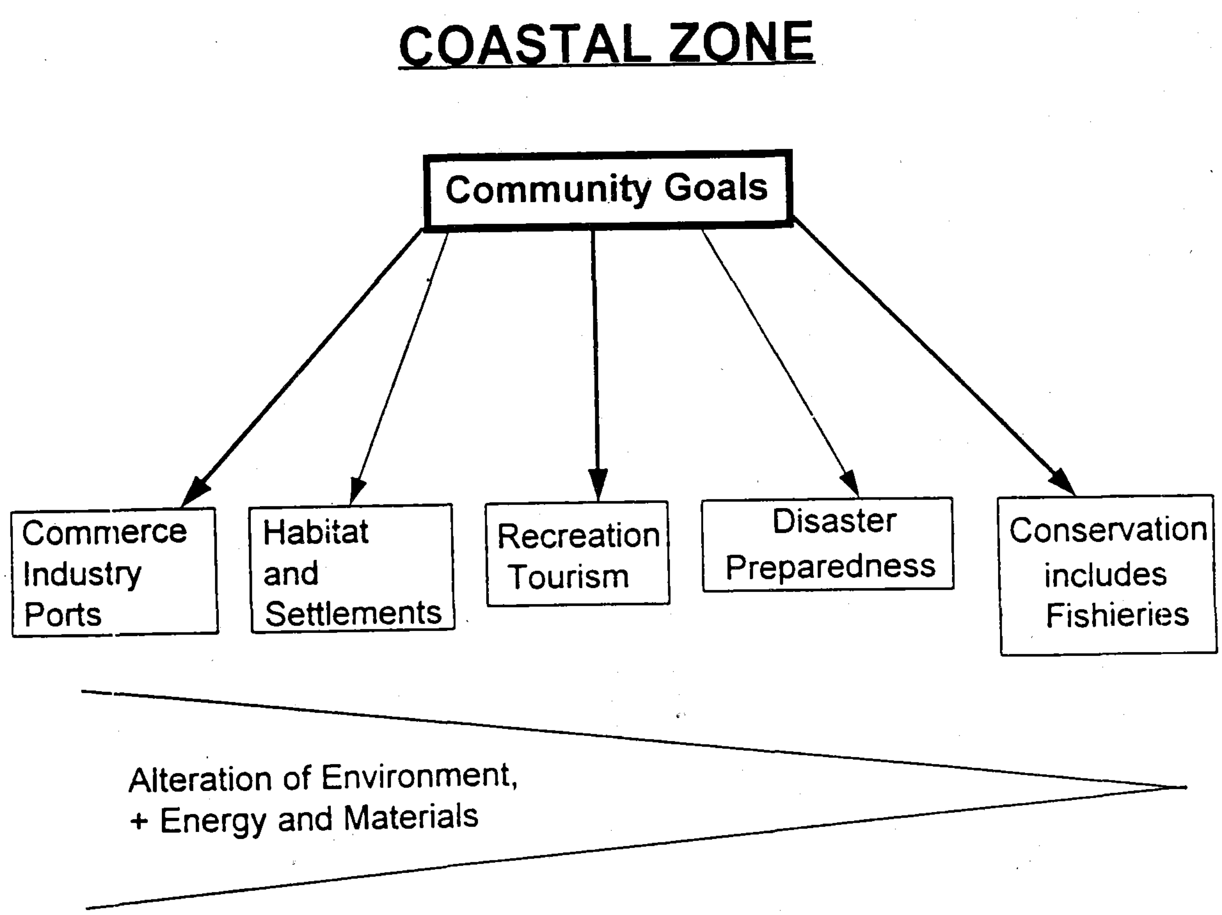

Figure 2

There are very few examples of successful instruments or organisations that attempt to satisfy all these prescriptions. The US/Asean Coastal Resources Management Project (CRMP), managed by ICLARM (1991), ventured to plan such instruments for certain coastal areas in Asia with the realization that different coastal areas are geographically, socially, and politically different and that it will probably take years before a CRMP can fully function. Several states in the United States have made some progress in fashioning broadly based instruments for coastal zone management. Hawaii provides an interesting example, with its Coastal and Ocean Management Initiative (COMI), which addresses the problems and opportunities identified over the last two or three years in coastal and ocean management planning. COMI is implemented by a private/public coordinating body, the Coastal and Ocean Management Policy Advisory Group (COMPAG), which meets several times a year, and which is associated with working groups (State of Hawaii 1992). This manner of proceeding made it easier, at least for now, to work without specific enabling legislation. Various attempts in the last two decades to create enabling legislation for integrated coastal zone management failed, most likely because the various government units concerned feared a diminution of their respective power bases. This suggests that we need better social constructs to prevent further deterioration of the coastal zone environment by economic development, more and more people, and inexorable natural changes.

These pressures challenge us to deal wisely with the land as well as the water and with the interaction between the two. Some responses are technical and managerial, with substitution of resources as one key; production of fishery products through certain kinds of aquaculture as opposed to fisheries is an example. There are also social and institutional substitutions such as a shore walk instead of a shore drive. Most importantly though there are ethical influences on decisions conditioned on different world views in a world that has increasingly become interconnected. Ethics or religion and their tenets about the place of people in the natural world will greatly influence the chances for sustainable development. Attitudes about social justice and responsibility of one generation for those that follow promise to have a powerful influence on the formulation of economic and social tools that enhance the forging of a "sustainable" world (Norgaard, 1992). With the new paradigms that a transition to greater sustainability would bring, the differences in time scales and horizons between natural and social environments will be reduced almost automatically. In the meantime, the world's coastal zones, and prominently the cities in them, are becoming crucibles at the interface of land and sea wherein attempts to achieve sustainability confront greater pressures but also offer greater long-term rewards than elsewhere in the world.

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