A Review of Mangrove Biodiversity Conservation and Management

June 2002

By

Donald J. Macintosh and Elizabeth C. Ashton

Centre for Tropical Ecosystems Research
(cenTER Aarhus)

Final Report 10/06/2002

Funded and Supported by:

The World Bank

and

Centre for Tropical Ecosystems Research (cenTER Aarhus),

University of Aarhus, Denmark

Authors:

Prof. Donald J. Macintosh

Centre for Tropical Ecosystems Research

E-mail: don.macintosh@biology.au.dk

Dr. Elizabeth C Ashton

Centre for Tropical Ecosystems Research

E-mail: ecashton@yahoo.com

Citation:

Macintosh, D. J. and Ashton, E. C. (2002). A Review of Mangrove Biodiversity Conservation and Management. Centre for Tropical Ecosystems Research, University of Aarhus, Denmark (pdf file).

Information Policy:

This review forms part of work in progress entitled "Mainstreaming Conservation of Coastal Biodiversity through Formulation of a generic Code of Conduct for Sustainable Management of Mangrove Forest Ecosystems" commissioned by the World Bank (see Background and Objectives section for details). Please do not copy or cite this document without first contacting the authors.

Disclaimer

The findings, interpretations, and conclusions expressed in this work are those of the co-editors and contributors and do not necessarily reflect the views of the Board of Executive Directors of the World Bank or the governments they represent, or of the International Society for Mangrove Ecosystems (ISME) and University of Aarhus. The World Bank, ISME and University of Aarhus do not guarantee the accuracy of the data included in this work. The boundaries, designations, colors, denominations, and other information shown on any map in this work do not imply on the part of the World Bank Group, (ISME) or University of Aarhus, any judgment or expression of any opinion on the legal status of any territory or the endorsement or acceptance of boundaries.

Copyright

Rights and Permissions

EXECUTIVE SUMMARY

OBJECTIVES

Recognising the importance of conserving mangrove forest ecosystems worldwide, the World Bank has commissioned a desk review with the title: "Mainstreaming Conservation of Coastal Biodiversity through Formulation of a generic Code of Conduct for Sustainable Management of Mangrove Forest Ecosystems".

This report is intended to serve as a resource document to facilitate the development of a Code of Conduct for the Sustainable Management of Mangrove Forest Ecosystems (here after referred to as "the Code of Conduct").

Formulation of the Code of Conduct will be based on existing knowledge, experience and concepts. The objective will be to arrest the recent and rapid destruction of the coastal mangrove ecosystems, to improve their management, and to conserve biodiversity in these critical natural habitats.

JUSTIFICATION

Mangrove forest ecosystems support important wetland communities of plants and animals. They are characterised by unique species of trees and shrubs that fringe the intertidal zone along sheltered coastal, estuarine and riverine areas in tropical and subtropical latitudes.

Coastal habitats across the world are under heavy population and development pressures. Mangroves have been particularly vulnerable to exploitation because they contain valuable wood and fisheries resources, and occupy coastal land that is easily converted to other uses. The scale of human impact on mangroves has increased dramatically over the past three decades or so, with many countries showing losses of 60-80% or more of the mangrove forest cover that existed in the 1960s. Compounding this problem, several of the countries with the most significant mangrove resources also have high human populations (e.g. Bangladesh, India, Indonesia, and Vietnam). Overall, the world's mangroves have declined in area by about 50%, and regionally Asia has lost 61% and Africa 55%; most of the remaining mangrove forests have also suffered moderate to severe degradation.

THE APPROACH NEEDED

Recognition of the environmental, social and economic impacts associated with the decline and degradation of mangrove forest ecosystems are now being addressed through legislative, management, conservation and rehabilitation efforts aimed at mitigating the negative impacts of previous (and planned) coastal development.

Examples of mangrove forest conservation are rather isolated, usually small areas not representative of how mangrove forests are managed overall. They do however, illustrate the problems and issues well and working remedies to solve them.

An integrated approach to mangrove management through coherent policy development and concerted action is increasingly being regarded as the best way to achieve conservation and sustainable use of the coastal resources which mangrove ecosystems support.

KEY CONSIDERATIONS

In formulating the Code of Conduct, it is recommended that the following considerations are included:

- **Resource estimation**

Although there have been recent estimates made of the world's mangrove resources (e.g. Spalding et al., 1997) better assessment is required of the mangrove area in any country or region. This is vitally important for policy-making, planning and resource management. Many countries still have poor or inadequate data on their mangrove resources.

Because mangroves are very dynamic systems occupying marginal coastal environments, it is also necessary to update resource assessment data frequently. Ground verification of habitat conditions (e.g. forest diversity) must be employed in support of aerial/remote estimations of mangrove areas.

- **Historical perspectives**

An understanding of the many aspects of human influences on biological diversity and their underlying driving forces is of crucial importance for setting priorities and directing conservation and sustainable use measures (UNEP, 1995). This is particularly necessary in the case of mangroves because so many people live within and adjacent to mangrove ecosystems. Thus, it is strongly recommended that the history of mangrove utilisation in a given country or region, including cultural and economic uses, is studied and recorded. Historical knowledge can explain much about the current status, habitat condition and other biodiversity indicators of mangrove ecosystems, provide an insight into local cultures and attitudes to resource use, and what the impacts of previous management policies towards mangroves have been.

- **Mangrove Biodiversity**

Because mangroves occupy the intertidal zone, they interact strongly with aquatic, inshore, upstream and terrestrial ecosystems and in this way mangroves help to support a diverse flora and fauna of marine, freshwater and terrestrial species.

It is essential to regard biological diversity at three levels: genetic, species and ecosystem. The genetic diversity in mangroves is almost unknown. The movement of mangrove plant genetic material for reforestation purposes, or other uses, must be controlled and recorded more carefully than at present. Genetic material should come from local sources wherever possible, using good quality mangrove forest stands as the source of the material.

Mangrove species diversity is well known for the larger animals and plants, but poorly known for micro-organisms and insects. A crucial aspect of biodiversity for mangrove management is that many species use the mangrove forest ecosystem only part of the time (eg. fish, birds, crustaceans, shellfish). Thus, the mangrove habitat supports many more species as visitors, or indirectly, and these support functions must be taken into account as part of conservation management.

The many unique species of mangrove animals and plants and their morphological and physiological specialisations to the diverse and dynamic habitat characteristics of mangroves make them extremely valuable for further research into biological adaptations. A number of mangrove plant and animal groups also provide valuable subjects for evolutionary studies.

Mangrove systems are diverse at the ecosystem level because mangroves can grow in a wide range of geographical, climatic, hydrological and edaphic (soil) conditions. There are also many strong and unique human cultural associations with mangroves country to country. Consequently the structure, productivity and functions of mangrove forest ecosystems are also highly variable. These characteristics at the ecosystem level must be considered as part of habitat and biodiversity assessment (in order to set conservation priorities area by area).

At the species and ecosystem levels, the following are critical to the success of mangrove biodiversity conservation:

- Protection of mangrove forest habitat - especially mixed species forests.
- Preservation of the natural hydrological regime operating in the ecosystem

- **Mangrove valuation**

The mangrove ecosystem has important direct and indirect economic, ecological and social values to man. Mangrove ecosystems have consistently been undervalued, usually because only their direct goods and services have been included in economic calculations (e.g. forestry resources), but this represents only a minor part of the total value of mangroves. By undervaluing mangrove ecosystems, "development" has too often favoured their rapid conversion and loss. Mangrove conversion usually leads to short-term economic gain at the expense of greater, but longer-term, ecological benefits and off-site values.

The non-market values, for example species biodiversity, and off-site functions such as nutrient export are not easily quantified, but have been shown to be significant. The total economic value of mangroves must be calculated in order to provide decision-makers with the real cost of converting mangroves to other apparently more profitable uses. In particular, long-term ecological benefits and off-site values should be included in valuations for mangroves.

Mangroves play an important role in the functioning of adjacent ecosystems, including terrestrial wetlands, peat swamps, saltmarshes, seagrass beds and coral reefs. There are harmful repercussions in these other ecosystems when common ecological processes are compromised through poor management decisions involving mangroves.

There is a need for new research to develop stronger valuation techniques/models that adequately value all the functions, attributes and services of the mangrove ecosystem. In particular new techniques are required to better assess the value of mangrove biodiversity and ecosystem support.

- **Conservation strategies**

First priority should be given to conserving the remaining areas of natural mangrove forest, especially areas supporting mature, seedling-bearing trees. Even small patches of mature forest (e.g. a few hectares in size) may be invaluable for the natural propagation of mangroves, and as a source of seedlings for restoration planting.

Core representative habitats of the region's biodiversity should be protected and linked with corridors to permit migration, adaptation and protection of the ecological linkages

Particularly valuable wetland habitats from an ecological and biodiversity perspective, can be conserved most effectively by assigning to them special status which is clearly recognised nationally, or internationally. This would include a designation as e.g. a national park, nature reserve, gazetted forest at national level, or e.g. Biosphere Reserve, Ramsar site, or World Heritage Site at the international level.

It is important to keep a protective zone of mangroves, particularly as a buffer against coastal erosion. Local guidelines must always be followed in this regard. The requirement is a minimum of 100 m, but preferably up to 500 m or 1 km (as advocated in the Mekong Delta, Vietnam, which is subject to typhoons) at the open coast, and 30-50 m along riverbanks.

Activities in the upland water catchment area should also be taken in to consideration for conservation and management of mangroves and where possible the links between habitats should be maintained (e.g. water catchment area - mangroves - seagrasses - coral reefs).

- **Habitat restoration**

A positive feature for mangrove ecosystem management is that mangrove forests are relatively easy to restore through natural regeneration, or via artificial restoration using planted seedlings. Natural re-colonisation is always preferable to planting mangroves because it means that the most appropriate species occupy the shoreline and natural succession can take place. However many of the functions and attributes of mangroves, including their productivity and biodiversity support can be regained through artificial restoration.

The planting of mangroves is simple, but to be effective mangrove restoration must be undertaken carefully, with the following activities planned and budgeted for:

1) site selection including detailed assessment of the hydrological conditions;
2) species selection; tree spacing, thinning and maintenance criteria established;
3) a forest protection and monitoring system introduced; and
4) a public information and awareness-building programme incorporated in support of the restoration effort.

As much as possible, mangrove restoration should involve mixed species planting, or at least species other than the *Rhizophora* spp. should be included.

- **Special considerations**

In storm-prone areas of the world, the coastal protection value of mangroves must be fully calculated and incorporated in management decision-making, as the storm mitigation functions of mangroves can be shown to far exceed the apparent gains from their exploitation for other forms of land development (e.g. Bangladesh, Vietnam).

The maintenance of hydrological linkages between upland catchment areas and coastal wetlands are essential for wetlands to function. This aspect of management is important everywhere, but becomes a crucial issue in the more arid regions of the world where mangroves occur (e.g. Pakistan).

- **Institutional issues**

The Code of Conduct should identify key linkages and co-ordination needs among government departments, NGOs, local communities, other user groups and public bodies, and entrepreneurs who have an interest in the use and conservation of mangroves. It would further recommend key legislation and enforcement mechanisms (e.g. government and/or community-based ones) required for the effective conservation, protection and sustainable use of mangroves.

Experience has shown that local communities have, by their own efforts alone, little prospect of improving mangrove management, but with NGO support to help built a sense of unity and common purpose, communities can influence policy and management decisions to their benefit. Public support is also important in this regard.

- **Ownership and Management**

There are now several examples of successful Partnerships (e.g. community-NGO-government-university researchers-public media) and Stewardship schemes helping to achieve sustainable management of mangrove forest ecosystems and a key aspect of their success lies in importing a sense of ownership over the mangroves to the local communities concerned.

OUTLINE

The Code of Conduct will formulate mechanisms for adequate legislation and the development, implementation and monitoring of coordinated policies for the protection of mangrove resources.

The main themes that the Code of Conduct will address concern measures to improve mangrove management and protection through Policy, People and Productivity. Conservation policies cannot succeed unless there is also help with problems of people and production. Mangrove restoration and conservation policies must increase livelihood options for local communities and together with the introduction of best practices, mangrove biodiversity protection can be sustainable.

Logical framework Analysis: Objectives of the Code of Conduct

OBJECTIVES	**INTERVENTIONS (Activities Required)**
Development Objective • **Protection** To arrest the recent and rapid destruction of coastal mangrove ecosystems, to improve their management, and to conserve biodiversity in these critical natural habitats	▪ Directly protect pristine mangrove areas ▪ Promote natural regeneration where mangrove ecosystems have the capacity for self-renewal ▪ Rehabilitate degraded mangrove ecosystems ▪ Protect and enforce mangrove buffer zones
Immediate Objectives • **Policy** Innovate and disseminate appropriate policies and strategies for management and conservation of mangrove resources and ecosystems and to have them adopted and implemented in focal regions and countries	▪ Promote use of economic incentives by governments and the private sector ▪ Disseminate information for better policy decisions ▪ Improve and reform Governance structures for management and conservation ▪ Restructure property rights regimes to protect mangrove resources and ecosystems ▪ Strengthen regulations enabling the sustainable harvest of mangrove resources ▪ Adopt policy reforms for sustainable management and conservation
• **People** Improve food security, livelihoods and quality of life of those people dependent on mangrove resources and ecosystems	▪ Increase livelihood opportunities ▪ Strengthen capacity of stakeholders ▪ Widen public awareness about the values of mangroves and the need for conservation
• **Productivity** Increase and sustain the productivity of mangrove resources such as timber, fuel wood, fish, molluscs and crustaceans	▪ Improve the use of best management practices ▪ Increase productivity from aquatic resources for commercial use, while protecting the livelihoods of subsistence users

TABLE OF CONTENTS

PREFACE

Mangroves have been regarded as wastelands by many for much of history. This has resulted in about 50% of the mangroves worldwide being lost. Mangrove ecosystems have been degraded or converted into agriculture, aquaculture, industrial or urban development. Recently, however society has begun to appreciate the benefits of mangroves and there is a growing awareness of their value. There are increasing efforts around the world to try and conserve, rehabilitate and manage mangrove biodiversity but the literature and success stories are limited. This review "Mangrove Biodiversity Conservation and Management" addresses this problem by reviewing the importance of mangrove biodiversity, examining the reasons for mangrove loss and identifying ways to improve management.

The information contained in this review has been obtained through country visits, published literature, meeting reports and correspondence. Chapter 0 provides the background and objectives to the review, chapter 1 an introduction to the review and chapter 2 a general introduction to mangrove biodiversity, what it is, where and why it is important. Chapter 3 gives examples of approaches and interventions to mangrove management. Chapter 4 provides implementation guidelines for mangrove management and conservation of biodiversity. Chapter 5 is a reference list for the review. Chapter 6 gives the background to the country case studies and Annex 1 provides the template for preparation of the country case studies.

ACKNOWLEDGEMENTS

This Review was commissioned by the World Bank Environment Department and prepared by the Centre for Tropical Ecosystems Research, University of Aarhus, Denmark.

This review is the product of consultations with many people across the world. We wish to thank all those who have contributed to the case studies under preparation.

We are especially grateful to Dr. Ronald Zweig, World Bank, Washington for arranging the contract for this study, and for all his encouragement during our work. Mr. Thomas Nielsen, Centre for Tropical Ecosystems Research, University of Aarhus, Denmark, kindly formatted this document and prepared it as a pdf file.

LIST OF TABLES

LIST OF FIGURES

GLOSSARY

Biodiversity

A condensed form of biological diversity means “the variability among living organisms from all sources including, *inter alia* terrestrial, marine and aquatic systems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems” (United Nations Environment Programme, 1992, p.27).

Conservation

Protection from change, loss or damage or protection of valued resources through the protection, management and care of natural and cultural resources (Encarta, 1999).

Direct use value

The productive or consumptive values derived from direct use or interaction with a biological resource which may be marketed or non-marketed.

Ecosystem

A dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit (Article 2 of the Convention of Biological Diversity).

Ecosystem Diversity

The variety of habitats, biotic communities and ecological processes in terrestrial, marine and other aquatic environments in a particular area, together with the processes and interactions that take place within and between these systems.

Ecosystem functions

The processes of production and dynamics of resources (organic matter, nutrients, biomass, elements) and energy through systems. A set of ecological processes responsible for providing an environmental good or service (Gilbert and Janssen, 1998).

Ecosystem resilience or resistance

Determines the persistence of relationships within a system, and is a measure of the ability of these systems to absorb changes in species composition and abundance and still persist without drastically changing the ecosystem performance.

Economic value

The value of a good or service placed by an individual or society through his willingness to pay using market price or other indicators.

Economic valuation

Measuring the preferences of people or society for a good or service or against economic activity.

Existence value

The benefit an individual or society receives from merely knowing that a good or service exists. Society's willingness to pay towards the conservation of biological resources for their own sake regardless of their current or optional uses.

Genetic Diversity

The variation within and between populations of species (i.e. individual plants, animals and micro-organisms), measured in terms of the variations between genes or DNA or amino acid sequences, as well as numbers of breeds, strains and distinct populations.

Genetic Resources

The genetic material of plants, animals and micro-organisms of value as a resource for future social, economic, environmental purposes.

Indirect use value

The value of an environment’s ecological functions which support or protect the life forms dependent on that environment, or an economic activity.

Integrated Coastal Zone Management (ICZM)

Used to describe a continuous and dynamic process that unites government and the community, science and management, sectoral and public interests in preparing and implementing an integrated

plan for the protection and development of coastal systems and resources (GESAMP, 1996).
Management The act or practice of handling, administering, supervising or controlling, entities, resources and activities.
Mangrove ecosystems Important wetland systems that fringe the intertidal zone along sheltered coastal, estuarine and riverine areas in tropical and subtropical latitudes. They support many types of plant and animal. The majority of plants are evergreen trees, although deciduous trees, perennial and evergreen shrubs, epiphytes, parasites and climbers, perennial grasses, palms and perennial ferns are also common constituents (Tomlinson, 1986), together with algae, fungi and microflora. Micro and macroscopic, terrestrial and aquatic (marine and freshwater), temporary and residential wildlife are all supported by mangroves (Hutchings & Recher, 1982; Hutchings & Saenger, 1987) forming a heterogeneous habitat. The mangrove physical environment includes waterways (estuaries, creeks, canals, lagoons and backwaters), mudflats, salt pans and islands (Kjerfve, 1990), and is often highly saline, frequently inundated, soft bottomed anaerobic mud.
Option value The potential value of a resource for future (direct and indirect) use by protecting or preserving it today.
Redundancy Implies that some species within ecosystems are expendable, because they do not provide a unique and essential contribution to ecosystem function.
Rehabilitation Includes both restoration and creation (Streever, 1999). Restoration = Returning a former mangrove forest area to forest cover through hydrological restoration and either followed by planting of seeds, seedlings or saplings or allowed to naturally recolonize. Creation = establishment of mangroves by converting existing non-mangrove habitats (uplands, mudflats) through activities by man namely establishment of appropriate hydrology and planting.
Species diversity The variation of species and subspecies among living organisms on earth.
Stability The ability of a system to return to the initial equilibrium state following a temporary disturbance.
Stakeholder People who use, affect or otherwise have interest in the mangrove ecosystem.
Sustainable development “Development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland, 1987) or “the management and conservation of the natural resource base and the orientation of technological change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development (in the agriculture, forestry and fisheries sectors) conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable” (FAO, 1988).
Total Economic Value (TEV) Comprises direct use value, indirect use value, option value and existence value.
Valuation The process of placing monetary value on goods and services that do not have accepted prices. Many environmental goods and services (such as biodiversity) do not enter the market and therefore have no commonly accepted market price.

0. BACKGROUND AND OBJECTIVES

Recognising the importance of conserving mangrove forest ecosystems worldwide, the World Bank has commissioned a desk review with the title:

> "**Mainstreaming Conservation of Coastal Biodiversity through Formulation of a Code of Conduct for Sustainable Management of Mangrove Forest Ecosystems".**

This review will build on the findings from an on-going "Shrimp Farming and the Environment" collaborative program supported by the Bank-Netherlands Partnership Program with, the Worldwide Fund for Nature (WWF), the Food and Agriculture Organisation of the United Nations (FAO) and the Network of Aquaculture Centres in Asia-Pacific (NACA). The program includes A Thematic Review of Coastal Wetlands and Shrimp Culture. The purpose of this supplementary work is to formulate informational and guidance materials in the form of a generic Code of Conduct for Sustainable Mangrove Forest Management (Code) for World Bank staff, development partners, and clients. The International Society for Mangrove Ecosystems (ISME) and NACA has already become an active collaborator. Other possible partner agencies such as FAO, IUCN, ITTO and WWF may also be consulted at a later stage.

Formulation of the Code of Conduct will be based on existing knowledge, experience and concepts.

The objective will be to arrest the recent and rapid destruction of the coastal mangrove ecosystems, to improve their management, and to conserve biodiversity in these critical natural habitats.

Project Activities

Three main activities are envisaged:

1) A review of the outputs from the above noted program on Shrimp Farming and the Environment, other mangrove and forest management programs, and the World Bank's Forestry Management Strategy, that can provide information on cross-sectoral issues relating to mangrove forestry, aquaculture, and fisheries management; biodiversity conservation and coastal storm protection.

2) This review would be followed by field visits to Asian, Latin American, and African countries to discuss with stakeholders the critical elements that should be included in the Code of Conduct. Consultations would include stakeholders at all levels, including neighbouring communities, government departments such as forestry and fisheries, and entrepreneurs involved in using mangroves for income generation. Discussions with relevant government departments in selected countries would also help to identify key areas where institutions should be strong and capable in promoting mangrove conservation measures. The interests of, and challenges to coastal communities would also be used in part to add the critical social dimension to the formulation of the Code of Conduct. World Bank staff and those from other multilateral and bilateral agencies and NGOs working on pertinent issues would also be consulted.

3) Toward the conclusion of the program, a workshop will be held at the World Bank for interested staff, and would also be attended by invited specialists and key agencies identified during the project to discuss the draft Code of Conduct.

Expected output

The main outcome of this work would be the formulation of a generic Code, with some country-specific case studies, that could serve as a guidance document for World Bank staff and clients in considering coastal zone management strategies for mangroves and conservation of the biodiversity for which mangroves provide a habitat. The Code would also identify key linkages and co-ordination needs among government departments, NGOs, nearby communities and entrepreneurs who have an interest in the use and conservation of mangroves. It would further recommend key legislation and enforcement mechanisms (e.g., government and/or community-based) required for the effective conservation, protection and sustainable use of mangroves. The information and structure of the Code would have direct relevance to a number of on-going Bank operations in Bangladesh, China, India, Indonesia, Philippines, Mozambique and Mexico and potentially to other countries, since coastal zone management is becoming increasingly important in the Bank's portfolio of activities.

Terms of Reference for Preparation of the Review Document:

Undertake a desk review, which will form the resource document to complement and support subsequent case studies leading towards the development of a generic Code of Conduct for Sustainable Management of Mangrove Forest Ecosystems.

What is needed is a desk review of all regulatory frameworks, laws, zoning, and any other actions that have been enacted by governments to protect mangroves. The review would also start with the rationale for conserving mangroves and their importance to biodiversity. The objective would be to use this report as a resource document that would complement subsequent case studies toward the development of a generic code of conduct for the above.

The specific terms of reference are listed in Table 0.1.

Preparation of the Review Document

Team leader

Professor Donald J. Macintosh, Centre for Tropical Ecosystems Research, University of Aarhus, Denmark.

Researcher

Dr. Elizabeth C. Ashton, Centre for Tropical Ecosystems Research, University of Aarhus, Denmark.

Correspondence

Don Macintosh (d.j.macintosh@stir.ac.uk Tel: 45 89 42 33 41)

Liz Ashton (e.c.ashton@stir.ac.uk Tel: 44 17 86 46 78 85)

Table 0.1: Terms of Reference for the Review

Specifically, the review document will: • *Briefly describe the extent and characteristics of mangrove ecosystems worldwide* • *Explain the rationale for conserving mangroves, highlighting their contribution to coastal protection, their support functions to coastal fisheries and aquaculture, and their contribution to sustaining biodiversity and unique habitats;* • *Explain the need for better management of mangroves in the overall context of coastal development;* • *Provide a detailed analysis, with examples, of the cross-sectoral issues, including forestry, fisheries management and aquaculture, biodiversity conservation; and coastal storm protection;* • *Review existing legislation, regulatory frameworks, zoning plans, etc. for mangroves and any other actions enacted by governments to protect mangroves. Give examples where such policy measures are working well, or where enforcement or other requirements are still inadequate;* • *Review the main institutional aspects of mangrove ecosystem management, explaining how far consultation and co-operation among the main stakeholders has been achieved to date, namely local coastal communities, private sector interests, and governmental departments and agencies, NGOs, the international community;* • *Relate the key issues identified for mangrove ecosystem management and conservation of biodiversity to other relevant studies and Codes of Conduct, e.g. World Bank policy document for Forest Management, Thematic Review of Mangroves and Shrimp Aquaculture, FAO Code of Conduct for Responsible Fisheries.*

1. INTRODUCTION

Mangrove biodiversity and conservation have received considerable attention in recent years since research has increased the understanding of the values, functions and attributes of mangrove ecosystems. At the same time, coastal habitats across the world are under heavy population and development pressures. The scale of human impact on mangroves has increased dramatically over the past three decades or so, with many countries showing losses of 50-80% or more, compared to the mangrove forest cover that existed even in the 1960s (Table 1.1).

Table 1.1: Estimated loss of original mangrove area in different regions (based on country data available in WRI, 1996)

South and Southeast Asia	Loss of original (%)	Africa	Loss of original (%)
Bangladesh	73	Angola	50
Brunei	17		
India	85	Djibouti	70
Indonesia	45	Equatorial Guinea	60
Malaysia	32	Gabon	50
Myanmar	58	Guinea	60
Pakistan	78	Guinea Bassau	70
Singapore	76	Kenya	70
Thailand	87	Liberia	70
Vietnam	62	Madagascar	40
		Mozambique	60
		Somalia	70
		South Africa	50
		Tanzania	60
		Zaire	50
Unweighted average	**61**		**55**

Note: no data given for South America.

Recognition of the environmental, social and economic impacts associated with the decline and degradation of mangroves are now being addressed through legislative, management, conservation and rehabilitation efforts aimed at mitigating the negative impacts of development on mangrove ecosystems. These include the introduction of new legislation and new governing bodies with clearer administrative or advisory roles on environmental issues; stronger conservation status for some mangrove areas of outstanding value (e.g. as Biosphere Reserves); and more emphasis on public awareness raising and education. However, many of the current management policies adopted are still sectoral in nature, which frequently leads to conflict of interests, and to continuing unsustainable exploitation of mangrove resources.

An integrated approach to coastal area management through coherent policy development and concerted action is increasingly being regarded as the best way to achieve conservation and sustainable use of mangrove and other coastal resources (for example Chua and Scura, 1992). This thematic review gives some indication of the problems facing mangrove conservation management, and particularly protection of the biodiversity associated with mangrove forest ecosystems. The review examines the efforts that have been used from a number of case studies across the world, analyses their effectiveness, assesses reasons for possible success and failure and gives some steps that should be taken to address problems. The main objective of this report is that it should serve as a resource document to facilitate the eventual development of a generic Code of Conduct for the Sustainable Management of Mangrove Forest Ecosystems, recognising particularly the importance of mangrove conservation and biodiversity protection.

A number of countries have been selected as possible subjects for the case studies to accompany and support the review. One geographical region, Southeast Asia, and three countries, Malaysia, Philippines and Thailand, wil be used, as illustrative examples. They are intended to serve as background for consultation with ISME, the World Bank and with representatives of other regions and countries that may be included in the review's reporting. Partial case studies have also been developed for a number of other countries, as shown below. The template for the case study material is provided in Annex 1.

This review is intended to begin the process of gathering first hand information on the legal and regulatory framework for mangroves and how these and other interventions are being used to protect and manage mangroves on a country by country basis. With the co-operation of ISME and other national bodies and representatives, it is planned to complete case studies for up to 8-10 countries representing the major regions of Asia, Africa and Latin America. In addition, examples of small island countries where mangroves are a significant habitat and resource may be included.

The list of candidate countries, which is by no means predetermined or exclusive, is provided below. There are also some very valuable lessons to be learned from coastal resources management experiences in developed countries, particularly Australia and USA.

Table 1.2: Candidate countries for case studies

REGION	COUNTRY	
ASIA	Bangladesh* Malaysia* Thailand*	India*++ Philippines* Vietnam*
AFRICA	Kenya* Ghana++	Senegal* Mozambique*
AMERICA	Brazil*++ Mexico	Nicaragua
MIDDLE EAST	Egypt* Abu Dhabi	Pakistan*
SMALL ISLANDS	Pacific (Fiji)++ Indian Ocean (Sri Lanka)*	Caribbean (St. Lucia)

**Denotes countries for which case study contributions are in progress*

++ Denotes regional sub centres of ISME

2. MANGROVE BIODIVERSITY AND CONSERVATION

The rationale for conserving mangroves and their importance to biodiversity is provided in this chapter. A general overview of mangrove biodiversity and distribution is given to help orientate the reader but a detailed review of the biological and ecological literature on mangroves should be sought elsewhere. Tomlinson (1986) describes the basic botany of mangroves. Hutchings and Saenger (1987) provide an overview of mangrove ecology based mainly on Australian work. Hogarth (1999) and Kathiresan and Bingham (2001) are recent good reviews on the biology of mangroves.

2.1 General introduction to mangroves

The term "mangrove" refers to a tidally influenced wetland ecosystem within the intertidal zone of tropical and subtropical latitudes. Mangrove also designates the marine tidal forest that includes trees, shrubs, palms, epiphytes and ferns (Tomlinson, 1986). The distinctive community of plants and animals associated with mangroves is sometimes referred to as the 'mangal' (Macnae, 1968).

The origins of the terms for mangrove are well researched by Vanucci (1989). She concludes that the word mangue is from West Africa, Senegal, Gambia and Guinea. The Portuguese adopted the word in the XV century and spread it throughout the world. Later the Spaniards adopted the words mangle and manglar. The English word mangrove is a derivation of the Portuguese or Spanish meaning grove made of mangue.

Mangrove ecosystems are heterogeneous habitats with an unusual variety of animals and plants adapted to the environmental conditions of highly saline, frequently inundated, soft bottomed anaerobic mud (See definition in Glossary). Not all mangroves are obligated to live in saline intertidal areas (Clough, 1992). Plants that are confined to the mangrove are called true mangroves; plants that can also occur elsewhere are called mangrove associates (Tomlinson, 1986). True mangrove plants develop morphological specialisations and special physiological mechanisms to adapt to the mangrove environment. They are taxonomically isolated from terrestrial relatives, occur only in mangrove forests and can form pure stands. Mangrove associates never grow in true mangrove communities and may occur in terrestrial vegetation. The mangrove fauna includes terrestrial, marine, temporary and permanent animal species, all of which have different adaptations to cope with the mangrove environment.

The diversity of mangroves is high, but the variety of mangrove ecosystems also makes it difficult to produce general guidelines for conservation and management of mangroves because each system is unique.

2.2 Distribution and area of mangroves

Mangrove ecosystems are estimated to cover 181,000 km^2 worldwide (Spalding et al., 1997). The global distribution of mangroves is shown in Figure 1 and estimates of mangrove area by region appear in Table 2.1. The best developed mangroves grow along humid sheltered tropical coasts for example in the delta systems of major rivers like the Ganges, Mekong and Amazon, and coastlines protected by large land masses - for example Madagascar, the Indonesian Archipelago and Papua New Guinea. Here mangroves often form the most extensive and diverse tidal forests with large tree girths of 50 cm or more and heights of 20 to 45 m.

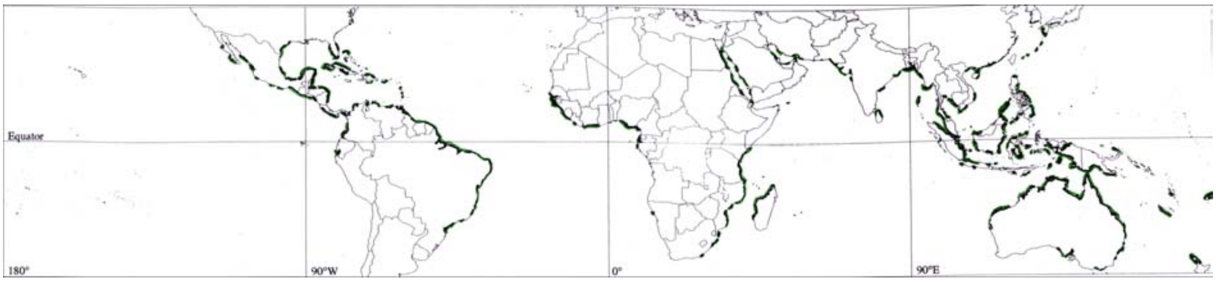

Figure 1 Global distribution of mangroves (Spalding et al., 1997).

Table 2.1: Mangrove area coverage by region

Region	**Mangrove Area (km^2)**
South and Southeast Asia	75,173 (41.5%)
The Americas	49,096 (27.1%)
West Africa	27,995 (15.5%)
Australasia	18,789 (10.4%)
East Africa and the Middle East	10,024 (5.5%)
Total Area	**181,077**

Source: Spalding et al. (1997)

Out of 102 countries recorded with mangroves, the ten countries with the largest areas (more than 5,000 km^2) are shown in Table 2.2. Indonesia, Brazil, Australia and Nigeria have 43% of the world's mangroves and each has between 25% and 60% of the mangroves in their respective regions (Asia, Americas, Australasia and West Africa). The considerable heritage of mangroves in these countries dictates that the political and management decisions relating to mangroves will have a significant effect on the global status of mangrove ecosystems in the future (Spalding et al., 1997).

Table 2.2: Mangrove area coverage by country

No.	Country	Mangrove Area (sq km)	Percentage	Cumulative %
1	Indonesia	42,550	23.5	23.5
2	Brazil	13,400	7.4	30.9
3	Australia	11,500	6.4	37.3
4	Nigeria	10,515	5.8	43.1
5	Cuba	7,848	4.3	47.4
6	India	6,700	3.7	51.1
7	Malaysia	6,424	3.5	54.6
8	Bangladesh	5,767	3.2	57.8
9	Papua New Guinea	5,399	3.0	60.8
10	Mexico	5,315	2.9	63.7
	Others	65,929	36.4	100
	Total Area	181,077	100	100

Source: Spalding et al. (1997)

Mangroves extend into temperate regions but are largely confined to the regions between 30^o north and 30^o south of the equator. The latitudinal limits of mangroves are 31^{o}22′N in southern Japan, 32^{o}20′N in Bermuda and to the south in Australia 38^{o}45′S, New Zealand 38^{o}59′S and the east coast of South Africa 32^{o}59′S (Spalding et al., 1997). At the latitudinal limits the mangrove vegetation is often restricted to a single species and tree girth and height are low.

Mangroves also occur naturally along arid coastlines, for example in Saudi Arabia, Yemen and northern Africa, and along the west coast of Australia and north-eastern coast of Brazil. Arid climates also reduce species diversity and restrict mangrove growth to low shrub formations. The effect of aridity rather then latitude on mangrove communities is well demonstrated in India. The Sundarbans mangroves in West Bengal comprise more than 20 species and represent 50% of India's mainland mangrove resource, whereas at similar latitudes on the arid west coast (Gujarat) only nine species occur and the mangrove forest contributes only about 12% of the total resource (Vishwas et al., 1993).

The species diversity and distribution of mangroves is variable at different spatial scales: global, regional, estuarine and intertidal (Duke et al., 1998). Duke (1993) divided the distribution of mangroves into two global hemispheres the Atlantic East Pacific and the Indo West Pacific. These regions have similar areas of mangrove forests, but the Indo West Pacific region is about five times more diverse with 58 species compared to 12. The Indo-Malesia region has the most species with 48 (Duke et al., 1998). Ricklefs and Latham (1993) offer a number of explanations for the high diversity in this region. Southeast Asia was the centre of origin of mangrove speciation, the presence of an adjacent diverse terrestrial flora, and a constant wet humid climate may have been contributory factors and the continuous presence of these factors since the end of the cretaceous may have enabled diversity to continue to increase when conditions were not ideal elsewhere, or prevented species extinction. In the latter sense, the Southeast Asian mangroves today represent an important refugium of mangrove biodiversity and therefore mangrove conservation and management are important.

Environmental factors, including temperature, salinity and rainfall are important key determinants that have a strong influence over the growth, survival and distribution of mangroves (Blasco, 1984). Low temperatures, both sea surface temperatures and air temperatures largely set the latitudinal limits of mangroves. Mangrove distribution correlates closely with the 24^{o}C mean sea surface temperature isotherm (Hutchings and Saenger, 1987). Mangroves can survive temperatures as low as 5^{o}C but are intolerant of extremes such as frost (Chapman, 1975).

Mangroves are adapted to saline or brackish waters, but the high salinity of seawater and sometimes hyper saline conditions occurring in intertidal areas, particularly arid countries, frequently restrict their growth. Seedlings of many important mangrove species, including *Avicennia*, *Rhizophora* and *Xylocarpus* have been shown to grow best in salinities of 10-20 ppt, that is about one third to two thirds the concentration of coastal seawater (31-35 ppt) (Clough, 1992).

In equatorial and tropical summer rainfall regions, mangroves are tall, dense and floristically diverse but in subtropical arid regions, with low, irregular or limited seasonal rainfall, the number of mangrove species that can survive is limited and they are stunted and less dense in their growth and development. *Avicennia marina* shows the greatest adaptation to extremely arid environments, being able to withstand hypersaline conditions upto 90 ppt, while *Rhizophora mangle* can grow in salinities up to 65 ppt (Macnae, 1968; Teas, 1979).

At the national and local level, many other factors influence the distribution of mangroves including soils, tides, geomorphology, mineral availability, soil aeration, winds, currents and wave action (Robertson and Alongi, 1992). The influence of man though is probably the single most considerable factor that affects the mangrove distribution pattern at all scales at present. The distribution patterns of mangroves today are the result of a wide range of past and present factors.

Mangrove fossil pollen suggests mangroves evolved from terrestrial rather than marine plants and are quite old, possibly arising after the first angiosperms, around 114 million years ago (Duke, 1993). There are two hypotheses that propose the origin of mangroves. The centre-of-origin hypothesis suggests that all mangrove taxa first appeared in the Indo-West Pacific and subsequently dispersed to other regions. The vicariance hypothesis states that all mangroves originated around the Tethys Sea and continental drift then isolated the flora in different regions resulting in diversification and distinct faunas. Ellison et al. (1999) evaluated these two hypotheses using 5 different analyses and they all supported the vicariance hypothesis. Mangroves originated in the Tethys Sea and the high diversity of mangroves in the Indo-West Pacific relates to conditions that favoured diversification. Continental drift provides explanations to the species distributions of mangrove vegetation. Limited dispersal through continental drift and sea current distributions are probably responsible for the easterly limit to mangroves in the Pacific (Ricklefs and Latham, 1993).

Knowledge of the mangrove area in any country or region is important for policy-making, planning and resource management (Spalding et al., 1997). However, reliable data on the areal extent of mangrove forests are difficult to obtain, or even nonexistent for many countries (Farnsworth & Ellison, 1997; Spalding et al., 1997). For example, estimates for the total area of mangroves in Indonesia range from 20,000 to 40,000 km^2 (Spalding et al., 1997).

An understanding of the history of mangrove utilisation in a given country or region is also vital to the planning process, as it explains much about the current habitat condition and other biodiversity indicators. The historical background also provides insight into to local cultures and attitudes to resource use and what the impacts of previous management policies have been.

2.3 History of loss and destruction of mangroves and their consequences

Historical records indicate that the original extent of mangrove forests has declined considerably under pressure from human activity. National proportions of original mangrove cover lost vary from 4 to 84% (Table 1.1), with the most rapid losses occurring in recent decades. For example, in Southeast Asia Malaysia lost 12% from 1980 to 1990 (Ong, 1995); the Philippines originally had 4,300 km^2 but now has 1,200 km^2 (Primavera, 2000); Thailand had 5,500 km^2 in 1961 but 2,470 km^2 in 1986 (Aksornkoae, 1993); and Vietnam 4,000 km^2 originally to 2,525 km^2 today (Spalding et al., 1997). Ong (1995) considers that the loss of 1% mangrove area per year in Malaysia is a conservative estimate of mangrove destruction in the Asia-Pacific region.

Mangroves have often been considered as unproductive land and their destruction and degradation have been due to the preference for short-term exploitation for immediate economic benefit, rather than long-term sustainable exploitation (Saenger et al., 1983). For example shrimp farming in the late 1980s early 1990s was perceived to have high profits and resulted in large scale conversion of mangrove areas. Underestimation of the total economic value of mangroves and of the impacts of human activities are major factors contributing to the widespread loss and degradation of mangrove ecosystems (Gilbert and Janssen, 1998). Serious environmental, social and economic impacts are associated with the decline and degradation of mangroves. For example in Vietnam where mangrove loss due to defoliants used during the Vietnam war, logging and aquaculture have led to coastal erosion, salinity intrusion and decline in natural shrimp and mud crab (*Scylla* species) populations (Hong and San, 1993).

The fundamental cause of mangrove forest loss is the increase in human population living near the coastal zone. Ong (1995) considers that burgeoning populations are possibly the biggest cause of mangrove destruction and degradation. An estimated 60% of the global population lives within roughly 100 km of the shore (WRI). This means that 3.4 billion people rely heavily on marine habitats and resources for food, building materials, building sites and agricultural and recreational areas. They also use coastal areas as a dumping ground for sewage, garbage and toxic wastes. Moreover, many more people in the non-coastal population live in agricultural and urban communities concentrated along rivers and in the surrounding hills. Pollution and poor land use practices within these watershed areas affect downstream marine habitats because sediments and pollutants are ultimately washed into coastal waters.

Humans inhabit mangroves in many places, usually belonging to traditional local communities that harvest fish and other natural resources but in recent years the coastal areas have become under intense pressure for development. Mangroves have been over exploited or converted to various other forms of land use, for example agriculture, aquaculture, salt ponds, terrestrial forestry, urban and industrial development and construction of dikes and roads (Macintosh, 1997). The scale of impact generally increases with the list of causes in Table 2.3. Mangroves can be affected by several different activities simultaneously or over time as land use patterns change. Population pressure, poverty and lack of livelihood options, changes in values and 'open access' nature all contribute to over-exploitation.

As well as the mangroves losing areal coverage they have also declined in terms of biological diversity and economic value, due to excessive harvesting of the most valuable trees and a shift in forest structure towards younger trees and secondary growth as the larger trees were removed. The main factor leading to the loss of mangrove biodiversity is habitat loss through conversion or degradation of the forest. Urbanisation and off-site activities can lead to degradation through siltation and changes in water temperature and flow, other physical factors and salinity. Contaminants may be directly toxic to some marine organisms and their effects may be instantaneous or cumulative.

Introduction of species can also cause habitat loss and loss of diversity. For example, the introduction of *Nypa fruticans* to West Africa where it is not found naturally has caused considerable problems through its continued spread (Wilcox, 1985).

Global warming could be a significant threat to mangrove cover and biodiversity. Rising water (as a result of melting ice caps) could drown coastal mangrove. The presence of existing agricultural and urban development and dikes would in many cases prevent the establishment of new mangrove areas. Projected climate change could have other effects, such as changes in ocean currents, salinity and surface temperatures. These would alter the species compositions and perhaps trigger local and global extinction's (McCarthy et al., 2001).

Many of the problems and causes for mangrove loss stem from failures in policy, management and enforcement. These need to be dealt with urgently; management interventions are discussed further in section 3.

Table 2.3: Causes of mangrove degradation and loss

Over-exploitation by traditional users Traditional use has historically had little impact upon mangroves because it is usually at a low level. However, as populations grow demand for products increase and this can lead to over-harvesting and a decline in the natural resource and in the absence of sustainable management practices this can lead to the decline in livelihoods of the mangrove-dependent communities. In many instances though the reason for over-exploitation is due to some other external pressure, for example drought, storms, and war. A good example is the loss of mangroves in Vietnam, which were heavily exploited for wood after the war ended in 1975 (Hong and San, 1993). The main causes of mangrove destruction in Africa stem from traditional uses. The Sunderbans in Bangladesh have been exploited for timber, fuelwood, bark tannin, animal fodder, native medicines and food (fish, shellfish, honey and wild animals) for centuries but population pressure has greatly increased the rate of exploitation, leading to serious degradation of the mangroves.
Commercial utilisation Mangrove wood (especially *Rhizophora* spp.) is good for charcoal production because it is heavy, dense, hard and with a high calorific value (Aksornkoae, 1993). Mangrove wood is also resistant to decay in saltwater, so it has been a favoured material for pilings and fishing structures in coastal areas. In several countries commercial forestry projects have used rotational felling and replanting of mangroves. However, poor management has often resulted in unsustainability. An exception being

the Matang Mangrove Forest Reserve in Peninsular Malaysia that has been managed for 100 years on a 30 year rotational cycle (Gan, 1995).
Conversion to other natural resources use Increasing populations put pressure on the production for food. Mangroves are often converted for salt production, agriculture and aquaculture. Large tracts of coastal mangrove in Asia have been converted to rice farming (FAO, 1982). Thailand lost 51% of its mangroves since 1961, 49% due to conversion to salt pans and aquaculture (Aksornkoae, 1993; Macintosh, 1996). The Philippines lost 73% of its mangroves between 1918 and 1994 about 70% due to the construction of aquaculture ponds (Primavera, 2000).
Conversion for other uses Increasing populations also put pressure for urban and industrial development of mangroves, including coastal infrastructure such as ports, harbours, airports and coastal mining activities. Many of the cities in Asia are built almost entirely on former mangrove land, for example Bangkok, Kuala Lumpur and Manila.
Indirect/Off-site activities Off-site activities, unrelated to the mangrove ecosystem but detrimental to it, for example oil pollution, diversion of upstream freshwater resources for irrigation and offshore dredging also have detrimental effects on the mangrove ecosystem. Indirect effects of agriculture on mangroves can be seen through diversion of freshwater by agricultural schemes and run-off of agricultural residues. For example, the interception of freshwater for agriculture has severely affected the mangroves in the Indus delta of Pakistan (Hogarth, 2001). In Sao Paulo, Brazil the mangroves have been heavily impacted by land fills, solid waste disposal, industrial and domestic effluents, chemical, organic contamination and oil spills from nearby ports and oil terminals (Lamparelli et al., 1997).
Natural disasters Storm damage, coastal erosion, naturally shifting hydrology, climate change and sea level rise
Management failure The existing policies for mangrove utilization and conservation are ambiguous and inconsistent. Uncertain land ownership and rules governing access to mangrove areas Illegal encroachment can be because the regulations are too complicated and ambiguous to follow, even government officials may not understand forest laws or recognize boundaries and consequently fail to implement or enforce rules. Governance and institutional failure to effectively manage coastal mangrove resources Poor planning of coastal land use and implementation of development plans Issues related to enforcement, realistic design of implementation of laws eg. zonation Lack of involvement of communities in decision making (management, development of legislation, enforcement). Lack of understanding and awareness of the value of mangrove ecosystems among various groups of people including policy makers, officials, developers and local people. Compatibility issues. Conflicts are common between the various departments involved. Weak co-ordination between different levels and different sectors of government Availability of infrastructure, manpower and equipment are inadequate for effective control over the utilization of mangrove resources.

Over the past 20 years mangrove ecosystems have attracted increased scientific attention. The UN agencies (UNESCO, UNDP, UNEP) and the United Nations University have supported various projects and studies in the Pacific, Asia, Africa and South America (Macintosh et al., 1991; UNEP, 1994), while there have been several status reports at regional and global level (FAO, 1982; Saenger et al., 1983; Spalding et al., 1997). The International Society for Mangrove Ecosystems (ISME) was formed as a non-government organisation based in Okinawa, Japan to continue to foster international co-operation in the study and management of mangrove ecosystems. As a result of these activities mangrove ecosystems have become recognised by many scientists, governments and planners as important and productive ecosystems that must be carefully managed on a sustainable basis. It has also been recognised that in many parts of the world mans activities have destroyed large areas of mangroves.

This increase in awareness of the importance of mangroves has led to rehabilitation of some areas (Field, 1996). So in a few regions, mangrove area is actually increasing as a result of forestry plantations and natural regeneration (Field, 1996). However, mangrove reforestation is often done as monospecies plantations and evaluation of the success of replanting is not often done and/or reported in the literature. Guidelines are needed for mangrove plantation to rehabilitate degraded coastal areas that incorporate mangrove biodiversity conservation.

2.4 Mangrove Biodiversity

Biological diversity and the term biodiversity have been described in many ways. The official definition is contained in Article 2 of the Convention on Biological Diversity (Glossary). All definitions emphasise the multiple levels (genetics, species and ecosystems) at which biodiversity can be considered. The composition and levels are shown in Table 2.4.

Genetic, species and ecosystem diversity are considered the natural diversity associated with mangroves and other ecosystems. In addition, there is a human component, or "cultural diversity" which refers to the values, driving forces and influences for the conservation and sustainable use of biological diversity by man. Cultural diversity varies widely within and between different cultures and recognises the important role of sociological, ethical, religious and ethnobiological values in human activities. An important point to note is that the concept of populations, whether of plants, animals or people applies to all levels of biodiversity. Further research for mangroves is needed at each level (genetic, species, ecosystem and cultural diversity).

An understanding of the many aspects of human population influences on biological diversity and their underlying driving forces is of crucial importance for setting priorities and directing conservation and sustainable use measures (UNEP, 1995). This last point is regarded as fundamental to the objective of developing a Code of Conduct for the sustainable management of mangrove ecosystems.

Table 2.4: The composition and levels of Biological Diversity

Genetic Diversity	**Species Diversity**	**Ecosystem Diversity**
Populations	Kingdoms	Biomes
Individuals	Phyla	Bioregions
Chromosomes	Families	Landscapes
Genes	Genera	Ecosystems
Nucleotides	Species	Habitats
	Subspecies	Niches
	Populations	Populations
	Individuals	
Cultural Diversity: human interaction at all levels		

Source: UNEP (1995).

2.4.1 Genetic diversity

Genetic Resources The genetic material of plants, animals and micro-organisms of value as a resource for future social, economic and environmental purposes.
Genetic Diversity The variation within and between populations of species (i.e. individual plants, animals and micro-organisms), measured in terms of the variations between genes or DNA or amino acid sequences, as well as numbers of breeds, strains and distinct populations.

The genetic patterns of variation are influenced by the probability and distribution of species establishment, their survival in response to stresses, opportunities for adaptation and reproductive dynamics (Namkoong and Koshy, 2001). Genetic capacities thus influence species and ecological dynamics. Genetic variation is both the product of evolution and the engine that drives the capacity of organisms to adapt (Namkoong and Koshy, 2001). Sufficient genetic variation within and between populations is necessary for continued evolution and to maintain diversity. Genetic diversity predisposes a high adaptability to changing environmental conditions needed to ensure present-day and future adaptability of the species. It is also needed to maintain options and potential for improvement to meet changing end use requirements.

Molecular techniques offer a means to survey and quantify genetic diversity through the acquisition, storage and comparison of linear sequences of amino acids and nucleotides, the fundamental building blocks of life (Sogin and Hinkle, 1997). Comparison of genetic elements that have been transmitted from generation to generation makes possible the measurement of genetic differences between members of populations and species (Sogin and Hinkle, 1997). Knowledge of genetic diversity can help influence systematics and our understanding of evolution as well as identifying potentially useful organisms to man. A diverse gene pool allows productive uses. It serves as a basis for the development of pharmaceutical products, in the fields of biotechnology and improvement of cultivated plants in terms of yield increases and to preserve their resistance to disease.

The knowledge on mangrove genetic resources is very sparse in the literature. There is limited information from DNA sequences, allozymes and growth adaptability experiments. It is highly important to know more information about this to make proper gene resource management especially for mangrove tree species.

There is significant inter- and intraspecific variability among mangroves and this variability may result from genotypic differences or from phenotypic responses to local environments (Kathiresan and Bingham, 2001). Genetic variability has been demonstrated through biochemical markers like foliar leaf waxes (Dodd et al., 1995, 1998) and isoenzymes (Duke, 1991) and in differences in length and volume of chromosomes (Das et al., 1994). A number of discontinuities and endemisms in mangrove species have been recorded. *Bruguiera hainesii* is discontinuous between western Malaysia and New Guinea (Tomlinson, 1986). *Sonneratia alba* appears to have several disjunct populations respectively centred on East Africa/Madagascar, India/Sri Lanka and Australasia (Spalding et al., 1997). *Pelliciera rhizophorae* is of a very limited distribution and endemic to the tropical Pacific coast of America (Tomlinson, 1986). The ecological requirements of the species may be the main reasons for many of the disjunctions. Mangrove hybrids are known for several species within these genera *Sonneratia, Rhizophora, Xylocarpus* and *Lumnitzera* (Duke and Bunt, 1979; Duke, 1984; Tomlinson, 1986), which suggests that the genetic isolation between species of some genera is not complete.

Mangroves are biochemically unique, producing a wide array of novel natural products some of which are used in traditional medicine (Bandaranyake, 1998) and others have potential commercial applications (Kathiresan, 2000).

Conservation of forest genetic resources is a subject of major national and international concern. Major threats to the integrity of forest genetic resources include inappropriate forest harvesting practices and the often uncontrolled and undocumented movement of forest germplasm for plantation establishment leading to loss of locally adapted populations. The management of mangrove genetic resources should be given the same attention as in other forest types. Mangroves have been deliberately introduced into areas beyond their natural distributional ranges to meet human needs. For example *Nypa fruticans* were introduced to west Africa from the Singapore Botanic Gardens in 1906 and 1912 (Wilcox, 1985) for their valuable thatching properties. Other introductions are not so well documented and are likely to affect the apparent distributional ranges.

In the light of nearly a complete lack of knowledge about the genetics of mangrove species, the precautionary principle should be applied, when mangroves are replanted. That is a local seed source should be used wherever possible as long as it is in sufficient numbers and of an acceptable quality (Brown and Schoen, 1994). With the large destruction and degradation of mangroves much of the original genetic pool has been lost and with indiscriminate planting the genetic resources are being diluted and mixed up. In the light of the huge pressures on mangrove forests and the lack of knowledge on the remaining natural forest mangrove genetic resources and their potentials, considerable efforts should be invested in research.

The genetic diversity of mangrove fauna is also not well known. Only recently Keenan et al. (1998) revised the genus *Scylla* an important commercial crustacean species and identified four species through the use of genetic techniques.

2.4.2 Species level

Species diversity
The variation of species and subspecies among living organisms on earth

Species diversity remains the most frequently and widely applied measure of biodiversity. The reasons for this are because many data exist for the species level. In practice, species diversity is measurable and it is thought to capture the essence of biodiversity (Gaston, 1996). Species diversity can be positively correlated with other measures for example, genetic variants, higher levels of taxonomic diversity, functional diversity and habitat diversity (Gaston, 1996). Measures of species diversity are important, as their stability over (long) periods of time are frequently seen as indicators of the well-being of ecological systems (Magurran, 1988).

The adaptations of mangrove flora and fauna to live in the intertidal environment provide important biodiversity that needs conserving. A brief introduction to the different groups is described in this section and the species at particular risk mentioned.

2.4.2.1 Flora

According to Tomlinson (1986) there are 54 true mangrove species in 20 genera belonging to 16 families, plus 60 mangrove associate species in 46 genera. In contrast, Duke (1993) includes 62 true mangrove species in 27 genera plus 7 hybrids. This is a low species diversity compared to the extremely high biodiversity found in e.g. coral reefs and tropical rainforests (Ricklefs and Latham, 1993). For example 223 tree species per ha have been recorded in lowland tropical rainforest in Sarawak (Proctor et al., 1983). Mangroves, on the other hand, are taxonomically diverse, the mangrove habit has evolved at least 16 times in 16 different families. The common features have evolved through convergence, not from a common descent. The principal mangrove families and genera are listed in Table 2.5. Most families are represented by a few species. However, out of the 34 species that represent the major components 25 species belong to just two families *Avicenniaceae* and *Rhizophoraceae*. These families dominate mangrove communities throughout the world.

Table 2.5: The principal species of mangrove plants

Family	Genus	Number of species	Plant form
Major components			
Avicenniaceae	*Avicennia*	8	Tree/Shrub
Combretaceae	*Laguncularia*	1	Tree/Shrub
	Lumnitzera	2	Tree/Shrub
Palmae	*Nypa*	1	Palm
Rhizophoraceae	*Bruguiera*	6	Tree
	Ceriops	2	Tree/Shrub
	Kandelia	1	Tree/Shrub
	Rhizophora	8	Tree
Sonneratiaceae	*Sonneratia*	5	Tree/Shrub
Minor components			
Bombacaceae	*Camptostemon*	2	Tree
Euphorbiaceae	*Excoecaria*	2	Tree/Shrub
Lythraceae	*Pemphis*	1	Shrub/Tree
Meliaceae	*Xylocarpus*	2	Tree
Myrsinaceae	*Aegiceras*	2	Shrub/Tree
Myrtaceae	*Osbornia*	1	Tree/Shrub
Pellicieraceae	*Pelliciera*	1	Tree
Plumbaginaceae	*Aegialitis*	2	Shrub
Pteridaceae	*Acrostichum*	3	Fern
Rubiaceae	*Scyphiphora*	1	Tree/Shrub
Sterculiaceae	*Heritiera*	3	Tree

Source: Tomlinson (1986)

Bacteria

Bacteria are fundamental to ecological processes in the mangrove yet they are the least studied group. Bacteria are important in controlling the chemical environment in the mangrove. For example sulfate-reducing bacteria are the primary decomposers in anoxic mangrove sediments and can control the iron, phosphorous and sulfur dynamics and contribute to soil and vegetation patterns (Sherman et al., 1998). Bacteria are critical in the cycling of Nitrogen and processing industrial wastes, e.g. mine waste. Some bacteria live symbiotically with other organisms, whilst others are parasitic or pathogenic (Kathiresan and Bingham, 2001).

Algae

Phytoplankton and algae communities can be diverse but depend on local environmental conditions. Mangrove pneumatophores and aerial roots are colonised by a film of diatoms and unicellular algae, as well as a turf of small red algae. Most characteristic is a mixed community of *Bostrychia*, *Caloglossa*, *Murrayella* and *Catanella*, which in various permutations of species, is found virtually throughout the tropics (Hogarth, 1999). Photosynthetic algae also grow on the mud surface, most are unicellular diatoms, but blue-green cyanobacteria are also present. Unattached red algae (Rhodophyta) *Gracilaria* and *Hormosira* can also be found in permanent patches.

Phytoplankton and algae communities make important contributions to the functioning of mangroves but contribution to overall productivity is low in estuarine mangrove areas because of the high turbidity, large salinity fluctuations and low light levels (Robertson and Blaber, 1992; Alongi, 1994). The high nutritional quality of phytoplankton may make them critical in supporting higher trophic levels (Robertson and Blaber, 1992). Microscopic algae alter the texture of the soil by affecting particle size and binding soil particles together with their mucous secretions. A number of algae also have potential commercial value, for example the red alga *Gracilaria changii* from Malaysian mangrove habitats is an excellent source of agar.

Fungi

Fungi are another much ignored group of organisms, which are fundamental to many aspects of decomposition and energy flow in mangrove forests (Hyde and Lee, 1995). Fungi occur on the vegetation (leaf litter and dead wood predominantly), in the soil and in the water of mangrove swamps. The diversity of mangrove fungi is indicated by Hyde (1990) who recorded 120 species from 29 mangrove forests around the world. These included 87 Ascomycetes, 31 Deuteromycetes and 2 Basidiomycetes. Recent surveys are revealing a number of range extensions, new species, and even new genera (see Kathiresan and Bingham, 2001 for review).

2.4.2.2 Fauna

Mangroves support a high diversity of fauna, micro- and macroscopic, terrestrial and aquatic (marine and freshwater), temporary and residential. What constitutes the “true” fauna of mangrove is much debated because there are animals, which are permanent residents (wholly dependent on mangroves), and others which are opportunist visitors. Examples of the residential organisms include vertebrates: kingfishers, mudskippers, snakes and mangrove monitor lizard; terrestrial invertebrates: spiders, ants, termites, moths and mosquitos; aquatic invertebrates molluscs, crustaceans and polychaetes (Hutchings and Recher, 1983; Hutchings and Saenger, 1987). A substantial proportion of the fauna comprises species derived from neighbouring terrestrial habitats. Most of the major groups of terrestrial animals are significantly represented in mangroves.

Table 2.6: Number of species of associated biota recorded from mangroves in the various geographic regions of the world.

Taxonomic group	**Region**					
	1	**2**	**3**	**4**	**5**	**6**
Flowering plants	110	80		28		20
Palms	73	42		20		8
Bacteria	10					
Algae	65	93		105		12
Fungi	25	14				
Lichens		105				
Bryophytes/Ferns	35	5		2		2
Protozoans	18			3		
Sponges/Bryozoans	5	7		36		1
Coelenterates/Ctenophores	3	6		42		12
Polychaetes	11	35		33		72
Non-polychaete worms	13	74		13		3
Echinoderms	1	10		29		23
Ascidians		8		30		13
Insects/Arachnids	500	72				
Amphibians	2			2		
Reptiles	22	3		3		
Birds	177	244		138		
Mammals	36	7		5		
Fish	283	156		212		114
Crustaceans	229	128		87		163
Molluscs	211	145	32	124		117
Total	1829	1234	32	912	0	560

Source: Saenger et al. (1983).
Region: 1 = Asia, 2 = Oceania, 3 = West Coast of the Americas, 4 = East Coast of the Americas, 5 =West Coast of Africa, 6 = East Coast of Africa and the Middle East.

The mangrove fauna has been poorly studied in comparison to the mangrove flora, with the exception of the most prominent groups, namely the large intertidal crustaceans and molluscs (e.g. Berry, 1975, Jones, 1984; Macintosh, 1988). Table 2.6 also reflects the lack of knowledge in some regions of the world. Gaps in the data in Table 2.6 reflect a lack of study of certain biota and regions, rather than an absence of species. In general, bacteria, protozoans and the lower plants have been much less studied than trees and larger animals. Among these less well-known groups of mangrove animals, many new species will almost certainly be found in future.

Animal diversity is also much higher in the Indo-West Pacific than in the Atlantic East region and at low latitudes (Jones, 1984; Reid, 1986; Ricklefs and Latham, 1993; Lee, 1998). Fauna diversity is related to flora diversity (Lee, 1999), which has implications for biodiversity management, ecological restoration and rehabilitation programmes.

Zooplankton

Diverse communities of zooplankton, high abundances (reaching 10^5 individuals m^{-3}) and high biomasses (up to 623 mg m^{-3}) have been recorded in mangrove habitats (Robertson and Blaber, 1992) and they are considered important in the regions food webs. Zooplankton can be divided into three size classes the microzooplankton (organisms between 20 and 199 µm), the mesoplankton (organisms between 200 µm and 2 mm) and the macrozooplankton (organisms larger than 2 mm). The microzooplankton include foraminiferans, ciliates, rotifers, copepod nauplii, barnacle nauplii and mollusc veligers. Copepods are the most abundant mesoplankton and jellyfish the most important macrozooplankton. Meroplankton (planktonic larval stages of benthic invertebrates) span the full range of zooplankton sizes and can constitute up to 70% of the zooplankton (Kathiresan and Bingham, 2001).

Invertebrate epifauna

Mangrove roots, trunks and branches attract rich epifaunal communities including sponges, hydroids, anemones, polychaetes, bivalves, barnacles, bryozoans and ascidians. These organisms are then important food sources for other invertebrates and fish (Farnsworth and Ellison, 1996).

Epibenthos, infauna and meiofauna

The mangrove sediments support high densities of epibenthic, infaunal and meiofaunal invertebrates. The macrobenthos include annelids, polychaetes, oligochaetes and hydrozoans. The meiofauna (defined as organisms ranging from 53 to 1000 µm) consist of nematodes, copepods and protozoans. Meiofauna are widely distributed and abundant but poorly studied, and their biodiversity is likely to be much higher than previously recorded. For example eight new genera of copepods were recorded from two weeks of sampling in Malaysia (M. Gee *pers. comm.*).

The abundance of meiofauna can number in the millions per square metre of soil. They are heavily concentrated in the upper centimetre of mud with numbers falling off rapidly below this depth (Somerfield et al., 1998). Meiofauna populations have high numbers of species and a high level of taxonomic diversity. For example, one set of meiofaunal samples from the mangroves of Hinchbrook Island, Australia yielded 1600 turbellarian flatworms, 200 nematodes, 9 harpactoid copepods and numerous ciliate protozoans, formaniferans, bivalve molluscs, oligochaetes, polychaetes, hydrozoans, archiannelids, kinorhynchs, amphipods, cumaceans and other crustaceans, tardigrades and gastrotrichs (Alongi, 1987).

Meiofauna are thought to be important in converting mangrove primary production to detritus and as a food source for many deposit feeding or surface grazing mangrove animals. Crabs, mudskippers, penaeid shrimps and a number of fish species (Sasekumar, 1981) are reported to consume large quantities of meiofauna.

Insects

Mangrove insects are diverse and abundant. Little is known about their significance, although they can play important ecological roles in the mangrove ecosystem. They may be permanent residents or only transient visitors to the mangrove. There are herbivores that feed on leaves, flowers, seeds or mangrove propagules; detritivores that eat dead wood or decaying leaves; more general foragers; and predators. Some insects play crucial roles as pollinators and all in turn represent a major food source for predators. The mangrove insect fauna resembles that of terrestrial forests with many species common to both, but there are also some exceptions and unique species. A few examples of the important and best studied insects are described below, but much more research on mangrove insects is required.

Numerous butterfly and moth species have been recorded from mangroves and can cause significant damage to the leaves. Honey bees can produce significant quantities of honey from mangroves which can be an important food source in some regions. Termites are an important component of the fauna but little is known about them. They burrow inside the trunks and branches of mangrove trees and maybe very important in breaking down dead wood. They are found mainly towards the landward fringe of the mangrove forest but an exception is a species found in Malaysia, which constructs an external nest on a tree trunk several metres above the highest point reached by the high tide, with narrow galleries that snake down the trunk to the aerial roots and upwards to the canopy.

Ants are often abundant in the mangrove tree canopy suggesting their ecological significance but again not much is known about ants. Sixteen ant species were recorded in an Australian mangrove (Clay and Andersen, 1996). The ant, *Polrachis sokolova,* from Australia, nests in the mangrove mud and can have their nests inundated by 61% of high tides, for periods of up to 3.5 hours (Nielsen, 1997). Weaver ants, *Oecophylla smaragdina*, found in mangroves of the Indo-Pacific constructs nests by folding leaves together using sticky secretions from a larva. *Oecophylla* feeds on the sugary secretions of the coccid bugs, which suck plant sap and other insects and will defend their nests and thus the mangrove tree by attacking with a sharp bite.

Mosquitos and sandflies can be found in abundance in mangroves due to the presence of shallow stagnant pools where they can breed. They are often a nuisance because of their biting of humans but also because they can be vectors of diseases such as malaria and yellow fever. This has often been a reason for mangroves to be regarded as wastelands and to be undervalued.

Synchronously flashing fireflies are associated with *Sonneratia caseolaris* mangrove trees in some areas in southern Asia through to the western Pacific. Fireflies (*Pteroptyx* spp.) are beetles of the family Lampyridae. In Selangor, Peninsular Malaysia the fireflies are a huge ecotourist attraction. For this resource to be conserved and managed much more research is required on the biology and ecology of the firefly because at present little is known.

Spiders

Web building spiders can occur in abundance. The female golden silk spider (*Nephila clavipes*) of the New World can build orb webs about 2m in diameter. Other web building spiders from the family Gasteracanthidae have brightly coloured bodies with projecting spikes and occur from the Caribbean to Australia. Mangroves also contain numerous wolf and jumping spiders, which descend from the trees at low tide and forage over the mud for insects. The lycosid *Pardosa* from Malaysia is adapted to a semi-aquatic life. Its hairy coat is water repellent, it shelters and breeds in air-filled burrows in the mud and feeds on juvenile fiddler crabs (Stafford-Deitsch, 1996).

Amphibians

Amphibians are rarely found in brackish or salt water but the crab-eating frog *Rana cancrivora* from Southeast Asia is an exception. The adults and larvae are common in mangroves.

Reptiles

Reptiles that commonly occur in mangroves include numerous species of snake and lizard, crocodiles, alligators and turtles. Some snakes only enter mangroves intermittently from adjacent terrestrial habitats to forage, for example pythons (*Python molorus*) and king cobras (*Ophiophagus hannah*). Some snakes are specialist to mangroves for example the cat snake *Boiga dendrophila* of Australia and Southeast Asia and the green pit vipers (*Vipera trimeresurus*). Sea snakes (Hydrophidae) also utilize the mangrove habitat. The primitive *Laticauda colubrina* breeds on land but other sea snakes are fully aquatic. In southeast Asia and Australia the mangrove monitor lizard (*Varanus indicus*) may reach up to 1 m in length and is often caught and used as bait for mud crab fisheries (Ashton, *pers. obs.*). In Central America, the American crocodile (*Crocodylus acutus*) and the common caiman (*Caiman crocodylus*) may occur in mangroves. In West Africa, the Nile crocodile (*Crocodylus niloticus*) is found, while from India through southeast Asia and Australia, as far as Fiji, the commonest mangrove species is the estuarine crocodile (*C. porosus*) which can reach up to 8 m in length.

Birds

Many bird species have been recorded from mangrove forests but many only spend part of their time in mangroves. They may migrate seasonally, commute daily or at different states of the tide and may use it as a feeding, nesting or refuge area. For example 200 bird species were recorded from mangroves in Australia but only 14 passerine species were confined to mangroves, with 11 other species being found predominantly in mangroves but frequently occurring elsewhere (Noske, 1996). Waders probe for buried invertebrates on the mudflats or amongst the mangrove trees. Herons, egrets and kingfishers catch fish in the shallow waters or prey on mudskippers and crabs on the mud surface. Storks, pelicans, ospreys and cormorants feed on large fish and may roost or breed in mangroves. Passerines like warblers, woodpeckers, flycatchers and hummingbirds depend on the trees or their associated invertebrate fauna for food. Mangroves are also the nesting sites for a number of threatened bird species, for example spoonbills (*Ajala ajala*) and the milky stork (*Mycteria cinerea*).

Detailed investigations of mangrove bird ecology are sparse and it is therefore difficult to analyse their true significance. However, considering their abundance it is likely to be considerable. In the Caroni swamp of Trinidad there are densely packed nesting colonies of cattle egrets (*Bubulcus ibis*) and snowy egrets (*Egretta thula*) and roosting scarlet ibis (*Eudocimus ruber*), all of which deposit large amounts of guano, which enrich the local area with nitrates and phosphates. The trees in the area tend to be taller and have denser foliage (Stafford-Deitsch, 1996).

Mammals

Few mammals are characteristic of mangrove habitats, most also occur in adjacent habitats, for example, antelopes, deer, wild pigs and rodents may be common in mangroves. However, sometimes mangroves harbour species that have been eliminated elsewhere and are now endangered for example the Bengal tiger (*Panthera tigris*) and Javan rhinoceros (*Rhinoceros sundaicus*).

Monkeys are common in mangroves and can be omnivores or herbivores. In west Africa (Southern Senegal) the vervet monkey (*Cercopithecus*) eats fiddler crabs (*Uca tangeri*) and *Rhizophora* flowers, fruit and young leaves. In southeast Asia macaques (*Macaca*) forage on the mud for crabs and bivalve molluscs but can be a major problem in replanting projects because they have a tendency to uproot *Rhizophora* propagules (Gan, 1995). Langurs (*Presbytis*) are also found in southeast Asia but they feed mainly on leaves and fruit of mangroves. Proboscis monkeys are found exclusively in Borneo mangrove forests. They can consume large amounts of leaves and fruit in one day and are therefore ecologically significant.

Bats are attracted to mangroves by their abundance of insects, fruit and nectar. Many species of insectivorous bats (Microchiroptera) are found consuming considerable quantities of insects. Fruit bats and flying foxes (Megachiroptera), exclusively Old World, are also abundant, using the trees as a roost and a source of food. In Peninsular Malaysia the long-tongued fruit bat (*Macroglossus minimus*) and the cave fruit bat (*Eonycteris spelaea*) eat *Sonneratia* nectar and pollen and are major pollinators of *Sonneratia*. *Macroglossus* has a specialisation for *Sonneratia* and has never been recorded away from mangrove areas. *Eonycteris* roosts in its tens of thousands in Batu caves, near Kuala Lumpur, about 38 km from the nearest mangroves, so the nightly foraging range is considerable. *Eonycteris* is also a major pollinator of the commercially important durian (*Durio zibethinus*). Durians flower and fruit for only a limited period each year so *Eonycteris* depends on *Sonneratia* inbetween. This demonstrates the interconnectivity between mangroves and terrestrial habitats and shows that they cannot be viewed in isolation.

Dugongs and cetaceans are completely aquatic mammals found in mangrove creeks and rivers. Dolphins, porpoises and whales visit mangroves periodically. In the Sunderbans, there are also the rare freshwater Ganges and Irrawaddy dolphins (*Platanista gangetica* and *Orcaella brevirostris*). Otters are common in southeast Asian mangroves and are considered a pest by aquaculturists in mangroves for pinching their fish and shellfish products.

Grazing occurs in some mangrove areas by domestic mammals. For instance, cattle, camels and goats in India, camels and buffalo in Arabian mangroves and in the Indus Delta of Pakistan and feral water buffalo in northern Australia. They can consume large quantities of mangrove foliage and have a significant impact on the mangrove ecosystem.

Fish

The species richness and abundance of fish is high in the creeks, pools and inlets of mangrove forests. Many of the fish are juveniles suggesting the mangrove habitat is a nursery area. Some fish species have commercial value, some are important links in the mangrove food web and others are only temporary residents but all are important in the mangrove ecosystem. Fish are important predators consuming amphipods, isopods, shrimp, nematodes, insects, gastropods, crabs, bivalves, other fish and planktonic larvae (Sasekumar et al., 1992). Mullets (*Liza* spp.) consume significant quantities of detritus.

Estimates of diversity depend heavily on catching methods and intensity so figures reported may not be directly comparable. However the following data indicate the diversity of mangrove-associated fish species. In Selangor, Malaysia 119 species were recorded, 83 species in Kenya, 133 from Queensland Australia, 59 species in Puerto Rico and 128 from the Philippines (Chong et al., 1990).

In the Indo-Pacific, mudskippers, a group of unusual amphibious fish, are common on the mudflats at low tide. A variety of anatomical, physiological and behavioural adaptations help them tolerate the mangrove environment. *Boleophthalmus* are largely deposit feeders, *Periophthalmus* and *Periophthalmodon* are predominantly carnivorous feeding on crabs, snails, insects, spiders, shrimp, copepods and amphipods, while *Scartelaos* is omnivorous (Clayton, 1993).

Crustaceans

Brachyuran crabs are the dominant mangrove fauna because they are morphologically, physiologically and behaviourally well-adapted to their environment. They are both abundant and diverse, although mainly dominated by two families Grapsidae and Ocypodidae. Other crustacea include the predatory swimming crabs Portunidae, hermit crabs, the commercially important penaid shrimps and a variety of burrowing species such as the mud lobster *Thalassina*, amphipods and isopods.

Many grapsid crabs are characteristic of mangrove habitats. They feed at low tide predominantly on fallen mangrove leaves and fruits but also scrape the epiphytic algae from the surface of mangrove roots, trunks or branches and some clamber into the branches to eat live leaves. At high tide they avoid predators like fish by retreating into burrows. The subfamily Sesarminae, particularly the genus *Sesarma* are the most important in species number and abundance. They closely resemble each other in morphology and therefore the taxonomy is complex and confusing, particularly in southeast Asia and Australia. Many species are inadequately described. Davie (1982) suggests about 20% of mangrove crab species in Australia are unnamed. In the Indo-Pacific Sesarmine crabs play an important role in the ecology of the mangroves through their selective destruction of propagules and huge consumption and breakdown of leaf litter (Robertson, 1986; Smith, 1987).

Ocypodidae are dominated by the fiddler crabs *Uca* spp., which are predominantly deposit feeders that ingest organic matter from the mud at low tide and assimilate the bacteria, diatoms and meiofauna that grow on the detritus. As only a small proportion of the total sediment is selected as food they need to process large amounts. Fiddler crabs are often very abundant in mangroves with densities up to 80 m^{-2} (Macintosh, 1984). The turnover rate of the soil is therefore huge and they play a major role in modifying the soil environment (retexturing the soil and altering its chemical composition). Fiddler crabs also play an important role in the mangrove ecosystem as a food source for numerous predators (monkeys, birds, snakes, fish, other crabs).

The mud lobster, *Thalassina*, is a subterranean deposit feeder that forms large mounds up to 2 m high. As with the other crabs in the mangrove forest it plays an important role as an ecosystem engineer (Jones et al., 1994). Large *Thalassina* mounds create dry habitats above tidal inundation level that are suitable for a variety of other species. Burrows increase the surface area of the mud. This has benefits to the mangrove plants by increasing diffusion of gases. It also allows the forest to be flushed more easily at high tide promoting nutrient exchange (Lee, 1998). Experiments have shown crabs can significantly affect the growth and productivity of mangrove trees (Smith et al., 1991).

Some mangrove crustaceans can have considerable commercial value for example the mud crab *Scylla* spp., from the family of swimming crabs Portunidae. It is the largest invertebrate predator in mangroves and is of considerable commercial value in some countries. Penaeid shrimps, which depend heavily on mangroves for feeding and breeding, are also very important commercially. Mantis shrimps, Stomatopoda, live in burrows in the mud are collected by man for food mainly on a subsistence level.

Some crustaceans can cause significant damage to mangroves, for example barnacles and burrowing isopods. Barnacles can kill mangrove seedlings if in very high abundance. Burrowing isopods can significantly affect root growth and development (Ellison and Farnsworth, 1990). Other crustaceans include the pistol shrimps that live under the mud surface and the hermit crabs, e.g. *Clibanarius* spp. that scavenge on the mud surface at high tide.

<u>Molluscs</u>

Molluscs live on and in mangrove mud, firmly attached to the roots, or forage in the canopy. They are mainly composed of gastropods and bivalves. Molluscs can be important in the ecology of the mangrove ecosystem. The detritivorous snails, *Terebralia palustris,* in Kenya aid nutrient cycling by processing mangrove litter (Slim et al., 1997). The mangrove snail, Thais spp. can help mangrove seedlings by eating barnacles. All gastropods and bivalves contribute to supporting higher trophic levels in the mangrove food web.

Gastropod snails are the most conspicuous molluscs that inhabit the mangroves. Most are deposit feeders that scrape organic particles from the surface. In some places gastropods are collected as a local food source, for example *Cerithidea* in southeast Asia and *Telescopium* in India.

Some bivalves are also important for commercial production, for example cockles and clams that are found in the mudflats adjacent to mangroves. Oysters and mussels, found attached to mangrove roots are also collected as a food source.Wood-boring bivalves, the shipworms, Teredinidae, can do extensive damage to mangroves.

2.4.2.3 Mangrove species at risk

A number of plants and animals that depend on mangrove ecosystems are at risk and have been recognised in the red data list (Table 2.7). Habitat loss through human encroachment is a primary cause for decline. These impacts are likely to continue, and worsen, as human populations expand further into the mangroves. Protection of mangrove-dependent animals requires effective management of the entire mangrove habitat. This may be complex and require evaluation of habitat needs on a species by species basis.

Table 2.7: Mangrove and mangrove-associated species at risk

Species	Common name	Status
Bruguiera gymnorrhiza	Mangrove	Extinct-Taiwan
Ceriops tagal	Mangrove	Vulnerable-Taiwan and South Africa
Grammatophyllum speciosum	Queen Orchid	Endangered- Thailand
Terebralia palustris	Mangrove whelk	Vulnerable-South Africa
Alligator mississippiensis	American alligator	Threatened-Florida, USA
Crocodylus acutus	American crocodile	Vulnerable-USA, Central and S America
Crocodylus porosus	Saltwater crocodile	Vulnerable; protected within reserves-India and Malaysia; collecting prohibited-Australia, India & Sri Lanka
Amazilia boucardi	Mangrove hummingbird	Endangered-Costa Rica
Ardea cinerea	Grey heron	Endangered-Malaysia
Ardea herodias	Great blue heron	Endangered-Puerto Rico
Camarhynchus heliobates	Mangrove finch	Critically endangered-Ecuador
Egretta alba	Great egret	Endangered-Malaysia & Puerto Rico
Eudocimus ruber	Scarlet ibis	Vulnerable-Venezuela, Trinidad and Tobago
Halcyon senegaloides	Mangrove kingfisher	Vulnerable-South Africa
Leptoptilos javanicus	Lesser adjutant stork	Vulnerable-S and SE Asia
Mycteria cinerea	Milky stork	Vulnerable-SE Asia, protected within a reserve on Pulau Dua off western Java; collecting prohibited in Malaysia except by aborigines
Pitta megarhyncha	Mangrove pitta	Near threatened-Bangladesh, Indonesia, Malaysia, Myanmar, Singapore, Thailand
Platalea minor	Black-faced spoonbill	Endangered-Russia, China, Hong Kong, Japan, Korea, Thailand, Vietnam and Taiwan
Macaca fascicularis	Long-tailed macaque	Near threatened-S and SE Asia, Protected within reserves-Malaysia
Nasalis larvatus	Proboscis monkey	Endangered-Found only in Borneo; protected within reserves

Panthera onca	Jaguar	Near Threatened-South American countries; protected within reserves in Columbia, Peru, Bolivia and Brazil; collecting prohibited within most of the range
Panthera tigris sumatrae	Sumatran tiger	Critically endangered-found only in Sumatra; collecting prohibited
Panthera tigris tigris	Bengal tiger	Endangered-protected within reserves in India, Bangladesh, Bhutan, Burma and Nepal
Presbytis femoralis	Banded langur	Near threatened-SE Asia
Procyon cancrivorus	Crab-eating racoon	Vulnerable-Trinidad and Tobago
Pteropus vampyrus	Malaysian flying fox	Protected within reserves-Malaysia
Sciurus niger avicennia	Mangrove fox squirrel	Conservation dependent-Found only in southern Florida where two breeding populations remain; protected under Florida legislation
Trichechus manatus latirostris	Florida manatee	Vulnerable-Florida, USA
Trichechus senegalensis	African manatee	Vulnerable-Africa
Trichechus manatus manatus	Antillean manatee	Vulnerable-C and S America
Trichechus manatus	American manatee	Vulnerable-USA, C and S America
Trichechus inunguis	Amazonian manatee	Vulnerable-Amazon river

Source: Saenger et al (1983); Hilton-Taylor (2000); http://www.redlist.org

2.4.3 Ecosystem diversity: structure, processes and functions

Ecosystem Diversity
The variety of habitats, biotic communities and ecological processes in terrestrial, marine and other aquatic environments in a particular area, together with the processes and interactions that take place within and between these systems.
Ecosystem functions
The biophysical processes of production and dynamics of resources (organic matter, nutrients, biomass, elements) and energy that take place through ecosystems. The level of function depends on the capacity of the ecosystem (onsite features) and certain aspects of its landscape context (e.g., connectedness to other natural/human features, accessibility to birds, fish).

Mangroves are diverse at the ecosystem level. They can grow in a wide range of geographical, climatic, hydrological and edaphic (soil) conditions. They cover the intertidal zone so they interact with aquatic, inshore, upstream and terrestrial ecosystems. They support a diverse flora and fauna of marine, freshwater and terrestrial species and they are exposed to varying human impacts at different intensities. There are also many strong and unique human cultural associations with mangroves country to country. Consequently the structure, productivity and functions of mangroves are also highly variable (Robertson and Alongi, 1992; Saenger and Snedaker, 1993), making it impossible to define a typical mangrove community or ecosystem. This has an important bearing on the policy and management of mangrove ecosystems, which is discussed later in this report (see Section 3).

Assessing the conditions of an ecosystem is a useful indicator of the threats to species level diversity. The decline of critical habitats implies that species dependent on such areas may also be in jeopardy. Changes in the extent of habitats are also relatively easy to measure; for example satellite imagery can now be used to measure mangrove forest areas very accurately. A practical application of the use of habitat area as an indicator of environmental change is the coastal zone of the Lower Mekong Delta in Vietnam. Through mangrove restoration and protection a World Bank/Danida funded project is trying to improve the much degraded coastal environment. Increase in the area of mangrove forest will be monitored as a simple indicator of environmental change.

Mangroves have a broad range of structural and functional attributes that promote their survival in the difficult, wide-ranging environmental conditions of the intertidal zone. These specialised adaptations have evolved independently a number of times in a taxonomically diverse group of plants. The range in structure of mangroves is due to stature, life form (tree, shrub, palm, fern) and above-ground root structure (prop roots, pneumatophores, buttresses and knee roots). Mangrove structure and stability not only influence the success and survival of the particular species but also promotes the establishment of other species. The mangroves provide shade, plenty of hard and vertical substrata for sessile intertidal organisms, usually fiercely competing for intertidal space, an abundance of organic material for a rich chain of decomposers and detritus feeders and a variety of microenvironments protected from wave action (Por, 1984; Ashton, 1999)

Indirectly, carbon production by the mangroves is important for coastal fisheries, since mangrove detritus released from the breakdown of plant materials is a major food source for prawns and fish. Mangroves also provide protection they are a sanctuary for birds and a nursery and spawning ground for commercially important fish, shellfish and invertebrates. Mangroves provide a role as habitat with nursery and feeding functions for a wide range of benthic and pelagic aquatic species (Robertson and Duke, 1990; Vance et al., 1990, 1996) and terrestrial and avian fauna (Hong and San, 1993). Mangrove root systems provide safe habitat and nursery for aquatic species (Thayer et al., 1987) and the branches provide resting and nesting areas for resident and migrant birds. The leaf litter and other organic materials produced by mangroves fuel the complex estuarine and nearshore food webs. All levels from bacteria, meiofauna, crabs, snails, birds and shrimp to fish feed on the detritus. Many of the species are important commercial species. Consequently, the value of mangrove fisheries resources sometimes exceeds forestry resources (Gan, 1995).

Mangrove structures also help perform important regulatory functions. By obstruction with their roots and trunks they reduce wave energy and are important in reducing coastal erosion and in protecting the coast from flooding (Othman, 1994, Tri et al., 1998). They also buffer the waterways from the direct effect of run-off waters by reducing silt and nutrient loads, they buffer salinity changes, supply and regenerate nutrients (Lugo and Snedaker, 1974).

The high abundance and productivity of mangrove plant and animal species also make them an important fundamental ecological link between other terrestrial and marine habitats. Mangroves play an important role in the functioning of adjacent ecosystems, including terrestrial wetlands, peat swamps, saltmarshes, seagrass beds and coral reefs. The maintenance of hydrological linkages between upland catchments and coastal wetlands are essential for wetlands to function. Pakistan is a good example where dams, barrages and irrigation schemes have reduced the flow of freshwater down the Indus river by 70% over the last 100 years, while silt deposition in the delta has reduced by 75%. These altered conditions, together with over-exploitation of mangrove wood, have led to a significant decrease in mangrove cover and biodiversity in the Indus Delta (Brown, 1997; Hogarth, 1999).

Table 2.8 gives a definitive list of environmental functions and how they can be classified into regulatory, productive, carrier and information functions (de Groot, 1993). Mangrove ecosystems perform most of the functions in Table 2.8. Table 2.9 shows that some ecological processes are common to more than one environmental function, which high lights the interconnectedness within the ecosystem (Gilbert and Janssen, 1998). Maintenance of biodiversity is associated with the key processes of fixation of solar energy and biomass production, storage and recycling of organic matter and nutrients and maintenance of nursery and migration habitats. Environmental functions provide goods/resources and services, which are then beneficial and useful to man in a number of ways (see section 2.5). The potential users and the economic value of mangroves feel the repercussions when common ecological processes (ecosystem diversity) are compromised through poor management decisions.

Table 2.8: Environmental functions

Regulation Functions	Protection against harmful cosmic influences Local and global energy balance Chemical composition of the atmosphere Chemical composition of the oceans Local and global climate Run-off and flood prevention Water catchment and groundwater recharge Prevention of soil erosion, sediment control Topsoil formation, maintenance of fertility Solar energy fixation, biomass production Storage /recycling of nutrients Storage/recycling of wastes Biological control mechanisms Migration and nursery habitats Biological (and genetic) diversity
Production Functions	Oxygen Water (drinking, irrigation) Food Genetic resources Medicinal resources Raw materials for construction Fuel and energy Biochemical Fodder and fertiliser Ornamental resources
Carrier Functions (providing space and a suitable substrate)	Human habitation (indigenous settlements) Cultivation (fish, crops, cattle) Energy conversion Recreation and tourism Nature protection
Information Functions	Aesthetic information Spiritual and religious information Historic information (heritage value) Cultural and artistic inspiration Scientific and educational information

Source: de Groot, 1993

Table 2.9: Important environmental functions in mangrove ecosystems and the ecological processes that are associated with them

Environmental Functions	Ecological Processes
Production of water	Hydrological cycle
Production of food	Fixation of solar energy and biomass production Storage/recycling of organic matter and nutrients Maintenance of nursery and migration habitats
Production of other biotic resources	Fixation of solar energy and biomass production Storage/recycling of organic matter and nutrients
Production of raw materials for building, construction and industry	Fixation of solar energy and biomass production Storage/recycling of organic matter and nutrients
Production of fuel and energy	Fixation of solar energy and biomass production Storage/recycling of organic matter and nutrients
Maintenance of biodiversity	Fixation of solar energy and biomass production Storage/recycling of organic matter and nutrients Maintenance of nursery and migration habitats
Production of juveniles for cultivation	Fixation of solar energy and biomass production Storage/recycling of organic matter and nutrients Maintenance of nursery and migration habitats
Regulation of environmental quality	Fixation of solar energy and biomass production Storage/recycling of organic matter and nutrients Sediment control
Prevention of soil erosion	Sediment control Buffering of storms
Flood mitigation	Buffering of storms
Scientific and educational information	All ecological processes

Source: Gilbert and Janssen, 1998.

Ecosystem functioning, stability and resilience may depend on habitat biodiversity. Heywood (1995) posed the view that all ecosystem services are affected to one degree or another by reductions in diversity. This fact follows simply from the greater resource capture, i.e. of energy, water, nutrients and sediments of diverse systems compared to simple systems. As society exerts a greater control and management of ecosystems of the world, great care must be taken to ensure their sustainability, which is due in large part to the buffering capacity provided by biotic complexity (Heywood, 1995).

It is assumed " that there are levels of biodiversity loss that can be sustained without inducing catastrophic change/fundamental reorganisation in all ecosystems" (Perrings et al., 1995). These levels are however unknown and with the reduction of diversity the possibilities for substitutions necessary for the preservation of functions under changing environmental conditions are decreased. Therefore the probability of the transition of the ecosystem into a different state arises (Perrings, 1998). This is the key importance of functional diversity in ecosystems (Fromm, 2000).

2.5 Mangrove goods, services, uses, benefits and values

The quality (genetic, species and ecosystem diversity) of mangroves drives the ecological processes that control the performance of environmental functions and therefore the supply of environmental goods, services and attributes. Use of these goods, services and attributes contributes to human benefits and the economic value they provide to end users (Figure 2).

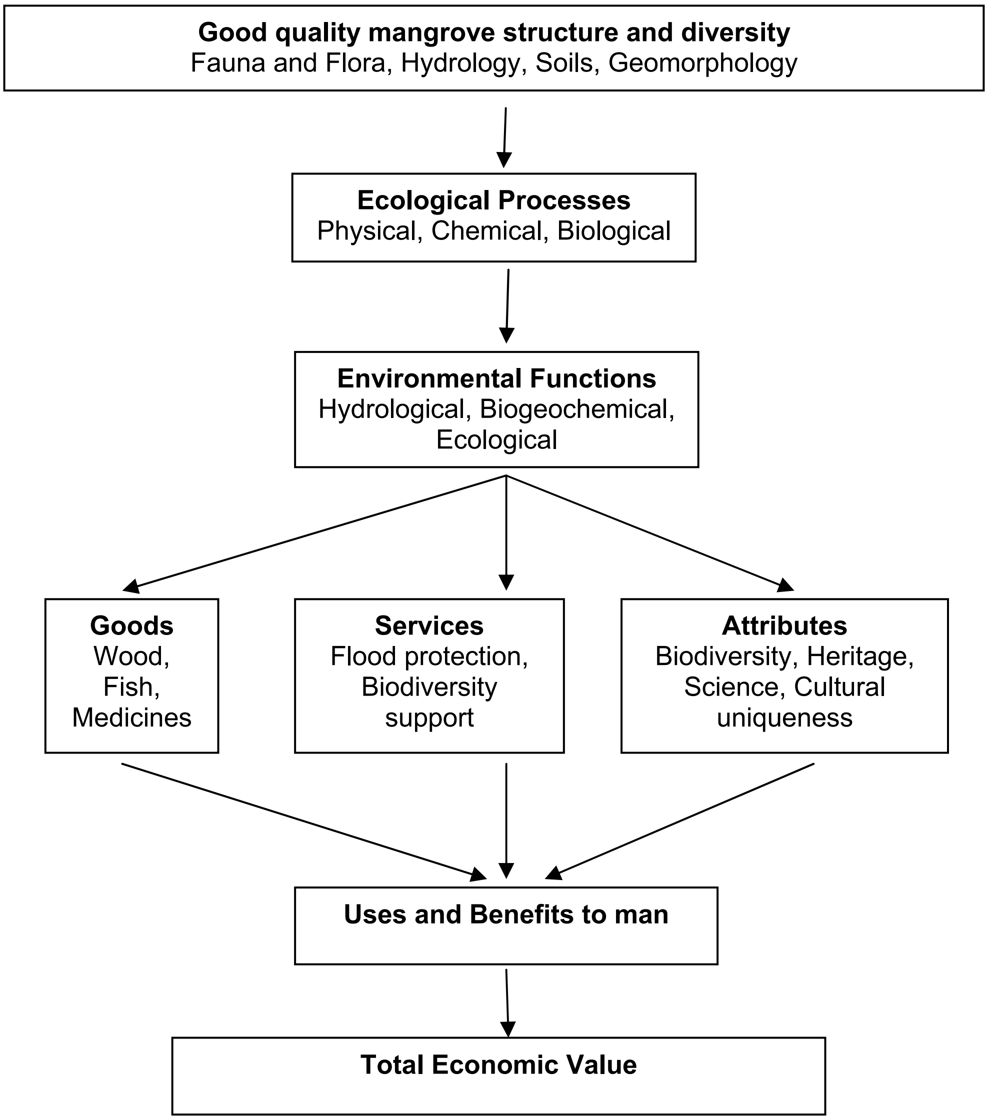

Figure 2 Diagrammatic representation of the links between mangrove structure and diversity and the supply of goods and services useful to man.

Environmental goods or resources can be supplied directly or indirectly. Directly produced goods include for example raw forestry materials such as wood for construction and fuel, fishery products such as crabs and gastropods and traditional medicinal resources (Table 2.10). Off-shore fish and shellfish, which use the mangrove ecosystem as a nursery and feeding habitat, are indirectly produced goods. Environmental services are processes or functions, which have value to individuals or society. They include sediment stabilisation and protection of shorelines from erosion (Table 2.10). The special attributes of a mangrove include its biodiversity and culture/heritage. They are not necessarily directly or indirectly used but are seen to have a value in themselves, enhanced by maintaining the mangrove in good quality.

These goods, services and attributes have economic values. Some can be traded using market mechanisms, but others cannot be so easily evaluated. The functions, attributes and values of mangrove biodiversity have only become recognised in the last decade, but are still difficult to quantify and are not yet widely appreciated.

Table 2.10: A summary of the main goods, services and attributes obtained from mangroves

Goods	Services	Attributes
Timber	Moderate storm impacts	Biological diversity
Fuelwood	Provide wildlife habitat (marine and terrestrial)	Socio-economic value
Fodder	Maintain biodiversity	Cultural value
Food	Dilute and treat wastes	Historic value
Nontimber products (e.g. medicines)	Provide harbours and transportation routes	Aesthetic value
Fish and shellfish	Provide human and wildlife habitat	Wilderness value
Fishmeal (animal feed)	Provide employment	Educational Value
Seaweeds (for food and industrial use)	Contribute aesthetic beauty and provide recreation	
Salt	Remove air pollutants, emit oxygen	
Drinking and irrigation water?	Sequester atmospheric Carbon	
Genetic resources	Cycle nutrients	
	Generate soil	
	Maintain array of watershed functions (infiltration, purification, flow control, soil stabilisation)	

2.5.1 Economic valuation of mangroves

Economic value

The value of a good or service placed by an individual or society through his willingness to pay using market price or other indicators

Economic valuation

Measuring the preferences of people or society for a good or service or against economic activity

Valuation

The process of placing monetary value on goods and services that do not have accepted prices. Many environmental gods and services (such as biodiversity) do not enter the market and therefore have no commonly accepted market price.

Direct use value

The productive or consumptive values derived from direct use or interaction with a biological resource which may be marketed or non-marketed

Indirect use value

The value of an environment's ecological functions which support or protect the life forms dependent on that environment, or an economic activity

Option value

The potential value of a resource for future (direct and indirect) use by protecting or preserving it today

Existence value

The benefit an individual or society receives from merely knowing that a good or service exists. Society's willingness to pay towards the conservation of biological resources for their own sake regardless of their current or optional uses.

Total Economic Value (TEV)

Comprises direct use value, indirect use value, option value and existence value

The mangrove ecosystem has important direct and indirect economic, ecological and social values to man. An important reason why mangrove ecosystems continue to be used in unsustainable ways is their economic value is not adequately represented in decision-making but also often economic valuations of mangroves have only included the direct uses and products of mangroves, for example forestry resources, but this represents only part of the total value of mangroves (Table 2.11). The non-market values, for example species biodiversity and off-site functions such as nutrient export, are not easily quantified but have shown to be significant (Table 2.12).

Table 2.11: The application of economic valuation to mangroves

		Location of Goods and Services	
		On-site or Direct use	**Off-site or Indirect use**
Valuation of Goods and Services	**Marketed**	Usually included in economic analysis, e.g., poles, charcoal, woodchips, crabs.	May be included in economic analysis, e.g. fish and shellfish caught in adjacent waters.
	Non-marketed	Seldom included in economic analysis, e.g., medicinal uses, fish nursery areas, feeding grounds for estuarine fish and shellfish, wildlife sanctuaries, biodiversity attributes, educational and research uses.	Usually ignored, e.g., nutrient flows to estuaries, buffer against storm damage, erosion control.

Modified from Hamilton and Snedaker (1984), Dixon (1991).

Valuation is complex and has a high level of uncertainty, due to a lack of knowledge of the processes as well as the fact that the processes are often intrinsically stochastic or chaotic. The total economic value of biodiversity assets is the sum of its use value (direct, indirect and future value) and non-use value (existence and bequest value). Assessing quantitatively indirect use value and non-use value components of biodiversity are very difficult and requires informed judgement rather than precise monetary calculations (Becker, 1999).

With the growing interest in mangrove conservation, there is an increasing scientific literature on the many values of mangrove forests (Table 2.12). These studies show that the on-site values of directly harvested products, such as fish, wood for charcoal and construction timbers, and tannins, often tend to be quite low relative to the total valuation at ecosystem level. For example, the off-site values for fisheries can be high (Leong, 1999), although such estimates involve significant uncertainty. Mangroves are also highly valued for coastal protection, the cost-savings (or avoidance costs) in reduced sea-dyke repair costs being one of the principal benefits provided by a coastal protection zone of mangroves, especially in storm-prone countries like Bangladesh and Vietnam (Macintosh, 1997). The role of mangroves in water quality control is still poorly understood, but replacing mangroves with other forms of water treatment can be extremely expensive.

Table 2.12: Comparison of Total Economic Value (TEV) from Different Mangrove Valuation Studies (USD ha^{-1} yr^{-1})

	Meilani, 1996	**Sathirathai, 1998**	**Cabrera et al 1998**	**Leong, 1999**	**Costanza et al 1997**
Components valued	3	4	4	7	5
Area (ha)	481.9	400	127,000	379	
Site	Mayangan Villages, West Java, Indonesia	Tha Po Village, Surat Thani, Thailand	Terminos Lagoon, Campeche, Mexico	Kuala Selangor, Malaysia	Global
Use Value					
Fisheries Resources	-	83	1,578	4,991	637
Aquaculture production	-	-	-	7,918	-
Forestry resources	-	-	1,082	-	230
Mangrove resources (local direct use)	765	141	-	102	-
Riverine resources	-	-	-	35[1]	-
Recreational benefits	-	-	-	915	496
Coastal protection	638 [2]	3,111	-	13,842	1,701
Nursery habitat	-	-	-	-	143
Carbon sequestration	-	85	-	-	-
Water filtration	-	-	1,193	-	-
Preservation value	1,785	-	1.02	33,554	-
Option value	(15)[3]	-	-	(40,622)	-
Existence value	(1,770)	-	-	(26,439)	-
Bequest value	-	-	-	(33,601)	-
Total Economic Value	**3,188**	**3,420**	**2,772**	**61,357**	**3,207**

Source: Leong, L. F. (1999). Notes: [1] Based on Chong, 1996, [2] Includes coastal protection (USD 637.9/ha/yr) and input of organic matter for shrimp production (USD 0.2/ha/yr), [3] Based on Ruitenbeek, 1994.

By undervaluing mangrove ecosystems, "development" has too often favoured their rapid conversion and loss. Mangrove conversion usually leads to short-term economic gain at the expense of larger, long-term ecological benefits and off-site values. The issue is how to decide between the true social and economic costs of mangroves and the potential gains from other uses? Further awareness should be generated on the potential value of mangrove ecosystems but also noting that not all mangrove ecosystems have the same structure and functions and therefore the same values for goods, services and attributes, such as forestry products, storm protection or ecotourism.

2.6 Reasons for mangrove conservation and management

Conservation

The protection of valued resources through the protection, management and care of natural and cultural resources.

The previous sections of this chapter have provided the background to the rationale as to why mangrove ecosystems should be conserved and managed wisely. This is a summary of the key points.

- To protect the unique biodiversity of mangroves
- The unique and valuable range of services and functions provided by mangrove forest ecosystems make them far more valuable than the sum of the products they generate
- Intact mangrove ecosystems can provide services that are significantly higher in value relative to alternative man made uses of land
- There are still many aspects of mangrove biodiversity that are not known and may provide further benefits to man
- To contribute to increased scientific knowledge through research on functional linkages
- Degradation of the mangrove ecosystem has had important environmental impacts on physico-chemical, biological and ecological properties that are sometimes not reversible
- There are complex linkages and interactions between the mangroves and other ecosystems and processes both upstream and downstream of the mangrove forest zone
- Protection of mangroves in their natural state provides an attractive habitat and species for sustainable, nature-based tourism, which is becoming a world industry and provides major benefits to local communities
- A refuge for intensely exploited or threatened species
- Protection of cultural diversity and livelihoods

3. APPROACHES AND INTERVENTIONS TO MANGROVE MANAGEMENT

This section describes some of the regulatory frameworks, laws and institutional responsibilities that have been adopted by various countries to protect mangroves. Examples from the country case studies in preparation are used to explain which measures are working well, and why, and the advantages and problems associated with each of the approaches and interventions described.

3.1 Background

The ecological, environmental and socio-economic importance of mangrove ecosystems is now widely appreciated amongst the scientific community, international agencies, governments, NGOs and coastal communities. The functional relationships between different ecosystems making up the coastal regions where mangroves are found underlie the need for a management approach that is much more integrated than has been achieved in the past. For this reason, the concept of Integrated Coastal Zone Management (ICZM) is defined below. While completely integrated management is rarely, if ever, achievable in practice, ICZM is a valuable developmental goal to set when considering the management of mangroves and other coastal resources.

Integrated Coastal Zone Management (ICZM)

A term used to describe a continuous and dynamic process that unites government and the community, science and management, sectoral and public interests in preparing and implementing an integrated plan for the protection and development of coastal systems and resources (GESAMP, 1996).

The approaches and interventions available to manage and conserve mangroves can be analysed conveniently by considering the various levels of administration involved, namely: International, National, State or Province, District or County, and Local Community (represented by e.g. villages or communes). Within each of these geographical/ administrative units, there are three main stages that can occur:

- Policy, planning and development
- Operation and management
- Restoration/rehabilitation

Regulatory and institutional frameworks play an important part in land use changes in coastal areas, but governance and institutional failure to effectively manage coastal resources can lead to a continuing loss and degradation of mangrove ecosystems. Poor planning, implementation and enforcement of coastal development plans are the other, and often-major causes of failure. Further problems arise when there are conflicting institutional responsibilities and/or policies and lack of co-ordination between different levels and sectors of government. Property rights and land tenure ownership are also critical factors in how coastal resources are used and managed.

3.2 International Level

Policy, planning and development.

At the International Level, the common approach to major environmental policy issues has been to formulate conventions, treaties and agreements, which all concerned countries become signatories to. These represent collective agreements among the international community over a common global or regional issue. International treaties provide a means of regulating access and exploitation of commonly shared resources, with potentially far-reaching impacts. Mangroves are today a global issue because more than 100 countries worldwide have mangrove resources (Spalding et al., 1997), while many other countries share concerns about the social and environmental consequences of trans-boundary investment in mangrove resources (e.g. in coastal oil exploration, fisheries and aquaculture) and international trade in mangrove products (e.g. shrimp and charcoal).

More than half a dozen international agreements and various regional agreements are directly relevant to the conservation of mangrove biodiversity. Some of the most important agreements are described in Table 3.1

There are a number of existing international frameworks available to help countries to conserve and manage mangrove biodiversity. These include (1) international agreements for regulating pressures on marine resources; (2) bioregional management approaches; and (3) protected area frameworks, such as the RAMSAR Convention and Man and the Biosphere (MAB) Programme. In the context of the coastal zone and mangrove forest ecosystems, one of the great advantages of these international protocols is that they can, in principle at least, be applied in trans-boundary situations. This is clearly important in many geographical settings worldwide where mangrove ecosystems traverse political boundaries. Ecosystems and species do not recognise political borders, which were usually defined for historical and geo-political reasons, without reference to ecological functions or processes. Protected areas that are established and managed across borders can therefore provide an important tool for coordinated conservation of ecological units and corridors. Examples include the Sundarbans mangroves shared by India and Bangladesh; the mangroves of the Kra Buri River system that separate southern Thailand and Myanmar; and the mangroves of the Gulf of Fonseca which is shared by Honduras and Nicuaragua.

Bioregional planning is one approach for dealing with transboundary issues and it is promulgated by the IUCN World Commission on Protected Areas (WCPA). Through this approach boundaries are adopted at the landscape scale. Within a bioregion there are three basic elements:

- **Core wild areas** that contain wild undomesticated plant and animal communities, and the habitat and site requirements needed for their survival
- **Buffer zones** adjacent to core areas where human communities manage land and resources in such a way as to minimize negative impacts on core areas
- **Corridors** that link core areas and buffer zones in a way that allows for plant and animal migrations and provide possibilities for changes e.g. those brought about by climate

Core wild areas, buffer zones and corridors are nested within bioregions where resident communities, landowners and resource users live and work. The goal of bioregional management is to establish, voluntarily, cooperative programmes across the entire region that provide appropriate treatment of those sites critical for biodiversity maintenance and restoration, while supporting local livelihoods and lifestyles (Pirot et al., 2000).

Co-operation between the respective countries national governments and possibly a number of international bodies is required. To optimise mangrove management compromises and a willingness on all sides to accept long-term management principles are necessary.

Table 3.1: Important International and regional agreements that are concerned with mangrove biodiversity conservation and management

Ramsar Convention on Wetlands of International Importance especially as waterfowl habitat Adopted in Ramsar, Iran February 1971 and came into force December 1975. It was the first modern global treaty on conservation and wise use of natural resources, now signed by over 110 countries. Legally binding agreement with the following objectives: • To promote the wise use and conservation of wetlands • To make environmental assessments before transforming wetlands • To establish nature reserves on wetlands • Through management to increases waterfowl population in appropriate wetlands
Convention on International Trade in Endangered Species of wild flora and fauna (CITES) Adopted in Washington, D.C. March 1973 and came into force July 1975 in response to the growing concern over large scale exploitation of wildlife for international trade which was threatening species with extinction. Aims to regulate international trade of wildlife (animals and plants dead or alive or any recognizable parts or derivatives of) threatened or endangered in the wild through a system of permits and controls.
The Convention on Biological Diversity (CBD) Adopted in Rio de Janeiro, Brazil, June 1992 and came into force December 1993. Signed by over 150 countries. Legally binding agreement with the three key objectives: • Biodiversity Conservation • Sustainable use of biodiversity • Fair and equitable sharing of the resulting benefits This Convention is the first global, comprehensive binding agreement to address all aspects of biological diversity: genetic resources, species, and ecosystems. It recognises - for the first time - that the conservation of biological diversity is "a common concern of humankind" and an integral part of the development process. To achieve its objectives, the Convention - in accordance with the spirit of the Rio Declaration on Environment and Development - promotes a renewed partnership among countries. Its provisions on scientific and technical co-operation, access to genetic resources, and the transfer of environmentally sound technologies form the foundations of this partnership. It requires countries to develop and implement strategies for sustainable use and protection of biodiversity and provides a forum for continuing dialogue on biodiversity related issues through the annual conference of the parties meetings. **The Ecosystem Approach** Adopted by the Conference of the Parties of the CBD, at its Fifth Meeting in Nairobi, 2000, as the primary framework for action under the Convention (decision V/6). It is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. Application of the ecosystem approach will help to reach a balance of the three objectives of the Convention. It is based on the application of appropriate scientific methodologies focused on levels of biological organisation, which encompass the essential processes, functions and interactions among organisms and their environment. It recognises that humans, with their cultural diversity, are an integral component of ecosystems.
Agenda 21 A comprehensive set of programmes of action to promote sustainable development into the 21st

century. Adopted, Rio, June 1992.

World Heritage Convention (WHC)

Adopted in Paris November 1972 and came into force December 1975. Convention concerning the protection of the World Cultural and Natural Heritage of outstanding value to humanity, monuments, groups of buildings, outstanding physical, biological and geological formations, habitats of threatened species of animals and plants, areas and sites with scientific, historical, archaeological, ethnological, anthropological, conservation or aesthetic value. By regarding heritage as both cultural and natural, the Convention reminds us of the ways in which people interact with nature, and of the fundamental need to preserve the balance between the two.

United Nations Framework Convention on Climate Change (UNFCCC) and The Kyoto Protocol

UNFCC was signed in Rio de Janeiro June 1992 and entered into force March 1994. The Kyoto Protocol was adopted in Kyoto, Japan December 1997 but has not yet come into force. “The ultimate objective of this Convention and any related legal instruments ..is.. stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system...within a time-frame sufficient to allow ecosystems to adapt naturally ... to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner".

Biodiversity conservation and maintenance is explicitly built into the UNFCCC as a part of the overarching objective. "'Adverse effects of climate change' means changes in the physical environment or biota resulting from climate change which have significant deleterious effects on the composition, resilience or productivity of natural and managed ecosystems or on the operation of socio-economic systems or on human health and welfare"

The Man and the Biosphere Programme and the Seville Strategy for Biosphere Reserves (MAB)

The intergovernmental UNESCO Conference on the Conservation and Rational Use of the Biosphere in 1968 gave rise to the Man and the Biosphere (MAB) Programme which is an interdisciplinary programme of research and training intended to develop the basis, within the natural and the social sciences, for the rational use and conservation of the resources of the biosphere, and for the improvement of the global relationship between people and the environment. UNESCO, 1986 and Seville, Spain March 1995.

<u>The Biosphere Reserve concept</u> was a key component for achieving MAB's objective to strike a balance between the apparently conflicting goals of conserving biodiversity, promoting economic and social development and maintaining associated cultural values. Biosphere reserves are areas of terrestrial and coastal/marine ecosystems or a combination thereof. Each reserve is, through appropriate zoning patterns and management mechanisms, intended to fulfil three complementary functions:

- A conservation function (to preserve genetic resources, species, ecosystems and landscapes);
- A development function (to foster sustainable economic and human development), and;
- A logistic support function (to support demonstration projects, environmental education and training, and research and monitoring related to local, national and global issues of conservation and sustainable development).

To carry out the complementary activities of nature conservation and use of natural resources, Biosphere Reserves are organised into three interrelated zones:

<u>A core area</u> that should be legally established and sufficiently large to meet the particular conservation objectives (i.e. give long-term protection to the landscape, ecosystem and species it contains). There may be several core areas in a single Biosphere Reserve to ensure a representative coverage of the mosaic of ecological systems. Normally, the core area is not subject to human activity, except research and monitoring and, as the case may be, to traditional extractive uses by local communities;

<u>A buffer zone</u> (or zones) which is clearly delineated and which surrounds or is contiguous to the core area. Activities are organised here so that they do not hinder the conservation objectives of the core area but rather help to protect it, hence the idea of "buffering". It can be an area for experimental research, for example to discover ways to manage natural vegetation, croplands, forests, fisheries, to enhance high quality production while conserving natural processes and biodiversity, including soil resources, to the maximum extent possible. In a similar manner, experiments can be carried out in the buffer zone to explore how to rehabilitate degraded areas;

A transition zone, constituting the area of co-operation that extends outwards, and which may contain a variety of agricultural activities, human settlements and other uses. It is here that the local communities, conservation agencies, scientists, civil associations, cultural groups, private enterprises and other stakeholders must agree to work together to manage and sustainably develop the area's resources for the benefit of the people who live there. Given the role that Biosphere Reserves should play in promoting the sustainable management of the natural resources of the region in which they lie, the transition area is of great economic and social significance for regional development.

The three zones are usually implemented in many different ways to accommodate local geographic conditions and constraints. This flexibility allows for creativity and adaptability, and is one of the greatest strengths of the concept. It should be noted that a number of BR simultaneously encompass areas protected under other systems (such as national parks or nature reserves) and other internationally recognised sites (e.g. World Heritage or Ramsar sites). At present there are 408 reserves in 94 countries.

Marine Protected Areas (MPA)

In 1986, the IUCN Commission on National Parks and Protected Areas (CNPPA) began promoting the establishment and management of a global representative system of marine protected areas. IUCN defines MPA as "any area of intertidal, subtidal terrain, together with its overlying water and associated flora and fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment" (Gubbay, 1995).

United Nations Convention on the Law of the Sea (UNCLOS)

An international agreement that sets conditions and limits on the use of and exploitation of the oceans. This convention also sets how the maritime jurisdictional boundaries of the different member states are set. UNCLOS was opened for signature on December 10, 1982 in Montego Bay, Jamaica and it entered into force on November 16, 1994. As of January 2000, 132 countries have ratified UNCLOS. Under UNCLOS, coastal states can claim sovereign rights over a 200-nautical mile exclusive economic zone (EEZ) in terms of exploration, exploitation, conservation, and management of all natural resources in the seabed, its subsoil, and overlaying waters.

UNEP Conference on Protection of the Marine Environment from Land-Based Activities.

This agreement provides an action plan for controlling pollution, habitat destruction, and other land-based activities affecting coastal and marine ecosystems. It is not binding but provides a framework for addressing some of the most significant stresses on marine species and ecosystems.

Food and Agricultural Organization (FAO) Code of Conduct For Responsible Fisheries (1995)

This Code is voluntary but certain parts of it are based on international law. The code is global in scope and is directed towards members and non-members of FAO, fishing entities, subregional, regional and global organizations, whether governmental or non-governmental, and all persons concerned with the conservation of fishery resources and management and development of fisheries, such as fishers, those engaged in processing and marketing of fish and fishery products and other users of the aquatic environment in relation to fisheries.

The Code "sets out principles and international standards of behaviour for responsible practices with a view to ensuring the effective conservation, management and development of living aquatic resources, with due respect for the ecosystem and biodiversity". The Code also recognises the nutritional, economic, social, environmental and cultural importance of fisheries and the interest of those concerned with the fishery sector.

Operation and management

While international cooperation at the policy and planning stages is usually successful, conflicts between neighbouring countries or states are more common at the operational stage due to different development priorities and economic interests. For example, destructive activities such as diversion of freshwater for irrigation, logging, or mining in upstream locations may seriously affect the ecology of mangroves in another (downstream) part of the system. Similarly, a foreign or trans-national company exploiting natural resources, such as oil or minerals, in or near a mangrove ecosystem may destroy the mangroves because they have a low perceived value compared to the products they are extracting. Examples include coastal oil exploration in Nigeria by international oil companies, and the exploitation of mangroves in Malaysia and Indonesia for wood chip to manufacture rayon by Japanese companies (Ong, 1982).

In general marine ecosystems receive far less protection than their terrestrial counterparts. Mangroves in particular are difficult to segregate into whether they are terrestrial forests or marine parks. Almost 20 years ago Saenger et al. (1983) noted that international agreements on national management plans for mangrove resources were becoming an increasingly urgent matter, and they remain so today. The debate surrounding the global trade in shrimp, much of which is produced in countries where large areas of mangrove have been converted to shrimp farms, is the leading current example of this issue.

Methods for international and regional management of mangroves include Marine Protected Areas (MPAs), Bio-regional management, Transboundary Protected Areas (TPA) and Biosphere Reserves (BR). The use of protected areas for conservation management has many advantages for mangroves and other coastal ecosystems. Spalding et al. (1997) reviewed the global status for mangrove conservation: *"There are 685 protected areas containing mangroves globally, distributed between 73 countries and territories. Countries with very large areas of mangroves have a significant number of protected areas notably Australia (180), Indonesia (64) and Brazil (63). However, Nigeria also with very large areas of mangroves does not have any within legally gazetted areas. The actual area of mangrove habitat protected though cannot be calculated because statistics are rarely available."*

There is also limited information about the effectiveness of MPAs. The 1995 report on the global assessment of MPAs revealed that most MPAs are much too small to encompass the breeding, nursery and feeding areas of many of the species found within them and thus adequately protect them and that many globally unique habitats receive no protection (Kelleher et al., 1995).

Examples of Bio-regional management vary in scale and focus. The concept includes integrated coastal zone management programs that offer a means of co-ordinating activities of the various government agencies and other institutions charged with coastal zone management. Within a number of countries policy makers and managers have moved from a sectoral approach to managing marine resources towards an integrated, total ecosystem strategy for regulating coastal development, fisheries harvesting and other practices affecting marine biodiversity.

The number of Transboundary Protected Areas (TBPAs) is now growing around the world. In 1988 there were only 59 such areas, mainly concentrated in Europe and North America: by 1997 this figure had grown to 136, distributed through all regions of the world (World Conservation Monitoring Centre (WCMC), 1998). Several factors have influenced this growth, including greater support from donors and international assistance for the establishment of TBPAs to enhance biodiversity conservation and sustainable resource use at an ecosystem scale.

Biosphere Reserves also deal with transboundary issues through adopting specific management schemes for different zones (core, buffer and transition areas). Biosphere reserves encompass one or more strictly protected core areas plus surrounding buffer zones, where limited extractive activities are permitted (Table 3.1).

Restoration/rehabilitation

Strong international support has been given to mangrove rehabilitation efforts in those countries and regions most affected by the destruction of mangrove forests. International cooperation in the Asia-Pacific region has been particularly effective with many countries sharing knowledge from many years experience of mangrove planting for reforestation purposes. International NGOs are the leading agencies in mangrove rehabilitation for example the Danish Red Cross (DRC, 1994) and the UK Save the Children Fund (Macintosh et al., 1998) started mangrove planting in Vietnam. Donor agencies have also contributed significant financial funds to help developing countries; for example the World Bank and Danida for restoring and protecting 50,000 Ha of mangrove forest in the lower Mekong Delta in Vietnam.

3.3 National Level

Policy, planning and development

Historically the responsibility of mangrove management at the national level has been assigned on a sectoral basis to executing agencies of the government, institutions for example Forestry, Fishery or Agriculture Departments. The agencies responsible for administering mangroves differ between each country and even between states and districts within countries (Table 3.2).

Table 3.2: Agencies with jurisdiction over and responsibilities for mangroves in various countries in SE Asia

Country	Overall Jurisdiction	Additional Responsibilities
Malaysia	Forestry Departments of each Malaysian State	Malaysia NATMANCOM
Philippines	Department of Environment and Natural Resources	Ministry of Natural Resources (Forest Research Institute, Bureau of Forest Development, Bureau of Fisheries and Aquatic Resources) Philippines NATMANCOM
Thailand	Royal Thai Forest Department (Ministry of Agriculture and Cooperatives)	National Research Council of Thailand Department of Fisheries Thailand NATMANCOM
Vietnam	Ministry of Agriculture and Rural Development (MARD)	Ministry of Science, Technology & Environment

NATMANCOM = National Mangrove Committee

Sectoral management has inevitably resulted in prejudices regarding their objectives, leading to conflicts of interest, to unsustainable resource use, and to poor and less powerful groups becoming more disadvantaged and disenfranchised (Brown, 1997). These limitations are now recognised as a major constraint to achieving sustainable development of mangrove resources. However, there is still resistance to change due to the entrenched nature of some sectoral interests and their perception of loss of status, autonomy and income under an integrated management approach involving other stakeholders. National Mangrove Committees (NATMANCOM) have been set up in some countries to advise the government. These NATMANCOMs comprise of academics that advise the national government.

At the national level governments should be encouraged to ratify international and bioregional conventions and agreements, and to bring them into law so that they are also legally adopted at national level. The formulation and implementation of adequate legislation and policies concerning biodiversity management of mangrove ecosystems is up to the government, but appropriate stakeholder participation must be arranged at both the planning and implementation stages. In the majority of countries, the major stakeholders will include most of the following sectors: forestry, fisheries, aquaculture, tourism, agriculture, mining and industry with, in many cases, representation from both the public and private sectors. In addition, jurisdiction over land and the environment may lie within other governmental departments, while other specialist authorities, and even the military, are commonly responsible for ports and harbours, other coastal infrastructure and navigation. Some national governments have established MPAs and many have identified priorities for protection in documents such as national environmental action plans and national conservation strategies.

Operation and management

Despite the shortcomings of sectoral management, there are a few good examples where sustainable utilisation of mangrove resources (= sustainable harvest or economic return, while at the same time maintaining the resource in a natural, or as close to its original state as possible) has been achieved through the efforts of a single sectoral authority. The management of the Matang Mangrove Forest Reserve in Malaysia is a very good example of sustained yield management for forestry and is widely referred to as the best managed mangrove forest area in the world, given its long history.

Sustained yield management for forestry - Matang Mangrove Forest Reserve (MMFR), Peninsular Malaysia.

Sustainable management has been achieved in the MMFR for 100 years, since the area approximately 40,000 ha was reserved in 1902, for the production of charcoal, firewood and poles. The clear management objective and Ten Year Working plans have contributed to the success The silvicultural operation runs on a 30 year rotation with thinnings at 15 and 20 years. The forest is subdivided into blocks of a few hectares, which are allocated to charcoal companies. Each block is clear-felled, leaving a 3 metre strip on the shoreward side to prevent erosion of the bank. The timber is cut into logs of a standard length which are transported by boat to the charcoal kilns at a nearby village. Due to the way the blocks are allocated for clear-felling, they are always surrounded by a mature forest so repopulation with mangrove propagules occurs rapidly. The debris (brances and bark) resulting from the clearing takes about two years to decompose. After one year the site is inspected and, if less than 90% of the areas is covered by natural regeneration, repopulation is assisted by artificial planting. Local villagers are contracted to rear suitable seedlings in small nurseries for this purpose. *Rhizophora apiculata* is the preferred species for charcoal and is planted at 1.2 m intervals. Any weeds, for example the mangrove fern *Acrostichum* spp., are destroyed by hand using chemical weed-killers. After 15 years the young trees are thinned to a distance of 1.2 m to prevent overcrowding and the timber removed is used for fishing poles. After 20 years the stand is again thinned to a distance of 1.8 m and the resulting timber used for the construction of village houses. Finally, after 30 years the block is clear-felled for charcoal production (Gan, 1995).

Restoration/rehabilitation

Many countries in SE Asia are now implementing restoration and rehabilitation of mangrove areas at the national level. In Vietnam, the 3.2.7 project and the 5 million hectare project are examples of national projects under direction from the government. One problem, however, is that such projects often have ambitious objectives, but are under resourced financially and technically. In particular, resources for monitoring the survival and growth of mangroves after planting are required, plus community education and awareness raising to ensure the restored areas are adequately protected in the longer term.

3.4 District Level

The local government operates at district level in many countries (similar equivalents in other countries include county authorities, or have local names e.g. Upazilla in Bangladesh, Amphur in Thailand).

Policy, planning and development

District/county authorities are commonly responsible for local land allocation and for the interpretation of national land policies. In Vietnam, for example, the district government operates a land department and makes important decisions on the allocation of coastal land for economic use (e.g. for aquaculture, tourism).

Operation and management

District offices are often lacking in technically trained staff and environmental issues are not usually regarded as a priority over economic development. It is therefore vitally important to involve the appropriate district departments in the planning and management of mangrove conservation efforts and to encourage them to act as the official point of contact for the local communities involved.

Restoration/rehabilitation

The attitude and interest of the District officer/chairman is often a key factor in how well conservation policy and local initiatives in mangrove restoration/rehabilitation are supported officially. With the support of the government at the District level mangrove conservation and management can be a success. An example of a success story is in the Philippines, where the local government unit (LGU) through the Municipal Mayor initiated the idea and supported mangrove reforestation in Buswang, Aklan.

3.5 Community Level

The ecology of coastal lands and coastal waters provides numerous livelihood opportunities, encouraging concentrations of populations and development activities (Brown, 1997). About 60% of the world's population live within 60 km of the sea (WRI internet). The livelihoods of coastal people are based upon the exploitation of both terrestrial and aquatic resources, for example timber and fuelwood and fish and shellfish. It is often the poorer people that are forced to generate a livelihood from coastal areas (DFID, 1998).

The expansion of markets has driven exploitation of natural resources to extremes in some places, where levels of investment create imbalance between alternative uses for the same resource (e.g. shrimp farms in the Philippines). In such cases the poor can be made poorer. Sustainable livelihoods for coastal communities are therefore dependent upon effective management of all interrelated activities in coastal areas to achieve sustainable use of both living and non-living resources, and equitable sharing of the benefits arising (Brown, 1997).

Policy, planning and development

Local coastal communities are playing an increasing role in planning and development of mangrove biodiversity conservation and management in certain regions through consultations and co-ordinated actions with international, national and district level institutions. Government policies have also changed in some countries, for example the Philippines introduced a Community Based Mangrove Forest Management Agreement (CBMFMA) in 2000 (DENR AO 2000-57). The CBMFMA gives the local communities a lease of the land for 25 years with the possibility for renewal for a further 25 years.

Where the local communities have played a key role in policy, planning and development the management of the mangrove area has been a success. Local policy and planning initiatives depend primarily on a strong local community organisation and participation and also official government recognition and support for the initiative. Good examples of such cooperation involving the local community, government backing and NGO support, can be found in the Philippines and Thailand as described below.

The Buswang Mangrove Reforestation Contract Project in the Philippines had enjoyed the full support of the government both district and national from the start. However, for the Yadfon Association in Southern Thailand official government recognition and support for the mangrove rehabilitation and conservation management was only achieved after successful results. A local NGO can help tremendously in local community planning and development initiatives and was a crucial factor for both the examples in the Philippines and Thailand.

Property rights have profound consequences for the patterns of resource use and management. Land tenure is a critical factor in how people manage and use the resources. The changes in land use over time and willingness to participate in rehabilitation efforts are related to these. In Vietnam the local peoples interest in participating in mangrove reforestation was severely constrained by the lack of land ownership by the local people. As tenants with limited ownership rights, poor farmers were unwilling to invest in mangrove management and opted for short term economic benefits from shrimp aquaculture. In South Sumatra there has been some resistance among the local people to the replanting of mangroves because the status of the trees would revert the land to the government of Forestry Service once the trees become productive. This is unacceptable to the local community members that are currently making a living in these areas.

<u>Operation and management</u>

Community-based mangrove management can be initiated from the local communities themselves if they see other successful rehabilitation programmes in the surrounding area. In most instances though community-based mangrove management is firstly promoted by local or international NGOs or government departments. Local NGOs involved in mangrove management projects often play the role as advisor, monitor and evaluator of the community project activities. The reasons for the success of the Buswang project in the Philippines was because the local NGO helped monitor the project, provided training courses for the families in leadership, development, enterprise management, environmental awareness, environmental laws and enforcement and suggested alternative livelihoods that were non-destructive to the mangrove.

<u>Restoration/rehabilitation</u>

One common reason for mangrove restoration and rehabilitation is to protect the coastal communities from typhoons. Examples of communities observing the benefits of mangrove rehabilitation and supporting such efforts include projects in the Red River Delta, Vietnam and Visayas, Philippines.

3.6 Other issues

- Ecotourism

Tourism is one of the fastest growing sectors of international trade and a powerful tool for national development but also has potential for social upset and environmental damage, for example pollution, clearing of forests for roads and infrastructure developments, drugs and prostitution (Clark, 1998). There are many forms of tourism but ecotourism or nature-based tourism should be promoted because it *reduces the negative social and environmental impacts of tourist visits* to an area. There are many definitions but ecotourism should incorporate a natural destination and provide direct financial benefits for *conservation* be it in the form of a reserve or reforestation. Protected areas are extremely attractive for tourists to visit, but it is important to know that the purpose of a protected area is to maintain habitat for flora and fauna, allowing species to exist and thrive without human interference. Whenever visiting a protected area, the visit should be made with minimal impact.

The mangrove ecosystems are a unique land/water interface, so there are many tourist activities. For example, hiking in the forest, bird watching, fishing and boat cruises. The diversity of landscapes, species and history of Can Gio mangrove forests attract Vietnamese people and foreigners. A key factor is it is easily accessible by road and ferry from Ho Chi Minh City. Therefore Can Gio Biosphere Reserve is an ideal destination for sightseeing, relaxation, study and ecotourism. The number of visitors to Can Gio has increased steadily in recent years and this trend is expected to continue as better transportation and other facilities are established

Table 3.3: Number of tourists visiting the Can Gio mangrove forests, Vietnam

	Number of visitors		
Year	**Vietnamese**	**Foreigners**	**Total**
1996	3,644	No data	
1997	26,999	221	27,220
1998	37,956	359	38,315
1999	42,004	232	42,236
2000	140,000	365	140,365
2001 (Jan-Jun)	116,300	50	116,350

- Environmental Law

Enforcement of laws is difficult due to conflicts of interest. Conflicting perspectives of various groups on environmental issues spawn many legal cases. These include the concept of land, the rights and obligations arising from land and resources, open access versus common property systems, and modes of natural resource management. It will be the judiciary that will help solve conflicts. Courts are the best place to resolve disputes in environmental justice. In their mandated role as legal arbiters, judges face the difficult challenge of striking a balance between economic development and the environment.

Professor Marvic Leonen, Department of Constitutional Law of the Philippine Judicial Academy "*The environment is about people, but unfortunately people in poor villages are often at the losing end of environmental battles due to the resources used against them by wealthy corporations*".

With rapid developments in the environmental arena and growing awareness of people's rights, more environmental conflicts will arise and thus environmental cases, therefore judges need a commanding knowledge of the emerging body of environmental law, in order to respond to cases effectively. Judges need to be able to veer away from traditional methods and find creative ways of resolving disputes as they step into a new role as guardians of natural heritage. As more environmental cases are filed at the local level, municipal and regional trial court judges have the unique opportunity of creating new jurisprudence that could change the way the legal system resolves disputes in this relatively new field. Laws need to cross state boundaries, need to be malleable to protect environment. The

Environmental Law Alliance Worldwide (ELAW) is an extensive communications network of public interest environmental lawyers around the world, which aims to assist in the expansion and effective implementation of policy and jurisprudence on environment and conservation through shared experiences and models from many jurisdictions.

3.7 Concluding remarks and lessons learnt

There is no general blueprint for the management and conservation of mangrove biodiversity. Each country and each region reveals its own unique set of issues for consideration. There are also advantages and disadvantages to each approach to management whether it be at the community level, the district level, the national government level or the international level (Table 3.4).

Table 3.4: Comparison of approaches to mangrove management

Approach	Advantages	Disadvantages
Community level	Sensitive to community needs Can be ecologically based Reasonably simple decision making, forward planning and enforcement	Problems with legislation and lack of funding Prone to corruption Lack of knowledge
Single national body	Sensitive to community needs Can be ecologically based Allows direct scientific input Reasonably simple decision making, forward planning and enforcement	Can be pressured by minorities May have narrow approach Unwillingness to enforce No objective, built in system of checks and balances
Several national or regional bodies	Inputs from many directions Development proposals can be staled in the system	Less sensitive to community pressure Inputs may be diluted Demarcation problems Cumbersome decision making, forward planning and enforcement Ecosystem may be split arbitrarily Split jurisdictions, sometimes overlapping, sometimes conflicting
Transnational Body	Availability of international development funds	Little sensitivity to community needs No sensitivity to ecological consequences Motivation largely paternalistic and economic No political responsibility No constituency

Modified from Saenger et al. (1983)

However, a number of lessons can be learnt from the practical experiences of mangrove management country to country, which have broad application in most situations involving mangroves. From these, a general framework can be proposed as a basis for developing a Code of Conduct for the sustainable management of mangrove ecosystems.

Regulatory frameworks, laws and legal status and institutional responsibilities often exist but usually break down and this is where the problems lie. It is necessary for as many countries as possible to provide whatever experiences they have had in implementing protection for mangrove ecosystems. These experiences and their applicability and constraints, need to be analysed and shared so that lessons can be learnt and better guidance can be provided for the future.

Examples of the lessons already learnt, that can be applied to increase the effectiveness of mangrove conservation and restoration efforts, include the following:

- Effective on the ground management is needed for successful implementation
- A close working relationship with local people and a sense of ownership should be promoted
- Awareness raising among all stakeholders is an important aspect of any conservation effort involving mangroves
- Potential economic benefits are important incentives for mangrove conservation/restoration

4. IMPLEMENTATION GUIDELINES FOR MANGROVE BIO-DIVERSITY CONSERVATION AND MANAGEMENT

Realising the importance of the mangrove ecosystem for fishery production, coastal stabilization, maintaining critical habitats for many common, threatened and endangered species, generating economic opportunities and providing people with products for subsistence and survival, the following recommendations are made to international, regional and national organisations whether governmental or non-governmental, and all persons concerned with the conservation and management of mangrove resources. The recommendations are made at the policy, planning and development stage, the operation and management stage, the rehabilitation stage and other important issues for mangrove biodiversity conservation and management are also high lighted.

Policy, planning and development

4.1 International Collaboration

Immediate steps for action to strengthen mangrove conservation by government agencies can be taken by enhancing international collaboration. All institutions should increase their international involvement in wetland conservation (Dugan, 1990). All countries should join the Ramsar convention and Convention on Biological Diversity which provide an especially important mechanism for collaboration.

Opportunities for exchange of information and transfer of technology in mangrove conservation and management should be sought out and promoted.

Government conservation agencies should assist development assistance institutions to review the impact of current policies and practices on mangroves and modify those that have a negative impact. They should build upon this to develop a series of activities that support mangrove conservation actions in developing countries, in particular those that are contracting parties of the Ramsar Convention (Dugan, 1990).

A greater flow of information between international institutions is desirable, as well as a regular programme review meetings where opportunities for cooperation could be identified.

NGOs should encourage their Government to join the Ramsar Convention and to use the Convention as a means for increasing international support for wetland conservation (Dugan, 1990).

4.2 Strengthen the legislative framework for management of mangrove diversity

Countries should provide adequate legislation for the protection of mangrove resources.

Countries should have a structured mechanism for effective federal and state collaboration.

Mechanisms should be formulated for co-operation and co-ordination between the different stakeholders involved in mangrove management.

Co-ordinated policies should be developed.

Implement and monitor policies and make adjustments where necessary to ensure objectives are met.

Improve the accessibility and understanding of legislation as the lack of available information or confusion can lead to the marginalisation of certain groups. A recommendation would be to inventory, publicise and popularise laws through the mass media, workshops and the provision of community based legal training advice centres.

Although Governments set national policies, NGOs have provided leadership by reviewing agricultural, water, tax and other policies leading to mangrove loss, by recommending changes, and by promoting their conclusions to the wider public. In support of Governments' work in this field, NGOs should if necessary take the lead in policy review. Many NGOs own and manage mangrove reserves and have developed innovative management measures for mangrove ecosystems. NGOs should identify critical mangrove sites and management problems not covered adequately by government measures, and pursue action to protect and manage these sites effectively. In some instances this will mean acquiring the sites, while in others it will mean encouraging governments to do so (Dugan, 1990).

4.3 Development of National Mangrove Plans

For proper management of a nation's mangrove resources a National Mangrove Plan is an essential priority (Saenger et al., 1983). See Table 4.1 for details. Each country with mangrove resources is urged to develop a National Mangrove Plan. Countries that have not yet formed a National Mangrove Committee (NATMANCOM) are urged to do so. These committees will be an expert group (from e.g. local NGOs and Universities) that should help develop the National Mangrove Plan.

Table 4.1: Development of a National Mangrove Plan

1	Define the total national resource by means of maps and inventories (Area and distribution of mangrove flora and fauna, physical aspects, quantification of yields, economic valuation and socio-economic structure of mangrove people)
2	Assess peoples needs in relation to sustainable uses of the resource while ensuring adequate reserves for preservation purposes
3	Assess the national and international significance of the resource in relation to: waterfowl migration, genetic reservoirs, regional and sedimentary stability and marine species migration
4	Define the criteria which must be satisfied for non-sustainable uses of the resource prior to any allocation of the resource to such an activity
5	Use 1 to 4 to define the areas necessary for sustainable uses and to define the areas for preservation
6	Define strategies necessary for the management and preservation of the nation's mangrove resources

Source: Saenger et al. (1983).

4.4 Preservation

In 1983 Saenger et al. reported "the opportunities to protect pristine mangrove areas are rapidly disappearing and it is important that governments act quickly and establish reserves which are representative of the untouched mangrove forests of their country as well as reserves that will protect unique and threatened species." Twenty years later such action is even more imperative. Mangrove areas recommended for preservation/conservation or to be declared as mangrove forest reserve are shown in Table 4.2.

Table 4.2: Mangrove areas recommended for conservation

1	Mangrove forests which are primary/pristine	Regardless of location virgin mangrove forest should be preserved or declared as forest reserves because these areas are important in maintaining ecological balance in the mangrove ecosystem. These areas are also needed for riverbank and shore protection, wildlife sanctuaries and for educational and research purposes.
2	Mangrove areas subjected to significant environmental hazards for example storms, erosion, floods	Mangrove forests which act as natural barriers/buffers against shore erosion, strong winds and storm floods should be left untouched.
3	Mangrove areas near or adjacent to traditional productive fry and fishing grounds	Considering the importance of mangroves for breeding, spawning and nursery grounds for a variety of fish and shellfish mangroves near or adjacent to traditional productive fry and fishing grounds should not be alienated or released for development.
4	Mangrove areas near populated areas/urban centres	These mangrove areas should be conserved for utilization by people either those who are dependent on the mangrove forest products for their livelihood/ domestic needs (e.g. firewood, crabs, molluscs) or for tourism.
5	Mangrove forests on small islands	These mangroves serve as a major ecological component of the island ecosystem and should in no case be disturbed.
6	Mangrove areas adjoining the mouth of major river systems	To maintain the ecological balance of estuarine areas there should be buffer zone areas of mangroves preserved on both sides of the mouth of the river fronting the sea.

Modified from: National Mangrove Committee of the Philippines

In countries where pristine mangrove areas no longer exist, the priority should be to protect any stands of mature mangroves that are reproductively viable. Even in disturbed areas, reproductively active trees and shrubs are valuable because many mangrove species have good dispersal mechanisms (floating, saltwater tolerant fruits or propagules). Similarly, the pollination of mangrove flowers is aided by insect and bat pollinators in the case of *Sonneratia* species, while other mangroves are wind-pollinated.

Mangrove stands that are reproducing well are particularly valuable as a source of propagules and seedlings for planting out in rehabilitation areas. Mangrove species of the family Rhizophoraceae are used for most restoration projects and trees of all the main groups within this family produce distinctive, spear-shaped propagules (*Rhizophora, Bruguiera, Ceriops*, *Kandelia*). While these are easy to collect, lack of an adequate supply of propagules, in terms of both quantity and quality, has been a common reason for the poor success of many rehabilitation projects. The sourcing of propagules can be very problematical in regions where there is little mature forest left, consequently the identification and protection of good seed-producing forest stands is a vital aspect of mangrove conservation.

Operation and management

4.5 Integrate all levels of sectoral planning and decision making

Coordination and facilitation of contacts between stakeholder institutions and individuals is a key feature of mangrove management and will usually determine the eventual success of a project. Cooperation should be promoted among the different sectors and stakeholders, government, private sector and local community groups to achieve common objectives.

Interdisciplinary teams charged with planning and implementing mangrove management should be formed. One carefully chosen organization should take a lead role in facilitating coordination.

Pirot et al. (2000) suggest the characteristics of a lead agency should include:

- willingness and capacity to take on role of lead agency
- an understanding of mangrove ecosystem management
- an appreciation of the role of the local and traditional knowledge in management
- an appreciation of the importance of involving local communities in management
- negotiating, participatory and facilitation skills
- ability to establish and provide a point of coordination for the network of stakeholders
- high degree of political sensitivity

"The lead organization cannot direct what is to be done and should not use its position to usurp the responsibilities of other participants. Instead it has to facilitate the actions and responsibilities of others, without being unduly influenced by its own vested interest. Lack of sensitive coordination will lead to confusion and inaction that, in turn, will hinder the achievement of project objectives" (Pirot et al (2000).

There should be a close working relationship with the local people

Cooperation among sponsoring and donor agencies is also an important factor and must be integrated with overall efforts to ensure coordination amongst stakeholders.

4.6 Institutional Capacity Strengthening

Need for an effective institutional mechanism that co-ordinates the activities and objectives of all government agencies involved with mangrove management.

It is important to have effective implementation on the ground and enforcement of laws should be a top priority.

It is urgent need to develop local expertise in mangrove economics and all agencies should have training and awareness programs. Each country should review the management capacity of its personnel. Priorities for training should be selected and appropriate institutions and courses identified. Training institutions should review current courses in mangrove resource management and examine how they can be improved.

Capacity building should also include assisting stakeholders (local communities and community based organizations, government agencies and departments, university departments, research institutions, private companies, national and international NGOs) to increase their capability to participate in mangrove management. For example by providing boats, or boat repair facilities to fishermen and enforcement officers, or by providing equipment to monitor water pollution.

Restoration/rehabilitation

4.7 Rehabilitate and restore degraded ecosystems and promote the recovery of threatened species

The FAO Code of Conduct For Responsible Fisheries (1995) states in Article 6.8 that "All critical fisheries habitats in marine and freshwater ecosystems, such as wetlands, mangroves, reefs, lagoons, nursery and spawning areas, should be protected and rehabilitated as far as possible and where necessary."

Streever (1999) defines rehabilitation as including both restoration and creation. Restoration is the return of a former mangrove forest area to forest cover through hydrological restoration and either followed by planting of seeds, seedlings or saplings or allowed to naturally recolonize. Creation is the establishment of mangroves by converting existing non-mangrove habitats (uplands, mudflats) through activities by man namely establishment of appropriate hydrology and planting.

Any rehabilitation project should seek to restore maximum benefits at the minimum cost. There are a number of methodologies for rehabilitation that can be used and are predictably successful (PCARRD, 1991; Lewis and Marshall, 1997; Turner and Lewis, 1997; Lewis and Marshall, 1998; Lewis, 1999). The costs range from USD 200-700 per ha (Table 4.3). After review of the rehabilitation options the process is inexpensive relative to the benefit. However, the problem of technology transfer and application of best practices is still an important management issue.

Table 4.3: Examples of mangrove rehabilitation projects and estimates of mangrove restoration costs

Location and project	Planting details	Basis of cost estimate	Average cost (USD/ ha)	Source
Florida and Texas, USA	Various	Synthesis of all projects. Excavation and planting of seedlings at all sites in most cases	45,000	King and Bohlen (1994)
Indian River Lagoon, Florida USA	No planting, just hydrological restoration	All costs including design, permitting, construction and monitoring	225	Brockmeyer et al (1997)
Pattani, Southern Thailand	Mixed species plantings from seedlings	Direct planting costs only. All project costs included	288 958	Wetlands International
Don Sak National Forest Reserve, Surat Thani, Thailand	Primarily *Rhizophora apiculata* propagules	Actual costs from records of expenditure. No monitoring	709	Lewis et al (in press)
Mekong Delta, Vietnam	Mainly *Rhizophora*	Direct planting using propagules, including land survey, site preparation and protection	320	RMFP (1998)
Red River Delta, Vietnam	Mainly *Kandelia*	Direct planting and protection costs only using propagules. All project costs included	84 164	Macintosh (2000)

Successful rehabilitation depends on a number of site conditions these include hydrology and soils. If the normal tidal flooding regime has been disrupted for example through building of fish/shrimp ponds then restoration of normal tidal flooding through breaching of dikes can achieve restoration or greatly improve chances of success (Stevenson et al, 1999). Failure to properly assess the existing and proposed hydrologic conditions is the primary cause of failure in mangrove restoration projects (Lewis, 1999). Large scale planting of propagules of *Rhizophora* spp. on existing unvegetated natural mudflats, for example, where natural tidal conditions are typically too wet for mangroves to establish naturally or thrive, have resulted in large scale failures and a waste of limited funds for mangrove restoration (Lewis, 1999). Mudflats are also valuable habitats with high productivity, for both nature (eg. Migratory birds) and for man (as sites for cockle and clam beds). Thus, conversion of mudflats to mangroves may not make ecological sense (Erftemeijer and Lewis, 2000). There is a clear intertidal zone suitable for mangroves, starting from the upper level of most mudflats (MHWN).

Human activities with mangrove soils, through excavation to create aquaculture ponds or dredging for tin can often result in potential acid sulfate soils and changes in soil structure and quality.

If surrounding mangrove forests have been eliminated or reduced in such numbers as to reduce or eliminate large scale natural colonization by propagules planting of mangroves may be essential. Lewis (1999) proposed five sequential steps to be taken to design and implement any successful mangrove rehabilitation project (Table 4.4).

Table 4.4: Steps to designing and implementing a successful mangrove rehabilitation project

1	Understand the autecology (individual species ecology) of the mangrove species at the site, in particular the patterns of reproduction, propagule distribution and successful seedling establishment
2	Understand the normal hydrologic patterns that control the distribution and successful establishment and growth of targeted mangrove species
3	Assess the modifications of the previous mangrove environment that occurred that currently prevents natural secondary succession
4	Design a restoration program to initially restore the appropriate hydrology and utilise natural volunteer mangrove propagule recruitment for plant establishment
5	Only utilise actual planting of propagules, collected seedlings, or cultivated seedlings after determining that natural recruitment will not provide the quantity of successfully established seedlings, rate of stabilisation, or rate of growth of saplings established as goals for the restoration project

PCARRD (1991) provided easy guidelines for mangrove plantation development and management. Simple easy to follow guidelines were given for seed collection, handling, transport and production; selection and preparation of planting site; protection and management of mangrove plantation. A few of the key points are given in Table 4.5.

Table 4.5: Plantation development and management

Seed Collection • Timing of seed production varies from place to place and tree species • Collect local seeds to ensure survival and adaptation of young plants to planting site and reduce the incidence of seed damage because of handling and transport • Collect only mature seeds (immature seeds often don't survive) • Tree collection of seeds is easiest at high tide from a boat. Ground collected seeds have a higher incidence of insect attack and are to be used as little as possible
Seed quality • Discard abnormal and injured seeds. • Eliminate seeds with holes (even pin sized) because these are usually infested by a beetle Poecellips fallax. Infested seeds can easily contaminate the other seeds
Seed Handling and Transport • Retain pericarp (brown cap structure in Rhizophora) to provide protection to the shoot • Keep seeds under a shed and cover with green banana leaves to prevent excessive loss of seed moisture • Bundle seeds in 50s or 100s to facilitate counting and handling • Keep seeds horizontal and covered with moist sacks to properly protect from heat when transporting
Seed storage • Clean and treat the seeds with fungicide (e.g. Benlate) and insecticide (e.g. Azodrin) at manufacturers specification before storage • Air dry seeds for one day • Place seeds in plastic bags, seal and keep at room temperature (can keep like this for 1 to 4 months and still have 60-90% germination depending on the species) • *Rhizophora* seeds can be kept in a shed under room temperature for two weeks without adversely affecting viability, as long as don't get wet
Seedling production • *Rhizophora* can be directly seeded by placing hypocotyl end vertically in mud and removing pericarp • *Ceriops* and *Bruguiera* although have shorter propagules can be planted directly in less inundated areas • *Sonneratia* and other small seed mangrove species should be raised in a nursery. Best Sonneratia germination obtained if fruits are soaked in tap water for 7 days, mashed and seeds sown on flooded seedbeds using waterlogged mangrove soil. • In nurseries use mangrove forest top soil in polyethylene plastic bags, direct sow seeds, place under partial shade and irrigate daily with brackishwater • *Avicennia* and other small seed mangrove species wildlings (wild seedlings) can be transplanted to planting site successfully. Best size range for *Avicennia* is 60 to 90 cm tall. Can be planted earthballed or bareroot. Bareroot collected wildlings must be placed in plastic bags to prevent roots drying

Selection of Planting Site and Species

- Mangrove zonation results from the combined effects of tidal inundation, exposure to wind, waves and water currents, soil properties, morphology of species, salinity, light and species association. Environmental factors and natural mangrove zonation should be taken into account in determining what species are particularly suited to the planting site.
- Seaward zone - daily inundated. Soil ranges from sandy to sandy loam, mudflat or coralline type. Usually inhabited with *Avicennia, Sonneratia, Aegiceras* and *Rhizophora mucronata.*
- Middle zone - daily inundated except during neap tides. Soil clayey, silty to silty clay. Usually inhabitated with *Avicennia, Aegiceras, Bruguiera, Ceriops, Excoecaria agallocha, Lumnitzera racemosa, Scyphiphora hydrophyllacea* and nipa.
- Landward zone – unaffected by tidal inundation over long periods of time except during high Spring tides. Soil clayey yo silt clay. Vegetation highly diverse because of the presence of mangrove associates, vines and epiphytes. Mangrove species similar to middle zone but can also include *Acanthus, Heritiera littoralis, Barringtonia racemosa, Hibiscus tilaceus* and *Thespesia populnea*
- Riverine fringes at mouths of rivers commonly have Avicennia, Aegiceras and Rhizophora species and in interior riverbanks these species and Bruguiera and Xylocapus granatum can be found

Preparation of Planting Site

- Compartmentalize plantation area into manageable sizes for each planter to allow planting, maintenance and monitoring activities easier.
- Leave 3–5 m between compartments for pathways or in extensive areas a 10 m highway for passage of boats, which should be determined by the users.
- Establish fence or stakes around the perimeter to protect young plants from trespassers while providing them a guide on the way to take especially at high tide.
- Clear planting sites from debris because these injure young plants as tide rises

Planting

- Use species that match zonation
- Direct seeding is recommended as entails less labour costs and has high survival rate.
- On soft ground push seeds 1/3 to ½ of the total length of the hypocotyls. On hard grounds firstly dig hole and plant ¼ to 1/3 total length of hypocotyls. Best spacing 1 m x 1 m (Gan, 1995).
- Wildlings are direcly planted on same day collected. Hole dug to freely accommodate earth and roots, ideal spacing 2 m x 2 m.
- Proper timing is critical for success. Should coincide with season of available mature seeds, calm weather and long days of low tide during the day

Protection

- Beetles (Coleoptera: Scolytidae) bore into seedlings and can cause mortality. Air drying of seedlings for 7-14 days before planting protects seedling from infestation during critical first 3 months
- Scale insects (Homoptera:Diaspididae) attack leaves of *Rhizophora* causing premature leaf fall. Severe infestation can lead to complete defoliation and seedling mortality. Infected seedlings should be buried in the mud to prevent destructive population build up. Spraying of insecticides is not practical it will only contaminate area and affect other life forms.
- Barnacles (Crustacea: Cirripedae) can attach to seedlings in high numbers and adversely affect respiration and photosynthesis. Infestation can be minimised by planting fully hardened seedlings, planting the right species at the right site, planting in shallowly inundated sites during high tides, or areas that are fully exposed for at least 3-4 hours a day at low tide. Barnacles can be scraped off every two months if done carefully but tedious and impractical.
- Sesarmid crabs (Crustacea: Grapsidae) inflict damage on young seedlings by eating bark and young leaves. When crab damage and also attack by monkeys is severe, shielding with bamboo tubes can protect the seedlings, although this is expensive. Drying seedlings for two weeks prior to planting makes seedlings less prone to damage.
- Diseases. Cuts can serve as entry for microoganisms. To prevent infection coat with coal tar or paint.
- Weeds. *Acrostichum* fern forms dense, tall thickets when canopy opens up. Natural colonization is difficult and survival of seedling reduced. Fern can be manually uprooted.

Other issues

4.8 Improve and enhance the scientific knowledge base

A common need idenitified in this study is to develop and improve the scientific knowledge base on mangrove ecology and biodiversity. A lack of knowledge of mangrove ecosystems, their extent, status and linkages to other ecosystems, hampers efforts to conserve and manage mangroves, leading and can lead to the unsustainable exploitation of the coastal resources. An interdisciplinary team of scientists, engineers, economists and social scientists is necessary to help identify priority issues and strategies.

Successful examples of good sustainable management and conservation of mangrove biodiversity should be better disseminated and opportunities created for study visits and other mechanisms to exchange knowledge and experiences.

There are considerable skills available in a wide range of disciplines concerning mangrove management throughout the world. Opportunities should be provided for greater interactions between scientists, managers and policy makers through meetings, workshops, symposia, newsletters and the Internet. This would foster valuable interdisciplinary exchange of ideas on the management of mangrove ecosystems.

One very useful method is to use the mangrove email discussion list. This provides a global forum for the exchange of information between mangrove researchers (http://possum.murdoch.edu.au/~mangrove/submang.htm). To subscribe to this list send an email message to majordomo@essun1.murdoch.edu.au with the subject and message body reading subscribe mangrove.

There is an urgent need for genetic studies on mangrove ecosystems

There is a lack of information on mangrove genetic diversity. Considerable efforts should be invested investigating the remaining natural forest mangrove genetic resources and their potentials.

Taxonomy research on flora and fauna species diversity

The development of a national database would help with monitoring the status of mangrove diversity.

More research is needed on the ecological functions of the mangrove ecosystem and its interdependency with other habitats and diversity.

Research on the indirect use values of mangroves (benefits derived from the ecological and social functions) is crucial to fully incorporate the environmental costs associated with management actions.

Mangrove biodiversity database

A comprehensive information database of mangrove biodiversity (genetic, species, ecosystem processes and functions, social and economic values) in each country is necessary to monitor the status of mangrove biological diversity, realise its economic potential and areas of application, and is essential toward adequate protection in the management of and access to these resources. The data collected will assist the state governments in better understanding their natural resources and developing policies integrating economics and the environment.

The Global Mangrove Database and Information System (GLOMIS) based at the International Society of Mangrove Ecosystems Secretariat in Okinawa, Japan is a searchable database of scientific literature relating to mangroves, institutions and scientists working on all aspects of mangroves, as well as regional projects and programmes related to mangroves (http://www.glomis.com).

4.9 Develop economic instruments to value mangrove biodiversity

Economic arguments carry the greatest weight in conservation and management of mangroves. However, the true economic value of mangrove diversity and natural resources is difficult to measure and important ecological processes and functions undervalued. All development plans and policies should include economic valuations that fully reflect the sociological, ecological and environmental costs of resource use, physical developments and pollution.

The availability of funds is a key factor in determining the success of protected biodiversity conservation management. Raising income is essential to viability and sustainability. Identify and quantify appropriate charges that can be made to public (tourists and other visitors) and to all other interests including public utilities and commercial entities benefiting from facilities, amenities and natural resources. Income derived should be used to offset operation and maintenance costs of protected area.

Examples of possible economic valuations and tools:

Tax relief for industries which implement pollution preventative measures

Favourable loans for environmental projects

Grants for environmental commitments and protection of critical areas

Financial support to scientific studies, training and capacity building in mangrove management and conservation

Provide incentives for the private sector to support research in mangrove diversity management.

Market prices for mangrove resources and its functions.

4.10 Creating Awareness

All countries with mangroves should immediately institute an extensive programme that develops awareness among the different sectors/stakeholders (in particular local decision makers) of the value of the mangrove ecosystem resources, functions and services.

Also promote and encourage understanding and the importance of mangrove ecosystems through the media and education programmes.

International development-assistance institutions (WB, Danida etc) should also consider the full value of mangroves and their hydrological sensitivity relative to direct and indirect impacts resulting from projects (e.g. road and drain construction and irrigation projects).

In many countries the greatest strength of NGOs is public awareness. NGOs should review the information activities of others and prepare programmes that fill important gaps. Work with schools and colleges, and with the general public through campaigns and media events is likely to be particularly effective, and will draw upon the unique qualities of many NGOs (Dugan, 1990). NGOs can generate public awareness of policy issues, and site-specific conservation problems and either support government action or press when it is lacking (Dugan, 1990).

5. REFERENCES

Aksornkoae, S., 1993. *Ecology and Management of Mangroves*. IUCN, Bangkok, Thailand, 176 pp.

Alongi, D. M., 1987. Intertidal zonation and seasonality of meiobenthos. *Marine Biology* **95:** 447-458.

Alongi, D. M., 1994. Zonation and seasonality of benthic primary production and community respiration in tropical mangrove forests. *Oecologia* **98 (3-4):** 320-327.

Ashton, E. C., 1999. *Biodiversity and community ecology of mangrove plants, molluscs and crustaceans in two mangrove forests in Peninsular Malaysia in relation to local management practices*. DPhil thesis, University of York, U.K.

Bandaranayake, W. M. (1998). Traditional and medicinal uses of mangroves. *Mangroves and Salt Marshes* **2:** 133-148.

Becker, B., 1999. Sustainable use of biodiversity. In: Pullin, R.S.V., Froese, R. and Casal, C.M.V. (Eds.) ACP-EU Fisheries Research Initiative. Proceedings of the Conference on Sustainable Use of Aquatice Biodiversity: Data, Tols and Cooperation. Lisbon, Portugal, 3-5 September 1998. ACP-EU Fish. Res. Rep. 6: 70 p.

Berry, A. J., 1972. The natural history of West Malaysian mangrove faunas. *Malayan Nature Journal* **25:** 135-162.

Berry, A. J., 1975. Molluscs colonizing mangrove trees with observations on *Enignomia rosea* (Anomiidae). *Proceedings of the Malacological Society* **41:** 589-600.

Blasco, F., 1984. Taxonomic considerations of the mangrove species. In: S. C. Snedaker and J. C. Snedaker (Eds.) The mangrove ecosystem: Research methods. UNESCO, Paris, pp. 81-89.

Brockmeyer, R. E., Rey, J. R., Virnstein, R. W., Gilmore, R. G. and Earnest, L., 1997. Rehabilitation of impounded estuarine wetlands by hydrologic reconnection to the Indian River Lagoon, Florida. *Journal of Wetlands Ecology and Management* **4:** 93-109.

Brown, B. E., 1997. *Integrated Coastal Management: South Asia*. Department of Marine Sciences and Coastal Management, University of Newcastle, Newcastle upon Tyne, United Kingdom.

Brown, A.H.D. and Schoen, D.J., 1994. Optimal sampling strategies for core collections of plant genetic resources. In: Loeschcke, V., Tomiuk, J. and Jain, S.K. (Eds.) Conservation Genetics. Birkhauser Verlag Basel, Switzerland.

Brundtland, 1987. *Our Common Future*. Report of the World Commission on Environment and Development. Oxford University Press, Oxford

Cabrera, M. A., Seijo, J. C. Euan, J. and Perez, E., 1998. Economic values of ecological services from a mangrove ecosystem. *International Newsletter of Coastal Management* **33:** 1-2.

Chapman, V. J. (1975). Mangrove biogeography. In: Walsh, G. E., Snedaker, S. C. ad Teas, H. J. (Eds.) Proceedings of the International Symposium on biology and management of mangroves pp. 3-21. University of Florida, Gainesville.

Chong, V. C., 1996. Supplementary report of MNI Newsprint Paper Mill (Unpublished).

Chong, V. C., Sasekumar, A., Leh, M. U. C. and D'Cruz, R. (1990). The fish and prawn communities of a Malaysian coastal mangrove system, with comparison to adjacent mud flats and inshore waters. *Estuarine, Coastal and Shelf Science* **31:** 703-722.

Chua, T.-E. and Scura, L. E. 1992. *Integrated Framework and Methods for Coastal Zone Management*. ICLARM, Manila.

Clark, J. R., 1998. *Coastal seas the conservation challenge*. Blackwell Science Ltd, Oxford, 134 pp.

Clay, R. E. and Andersen, A. N., 1996. Ant fauna of a mangrove community in the Australian seasonal tropics, with particular reference to zonation. *Australian Journal of Zoology* **44 (5):** 521-533.

Clayton, D. A., 1993. Mudskippers. *Oceanography and Marine Biology Annual Review* **31:** 507-577.

Clough, B.F., 1992. Primary productivity and growth of mangrove forests. In: A.I. Robertson and D.M. Alongi (Eds.) Tropical Mangrove Ecosystems. American Geophysical Union, Washington, D.C. pp. 225-249.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M. Hannon, B., Limberg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., Sutton, P. and van der Belt, M. (1997). The value of the world's ecosystem services and natural capital. *Nature* **387:** 253 - 260

Das, A. B., Basak, U. C. and Das, P., 1994. Karyoptype diversity in three species of Heretiera, a common mangrove tree on the Orissa coast. *Cytobios* **80(321):** 71-78.

Davie, P., 1982. List of mangrove crabs in Australia. *Operculum* **5(4):** 204-7.

de Groot, R., 1993. *Functions of Nature: Evaluation of Nature in Environmental Planning, Management and Decision Making*. Wolters-Noordhoff, Groningen, the Netherlands.

DFID, 1998. Sustainable Rural Livelihood. What contribution can we make? Carney, D. (Ed) Department for International Development, 213p

Dixon, J., 1991. Economic valuation of environmental resources. In: Winpenny, J. T. (Eds.) Development research: the environmental challenge. Overseas Development Institute, London.

Dodd, R. S., Fromard, F., Rafii, Z. A. and Blasco, F., 1995. Biodiversity among West African, *Rhizophora*: Foliar wax chemistry. *Biochemical Systematics and Ecology* **23 (7-8):** 859-868.

Dodd, R. S., Rafiik, Z. A., Fromard, F. and Blasco, F., 1998. Evolutionary diversity among Atlantic coast mangroves. *Acta Oecologia* **19 (3):** 323-330.

DRC, 1994. *A Coastal Environmental Preservation Project in Thai Binh Province Project Document*, Danish Red Cross and Viet Nam Red Cross.

Dugan, P.J., 1990. *Wetland Conservation: A review of current issues and required action*. IUCN, Gland, Switzerland, 96 pp.

Duke, N. C., 1984. Observations on the floral and vegetative phonologies of North eastern Australian mangroves. *Australian Journal of Botany* **32:** 87-99.

Duke, N. C., 1991. A systematic revision of the mangrove genus *Avicennia* (Avicenniaceae) in Australia. *Australian Journal of Botany* **27:** 657-678.

Duke, N. C., 1993. Mangrove floristics and biogeography. In: A. I. Robertson and D. M. Alongi (Eds.) Tropical Mangrove Ecosystems. American Geophysical Union, Washington, D.C., U.S.A. pp. 63-100.

Duke, N. C., Ball, M. C. and Ellison, J. C., 1998. Factors influencing biodiversity and distributional gradients in mangroves. *Global Ecology and Biogeography Letters* **7:** 27-47.

Duke, N. C. and Bunt, J. S. (1979). The genus *Rhizophora* (Rhizophoraceae) in northeastern Australia. *Aust. J. Bot*. **27:** 657-678.

Ellison, A. M. and Farnsworth, E. J., 1990. The ecology of Belizean mangrove-root fouling communities: I. Epibenthic fauna are barriers to isopod attack of red mangrove roots. *Journal of Experimental Marine Biology and Ecology* **142:** 91-104.

Ellison, A. M., Farnsworth, E. J. and Mertkt, R. E., 1999. Origins of mangrove ecosystems and the mangrove biodiversity anomaly. *Global Ecology and Biogeography* **8:** 95-115.

Erftemeijer, P.L.A. and Lewis, R.R., 2000. Planting mangroves on intertidal mudflats:habitat restoration or habitat conversion? In: Sumantakul, V. et al (Eds.) Enhancing Coastal Ecosystem Restoration for the 21st Century. Proceedings of a Regional Seminar, ECOTONE VIII, Royal Forest Department of Thailand, Bangkok, Thailand, pp.156-165.

Encarta, 1999. ENCARTA World English Dictionary, Bloomsbury Publishing

FAO, 1982. *Management and utilization of mangroves in Asia and the pacific*. Food and Agricultural Organization of the United Nations, Rome.

FAO, 1988. *Aspects of FAO's policies, programmes, budget and activities aimed at contributing to sustainable development*. Document to the ninety-fourth Session of the FAO Council, Rome., 15-25 November 1988. Rome, FAO. CL 94/6.

FAO, 1995. *Code of Conduct for Responsible Fisheries*. Food and Agricultural Organization of the United Nations, Rome, Italy. 41 pp

Farnsworth, E. J. and Ellison, A. M., 1996. Scale-dependent spatial and temporal variability in biogeography of mangrove root epibiont communities. *Ecological Monographs* **66 (1):** 45-66.

Farnsworth, E.J. and Ellison, A.M., 1997. The Global Conservation Status of Mangroves. *Ambio* **26(6):** 328-334.

Field, C. D., 1996. *Restoration of Mangrove ecosystems*. International Society for Mangrove Ecosystems. Okinawa. Japan. 250pp.

Fromm, O., 2000. Ecological structure and Functions of Biodiversity as Elements of its Total Economic Value. *Environmental and Resource Economics* **16:** 303-328.

Gan, B. K., 1995. *A working plan for the Matang mangrove forest reserve (fourth revision)*. Published by the State Forest Department of Perak Darul Ridzuan, Malaysia.

Gaston, K. J., 1996. *Biodiversity. A biology of numbers and difference*. Blackwell Science, Oxford.

GESAMP, 1996. *The contributions of science to integrated coastal management*.

Gilbert and Janssen, R., 1998. Use of environmental functions to communicate the values of a mangrove ecosystem under different management regimes. *Ecological Economics* **25:** 323-346.

Gubbay, S., 1995. *Marine Protected Areas: Principles and techniques for management*. Chapman and Hall

Hamilton, L. and Snedaker, S. (1984). *Handbook for mangrove area management*. East/West Center Hawaii 123 pp.

Heywood, V. H., 1995. *Global Biodiversity Assessment*. Cambridge: Cambridge University Press.

Hilton-Taylor, C., 2000. *2000 IUCN Red list of Threatened species*. IUCN, Gland, Switzerland and Cambridge, UK.

Hogarth, P. J., 1999. *The Biology of Mangroves*. Oxford University Press.

Hogarth, P. J., 2001. The decline in Indus Delta mangroves: causes, consequences and cures. Proceedings of International Conference on mangroves, Kuwait, 1998. Kuwait Institute for Scientific Research, Kuwait.

Hong, P. N. and San, T. H., 1993. *Mangroves of Vietnam*. International Union for the Conservation of Nature (IUCN), Regional Wetlands Office. 173p

Hutchings, P. A. and Recher, H. F., 1982. *The fauna of Australian mangroves*. Proceedings of Linnean Society of N.S.W. 106 (1): 83-121.

Hutchings P. and Saenger, P., 1987. *Ecology of Mangroves*. University of Queensland Press, Queensland, Australia, 388 pp.

Hyde, K. D., 1990. A comparison of the intertidal mycota of five mangrove tree species. *Asian Marine Biology* **7:** 93-108.

Hyde, K. D. and Lee, S. Y., 1995. Ecology of mangrove fungi and their role in nutrient cycling: What gaps occur in our knowledge? *Hydrobiologia* **295:** 107-118.

Jones, D. A. (1984). Crabs of the mangal ecosystem. In: F. D. Por and I. Dor (Eds.) Hydrobiology of the Mangal. Dr. W. Junk Publishers, The Hague, pp. 89-109.

Jones, C.G., Lawton, J.H., Shachak, M., 1994. Organisms as ecosystem engineers. *Oikos* **69:** 373-386.

Kathiresan, K., 2000. A review of studies on Pichavaram mangrove, southeast India. *Hydrobiologia* **430 (1):** 185-205.

Kathiresan, K. and Bingham, B. L., 2001. Biology of mangroves and mangrove ecosystems. *Advances in Marine Biology* **40:** 81-251.

Keenan, C. P., Davie, P. J. F., Mann, D. L., 1998. A revision of the genus *Scylla* De Haan, 1883 (Crustacea: Decapoda: Brachyura: Portunidae). *The Raffles Bulletin of Zoology* **46(1):** 217-245.

Kelleher, G., 1999. *Guidelines for Marine Protected Areas*. IUCN, Gland, Switzerland and Canbridge, UK. Xxiv + 107 pp.

Kelleher, G., Bleakley, C. and Wells, S., 1995. *A Global representative system of Marine Protected Areas*. Great Barrier Reef Marine Park Authority, The World Bank and IUCN. 4 vols.

King, D. and Bohlen, C., 1994. Estimating the costs of restoration. *National Wetlands Newsletter* **16:** 3-8.

Kjerfve, B., 1990. *Manual for investigation of hydrological processes in Mangrove Ecosystems*. UNESCO/UNDP, Published in New Delhi, India. 79p

Lee, S. Y., 1998. Ecological role of grapsid crabs in mangrove ecosystems: a review. *Marine and Freshwater Research* **49:** 335-343.

Lee, S.Y. 1999. Tropical mangrove ecology: Physical and biotic factors influencing ecosystem structure and function. *Australian Journal of Ecology* **24:** 355-366.

Leong, L.F., 1999. *Economic valuation of the mangrove forest in Kuala Selangor, Malaysia*. MSc thesis. Universiti of Malaya, K.L., Malaysia.

Lewis, R.R., 1999. Key concepts in successful ecological restoration of mangrove forests. In: Proceedings of the TCE-Workshop No. II, Coastal Environmental Improvement in Mangrove/Wetland Ecosystems, 18-23 August 1998, Ranong, Thailand. Danish-SE Asian Collaboration in Tropical Coastal Ecosystems (TCE) Research and Training. NACA, P.O. Box 1040, Bangkok, Thailand 10903, pp.12-32.

Lewis III, R. R (*in prep.*). Mangrove Management and Restoration Dictionary. In: Macintosh, D. J., Phillips, M. J., Lewis III, R. R. and Clough, B. Thematic Review on Coastal Wetland Habitats and Shrimp Aquaculture. Component of the WB/NACA/WWF/FAO Programme on Shrimp Farming and the Environment

Lewis, R.R. and Marshall, M.J., 1997. Principles of successful restoration of shrimp aquaculture ponds back to mangrove forests. In: Programa/Resumenes de Congresson de Ciencias del Mar, Marcuba '97, Habana, Cuba (Abstract) pp. 126.

Lewis, R.R. and Marshall, M.J., 1998. Principles of successful restoration of shrimp aquaculture ponds back to mangrove forests. In: World Aquaculture Society Book of Abstracts, Aquaculture '98, Las Vegas, Nevada (Abstract), pp.327.

Lugo, A. C. and Snedaker, S. C. (1974). The ecology of mangroves. *Annual Review of Ecology and Systematics* **5:** 39-64

Macintosh, D.J., 1984. Ecology and productivity of Malaysian mangrove crab populations (Decapoda: Brachyura). In: E. Soepadmo, A.N. Rao, D.J. Macintosh (Eds.) Proceedings of the Asian Symposium on mangrove environment, research and management. University of Malaya and UNESCO. Pp.354-377.

Macintosh, D. J., 1988. The ecology and physiology of decapods of mangrove swamps. *Symposia of the Zoological Society of London* **59:** 315-341.

Macintosh, D.J., 1996. Mangroves and coastal aquaculture: doing something positive for the environment. *Aquaculture Asia* **1(2):** 3-8.

Macintosh, D.J., 2000. Danish Red Cross Environmental Preservation Programme Phase II 1997 – 2000 in Red River Delta. Centre for Tropical Ecosystems Research, Aarhus University, Denmark.

Macintosh D. J and Zisman, S. (1997). The Status of Mangrove Ecosystems: Trends in the Utilisation and Management of Mangrove Resources. International Union of Forest Research Organisations (unpublished) Available at: http://iufro.boku.ac.at/iufro/iufronet/d1/wu10700/unpub/macint95.htm

Macintosh, D. J., Aksornkoae, S., Vanucci, M., Field, C., Clough, B. F., Kjerfve, B., Paphavasit, N. and Wattayakorn, G., 1991. *Final Report of the Integrated Multidisciplinary Survey and Research Programme of the Ranong Mangrove Ecosystem*. Project RAS 86/120. National Research Council of Thailand, Bangkok, Thailand, 183 pp.

Macintosh, DJ, Levine, S. and Overton, JL, 1998. *Evalution report on Save the Children Fund Mangrove Planting Project, Thach Ha District (Ha Tinh Province) Vietnam*. Save the Children Fund, Hanoi, Vietnam and Centre for Tropical Ecosystems Research, Aarhus University, Aarhus, Denmark. 83pp.

Macnae, E., 1968. A general account of the fauna and flora of mangrove swamps and forests in the Indo-West Pacific Region. *Advances in Marine Biology* **6:** 73-270.

Magurran, A. E., 1988. *Ecological diversity and its measurement*. Croom Helm Ltd., London.

McCarthy, J. J., Canziani, O. F., Leary, N. A., Dokken, D. J. and White, K.S., 2001. *Climate Change 2001: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. GRID, Arendal.

Meilani, M. M., 1996. Studi pola pemanfaatan hutan mangrove untuk usaha perikanan: studi kasus di Desa Mayangan Kecamatan Pemanukan, Kabupaten Subang, Jawa Barat. Fakultas Perikanan, Institut Pertanian Borgor, Borgor.

Namkoong, G. and Koshy, M. P., 2001. Decision making in gene conservation. Forest Genetic Resources No.28. FAO, Rome.

Noske, R. A., 1996. Abundance, zonation and feeding ecology of birds in mangroves of Darwin Harbour, Northern Territory. *Wildlife Research* **23:** 443.

Nielsen, M. G., 1997. Nesting biology of the mangrove mud-nesting ant *Polyrhachis sokolova* Forel (Hymenoptera: Formicidae) in northern Australia. *Insectes Sociaux* **44 (1):** 15-21.

Ong, J. E., 1982. Mangroves and aquaculture in Malaysia. *Ambio* **11(5):** 252-257.

Ong, J. E., 1995. The ecology of mangrove conservation and management. *Hydrobiologia* **295:** 343-351.

Othman, M. A., 1994. Value of mangroves in coastal protection. *Hydrobiologia* **285:** 277-282

PCARRD, 1991. *The Philippine recommends for mangrove production and harvesting*. Los Banos, Laguna, 96 pp.

Perrings, C. (1998). Resilience in the dynamics of Economy-Environment Systems. *Environmental and Resource Economics* **11:** 503-520.

Perrings, C., Maler, K. G., Folke, C., Holling, C. S. and Jansson, B. O. (1995). Introduction: Framing the problem of Biodiversity Loss". In: Perrings, C., Maler, K. G., Folke, C., Holling, C. S. and Jansson, B. O. (Eds.) Biodiversity Loss. Economic and Ecological Issues. Cambridge University Press.

Pirot, J.Y., Meynell, P.J. and Elder, D., 2000. *Ecosystem Management: Lessons from Around the World. A Guide for Development and Conservation Practitioners*. IUCN, Gland, Switzerland and Cambridge, UK x + 132 pp.

Por, F. D., 1984. The ecosystem of the Mangal: general considerations. In: F. D. Por and I. Dor (Eds.) Hydrobiology of the Mangal. Dr. W. Junk Publishers, The Hague, pp. 1-26.

Proctor, J., Anderson, J. M., Chai, P. and Vallack, H. W. (1983). Ecological studies in four contrasting lowland rain forests in Gunung Mulu National Park, Sarawak. *Journal of Ecology* **71:** 237-260.

Primavera, J. H., 2000. Development and conservation of Philippine mangrove: institutional issues. *Ecological Economics* **35:** 91-106.

Reid, D. G., 1986. *The Littorinid molluscs of mangrove forests in the Indo-Pacific region*. British Museum (Natural History), Cromwell Road, London, 228 pp.

Ricklefs, R. E. and Latham, R. E., 1993. Global patterns of diversity in mangrove floras. In: R.E.Ricklefs and D. Schulter (Eds.) Species diversity in ecological communities. University of Chicago Press, Chicago, pp. 215-229.

Robertson, A. I., 1986. Leaf-burying crabs: their influence on energy flow and export from mixed mangrove forests (*Rhizophora* spp.) in northeastern Australia. *Journal of Experimental Marine Biology and Ecology* **102:** 237-248.

Robertson, A. I and Alongi, D. M., 1992. *Tropical Mangrove Ecosystems*. Coastal and Estuarine Studies 41. American Geophysical Union. Washington D.C. p329.

Robertson, A. I. and Blaber, S. J. M., 1992. Plankton, epibenthos and fish communities. In: A. I. Robertson and D. M. Alongi (Eds.) Tropical Mangrove Ecosystems. American Geophysical Union, Washington DC, USA, pp. 173-224.

Robertson, A. I. and Daniel, P. A., 1989. The influence of crabs on litter-processing in high intertidal mangrove forests in tropical Australia. *Oecologia* **78:** 191-198.

Robertson, A. I. and Duke, N. C. (1990). Mangrove fish-communities in tropical Queensland, Australia: spatial and temporal patterns in density, biomass and community structure. *Marine Biology* **104:** 369-379

Ruitenbeek, H. J., 1994. Modelling economy-ecology linkages in mangroves: Economic evidence for promoting conservation in Bintuni Bay, Indonesia. *Ecological Economics* **10:** 233-247.

Saenger, P. and Snedaker, S. C., 1993. Pantropical trends in mangrove above-ground biomass and annual litterfall. *Oecologia* **96:** 293-299.

Saenger, P. Hegerl, E. J. and Davie, J. D. S., 1983. Global status of mangrove ecosystems. *The Environmentalist* **3 (3):** 1-88.

Salm, R. V. and Clark, J. R., 1984. *Marine and Coastal Protected Areas: A Guide for Planners and Managers*. IUCN, Gland, Switzerland, xiii + 302 pp.

Sasekumar, A., 1981. *The ecology of meiofauna on a Malayan mangrove shore*. PhD Thesis, Department of Zoology University of Malaya, Kuala Lumpur, Malaysia.

Sasekumar, A., Chong, V.C., Leh, M.U. and D'Cruz, R., 1992. Mangroves as a habitat for fish and prawns. *Hydrobiologia* **247:** 195-207.

Sathirathai, S., 1998. *Economic valuation of mangroves and the roles of local communities in the conservation of natural resources: Case Study of Surat Thani, South of Thailand*. Economy and Environment Program for Southeast Asia Research Report.

Save the Children Fund, 1998. *Report of an evaluation of the Save the Children Fund Mangrove Planting Project, Thach Ha District (Ha Tinh Province), Vietnam*. Save the Children Fund, Hanoi, Vietnam and Centre for Tropical Ecosystems Research, Aarhus University, Aarhus Denmark, 82 pp.

Sherman, R. E., Fahey, T. J. and Howarth, R. W., 1998. Soil-plant interactions in a neotropical mangrove forest: Iron, phosphorous and sulfur dynamics. *Oecologia* **115 (4):** 553-563.

Slim, F. J., Hemminga, M. A., Ochieng, C., Jannink, N. T., Cocheret de la Moriniere, E., and van der Velde, G., 1997. Leaf litter removal by the snail *Terebralia palustris* (Linneaus) and sesarmid crabs in an East African mangrove forest. *Journal of Experimental Marine Biology and Ecology* **215:** 35-48.

Smith, T. J., 1987. Seed predation in relation to tree dominance and distribution in mangrove forests. *Ecology* **68:** 266-273.

Smith, T.J., Boto, K.G., Frusher, S.D. and Giddins, R.L., 1991. Keystone species and mangrove forest dynamics: the influence of burrowing by crabs on soil nutrient status and forest productivity. *Estuarine, Coastal and Shelf Science* **33:** 19-32.

Sogin, M. L. and Hinkle, G., 1997. Common measures for studies of Biodiversity: Molecular Phylogeny in the Eukaryotic Microbial World. In: Reaka-Kudla, M.L., Wilson, D. E. and Wilson, E. O. Biodiversity II Understanding and Protecting our Biological Resources. Joseph Henry Press Washington, D.C. pp. 109-122.

Somerfield, P. J., Gee, J. M. and Aryuthaka, C., 1998. Meiofaunal communities in a Malaysian mangrove forest. *Journal of the Marine Biological Association of the United Kingdom* **78:** 712-732.

Spalding, M. D., Blasco, F. and Field, C., 1997. *World Mangrove Atlas*. The International Society for Mangrove Ecosystems, Okinawa, Japan. 178 pp.

Stafford-Deitsch, J., 1996. *Mangrove: The forgotten habitat*. IMMEL Publishing Limited, London. 277 pp.

Streever, W., 1999. *An international perspective on wetland rehabilitation*. Kluwer Academic Publishers, Dordrecht, The Netherlands, 338 pp.

Stevenson, N. J., Lewis, R.R. and Burbridge, P. R., 1999. Disused shrimp ponds and mangrove rehabilitation. In: Streever, W. (Ed) An international perspective on wetland restoration. Kluwer Academic Publishers Dordrecht, The Netherlands, 338 pp.

Teas, H. J., 1979. Silviculture with saline water. In: Hohaender, A. (Ed) Biosaline concepts, Plenum Publishing Cooperation.

Thayer, G. W., Colby, D. R., Hettler, W.R., 1987. Utilization of the red mangrove prop root habitat by fishes in south Florida. *Marine Ecology Progress Series* **35:** 25-38.

Tomlinson, P.B., 1986. *The botany of mangroves*. University Press, Cambridge, 419 pp.

Tri, N. H., Adger, W. N. and Kelly, P. M., 1998. Natural resources management in mitigating climate impacts: the example of mangrove restoration in Vietnam. *Global Environmental Change* **8(1):** 49-61

Turner, R. E. and Lewis, R. R., 1997. Hydrological restoration of coastal wetlands. *Wetlands Ecology and Management* **4(2):** 65-72.

United Nations Environment Programme, 1992. Environmental Data Report 1991/1992 prepared by GEMS Monitoring and Assessment Research Centre, London, UK in cooperation with World Resources Institute, Washington, DC and UK Department of the Environment, London Blackwell Ltd Oxford, UK, 408 pp.

United Nations Environment Programme, 1994. Assessment and monitoring of climate change impacts on mangrove ecosystems. UNEP Regional Seas Reports and Studies 154. United Nations Environment Programme, Nairobi, Kenya.

United Nations Environment Programme, 1995. *Global Biodiversity Assessment*. Cambridge University Press.

Vance, D. J., Haywood, M. D. E. and Staples, D. J., 1990. Use of Mangrove Estuary as a Nursery Area by Postlarval and Juvenile Banana Prawns, *Penaeus merguiensis* de Maan, in Northern Australia. *Estuarine, Coastal and Shelf Science* **31:** 689 – 701

Vance, D. J., Haywood, M. D. E. Heales, D. S., Kenyon, R. A., Loneragan, N. R. Pendrey, R. C., 1996. How far do prawn and fish move into mangroves? Distribution of juvenile banana prawns *Penaeus merguiensis* and fish on a tropical mangrove forest in northern Australia. *Marine Ecology Progress Series* **131:** 115 - 124

Vanucci, M., 1989. *The mangroves and us: a synthesis of insights*. Indian Association for the advancement of Science, New Delhi, India.

WCMC, 1998. Report concerning the Map on nature conservation sites designated in application of international instruments at Pan-European level.

White, A. T. and Cruz-Trinidad, A., 1998. *The Value of the Philippines Coastal Resources: Why Protection and Management are Critical*. Coastal Resources Management Project, Cebu City, Philippines.

Wilcox, B. H. R., 1985. Angiosperm flora of the mangrove ecosystem of the Niger Delta. In: The Mangrove Ecosystems of the Niger Delta. Wilcox, B. H. R. and Powell, C. P. (Eds.) Proceedings of a workshop, University of Port Harcourt, Port Harcourt, Nigeria, pp.34-44.

WRI, 1996. *World Resources 1996-7 A guide to the Global Environment*. WRI/UNEP/UNDP/WB. Oxford University Press, New York 342 pp.

Web sites

World Resources Institute http://www.wri.org
World Conservation Union http://www.iucn.org
World Conservation Monitoring Centre http://www.wcmc.org.uk
World Commission on Protected Areas
http://wcpa.iucn.org/biome/marine/marine.html

6. Country Case Studies

6.1 Background

The case studies presented here have been selected to reflect the wide diversity of mangrove ecosystems worldwide and the many factors affecting their exploitation, management and conservation. Diversity in this context refers to the variation between countries and regions in biogeography, coastal geomorphology, climate, and human use of the mangroves, as well as their natural habitat and species diversity. From the information provided in the case studies, it is possible to highlight some important principles and consistently occurring issues for guidance in developing a Code of Conduct.

Country experts were contacted for the Case Studies and provided with a template for preparation of the Country Case Study. This is provided in Annex 1.

ANNEX 1: Template for Preparation of Country Case Studies

Note to authors: Please use a hierarchical pattern for each case study.
Follow these guidelines (adapting where necessary):

- **Brief background to the country**
  - Regional setting
  - Size
  - History
  - Population
  - Short summary of mangrove resources and biodiversity
    (to include genetic level resources, species and habitats)

- **Give examples of the cross-sectoral issues involved in mangrove management**
  - Forestry
  - Fisheries
  - Aquaculture
  - Other sectors (e.g. agriculture, mining)
  - Coastal protection
  - Tourism and recreation
  - Biodiversity conservation
  - Research and education
  - Others

- **Provide information on the existing legislation**
  - Regulatory frameworks
  - Laws and legal status
  - Zoning plans
  - Any other actions enacted by governments to protect mangroves
    (Copies of any written legislation covering mangrove wetlands would be very helpful).

- **Institutional responsibilities for mangroves**

- **Implementation issues**
  - Are the policy measures working well, or are enforcement or other measures still inadequate?

- **Co-operation, feedback mechanisms and monitoring**
  - Co-management and other initiatives
  - Role of major stakeholders. Explain how far consultation and co-operation among the main stakeholders has been achieved to date, namely:
    - Governmental departments and agencies
    - Local coastal communities
    - Private sector interests
    - NGOs
    - International community and agencies

- Other problems or constraints