जहाँ है हरियाली।
वहाँ है खुशहाली ॥

सत्यमेव जयते

Mangroves for the Future
INVESTING IN COASTAL ECOSYSTEMS

Sharing Lessons on Mangrove Restoration

Proceedings and a Call for Action from an MFF Regional Colloquium
30–31 August 2012, Mamallapuram, India

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Cover photo: *Nypa* planted in an abandoned shrimp farm, Trat, Thailand © MFF

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Proceedings and a Call for Action from an MFF Regional Colloquium

30–31 August 2012, Mamallapuram, India

Organised by

Ministry of Environment and Forests, Government of India
The MFF National Coordinating Body, India

and

Mangroves for the Future (MFF)

with support from

Bay of Bengal Large Marine Ecosystem Project (BOBLME)
M. S. Swaminathan Research Foundation, Chennai

and

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Abbreviations

ADB	Asian Development Bank
BAPPEDA	Regional Development Planning Board (Indonesia)
BAPPENAS	State Ministry of National Development Planning (Indonesia)
BAU	Bangladesh Agricultural University
BDT	Bangladesh taka
BFD	Bangladesh Forest Department
BFRI	Bangladesh Forest Research Institute
BOB IGP	Bay of Bengal Inter-Governmental Panel
BOBLME	Bay of Bengal Large Marine Ecosystem Project
CBACC-CF	Community-Based Adaptation to Climate Change through Coastal Afforestation Project
CBD	Convention on Biological Diversity
CBEMR	Community-based Ecological Mangrove Restoration
CBMR	Community-Based Mangrove Reforestation
CBO	Community-based organization
CEC	Central Executive Committee
CFD	Coastal Forestry Division (Pakistan)
CHAMPS	Coastal Health Archive and Monitoring National Programmes
CMC	Co-Management Committee
COP	Conference of Parties
CRZ	Coastal Regulation Zone
DFID	Department for International Development (UK)
DLS	Department of Livestock Services (Bangladesh)
DoF	Department of Fisheries (Bangladesh)
DRR	Disaster risk reduction
DWLC	Department of Wildlife Conservation (Sri Lanka)
EBA	Ecosystem-based adaptation
ECCDI	Ecosystems Conservation and Community Development Initiative
EMR	Ecological mangrove restoration
ETM	Enhanced Thematic Mapper
FAO	Food and Agriculture Organization of the United Nations
FB	Fund Board
FFF	Forest, Fish, Fruit
FREDA	Forest Resource Environment Development and Conservation Association
GEER	Gujarat Ecological Education and Research Foundation
GEF	Global Environment Facility
GIS	Geographic Information System
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GPS	Global Positioning System
HRA	High Risk Area
ICM	Integrated Coastal Management
ICAM	Integrated Coastal Area Management
IDR	Indonesian rupiah
IMFFS	Integrated Mangrove Fishery Farming System
INGO	International non-governmental organization
INR	Indian rupee

IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
JFM	Joint Forest Management
JFMC	Joint Forest Management Committee
JMM	Joint Mangrove Management
LDCF	Least Developed Countries Fund
LKR	Sri Lanka rupee
M&E	Monitoring and evaluation
MAP	Mangrove Action Project
MAPP	Method for Impact Assessment of Programmes and Projects
MEALS	Mangrove Empowerment and Livelihood Security
MERN	Mangrove and Environmental Rehabilitation Network
MFD	Myanmar Forest Department
MFF	Mangroves for the Future
MLE	Monitoring, learning and evaluation
MMAF	Ministry of Marine Affairs and Fisheries (Indonesia)
MMK	Myanmar kyat
MOECAF	Ministry of Environmental Conservation and Forestry (Myanmar)
MOEF	Ministry of Environment and Forests (India)
MSSRF	M. S. Swaminathan Research Foundation
NAQDA	National Aquaculture Development Authority of Sri Lanka
NGO	Non-governmental organization
NSAP	National Strategy and Action Plan
PAN	Potential Area Number
PC	People's Committee
PFE	Permanent Forest Estate
PoW	Programme of Work
PRA	Participatory Rural Appraisal
REDD	Reducing Emissions from Deforestation and Forest Degradation
SBR	Sundarban Biosphere Reserve
SCCDP	Sindh Coastal Community Development Project
SFD	Sindh Forest Department (Pakistan)
SIDA	Swedish International Development Cooperation Agency
SOP	Standard Operating Procedure
SPOT	Système Pour l'Observation de la Terre
SRS	Simple random sampling
SUPARCO	Space and Upper Atmosphere Research Organization
TAO	Tambon Administrative Organisation
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
VDMC	Village Development and Mangrove Council
VND	Viet Nam dong
WCS	Wildlife Clubs of Seychelles
WWF	World Wide Fund for Nature

जयंती नटराजन
Jayanthi Natarajan

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FOREWORD

I am pleased to present *Sharing Lessons on Mangrove Restoration*, published by IUCN, International Union for the Conservation of Nature and Natural Resources.

This publication contains edited versions of the papers presented at the Mangroves for the Future Regional Colloquium on Sharing Lessons on Mangrove Restoration, which was held in Mamallapuram, 30-31 August 2012.The colloquium was a great success and provided a common platform for all stakeholders to discuss, learn and share experiences regarding the restoration of mangrove ecosystems across the Asian region.

I am pleased that this new publication can be launched at the Convention on Biological Diversity, Conference of the Parties (CBD COP-11) in Hyderabad, October 2012, as the contributed papers have relevance to several of the Aichi Targets on Biodiversity. The publication of this book is also timely as it can inform Governments and Civil Society Organizations in Asia about past and on-going mangrove restoration efforts. It is hoped that this publication will be useful not only to countries in Asia, where most of the world's mangroves are found, but to a global audience as well.

Last year we celebrated the International Year of Forests. This year India is hosting the CBD COP-11. The eco-restoration is an agenda item of COP. Moreover Coastal and Marine Biodiversity is one of the four themes identified for the High Level Segment. To top all this, the current decade (2011-2020) has been declared as the United Nations Decade on Biodiversity. The International Day on May 22, 2012 was also in praise of Coastal and Marine Biodiversity. All these, I hope, will go a long way in reaffirming our collective commitment to nurturing all facets of Coastal and Marine biodiversity.

I congratulate all those who were involved in this endeavor and in particular the colloquium organizing and scientific committees consisting of members from the Ministry of Environment and Forests of India and the Mangroves For the Future initiative.

I wish to put on record the overall guidance and support provided by Shri. M. F. Farooqui, Special Secretary and Chairman of National Coordination Body of the MFF (India) Programme and diligent efforts put in by Dr. J. R. Bhatt, Adviser and Mr. Hem Pande, the Joint Secretary in this assignment.

(Jayanthi Natarajan)

Preface

Since 2008, the Mangroves for the Future (MFF) initiative has, through its small and large grant facilities, supported mangrove planting and restoration activities in the MFF member countries. These activities have supplemented a large repository of other information and data on mangrove restoration built up over the past two to three decades, and especially following the 2004 Indian Ocean tsunami.

Since the 2004 tsunami, mangrove restoration has become a priority for national governments in their quest to provide security against sea storms and other natural hazards. Governments, coastal ecologists, international and national NGOs, local CBOs and coastal communities have shown great interest in mangrove-related activities for this and other reasons, including biodiversity conservation and livelihood support. Thus, international funding agencies and bilateral donors, as well as government agencies, have provided considerable financial support for numerous mangrove projects; these have been quite diverse in terms of their objectives, including *inter alia* mangrove conservation and restoration, planting of mangrove bioshields, and mangrove education and protection. Similarly, the project implementing agencies (particularly INGOs, NGOs and CBOs) also have displayed diverse interests and management approaches. This diversity of interests, approaches and attitudes to mangroves and their management must be understood in the context of the larger development perspective and the concept of integrated coastal area management.

Members of coastal communities traditionally have used mangroves and their products widely for timber, fuelwood, food and livelihood activities, especially fisheries, but also including coastal agriculture, aquaculture and salt production. Many of these traditional practices date back centuries, but still continue in particular geographic settings, revealing that many coastal communities continue to depend on the health and productivity of mangroves, estuaries and lagoons for many of their basic needs.

Among the numerous mangrove projects that have been supported, some have contributed substantially to improving coastal ecosystems and associated livelihoods. Yet many projects have also had disappointing results, and too many have simply planted mangrove seedlings without giving adequate attention to the wider ecosystem and socio-economic impacts of mangrove planting. Overall, because of the highly project-oriented nature of these activities, there has been very little critical evaluation of the consequences of these projects, or compiling of the lessons to be learned. In Sri Lanka, for example, an evaluation of mangrove planting projects noted that greater control should be exercised in future interventions in conservation and management of mangroves, and requested that guidelines on mangrove restoration best practices be prepared and made widely available. Furthermore, it recommended that until such guidelines are provided, mangrove planting should receive prior approval from the relevant authority.*

In summary, it has become clear that mangrove restoration activities need to be examined from the standpoint of their societal values, and how they can contribute to improving the health of coastal ecosystems and conserving biodiversity within the context of integrated

* IUCN, 2011. *An Appraisal of Mangrove Management in Micro-tidal Estuaries and Lagoons in Sri Lanka*. Colombo: IUCN Sri Lanka Country Office, 116 pp.

coastal area management. To address these concerns, MFF's Regional Steering Committee decided that a Regional Colloquium should be held to share best practices on mangrove restoration and critically review the lessons learned.

The Colloquium

The Colloquium was held on 30–31 August 2012 at the Radisson Blu Resort Temple Bay, Mamallapuram, near Chennai, India. Its main objectives were to:

1. Examine the various experiences from the countries where mangrove projects have been carried out.
2. Enable countries to critically examine the merits and demerits of these mangrove projects.
3. Share experiences so that countries can replicate the good practices.

The Colloquium programme is provided in Annex 1. The event was concluded with an optional field trip to the Pichavaram mangroves near Chidambaram on 1–2 September.

Fifty international participants (from MFF member and outreach countries; selected MFF partners; other identified international experts) and national participants from India attended the Colloquium (Annex 2).

The Colloquium was opened ceremonially by lighting the traditional oil lamp. Ms Meenakshi Datta Ghosh, Country Representative, IUCN India, welcomed the participants and Dr Steen Christensen, MFF Coordinator, gave an introduction and brief about the Colloquium. Dr J. R. Bhatt, Member Secretary of the MFF National Coordinating Body, India, speaking on behalf of Mr M. F. Farooqui, Special Secretary, Ministry of Environment and Forests, Government of India, traced the events leading to the holding of the Colloquium, and highlighted the importance of its outputs in the deliberations of the upcoming CBD Conference of the Parties (COP-11) in India in October 2012. Dr N. M. Ishwar, MFF National Coordinator, India, proposed the Vote of Thanks.

The Colloquium included presentations from MFF member countries and other invited countries in the Asia region on their experiences from mangrove restoration projects, particularly in relation to improving coastal ecosystems and the livelihoods of local people. In particular, the colloquium provided an opportunity to:

- Examine the available scientific information and knowledge.
- Debate the contrasting viewpoints stemming from the diversity of ideas and perceptions among different resource users and interest groups concerning mangrove ecosystems.
- Address the inadequacy of information for building knowledge on the economic significance of mangroves.
- Seek sustainable solutions to the complex problems currently encountered, not only from science, academia, lobby groups, industries and government representatives, but also through a society-wide dialogue.

Topics for the Colloquium included:

a) The economic and financial values of mangroves, and the need for restoration.

b) New planting and restoration – the basic tenets including geomorphological context of coastal ecosystems, interest in mangroves, impacts of mangroves in their natural state and planted (or cultivated) state, impacts of mangroves on other economic activities/sectors such as fisheries, agriculture, tourism, biodiversity, hazard mitigation, and urban planning (in terms of flood protection and drainage).

c) Demonstration of the benefits of mangrove restoration activities, and examination of the intended or unintended harmful effects of such activities on the ecosystem.

d) Mangrove planting based on simplistic thinking and insensitive to physical geography, geomorphology, and the complexity of ecosystem structure and functioning.

e) The need for accommodating the collective voices of the primary resource users of mangrove ecosystems.

f) Guidelines for good practices, monitoring indicators, and accountability mechanisms.

g) Examination of the predictable relationships between mangroves and impacts of climate change, specifically in regard to protection from coastal hazards (for example cyclones, erosion, floods, and in their role as bioshields), and food security (for example drainage, soil salinization and waterlogging).

The closing session of the Colloquium was held on the afternoon of 31 August, with the distinguished presence of Mr Hem Pande, Additional Secretary, Ministry of Environment and Forests, Government of India. The participants deliberated and agreed on the recommendations contained in a "Call for Action" paper, to be provided to the CBD COP-11 in Hyderabad, India, in October 2012 (see next section). Dr Balakrishna Pisupati, Chairman, National Biodiversity Authority of India, briefed the participants on the expectations from COP-11, and Mr Hem Pande explained the links between COP-11 and the outputs of the Colloquium.

The Colloquium closed with the presentation of certificates for those who attended the scientific presentations training course, conducted immediately before the event by Dr Chris O'Brien, Regional Coordinator of the Bay of Bengal Large Marine Ecosystem Project (BOBLME).

Dr Steen Christensen, MFF Coordinator, gave the closing remarks, and Mr Shamsul Haq Memon from Pakistan proposed a Vote of Thanks on behalf of the participants.

Call for action

Preamble

The Ministry of Environment and Forests of India, together with Mangroves for the Future (MFF), a regional initiative to promote investment in coastal ecosystem conservation for sustainable development, convened a Regional Colloquium at Mamallapuram in Tamil Nadu, 30–31 August 2012, to share lessons on mangrove conservation, restoration and rehabilitation.

Resource persons from nine MFF Member and Outreach countries – Bangladesh, India, Indonesia, Myanmar, Pakistan, Seychelles, Sri Lanka, Thailand and Viet Nam – and international experts from Australia, Denmark, Germany and the United States participated in the Colloquium. After reviewing lessons learned from mangrove restoration and planting projects undertaken since the 2004 Indian Ocean tsunami, guidelines for good practices in mangrove restoration and rehabilitation were discussed, with a focus on the need for community involvement, benefit-sharing and livelihood improvement, long-term monitoring, and accountability. The Colloquium also considered the role that mangroves can play in climate change adaptation and mitigation, including their potential contribution to ecosystem-based disaster risk reduction.

However, the Colloquium also recognized that, despite the wealth of scientific knowledge, technical expertise and good practices available to support mangrove restoration/rehabilitation and monitoring, they are not being applied widely or well-enough to offset the continued degradation of mangroves in most countries.

Resulting from the sharing of experiences from mangrove restoration/rehabilitation projects, plus critical examination of the status of mangrove ecosystems today in the nine participating countries, **A Call for Action** was prepared, to go forward to the International Conference on Biodiversity (COP-11) in Hyderabad, India, 1–19 October 2012.

A Call for Action

Recognizing that millions of people in South and Southeast Asia still depend heavily on the health and productivity of mangroves, estuaries and lagoons for their basic food, materials and livelihood needs;

but also recognizing that large areas of mangrove habitat continue to be destroyed or degraded in many countries, despite the collective efforts of governments, NGOs and international agencies to rehabilitate mangroves since the 2004 Indian Ocean tsunami;

and recognizing that a wealth of scientific knowledge and good practices in mangrove restoration/rehabilitation exist that can be shared among the countries of the Indian Ocean and Southeast Asia;

The Colloquium calls for the following principles and practices be incorporated into: a) government policies and national plans for coastal area management; b) regional cooperation and development programmes; and c) individual projects supporting the rehabilitation and sustainable use of mangroves for the benefit of coastal communities and the wider society:

Sound Management Principles

1. Mangroves should be managed according to the ecosystem-based approach and following the principles of wise-use as defined by the Ramsar Convention on Wetlands; and further links and synergies between these approaches should be developed.

2. Site-specific and appropriate restoration and management approaches are necessary, as part of an integrated coastal area management approach; mangroves cannot be restored/ rehabilitated and protected in isolation from other coastal and upstream processes, and the human impacts on them.

Economic Justification

3. Greater investment in national and regional mangrove restoration programmes is needed, supported by stronger policy and legislative measures to protect mangrove ecosystems and the welfare of traditional mangrove-dependent communities.

4. The full economic value of mangrove ecosystem goods and services should be estimated so that sound development planning decisions can be made, and innovative sustainable financing mechanisms (e.g. access and benefit-sharing, income generation from mangrove ecotourism) designed to support mangrove conservation and sustainable use.

Enabling Policies and Safeguards

5. There is a particular need to enact policies to restore abandoned aquaculture farms using techniques that can recover the hydrological and soil conditions to their near-to original state, so that they can be converted back to productive wetlands or integrated mangrove-aquaculture systems.

6. Special care should be taken in the management of micro-tidal barrier-built estuaries and lagoons. Because of their semi-enclosed nature and demographic pressures, they are highly sensitive to human impacts, amongst others. Mangrove restoration in such areas must follow guidelines that safeguard other aquatic fishery habitats and fishery-based livelihoods, plus the other ecosystem services that estuaries and lagoons provide.

7. Coastal mudflats and other low-lying shore types should also be treated with particular care to avoid planting mangroves below their natural intertidal level, or where there are mudflat habitats critical to endangered wildlife.

Actions to Ensure Success

8. The following actions are essential to ensure effective long-term mangrove management and sustainable use:

    - Consultation with and participation of local communities in all mangrove restoration, protection and management activities.

    - Resolution of land tenure, resource access or use issues, policy failures or other issues that will affect the outcome of mangrove restoration and sustainable use management efforts.

    - Respecting and using the traditional knowledge and cultural beliefs that local people have about mangrove ecosystems.

    - Mangrove restoration and environmental awareness and educational programmes for key mangrove resources user groups, plus learning and participatory activities, particularly for children and youths.

- Applying modern, macro-level technology for coastal monitoring (e.g. remote sensing and GIS) that can detect large-scale and long-term environmental change.
- Monitoring of specific mangrove restoration and rehabilitation areas using simple, empirical and modern techniques (agreed and standardized), which can involve local communities and operate over meaningful time periods (5–10 years).
- Strengthening and empowering grassroots institutions to plan, implement and monitor mangrove restoration programmes in partnership with other stakeholders.
- Interventions that improve the livelihoods of traditional mangrove users, preferably by providing alternative and more diversified livelihood opportunities to reduce the pressures on mangrove resources.
- Partnerships and co-management involving local communities/other civil society groups (including the private sector) and government are essential to achieving positive long-term outcomes and recognition for the role of local communities in mangrove restoration and management.

Climate Change Considerations

9. Mangroves are capable of sequestering very high quantities of carbon compared with other forest types. Applied research should be conducted on the ecological and economic value of mangroves as a carbon sink, and the potential to benefit mangrove-dependent communities through the emerging forest carbon marketing mechanisms.

10. Where appropriate, mangrove ecosystem restoration/rehabilitation should be included in national climate change adaptation strategies, because mangroves can play a major role in building resilience against climate change and natural disasters in the coastal zone by providing coastal communities with increased food and income security; as well as improving environment and physical protection against erosion, storms and other extreme climatic events.

Regional Cooperation

11. Regional programmes (such as MFF, BOBLME and BOB IGP) should be upscaled and/or extended, as these have demonstrated great potential for promoting regional good practices, information sharing and capacity development to support coastal and marine ecosystems management.

12. Applied research to develop a regional inventory of mangrove resources, case studies and best management practices, and to identify gaps in knowledge about mangrove ecosystems, should be initiated as a regional effort to support the development of national and transboundary management plans for mangroves.

13. The Colloquium urged that the many agencies, bodies, programmes and projects working in the coastal zone should collaborate to the extent possible to improve regional understanding of coastal resources management, in order to optimize results and benefits, and avoid duplication of work.

October 2012

Map of the main localities and study sites mentioned in the text. For details see individual papers. Map © IUCN.

Session I

Economic and Environmental Values of Mangroves

Valuation, carbon sequestration potential and restoration of mangrove ecosystems in India

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Abstract

Mangroves are an important component of India's coastal resources endowment. Distributed along the east and west coasts, and covering an area of 4,663 km², these relatively rare ecosystems play an important role in supporting livelihoods and human well-being through a range of ecosystem services. Although these habitats continue to decline globally, they are being well-maintained in India through a range of effective conservation and restoration measures.

Restoring and conserving mangroves form a key component of India's ecosystem-based climate change response strategies. This paper provides an overview of the status and trends of mangroves in India, emphasizing the value of the mangrove ecosystem services that have influenced policy and decision-making. It describes the likely impacts of climate change on these ecosystems, and provides an overview of the restoration techniques used in various parts of the coastal zone. Lastly the paper discusses the policy environment for conservation and sustainable management of mangroves.

India has evolved techniques for better conservation and management of mangroves based on scientific principles. A GIS-based mangrove atlas has been prepared with detailed information about mangrove resources and management issues. The major issues have been identified as mangrove degradation and a lack of people's participation in mangrove management. The causes of these have been identified as, respectively, hypersalinity and the lack of supplementary livelihoods. After testing several techniques to reverse mangrove degradation, the "fishbone design" has been selected as the best model for restoration. To mobilize and organize local communities, a Joint Mangrove Management (JMM) model has been successfully demonstrated. These models are now being replicated in other areas.

Keywords: mangroves, economic benefits, restoration, carbon sinks, India

1. Introduction

Mangrove forests are among the most productive ecosystems on earth. They are carbon-rich forests with a standing crop greater than any other aquatic ecosystem. Mangroves are often called "tidal forests", "coastal woodlands" or "oceanic rainforests" (Kathiresan and Bingham 2001; Kathiresan and Qasim, 2005; Spalding *et al*., 2010; Kathiresan, 2011a).

About 90% of mangrove forests are found in developing countries, though they are nearing extinction in 26 countries. Their long-term survival is threatened by fragmentation of the remaining forests, making it possible that the ecosystem services supplied by mangroves will be lost entirely within 100 years (Duke *et al*., 2007). Globally, mangrove habitats continue to disappear; the annual rate of loss was 0.66% in 2000–05 (FAO, 2007). This paper examines the status of mangrove forest cover in India, the planting techniques and practices being followed, and the value of the mangroves in terms of carbon sequestration.

1.1 Mangrove forests in the world and India

Mangroves are largely restricted to the tropics and a few warm temperate regions between latitudes 30° north and 30° south, with the largest proportion found between latitudes 5°

north and 5° south. About three-quarters of the world's mangroves occur in just 15 countries. Mangroves cover an estimated 15.2 million ha (0.4% of all forests, <1% of tropical forests) in 123 countries and territories (FAO, 2007). This estimate, however, is 12.3% less than the most recent estimate by Giri *et al*. (2011). Mangroves are most extensive in Asia (39%), followed by Africa (21%), North and Central America (15%), South America (12.6%), and Oceania (Australia, Papua New Guinea, New Zealand, South Pacific) (12.4%) (FAO, 2007). They grow better in wet equatorial climates than they do in seasonally monsoonal or arid climates. Growth and biomass production of mangroves decrease with increasing latitude.

Mangroves comprise a relatively small group of 73 species of trees and shrubs (Spalding *et al*., 2010). Eleven mangroves species face an elevated threat of extinction. Particular areas of concern include the Atlantic and Pacific coasts of Central America, where as many as 40% of mangrove species are threatened with extinction. Globally, mangrove species found primarily in high intertidal and upstream estuarine zones are most threatened because they are often the first cleared for development of aquaculture and agriculture. The loss of mangrove species will have devastating economic and environmental consequences for coastal communities, especially in areas with low mangrove diversity and high mangrove area or species loss. Several species at high risk of extinction may disappear well before the next decade if existing protective measures are not enforced (Polidoro *et al*., 2010).

India has a total mangrove cover of 4,662.56 km^2 (Forest Survey of India, 2011), or 0.14% of the country's land area, 3% of the global mangrove area, and 8% of Asia's mangroves. About 59% of this cover is on the east coast along the Bay of Bengal, 28% on the west coast bordering the Arabian Sea, and 13% on the Andaman and Nicobar Islands. India's mangroves can be broadly categorized into deltaic, backwater-estuarine and insular types. Deltaic mangroves are found along the east coast within the deltas of the Ganges, Brahmaputra, Mahanadhi, Krishna, Godavari and Cauvery Rivers. Estuarine mangroves are found on the west coast in the estuaries of the Indus, Narmada and Tapti Rivers. They are also grow in the backwaters, creeks and neritic inlets of these areas. Insular type mangroves are found in the Andaman and Nicobar Islands. Their growth is supported by tidal estuaries, lagoons and rivulets. These differences in distribution can be attributed to two reasons: i) the east coast has large estuaries with deltas formed by runoff and deposition of sediments, whereas the west coast has funnel-shaped estuaries and generally lacks deltas; and ii) the east coast has a gentle slope with extensive flats for mangrove colonization, whereas the west coast slopes steeply.

On the east coast of India, no studies have singled out damming of rivers as leading to destruction of mangroves. However, some studies by the M.S. Swaminathan Research Foundation have found a change in mangrove species composition caused by reductions in the periodicity and quantity of fresh water reaching the mangrove environment. The most extensive mangroves in this region are found in the Sundarbans in West Bengal (46.2%). Extending across the boundary between India and Bangladesh, the Sundarbans is the largest single block (about 10,000 km^2) of mangrove forest in the world. It is the home of globally threatened species such as the Royal Bengal tiger, sea turtle, fishing cat, estuarine crocodile, Gangetic dolphin, and river terrapin (Forest Survey of India, 2011). Tables 1 and 2 opposite detail the status and trends of mangrove cover in India's states and union territories.

Table 1 Mangrove cover by state, India (km²)

State/ Territory	1987	1989	1991	1993	1995	1997	1999	2001	2003	2005	2009	2011	Change from 2009
Andhra Pradesh	495	405	399	378	383	383	397	333	329	354	353	352	*–1*
Goa	0	3	3	3	3	5	5	5	16	16	17	22	+5
Gujarat	427	412	397	419	689	901	1,031	911	916	991	1,046	1,058	+12
Karnataka	0	0	0	0	2	3	3	2	3	3	3	3	0
Kerala	0	0	0	0	0	0	0	0	8	5	5	6	+1
Maharashtra	140	114	113	155	155	124	108	118	158	186	186	186	0
Orissa	199	192	195	195	195	211	215	219	203	217	221	222	+1
Tamil Nadu	23	47	47	21	21	21	21	23	35	36	39	39	0
West Bengal	2,076	2,109	2,119	2,119	2,119	2,123	2,125	2,081	2,120	2,136	2,152	2,155	+3
Andaman and Nicobar Is.	686	973	971	966	966	966	966	789	658	635	615	617	+2
Daman and Diu	0	0	0	0	0	0	0	0	1	1	1	1.56	+0.56
Puducherry	0	0	0	0	0	0	0	1	1	1	1	1	0
Total	4,046	4,255	4,244	4,256	4,533	4,737	4,871	4,482	4,448	4,581	4,639	4,662.56	+23.56
Change	+209	*–11*	+12	+277	+294	+44	*–389*	*–34*	+133	+58	+23.56	–	–

Source: Forest Survey of India (2011).

Table 2 Density of mangrove cover by state, India

State/Territory	Very dense	Moderately dense	Open	Total	Change from 2009
Andhra Pradesh	0	126	226	352	-1
Goa	0	20	2	22	5
Gujarat	0	182	876	1,058	12
Karnataka	0	3	0	3	0
Kerala	0	3	3	6	1
Maharashtra	0	69	117	186	0
Orissa	82	97	43	222	1
Tamil Nadu	0	16	23	39	0
West Bengal	1,038	881	236	2,155	3
Andaman and Nicobar Is.	283	261	73	617	2
Daman and Diu	0	0.12	1.44	1.56	0.56
Puducherry	0	0	1	1	0
Total	1,403	1658.12	1601.44	4662.56	23.56

Source: Forest Survey of India (2011).

2. Valuation of mangrove systems in India

Mangroves provide a wide range of ecosystem services. They serve as breeding, feeding and nursery grounds for many fishes in offshore and inshore waters. They also provide feeding and breeding grounds for birds, reptiles and mammals. They are a source of forest products such as firewood, timber and honey. The benefits provided by these ecosystems are much wider in range than those provided by concrete seawalls or other physical structures constructed for coastal protection.

A study of the role played by mangroves in fisheries income has revealed that a mangrove-rich area provides up to 70 times more catch and income than a mangrove-poor area (Kathiresan and Rajendran, 2002). In addition, many rural communities use mangroves to produce honey, fodder and traditional medicines. Experience from the 2004 Indian Ocean tsunami indicates that mangroves, along with *Casuarina* plantations, reduced the impact of waves and protected shorelines against damage along the Tamil Nadu coastline (Danielsen *et al*., 2005; Kathiresan and Rajendran, 2005). However, in places the tsunami damaged mangroves; for example, between 51% and 100% of mangroves in the four Nicobar islands of Camorta, Katchal, Nancowry and Trinkat were damaged. Badola and Hussain (2005) carried out an economic assessment of the storm protection function of the Bhitarkanika mangrove ecosystem in three selected villages, using the cyclone of 1999 as a reference point. This found that the highest losses were in the village sheltered not by mangroves but by embankments, and the lowest per capita damage in villages with mangrove barriers. Das and Vincent (2009) validated the storm protection function of mangroves in Orissa on India's east coast. They established that villages with wider mangrove belts between them and the coast suffered significantly fewer deaths than those with narrower or no mangrove belts.

In recent years, a growing body of research has explained the contribution of mangroves in concrete economic terms, making comparison possible with other economic uses with defined cost and benefit streams. Putting a monetary value on ecosystem services provides an incentive for landowners or those with land-use rights (both government and private owners) to make sustainable land-use decisions. It can also help in rationalizing incentive systems through the use of instruments such as payments for ecosystem services, a means of incentivizing local resource stewardship.

Globally, mangrove forests have been estimated to provide US$1.6 billion or more each year in ecosystem services (Costanza *et al*., 1997), and also support coastal livelihoods. In American Samoa, mangroves covering just 0.5 km^2 have an estimated annual value of US$50 million (Spurgeon and Roxburgh, 2006). In Thailand, high values of US$2.7–3.5 million/$km^2$ have been reported (Sathirathai and Barbier, 2001).

Limited efforts have been made to value ecosystem services in India. The country's mangroves account for 2.5% of the global economic value of mangroves, estimated at US$4,522,398,075 (Costanza *et al*., 1997). Khaleel (2008) estimated the economic value of mangroves in North Malabar at US$10,960 per hectare per year. This makes them about 25 times more valuable in economic terms than paddy cultivation (Kathiresan, 2011b). The protection value of one hectare of intact mangroves in Orissa against a cyclone in 1999 was estimated at US$8,700, when one hectare of cleared land fetched only US$5,000. Thus, protecting mangroves as storm shelters generated more economic value (Das and Vincent, 2009).

3. Carbon sequestration potential

Mangroves are among the most carbon-rich forests in the tropics. Their carbon sequestration potential is estimated to be up to 50 times greater than tropical terrestrial forests. This is because of their high levels of below-ground biomass and considerable storage of organic carbon in mangrove sediment soils. Globally, mangroves accumulate up to 25.5 million tonnes of carbon annually (Ong, 1993), and provide more than 10% of the organic carbon essential to the world's oceans (Dittmar *et al.*, 2006). Covering 2,118 km^2, the mangroves of the Indian Sundarbans are thought to absorb over 41.5 million tonnes of carbon dioxide daily, valued at around US$79 billion in the international market. Maintaining this function will help to control rises in atmospheric temperatures and associated climatic changes.

Globally, mangrove deforestation generates emissions of 0.02–0.12 picogrammes of carbon per year, up to 10% of total emissions from deforestation. Thus, failing to preserve mangrove forests can cause considerable carbon emissions and lead to climate change (Spalding *et al.*, 2010; Donato *et al.*, 2011). Therefore, mangrove restoration could be a novel mitigation option against climate change.

Mangroves are especially valuable for carbon sequestration because they accumulate large amounts of carbon in the soil, whereas terrestrial forests keep most of it in tree trunks and branches. Older mangrove forests accumulate relatively more soil carbon that younger forests. The other positive aspect of mangroves is that, with time, planted mangroves sequester similar quantities of carbon to natural forests.

Technical difficulties hamper carbon measurement in mangrove ecosystems, especially below-ground carbon accumulation, the dynamic nature of mangrove forests, and the need to better understand and quantify the other economic values of mangroves, especially for aquaculture and coastal infrastructure development.

Both the Clean Development Mechanism and the Verified Carbon Standard have established methodologies for measuring, monitoring, and paying for the carbon captured in mangrove forests. However, the tools available so far do not adequately address the most important aspect of mangrove carbon: the soil carbon (Zwick, 2010). Mangroves are open ecosystems with both shore gain (by accretion) and shore loss (by erosion) occurring simultaneously in different parts of the ecosystem as a result of positive or negative sedimentation rates. The dynamic nature of mangroves should be taken into account when selecting sites for carbon sequestration. It will also be necessary to develop guidance and standards for sequestering carbon through wetland restoration projects, which can deliver tangible and equitable benefits for local communities.

4. Potential impacts of climate change on mangrove ecosystems

Mangroves are highly adapted to coastal conditions. In the face of climate change, many of the regulating services of mangroves have increased relevance, especially their capacity to moderate the force of storms and floods. Various studies indicate that mangroves reduce wave forces by up to 70–90% with their extensive and dense above-ground root systems. Mangrove ecosystems moderate climatic extremes by providing shade and increasing air humidity, while also reducing wind velocity and soil water evaporation. In short, they are a first line of defence for coasts and coastal communities, since they buffer storm and wave forces, even those generated by cyclones, while binding coastal land that would otherwise erode away.

As stated before, mangroves provide a symbiotic link between land and sea, so are bound to be influenced by terrestrial, atmospheric, hydrological and marine conditions. They are potentially vulnerable to changes in any of these, and hence are especially likely to be affected by climate change (Solomon *et al*., 2007). The ability of mangroves to adapt to rising sea levels hinges on the response of individual species (hence the importance of species selection), and the availability of space for mangroves and other coastal vegetation to migrate inland. However, such possibilities could be drastically limited if land use in coastal zones does not provide that space.

The principal components of global climate change are: i) rise in atmospheric carbon dioxide levels; ii) rise in atmospheric and sea temperatures; iii) increase in extreme high water events and storms; iv) changes in precipitation; and v) sea level rise. These components may act synergistically upon mangroves, which are likely to be one of the first ecosystems to be affected because of their location at the interface between land and sea. However, mangroves exhibit resistance and resilience against some of the potential impacts of climate change.

4.1 Rise in atmospheric carbon dioxide levels

The Intergovernmental Panel on Climate Change (IPCC) forecasts an atmospheric carbon dioxide concentration of 730–1,020 parts per million (ppm) by 2100 (Solomon *et al*., 2007). Predictions of the likely impacts of rising carbon dioxide levels on mangroves are based on small-scale experiments, on only a few species, principally on seedlings and saplings rather than mature trees, and in simplified conditions. In some species, growth is increased by raised levels of carbon dioxide, whereas in others it is unaffected or even reduced. The effects may be temporary and could also vary according to salinity conditions (Ball and Munns, 1992; Ball *et al*., 1997; Snedaker and Araújo, 1998).

The possible effects on mangrove ecosystems include a slight extension into areas of higher salinity (because of enhanced water-use efficiency), and some changes in species composition, as species may be differentially affected.

4.2 Temperature rise

Over the past century, the global average surface temperature has risen by about 0.74°C; the rise by 2100 may be 1.1–6.4°C (Solomon *et al*., 2007). Experimentally increasing temperature usually results in increased biomass production. At the ecosystem level, the impact is likely to be insignificant: mangroves experience diurnal temperature ranges greatly in excess of the predicted rise in average temperature.

The global distribution of mangroves is limited by temperature, with the position of the 20°C winter isotherm almost exactly delimiting the global distribution of mangroves. A rise in global average temperature may plausibly allow a modest geographical expansion of mangroves north and south of the equator. This would probably be limited by intermittent cold events and by topography.

4.3 Storms

An increase in the frequency and severity of tropical storms is predicted as the climate changes (Solomon *et al*., 2007). Severe storms cause defoliation, tree death and soil erosion.

Mangrove ecosystems recover over a period of years. An increase in severity and frequency of storms would limit both the possibility and the rate of recovery.

4.4 Increased precipitation

A global increase in average precipitation of up to 25% is predicted, with considerable regional variation (Solomon *et al*., 2007). Mangroves require a delicate mix of fresh water and sea water to be able to live, grow and perpetuate. Increased precipitation may generally benefit mangroves, allowing for example increased growth and reproduction, and improved propagule survival and settlement. The outcome may therefore be an expansion in mangrove area.

4.5 Sea level rise

Average sea level is predicted to rise by 0.18–0.59 m by 2100; some models put the likely rise at up to one metre (Snedaker and Araújo, 1998; Nicholls and Cazenave, 2010). About three-quarters of this rise is attributed to thermal expansion of sea water, and the rest to melting of ice. Some studies show sedimentation keeping pace with current rates of local sea level rise, others conclude that the majority of mangrove sites have not been keeping pace (Alongi, 2008; Gilman and Ellison, 2010).

Overall, it has been estimated that global climate change is likely to result in the loss of 10–20% of mangroves worldwide, with some areas likely to lose a much higher proportion of their mangroves than others. Particularly vulnerable regions include East Africa, the Bay of Bengal, and the western Pacific (Alongi, 2008).

A recent study revealed the disappearance of two islands in the Indian Sundarbans, Suparibhanga and Lohacharra, and identified twelve more in the southernmost part of the region threatened with submergence (Anon, 2006). These changes have been attributed to rising sea levels. Another issue in the Sundarbans concerns the Sundari tree (*Heritiera fomes*), which is heavily affected by top-dying disease. This is believed to be caused by an array of factors linked to climate change – increased soil salinity, excessive flooding, sedimentation, nutrient imbalance and cyclone-induced stresses.

5. Management of mangroves – some lessons from India

5.1 Preparation of GIS-based mangrove atlas

In 1996, the M. S. Swaminathan Research Foundation (MSSRF) began a detailed study of mangrove management in the eastern coastal states of India, financed by the India–Canada Environment Facility. Using data collected from 1996 to 2004, MSSRF published a comprehensive mangrove atlas for Tamil Nadu, Andhra Pradesh and Orissa (Selvam *et al*., 2001; Ravishankar *et al*., 2004a, 2004b). This GIS-based atlas contains a wealth of scientific information about mangrove resources, used extensively by various agencies to develop mangrove management plans. The atlas was the first successful step taken in India to understand mangrove conservation and management (Kathiresan, 2005).

5.2 Demonstration of Joint Mangrove Management (JMM)

The MSSRF mangrove atlas helped to identify the critical issues influencing better management of mangrove resources. One issue was the lack of a participatory approach in management. To tackle this, MSSRF and several State Forest Departments successfully demonstrated a pilot project on Joint Mangrove Management (JMM) (see also Selvam, Ramasubramanian and Ravichandran, this publication). This was a breakthrough in the restoration and conservation of mangroves through people's participation in India. The JMM project involved 5,240 families from 28 villages in three states – Tamil Nadu, Andhra Pradesh, Orissa – on India's east coast. About 1,475 ha of mangroves were restored by planting 6.8 million mangrove saplings, with survival rates of between 75% and 80%. To empower local people, 194 self-help groups were organized to implement poverty alleviation programmes such as supplementary income-generating activities for firewood, fodder, fencing and house construction. Based on this pilot project, comprehensive guidelines for promoting JMM in India have been proposed (Kathiresan, 2005). The model has also been replicated in other parts of India (Selvam, 2001; Ravishankar and Ramasubramanian, 2004; Kathiresan, 2005).

5.3 Supplementary livelihoods

People who depend on mangrove resources can be provided with supplementary livelihoods to reduce exploitation pressure and conserve these resources. Possible livelihood activities include animal husbandry (pig, goat and cattle rearing), cultivating higher-yielding crop varieties, changing cropping patterns and practices, duck raising, small cottage industries, tailoring, carpet weaving, mushroom cultivation, seed collection, apiculture, honey collection, pearl and fish culture, fishing and ecotourism. Unlike other forests, the direct economic benefits from mangroves are limited. Fishing in mangroves is the only source of income for mangrove-dependent communities. However, activities that integrate mangrove conservation with fishery development can be promoted, such as traditional canal fishing methods, crab fattening in mangrove waters, and oyster and clam culture. These can increase the economic stake of the local community in mangrove restoration, conservation and management.

For example, MSSRF, with financing from MFF, has demonstrated an Integrated Mangrove Fishery Farming System (IMFFS), in which mangroves, halophytes, fish, crabs and shrimps are cultivated in the same farm (see also Selvam, Sivakumar and Ramasubramanian, this publication). In IMFFS, which has been piloted with communities, government agencies and shrimp farmers, aquaculture ponds are designed to provide space for growing saline-tolerant vegetation, including mangroves and halophytes. Up to 35% of the available space is kept for mangroves and halophytes, and the rest used to hold sea water for fish culture. This system is currently undergoing further development for polyculture of several food fishes.

6. Mangrove restoration techniques – some lessons from India

Restoring mangroves is often recommended when the ecosystem has been modified to such an extent that it cannot regenerate naturally. Although restoration frequently emphasizes planting as the primary method, mangroves can regenerate naturally if the normal tidal hydrology is restored and the supply of seeds or propagules of mangroves from adjacent stands re-established. If hydrology is normal, but the influx of seeds or propagules is disrupted, then mangroves can be successfully established by planting. Alternatively, when the hydrology is disrupted but the availability of seeds or propagules is normal, then mangroves can be established by hydrological restoration (Kathiresan, 2011b).

Successful reforestation of abandoned fish ponds requires the restoration of original soil conditions and hydrology. Earthworks need to be carried out to remove the pond dykes and close the fish ponds. As these dykes are usually constructed with soil from pond excavation, restoration can be carried out by simply reversing this process, and filling the ponds with the material from the surrounding dykes.

Planting of mangroves is largely confined to two types: i) direct planting of seeds or propagules in the muddy areas; and ii) planting of seedlings obtained from nurseries. In the first type, propagules can be used directly as long as they are plentiful. The second can be adopted for seeds that are available seasonally and in small quantities. In this type, nurseries are developed in the upper parts of intertidal areas, using polythene bags, for 6–12 months (or until saplings grow to 30–60 cm; see below). The plants are then transplanted in the field according to their zoning patterns. Direct planting of propagules is often unsuccessful if the area is exposed, with unfavourable climatic conditions or strong waves, or if propagule-eating crabs are abundant. In such areas, nursery seedlings should be used.

The propagules of Rhizophoraceae mangroves – *Rhizophora*, *Kandelia*, *Ceriops* and *Bruguiera* – can be planted directly, whereas the relatively small seeds or propagules of *Avicennia*, *Sonneratia* and *Excoecaria* can be raised in a nursery and then transplanted. The nursery should preferably be established in mangrove areas, where original mangrove soil is available. Young plants can occasionally be flooded by sea water, but this is not essential. A source of fresh water (not sea water) should be readily available, as young plants need regular watering in their initial stages. Growing bags should be filled with the original mangrove soil. Seeds or propagules with a high germination success rate can be put directly in the bags, but for all other seeds it is advisable to let them germinate first in special germination trays. These should be filled with pure sand, keeping the humus content as low as possible to avoid development of fungi. Seeds do not need external nutrients to germinate. Some seeds need special treatment before being sown. Fruits of *Sonneratia* spp. must be kept in wet sand until they rot; then they can be removed and left to dry for a few hours before being sown. Seedlings of most species prefer some protection from direct sunlight for better growth. Seedlings are ready for planting in the field as soon as they have developed a strong stem, usually when they are 30–60 cm tall. Development of air-breathing roots (pneumatophores) starts after planting in the field. Planting should preferably take place in a period when low tides occur during the day and very high tides are less frequent.

In India, different planting techniques are followed depending on local conditions, especially tidal amplitude. In Gujarat, a “raised bed” is used for dibbling *Avicennia* seeds to avoid problems with strong tidal currents and washing away of seeds. In Karnataka, mangroves are planted in holes made in coconuts to ensure better rooting and establishment. In Kerala, mangroves are raised in cut bamboo containers and transplanted. In the eroded areas of Tamil Nadu, dead palmyra palms are used to strengthen the substrate, and mangrove seedlings are also planted in earthen pots. In Andhra Pradesh and Tamil Nadu, canal planting in a fishbone pattern has proved successful in saline blank areas where the tidal amplitude is low (see also Selvam, Ramasubramanian and Ravichandran, this publication).

6.1 Canal-bank planting – a specific planting technique

Mangroves in Tamil Nadu and Andhra Pradesh are widely degraded, usually as a result of high soil salinity due to irregular tidal flushing and low tidal amplitude. To overcome this situation, the canal-bank planting technique has been developed. In this, canals are constructed to promote regular tidal inundation of highly saline soils, which leaches out salts and improves conditions for regeneration of mangroves. This approach has been successfully demonstrated in mangrove forests at Pichavaram, Tamil Nadu, by MSSRF (MSSRF, 2002). The technique was first attempted in 1987 in mangrove forests at Muthupet, Tamil Nadu, and different models have since been developed (Baruah, 2004; Table 3). Among these, the fishbone design has been found to perform best and is currently the preferred model.

Table 3 Different models of canal-bank planting used in mangrove forests at Muthupet, Tamil Nadu

Model	Year of implementation	Specification
Linear design	1987–1998	Canals in parallel rows at right angles to the major source of water. Canal top width 1 m to 1.5 m.
Box design (modified linear design)	1998–1999	Parallel rows interconnected at regular 20-m intervals, thus looking like boxes. Dimension of main canals and side canals is the same: top width of 2 m, bottom width of 75 cm and depth of 75 cm.
Modified box design	1999–2001	Width of main canal increased from 2 m to 3 m for better flushing. A metre-wide gap left on all four sides of the box-like structure.
Fishbone design (technically the best design)	2001–2004	A feeder canal leads to distribution canals on either side, angled at 30° in the direction of water flow. Width of feeder canal is 3 m (top), 1 m (bottom) and 1 m (depth). Width of distribution canal is 2 m (top), 75 cm (bottom) and 75 cm (depth).
Modified fishbone design	2004	Distribution canals are linked to avoid blind endpoints. Feeder canals are at 50-m distance and distribution canals are at 20-m distance. Design also looks like a box design, but the distribution canals are angled at 30°, not perpendicular to the feeder canal.

Source: Baruah (2004).

6.2 Species selection for restoration

Species selection is critical for successful restoration of mangroves. Selection can be based on criteria such as planting purpose, adaptability, occurrence, availability of mature propagules, size of propagules, and zoning pattern of species.

6.2.1 Purpose of planting

Species selection must be carefully tailored to the desired objectives of planting (Table 4). Coastal protection, for example, has been largely successful with *Sonneratia alba*, *Sonneratia apetala*, *Avicennia officinalis* and *Rhizophora* spp. in countries such as India, Viet Nam, China and Bangladesh.

6.2.2 Adaptability of species

Every mangrove species has adapted to the climatic and edaphic conditions of its preferred site. For example, adaptability to salinity varies among different mangrove species: *Avicennia*

Table 4 Species selection according to planting objective

Planting objective	Mangrove species
Regeneration of mangroves	*Avicennia marina*, *A. officinalis*, *Aegiceras corniculatum*, *Excoecaria agallocha*, *Acanthus ilicifolius*
Coastal protection against tidal waters, erosion and cyclones	*Rhizophora apiculata*, *Rhizophora mucronata*, *S. alba*, *A. marina*, *A. officinalis*, *H. fomes*, *Kandelia candel*
Protection of lagoons and estuaries	*A. marina*, *Avicennia alba*, *A. officinalis*, *Bruguiera cylindrica*, *R. apiculata*, *R. mucronata*, *Rhizophora stylosa*, *Sonneratia caseolaris*, *S. alba*, *K. candel*, *A. ilicifolius*
Dyke protection along the sea and aquaculture farms	*A. marina*, *A. alba*, *A. officinalis*, *Ceriops tagal*, *R. apiculata*, *R. mucronata*, *R. stylosa*, *S. caseolaris*, *B. gymnorrhiza*, *E. agallocha*
Introduction to new mudflats	*R. mucronata*, *R. apiculata*, *A. marina*, *A. officinalis*, *A. corniculatum*
Harvest of forest products, timber, charcoal and firewood	*S. alba*, *S. apetala*, *A. marina*, *A. officinalis*, *R. apiculata*, *R. mucronata*, *C. tagal*, *B. gymnorrhiza*, *K. candel*, *H. fomes*, *Xylocarpus granatum*
Enhancement of fishery resources	*Avicennia* spp., *Bruguiera* spp.

Source: Kathiresan (1994, 2011b).

Table 5 Adaptability of mangrove species to different sites

Mangrove Species	Adaptability / Preferred Site
A. marina	Relatively dry tidal lands, river banks or highly saline flats, arid zones
B. gymnorrhiza, *H. fomes*	Areas with a large freshwater supply
C. tagal	Highly saline areas
Nypa fruticans	Site covered with grasses and subject to lower tidal inundation, low salinity
R. apiculata	Muddy sites of estuaries and mudflats
R. mucronata	Muddy sites of estuaries and mudflats
R. stylosa	Close to sea, areas of low tidal amplitude
S. alba	Close to sea, moderately saline areas
X. granatum	Low saline sites, areas of low tidal amplitude

Source: Kathiresan (1994, 2011b).

and *Aegiceras* are salt excretors; Rhizophoraceae members are salt excluders; and *Excoecaria*, *Sonneratia* and *Xylocarpus* are salt accumulators. Hence, species adaptability needs to be considered when selecting species for planting, as Table 5 shows.

6.2.3 Natural occurrence of species

Mangrove species selection can be based on species that occur naturally in the locality. It is also necessary to collect data on the historical occurrence of species. For example, in the Muthupet mangrove forest in south-east India, *R. mucronata* was recorded as present in the 19th century, though it is now absent. Therefore, efforts to replant *R. mucronata* in the area should be encouraged. Introducing such species will conserve native species, as well as enrich species diversity.

6.2.4 Availability and maturity of seeds and seedlings

Species selection can be based on the availability and maturity of planting material from the locality. This in turn depends on successful flowering and fruiting of the species. Some native species may not produce a sufficient amount of seeds, and these should not be used for restoration work. Only those which produce sufficient quantities of mature seeds should be considered for planting.

6.2.5 Size of propagules

In general, large viviparous propagules can establish themselves in waters more subject to tidal buffeting, and small propagules tend to establish themselves landwards. This differential ability of seeds to establish at different tidal heights is attributable to their size. Under natural conditions, small propagules drift further inland and establish themselves in shallower water where it is easier for them to anchor themselves (thus producing a species zoning based on propagule size).

6.2.6 Zoning pattern

Zoning is critical to the success of any restoration. In general, *Rhizophora* spp. are known to survive well at tidal heights corresponding to mid-water and low-water levels, and *Avicennia* spp. survive better at mid-water, but not at low-water, levels (Table 6).

Table 6 Zonal preference of mangrove species

Tidal zone	Species preference
High and mid-water levels	*A. marina*, *B. cylindrica*, *B. gymnorrhiza*, *Bruguiera parviflora*, *Bruguiera sexangula*, *Ceriops decandra*, *C. tagal*, *E. agallocha*, *Scyphiphora hydrophyllacea*, *Heritiera littoralis*, *H. fomes*, *S. caseolaris*, *X. granatum* and *Xylocarpus mekongensis*
Mid and low-water levels	*Rhizophora* spp., *S. alba* and *A. corniculatum*
High-water level	*N. fruticans* and *Lumnitzera* spp.

Source: Kathiresan (1994, 2011b).

6.3 Habitat selection

Site selection for restoration should be based on criteria such as tidal amplitude, soil conditions, light conditions, sedimentation, pollution status, and weed and pest problems. The site should also be free from migratory sand deposition and algal growth.

6.3.1 Tidal amplitude

Tidal amplitude, measured as the distance between the highest high-tide and lowest low-tide water marks, is an important factor in species selection. The frequency of flooding varies widely depending on intertidal slope, tidal variation and other factors. *Rhizophora* spp., *S. apetala* and *S. alba* prefer high tidal amplitudes; *Avicennia* spp. prefer a moderate tidal amplitude; and *Xylocarpus moluccensis*, *S. caseolaris*, *N. fruticans*, *B. gymnorrhiza*, *A. ilicifolius* and *E. agallocha* prefer low tidal amplitudes.

6.3.2 Soil conditions

Salt-tolerant mangrove species include: *A. marina*, *Lumnitzera littorea*, *Lumnitzera racemosa*, *Rhizophora* spp., *A. corniculatum*, *C. tagal*, *E. agallocha*, *K. candel*, *S. alba*, *X. granatum* and

X. mekongensis. Mangrove species requiring low salt levels are *S. caseolaris*, *N. fruticans*, *H. fomes*, *B. sexangula*, *B. cylindrica*, *X. moluccensis* and *A. ilicifolius*. These species prefer sites with a flow of fresh water. Where the presence of salt marsh species such as *Suaeda* indicates hypersalinity of the soil, these species must be removed before restoration can start. Mangroves are often killed if their pneumatophores are covered by silt, affecting their ability to transport oxygen to their roots. *Rhizophora* spp. can survive in such soils and also in areas with high levels of hydrogen sulphide because they have aerial roots.

6.3.3 Light conditions

A. marina exhibits good resistance to high sunlight intensity with hot and dry conditions. Other species that tolerate more light are *L. racemosa*, *L. littorea*, *S. alba*, *X. granatum*, *X. mekongensis*, *K. candel*, *E. agallocha*, *C. tagal*, *B. gymnorrhiza* and *A. corniculatum*. Species unsuitable for hot and dry conditions include *N. fruticans*, *B. sexangula*, *H. fomes*, *S. caseolaris*, *B. parviflora*, *H. littoralis* and *Cynometra iripa*. Mangrove species that can tolerate shady conditions include *A. ilicifolius*, *B. gymnorrhiza*, *B. sexangula*, *B. cylindrica*, *C. decandra*, *E. agallocha*, *X. granatum*, *X. mekongensis* and *H. littoralis*.

6.3.4 Sedimentation

Changes in coastal mangroves can often be attributed to changes in hydrology. In areas where sediment accretion is high, pneumatophore-bearing *Avicennia* spp. are not suitable, and stilt-root bearing species should be planted instead.

6.3.5 Pollution

Members of the Rhizophoraceae family may be suitable in sites with high metal pollution and oil pollution. *Avicennia* is also known to be tolerant to high organic pollution.

6.3.6 Weed and pest problems

The mangrove fern *Acrostichum* spp. causes major losses to mangrove forestry, and is indicative of acid soil conditions. Salt marsh species such as *Suaeda* can also interfere with the growth of mangrove seedlings in planting sites. Their presence indicates hypersaline soil. In such areas, it is necessary to flush the soil properly with tidal water if restoration is to succeed. It should also be noted that *Avicennia* spp. suffer more damage from herbivores than *Rhizophora* spp. In general, planting with mixed species (especially using Rhizophoraceae mangroves) provides greater resistance against harmful insects and diseases.

6.4 Conditions for planting

6.4.1 Zoning patterns

When planting mangroves it is necessary to follow the natural pattern of species zoning in an area. In general, mangrove plants follow a pattern according to the length and size of their seeds (see above). For example, long propagules tend to colonize along the tidal zone and smaller ones establish themselves in landward intertidal areas.

6.4.2 Seasons

Planting seasons vary according to species, salinity and other conditions. For example, in the Indian Sundarbans, seeds are available from July–September for *B. gymnorrhiza*, *R. mucronata* and *X. granatum*; September–October for *S. apetala*; June–July for *A. alba*;

and August–September for *A. marina*. The extreme seasons during which salinity is high, or waves are high with strong winds, are unsuitable for planting mangroves. In general, the post-monsoon seasons with moderate salinity are ideal for restoration/plantation activities.

6.4.3 Timing of planting operations

Proper planning of time, duration, number of seedlings, labour requirements and transport facilities is necessary for successful planting operations. The ideal time for planting is when the tide is low. Seedlings have to reach the planting sites before low tide so as to be ready for planting. For direct planting, it is possible to plant seeds as and when the tidal level permits workers to implant seeds at arm's length.

6.4.4 Planting depth and spacing

Propagules are generally planted with their pointed tip in the muddy soil. The depth of planting increases with the length of the propagules; small seeds should be embedded gently in the soil. Plant spacing is normally 1–2 m; using a longline rope helps to keep plants evenly spaced.

6.4.5 Soil conditions

Generally, mangroves prefer soft, clay mud for their growth, not calcified hard or sandy areas. As for frequency of soil flooding, a higher frequency suits species with longer propagules, and a lower frequency those with shorter propagules.

6.4.6 Gap filling

Mangrove seedlings require protection against grazing pressure and damage by fish nets. Damaged seedlings should be removed and the gaps infilled with fresh seedlings.

6.4.7 Storage of planting material

The propagules of *Rhizophora*, *Avicennia*, *Bruguiera*, and *Ceriops* (but not of *Kandelia*) can be stored for a week in brackish water. Fruits or seeds of *Sonneratia* and *Xylocarpus* can be stored for longer periods.

6.5 Monitoring of mangrove restoration

New plantations need to be closely monitored to ensure their survival and growth. The following risk factors and appropriate remedial measures should be given close attention (Kathiresan, 1994, 2011b).

- **Algal growth**: Often a serious issue. The overgrowth of filamentous algae such as *Ulva*, *Enteromorpha* and *Chaetomorpha* can cover the leaves of seedlings and topple them into the water. This happens during summer and post-monsoon seasons, and can be prevented by hand-picking and erecting bamboo fencing for support.

- **Water hyacinth**: This aquatic weed accumulates during the monsoon season through the inflow of fresh water and bends the seedlings down. It can be removed by hand-picking.

- **Infestation by crabs, gastropods and barnacles**: Several species of crabs are known to grasp plant shoots. Often a heavy load of barnacles attaches itself to the low and middle tidal levels of the stems of seedlings. This can be prevented by scraping carefully with the help of a knife, without damaging the seedlings. In areas where barnacle, crab and gastropod infestations are serious, it is best to use taller, nursery-raised seedlings for planting.

- **Infestation by insects**: Moth larvae and other insects also create problems. They can be controlled by simply washing the seedlings with sea water.

- **Siltation**: Occurs during the monsoon period. Silt deposits on the leaves and stems often retard growth and can even kill plants. They can be cleaned off by washing the seedlings with sea water.

- **Cattle grazing**: This is a serious problem. Besides grazing, trampling by cattle can flatten the young seedlings. This can be prevented by erecting thick wire fences, or by planting *E. agallocha*, *A. ilicifolius* or *Caesalpinia crista* for protection.

- **Garbage**: Solid waste materials dumped into waterbodies and the sea can clog mangrove habitats. This can be prevented by erecting bamboo fences and water gates to trap the waste at its entry points.

- **Strong currents/high waves/strong winds**: These create dangerous situations. To overcome such problems, strong fences should be erected, or planting should be at a deeper level and the seedlings supported with bamboo poles.

6.6 Integrating coastal livelihoods in restoration programmes

An integral part of implementing mangrove restoration plans is ensuring community participation. As discussed in section 5.2, the success of JMM has been in providing technical inputs to identify the causes of degradation, developing restoration techniques, and mobilizing and organizing the local communities. Similarly, in the Sundarbans, the Forest Department has formed 54 forest protection committees and 11 eco-development committees covering 47,325 families in an area of 87,287 ha. This initiative has led to a remarkable improvement in the relations between people and the Forest Department, in saving most of the tigers that stray into inhabited areas, in protecting plantations, and in voluntary patrolling to protect the forest (see also Vyas and Sengupta, this publication). Other eco-development activities in the Sundarbans include:

1. Improving village roads, bridges and culverts.
2. Constructing jetties.
3. Supplying seedlings for forestry, orchards, and fuelwood and fodder plantations.
4. Providing poultry and pig-raising units.
5. Providing bee hives for apiculture.
6. Installing solar street lights and solar lanterns in remote villages.
7. Carrying out artificial insemination and immunization of cattle.
8. Conducting medical camps.
9. Providing smokeless *chullahs* (cooking stoves), nylon nets, and fencing nets.
10. Training local people in crab fattening, sewing, apiculture, nursery techniques and other activities to improve their skills and help them attain economic self-sufficiency.

Ecotourism generates employment for local people in the Sundarbans. Entry fees are collected from tourists entering the buffer area of the Sundarbans Tiger Reserve, and 25% of the revenue earned in the Reserve area is ploughed back into the eco-development committees. The success of these eco-development activities depends on the level of participation of the community, particularly of women members, in planning and implementation. Proper monitoring and evaluation is also vital.

Examples also exist of using microcredit operations as an incentive to promote community engagement. The Gujarat Ecology Commission, for example, has conducted a successful initiative in Gujarat with financing from the India–Canada Environment Facility and Gujarat state government. By involving local communities in regenerating mangroves, about 4,000 ha has been brought under mangrove cover in ten different villages within five years. Community participation has been institutionalized by forming 10 CBOs at the village level. A corpus fund has been created in each village by depositing part of the daily wage in a bank account. Out of a wage of INR 80, INR 56 is paid in cash and INR 20 deposited in the corpus fund. The remainder is treated as the community's contribution to the project fund. Sixty percent of this fund, along with the interest, is reserved for maintaining mangroves and other assets created under the project. The balance of 40% is used as a revolving fund to issue loans (at interest rates not exceeding bank rates) for income-generating activities by CBO members.

7. Mangrove conservation in India: policy and regulatory framework

The policy and regulatory framework for conserving India's natural resources is fairly well developed. Articles 48-A and 51-A (g) of the Directive Principles of State Policy of the Constitution of India affirm that "the State shall endeavour to protect and improve the environment and to safeguard the forests and wildlife in the country, and it is a duty of every citizen to protect and improve the national environment including forests, lakes, rivers and wildlife, and to have compassion for living creatures". Under the system of democratic decentralization enshrined in the 73rd Constitutional Amendment of 1993, local bodies consisting of elected representatives, one-third of whom are women, have been entrusted with the responsibility of safeguarding local environmental assets.

The conservation of coastal ecosystems, including mangroves, is set out in several policy and legal instruments. The National Forest Policy of 1988 stresses the principal aim of conservation as ensuring environmental stability and maintaining ecological balance, including atmospheric equilibrium. The production of direct economic benefits is subordinate to this goal. The National Conservation Strategy and Policy Statement on Environment and Development of 1992 highlight conservation and sustainable development of mangroves, as well as coastal areas and riverine and island ecosystems. Similarly, the National Forest Policy and National Wildlife Action Plan emphasize the conservation of mangroves based on scientific principles, including social and cultural aspects.

India's National Environment Policy, approved by the Cabinet in 2006, emphasizes mainstreaming conservation and sustainable use of environmental resources within developmental planning. The policy recognizes the role of coastal ecosystems such as mangroves in supplying various services necessary to support human well-being. It also recognizes the threats to these ecosystems from unplanned coastal development, and recommends including sustainable management of mangroves in integrated coastal zone management.

Besides these instruments, there are special acts such as the Karnataka Tree Act and Tamil Nadu Hill Preservation Act, which are specific to the states and apply to particular tree species needing protection. Mangroves are also protected by a range of regulatory measures, such as the studies required under the 1994 Environmental Impact Assessment Notification for specialized industries; monitoring of compliance with conditions imposed under environmental clearances issued by regional offices of the Ministry and State Pollution Control Boards; enforcement of emission and effluent standards among industries and other entities; and taking legal action against defaulters.

Integrated coastal zone management is central to the conservation and sustainable use of mangrove ecosystems in India. The Coastal Regulation Zone (CRZ) Notification of 1991 (revised in 2011) marks an important effort in this direction. The Notification recognizes mangrove areas as ecologically sensitive and categorizes them as CRZ-I, which puts them under the highest order of protection. Paragraph 8 (v) (4) (a) of the Notification provides that critically vulnerable coastal areas, including the Sundarbans and other identified ecologically sensitive areas, shall be managed with the involvement of the local coastal communities, including fisher folk. The destruction of mangroves by activities other than those specified in the Notification is prohibited and subject to punishment under the 1986 Environment Protection Act.

Relevant promotional measures by government include a centrally sponsored scheme for conservation and management of mangroves. Under this, 38 sites have been identified as suitable for planting mangroves or mangrove conservation and management. The central government provides full funding, on request, to coastal states and union territories for implementing approved management plans for these sites. Activities include survey and demarcation, afforestation and restoration of mangroves, alternative and supplementary livelihoods, protection measures, and education and awareness. During the past three years, the Ministry of Environment and Forests has provided INR 213 million to states and union territories in support of this scheme. Further, under the World Bank-financed Integrated Coastal Zone Management Project, INR 240 million has been allocated to delineate ecologically sensitive coastal areas, including mangroves. The project has also allocated INR 610 million, INR 185.1 million and INR 43.7 million respectively to Gujarat, Orissa and West Bengal for restoring and regenerating mangrove plantations.

8. Conclusions

Mangrove ecosystems are a key component of ecosystem-based mechanisms for adapting to climate change. To ensure they can play this role, however, restoration efforts need to be scaled up. An urgent need also exists to link management plans to landscape, as well as seascape, drivers and pressures. Sustainable management of livelihood interactions forms a crucial part of this process. Implementing an ecosystem-service-focused management approach requires major improvements in the capacity of site managers to undertake integrated management, as well as research on ecosystem service values. Our current understanding of mangrove ecosystem services is still limited. More research on biodiversity and ecosystem services is needed, including the impact of declining services on livelihoods. Lastly, we need to promote, on a larger scale, public participation and local stewardship of mangrove ecosystems. This will require vigorous efforts to create awareness at multiple levels, and incentive-based systems to enhance coastal communities' participation in conservation and management processes. These efforts are in line with the emphasis of India's National Environment Policy on mainstreaming sustainable management of mangroves into forest sector regulation, and on adopting a comprehensive approach to integrated coastal zone management.

Apart from the effects of global climate change, the annual loss of mangroves due to human activities is currently about 1% to 2% of their area. Without action, we may face the prospect of "*A world without mangroves … a world deprived of the ecosystem services offered by mangrove ecosystems, perhaps within the next 100 years*" (Duke *et al*., 2007).

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Indonesian mangroves: critical challenges and strategies for their sustainable management after the 2004 Indian Ocean tsunami

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Abstract

With an area of mangroves estimated at 9.7 million ha (State Forest Area: 3.9 million ha, Non-state Forest Area: 5.8 million ha), Indonesia is home to some of the world's most valuable natural resources. Unfortunately, the mangroves designated for conservation – with biodiversity and fish habitat values as well as value as reducers of seawater intrusion and flooding – have been completely destroyed in many locales and degraded extensively by human activities in others. Activities contributing to the destruction of marine and coastal resources include large-scale illegal fishing, fishing with explosives and cyanide, coral harvesting, and mining. The total area of damaged mangroves in Indonesia is 5.3 million ha (State Forest Area: 1.6 million ha, Non-state Forest Area: 3.7 million ha), or more than half of the country's remaining mangrove cover. The mangroves of Indonesia are reasonably well-documented and described floristically and ecologically, albeit in a widely scattered literature. They are common property and, therefore, different political, social, and economic and culture sectors have different perspectives on their values and functions. These lead to constant debate and conflict, while the degradation of mangroves continues on a vast scale. Indonesia's National Strategy for Mangrove Ecosystem Management is an attempt to put these ecosystems into a national perspective, and thus provide a basis for conservation and development at the level of provinces and districts (*kabupaten*). Also, as part of the intrinsic interest of these ecosystems, questions about the underlying causes of mangrove impoverishment should provide some insights into the general understanding of mangrove systems, their values, uses, and conservation and management strategies.

Keywords: mangroves, resource conservation, resource management, tsunamis, Indonesia

1. Introduction

Indonesia is a maritime country with many characteristic coastal habitats, inhabited by a complex mix of ethnic groups. A National Strategy and Action Plan (NSAP) has been prepared as part of the MFF programme in Indonesia to guide MFF implementation at the national level, with mangroves as the flagship ecosystem for integrated coastal zone management.

This paper provides an overview of the challenges and strategies for managing Indonesia's mangroves sustainably. It is based on the most recent data available from the lead government agencies concerned with mangroves, namely the Ministry of Forestry, Ministry of Marine Affairs and Fisheries, Ministry of Home Affairs, and State Ministry of Environment (Sukorahardjo *et al*., 2005). It also reviews the National Strategy for Mangrove Management (Sukardjo *et al*., 1997), and the revised version of 2006, Indonesia's National Strategy for Mangrove Ecosystem Management. The paper also presents a review of the ecological, socio-economic, institutional and legal issues surrounding mangrove management in Indonesia, followed by a brief overview of the MFF NSAP.

2. The mangroves of Indonesia

2.1 Ecological Issues

Indonesia stretches over 5,000 km from Sumatra in the west to Indonesian New Guinea in the east. It is the largest archipelagic state in the world, with a land and marine territory of about 7.7 million km^2, covering some 17,504 islands with over 81,000 km of coastline (only

Canada has a longer coastline). Indonesia's coastal and marine habitats include the most extensive mangrove forests in Asia, as well as seagrass beds and spectacular coral reefs, all of which provide breeding grounds for a large number of commercially valuable fish species, crustaceans (crabs and shrimps) and bivalves (cockles, mussels and oysters) (BAPPENAS, 2003). Mangroves are found throughout the archipelago in 22 of the 27 provinces, but are most concentrated in Indonesian New Guinea, East and South Kalimantan, Riau and South Sumatra. More than half of Indonesia's mangroves are found in Indonesian New Guinea (Moosa *et al*., 1996).

Although their general locations are known, the total area of Indonesia's remaining mangrove forests is uncertain. Various sources have put the figure at between 2.17 and 4.25 million ha. The latest (1995) official Ministry of Forestry estimate is 3,533,600 ha of State Forest Area distributed among several forest categories (Table 1).

Table 1 Ministry of Forestry estimates of mangrove area in Indonesia, 1995

Category	Area (ha)	Proportion (%)
Protection Forest	424,800	12
Nature Reserves	674,000	19
Normal Production Forest	683,600	19
Limited Production Forest	372,400	11
Conversion Forest	928,900	26
Forest converted	449,300	13
Total	3,533,600	100

In Sulawesi, estimates range from 285,000 ha to 81,000 ha of mangroves; the majority is found in South Sulawesi Province (Table 2). The methods of assessment and interpretation vary widely and thus the estimates of the total remaining mangroves in Sulawesi also range widely. Clearly further survey is required, but the lower estimates are thought to be more accurate, and the true figure may be even lower owing to rapid mangrove conversion. The larger estimates are most likely the result of inaccurate interpretation of aerial photographs:

Table 2 Ministry of Forestry estimates of mangrove area in Sulawesi, 1995

Province	Area range (ha)
South Sulawesi	34,000–104,030
Southeast Sulawesi	25,000–100,900
North Sulawesi	4,833–38,150
Central Sulawesi	1,700–42,000
Total	80,833–285,080

Apart from Indonesian New Guinea, where the current level of exploitation of mangrove is relatively low, the remaining large areas of mangroves in Sulawesi , Sumatra and Kalimantan are under increasing threat from competing resource users, particularly developers of brackish-water fish and shrimp ponds (*tambaks*), who frequently have conflicting aims and limited understanding of the functions of the mangrove ecosystem or its carrying capacity.

There is an urgent need for a set of guidelines on how to evaluate and classify an area of mangrove forest in terms of its present functions and its carrying capacity for sustainable management options; in other words, the most appropriate land use option for the future.

Mangrove forest is an evergreen plant community found mainly in the tropics on the fringes of naturally protected shorelines such as deltas and estuaries. The paucity of species occurring in mangrove forests is due to the peculiar conditions of their existence, few plants being able to tolerate and flourish in saline mud and with frequent inundation by sea water. The mangrove habitat is a dynamic land–water interface zone that can change through rapidly varying depths of inundation in both time and space. As such, mangroves provide a linkage between the land and the sea. Plants, animals, non-living material and plant nutrients are transferred landwards or seawards through mangroves. They act as a filter in reducing the damaging effect of major environmental changes, and as a source of nourishment for both aquatic and terrestrial animals, Mangroves also play a pivotal role in coastal protection and the maintenance of habitats for a large range of common, threatened and endangered species; hence they are of great importance in the maintenance of regional biodiversity. It is axiomatic that the management of mangroves has always to be a part of the management of the surrounding habitats and ecosystems into which they integrate.

2.2 Socio-economic issues

Mangroves represent a rich and diverse living resource, now recognized to be a major protector of coastal environments and a valuable national economic resource. The economic potential of mangroves stem from three main sources: forest products, estuarine nearshore fisheries, and ecotourism (UNEP/GEF/LPP Mangrove, 2002). Yet in general there is still little understanding among policy makers or the general public of the values and functions of mangrove forests, and, as a result, they are often regarded as degraded and worthless areas which should be used for other more productive purposes. The intrinsic value of the mangrove ecosystem is enormous, however, and only becomes apparent when large investments have to be made in constructing coastal protection structures and water treatment plants that attempt to reproduce the natural functions of the mangrove forest. The losses thus incurred are substantial, and offer adequate justification for establishing an appropriate management plan for mangrove forests (UNEP/GEF/LPP Mangrove, 2002).

Due to pressure from a growing human population, particularly in coastal areas, which leads to changes in land use and overexploitation of natural resources, mangroves are being depleted rapidly and degraded throughout the tropics. It has been reported that the conversion of mangrove areas to brackish-water fish and shrimp ponds (*tambaks*) represents the single greatest threat to mangroves in Indonesia. Survey results in Sulawesi, and casual observations from elsewhere in Indonesia, suggest that this is true, yet official statistics do not bear this out. In 1977 it was estimated that *tambaks* covered 174,605 ha in Indonesia; by 1993 this estimate had risen to 268,743 ha. Although this represents an increase of 54% in terms of total conversion, it is only 5,884 ha per year over the 16-year period. Various estimates of the total area of mangroves in Indonesia show that, at best, about 513,670 ha of mangroves have been lost between 1982 and 1993, or 46,497 ha per year, whereas under the worst scenario, 1,760,825 ha have been lost during the same period, or 160,075 ha per year. Although logging, conversion to agricultural use and coastal infrastructure development obviously account for some of these losses, “unofficial” clearing, i.e. clearing agreed at the local level only for low-technology *tambak* development, is considered to be responsible for a far greater proportion of mangrove loss than official figures show. These refer primarily to well-managed, high-technology *tambak* development and not the low-technology, speculative type so often found in regions such as Sulawesi.

A growing awareness of the protective, productive and socio-economic functions of tropical mangrove ecosystems, and of the consequences of their deterioration, has highlighted the need for the conservation and sustainable integrated management of these valuable resources. Given their multiple-use potential, it is imperative that the management of terrestrial and aquatic mangrove-based ecosystems be undertaken within the context of integrated coastal area management planning (UNEP/GEF/LPP Mangrove, 2002).

There are essentially three options for the management and development of mangroves: i) preservation of the ecosystem in its natural state; ii) utilization of the ecosystem to extract various goods and services on a sustainable basis; and iii) conversion (or destruction) of the natural ecosystem, usually for a single replacement use (UNEP/GEF/LPP Mangrove, 2002). For all three options, however, there is a basic lack of data on the best ways to proceed. For example, management plans for sustainable harvesting of wood products from mangrove forests using a variety of socio-economic criteria have only recently been generated; and the replanting of mangroves in abandoned *tambaks* is still the subject of much research and experimentation. The pressures to utilize mangrove forests sustainably, or otherwise, generally come from the people living in or around these forests, who rely on them as a source of raw materials and food; and state agencies such as the Ministry of Forestry, which wishes to harvest mangrove wood products. The pressure to convert mangrove areas to other uses generally comes from outside the area, either from private enterprise wishing to develop shrimp farming for export, or from private enterprises and government agencies wanting to develop a coastal area for urban, industrial or recreational purposes (UNEP/GEF/LPP Mangrove, 2002).

In practice, ecological and economic considerations cannot be separated when evaluating management alternatives for mangroves. This statement reflects the growing appreciation of the social and economic importance of mangrove ecosystems. To measure the value of mangroves accurately, the value of the goods and services produced by the ecosystem need to be considered and incorporated into the assessment of the relative merits of development alternatives. This requires the application of innovative economic evaluation techniques that take into account such externalities (UNEP/GEF/LPP Mangrove, 2002).

It is also recognized that the involvement of local people in the planning and implementation of mangrove management is essential for success (UNEP/GEF/LPP Mangrove, 2002). The socio-economic surveys carried out by the Sulawesi Mangrove Project have shown that mangroves are still perceived by many as an expendable resource. Both local people and some government staff appear to see little or no value in mangroves beyond their value as a source of coastal land for development and the assertion of land rights and ownership. This development value is perceived to outweigh any benefits from the continued existence of mangroves for coastal stabilization, crab production, fish nurseries and feeding grounds. It will require an enormous effort of political will, backed by the necessary financial resources, human capacity and public awareness programmes, to reverse this destructive trend. Such a policy will require government to improve awareness and understanding of the value of mangrove forests among local people; and to provide mechanisms for enhancing security of land tenure within mangrove areas, either via full ownership or some form of stewardship system.

3. Institutional and legal aspects of mangrove management

3.1 Institutional issues

In Indonesia, the utilization of mangrove forests and the mangrove forest ecosystem involves at least 18 different government agencies (see Table 3 below). Although each agency has a defined role, the definition is often unclear and frequently isolated from the roles and responsibilities of the other agencies. There is much overlap between the responsibilities of various government agencies and their roles are duplicated. The effect of this duplication and lack of coordination is a confusing fragmentation of policies and a costly duplication of human resources, equipment and administrative efforts which Indonesia can ill afford (UNEP/GEF/LPP Mangrove, 2002). These problems are not confined solely to Indonesia; the Philippines and Thailand, for example, also suffer from a similar overlap of responsibilities among the agencies concerned with mangrove management.

The list of agencies in Table 3 serves to reinforce the multiplicity of the uses to which mangroves are put and their value to the country. However, unless the responsibilities of each agency are clearly defined and communicated to the other agencies, and a priority ranking of responsibilities and jurisdiction by agency agreed and implemented, the current confused situation will persist and the undeniably good intentions about managing mangroves sustainably will dissipate (UNEP/GEF/LPP Mangrove, 2002).

Among those agencies with some form of mandate for the management of mangroves, a few key agencies, such as the Ministry of Forestry, Ministry of Agriculture, State Ministry of National Development Planning / BAPPENAS, State Ministry of the Environment, and Environment Impact Management Agency, have the most responsibilities. Of these, the Ministry of Forestry has the greatest responsibility, owing to its broad jurisdiction over all coastal forests, including mangrove forests, yet it has no cross-sectoral responsibility or authority to ensure that its activities are in harmony with those of other line agencies. These include the Ministry of Agriculture, which also plays a role in management of the mangrove resource, especially with regard to *tambak* production and nearshore fisheries. Most line agencies with management responsibility for a particular resource are unlikely to be integrated properly with the plans of other sectoral agencies.

Herein lies the fundamental institutional paradox in the management of mangroves and other coastal zone resources – different agencies act in their perceived sectoral best interests and generally fail to take an holistic view of the situation, even though the separation of sectoral interests in the coastal zone is contrary to the principles of sustainable resource management. This multi-sectoral stance notwithstanding, however, no single line agency, however large its mangrove mandate, should have overall responsibility for management of the resource, nor can it under the present government regulations (UNEP/GEF/LPP Mangrove, 2002). Within the institutional structure of the Indonesian government, only a coordinating ministry

Table 3 Agencies involved in the management of mangrove forests in Indonesia

1. The **Office of the State Minister of the Environment** has responsibility for coordination of regulations, guidance, monitoring, and evaluation of reports on the implementation of national policy on mangrove management.
2. The **Ministry of Forestry** has responsibility for guidance in the management of mangrove forests which encompasses protection, conservation and sustainability, rehabilitation, reforestation and utilization.
3. The **Environment Management and Control Agency**, has responsibility for approving environmental impact assessments and environmental management and monitoring plans for proposed alternative uses of mangrove forests.
4. The **Indonesian Institute of Science** has responsibility for coordinating information about the development of scientific knowledge and technology relating to the management of mangrove forests.
5. The **State Ministry of National Development Planning / BAPPENAS)** has responsibilty for coordinating planning, programmes and finance for management of mangroves.
6. The **Department of Industry** has responsibility for providing information on the quality standard of raw materials and ensuring efficiency in their utilization, along with the recycling of products derived from mangrove forests.
7. The **Department of Home Affairs** has authority for the coordination and guidance of activities related to planning, implementation and control of the management of mangrove forests in the regions.
8. The **Department of Agriculture** has responsibility for providing technical guidance for the management of agricultural commodities connected with mangrove forest resources.
9. The **Department of Education and Culture** has responsibility for promoting education based on knowledge of mangrove forests.
10. The **Department of Information** has responsibility for distributing information concerning the management of mangrove forests.
11. The **Office of the State Minister for Research and Technology** has responsibility for research and the development of science and technology in the management of mangrove forests.
12. The **National Land Agency** has responsibility for directing the allocation of land according to regional land-use plans and legal requirements.
13. The **National Coordinating Agency for Survey and Mapping** has responsibility for coordinating the inventory of mangrove forests and collecting basic data required for the development of a Geographic Information System (GIS).
14. The **Department of Tourism, Post and Telecommunications** has responsibility for developing tourism in mangrove forests.
15. The **Department of Transmigration and Forest Settlement** has responsibilty for the clearance of, and development of settlements in, mangrove forests.
16. The **Department of Health** has responsibilty for setting standards for the quality of raw materials derived from mangrove resources used in making medicines, their processing, and associated quality control procedures.
17. **Parliament** has an active role in the implementation of mangrove forest management through the laws and regulations which it approves.
18. The **National Marine Council** plays an active and leading role in coordinating, integrating, evaluating, directing and monitoring the uses of marine resources (living and non-living), and for establishing the National Policy of Ocean Sciences and Technology, including policies for marine sciences in Indonesia. The Council is chaired by the President of the Republic of Indonesia.

such as BAPPENAS, with the support of the local government planning agencies, or the State Ministry of the Environment, have such powers. It is this jurisdiction over the regional spatial plans (*rencana umum pembangunan tingkat daerah* and *rencana umum tata ruang daerah*) that provides the key to the successful implementation of sustainable coastal zone management (UNEP/GEF/LPP Mangrove, 2002).

On the common understanding that new layers or levels of bureaucracy are neither required nor practical, it is necessary to proceed within the existing institutional framework with a mandate to manage mangroves at central and regional levels. The framework for linking together sectoral line agencies on policy issues provided by coordinating agencies such as BAPPENAS for national policy, and BAPPEDA Tk I and II for regional policy, is perfectly adequate. What is currently lacking or insufficient in this regard can be summarized as follows:

- A clear definition among the various line agencies of their various roles and responsibilities for managing the mangrove resource sustainably.

- Sufficient appreciation among both line agencies and, to some extent, coordinating agencies, of the pivotal role played by the latter in deciding the most appropriate management strategy and plans for mangrove resources and other vital coastal resources via application of the Spatial Planning Act of 1992.

- Sufficient planners and resource scientists in the local BAPPEDA Tk I and II offices to provide the inputs needed for spatial plans and natural resource databases.

An urgent need exists for a readjustment in government away from narrow sectoral interests towards a more integrated, multi-sectoral approach to managing resources, including mangroves, and this can only be achieved by strengthening and expanding the planning and coordinating roles of BAPPENAS and the Ministry of the Environment at the central level, and BAPPEDA at the regional and local levels. It should not be forgotten that, although central agencies can provide policy guidance to the regions, it is the regional authorities at both Tk I and Tk II that actually implement policy. The many examples of inappropriate local use of natural resources, including mangroves, can be attributed largely to a lack appreciation by the various government and private resource stakeholders of the planning process coordinated by the BAPPEDA Tk I and Tk II and underpinned by the Spatial Planning Act. Highlighting, strengthening and expanding the role and effectiveness of the BAPPEDA Tk I and Tk II in ensuring the most appropriate allocation of resources and their sustainable use is one of the fundamental objectives underlying Indonesia's National Mangrove Strategy.

This goal has already been partly achieved through the efforts of the Land Resources Evaluation Project, the Marine Resources Evaluation Project, and the Mangrove Rehabilitation and Management Project in Sulawesi, all of which aim to improve the planning and management capacities of regional BAPPEDA staff. The main objectives of the Marine Resources and Sulawesi Projects are to work with BAPPEDA to improve the planning and sustainable management of coastal and marine resources, to develop further and strengthen the existing marine and coastal information system, and to provide inputs to provincial and local spatial plans (UNEP/GEF/LPP Mangrove, 2002).

3.2 Legal issues

Basic legislation for the coastal environment (including mangroves) is already in place, in the form of statutes on maritime jurisdiction, environmental protection, and the conservation of living natural resources (UNEP/GEF/LPP Mangrove, 2002). In addition, aspects of environmental protection and natural resource management are increasingly being incorporated into public policy. The regulatory framework for coastal resource management, including the management of mangroves, is derived from several sources. At the highest levels are the fundamental principles contained in the 1945 Constitution, the State Philosophy (*Pancasila*), and the various policy statements expressed in Presidential Decrees or coordinated government statements. Some of the most important policies are found in the periodic Outlines of State Policy, the Long-Term (25-year) Development Plans, and the Five-Year National Development Plans. Table 4 lists the laws, regulations and decrees relevant to the coastal zone and mangroves (UNEP/GEF/LPP Mangrove, 2002).

Table 4 Laws, regulations and decrees applicable to mangroves in Indonesia

1.	Basic Law of 1945, Article 33, Paragraph 3
2.	Law No. 5, 1960, Basic Agrarian Provisions
3.	Law No. 5, 1967, Basic Forest Provisions
4.	Law No. 5, 1974, Principles of Government in the Regions
5.	Law No. 11, 1974, Irrigation
6.	Law No. 5, 1979, Village Government
7.	Law No. 4, 1982, Basic Provisions for Environmental Management
8.	Law No. 9, 1985, Fisheries
9.	Law No. 5, 1990, Conservation of Living Natural Resources and their Ecosystems
10.	Law No. 9, 1990, Tourism
11.	Law No. 24, 1992, Spatial Land Use
12.	Govt. Regulation No. 64, 1967, Delegation of Authority, Estates, Fisheries, and Forestry Affairs to Swantantra Region 1
13.	Govt. Regulation No. 28, 1985, Forest Protection
14.	Govt. Regulation No. 29, 1986, Environmental Analysis
15.	Govt. Regulation No. 15, 1990, Fisheries
16.	Govt. Regulation No. 20, 1990, Monitoring Water Pollution
17.	Govt. Regulation No. 27, 1991, Swamps
18.	Govt. Regulation No. 35, 1991, Rivers
19.	Govt. Regulation No. 45, 1992, Regional Autonomy at Regional Level 11
20.	Presidential Decree No. 57, 1989, Steering Committee for National Land Classification Management
21.	Presidential Decree No. 32, 1990, Management of Protected Areas

It is clear that the highest levels of government in Indonesia provide strong policy guidelines for the sustainable management and conservation of natural resources, including coastal resources and mangroves, and that such guidelines provide a firm foundation on which to draw up a National Mangrove Charter for Indonesia. Yet although the basic legislation to conserve and manage mangroves sustainably is present in principle, it is not yet fully realised in practice. For the most part, Indonesia's existing laws, decrees and regulations do not provide a clear basis for establishing detailed policies for coastal activities and resources, including the management of mangroves, or for creating an integrated management system that would combine the activities of various agencies within a single, focused programme (UNEP/GEF/LPP Mangrove, 2002).

With respect to biodiversity conservation, Law No. 5 of 1990 on the Conservation of Living Natural Resources and their Ecosystems adopts the concepts of sustainable use and ecosystem integrity. This law also provides the basis for establishing and operating protected natural areas, including areas in the coastal zone. One of the main ways of achieving the aims of Law No. 5 is defined in Law No. 24 of 1992, which integrates other management functions in the context of overall spatial land-use management. This law is one of the strongest in that it provides a mechanism for identifying sustainable land-use options in the provinces and districts, and a legal basis for ensuring that land use conforms to spatial plans. It is this law which is likely to provide a foundation for strengthening the legal and institutional framework for effective management of coastal resources in general, and mangroves in particular. It must be remembered, however, that even with detailed enabling legislation in place, and an improved understanding among different agencies of the laws and regulations relating to the use of mangroves, effective law enforcement can still be undermined by social and economic constraints, for example low wages for forest guards (UNEP/GEF/LPP Mangrove, 2002).

4. Overview of National Strategy and Action Plan

4.1 The need for strategic action

The problems and issues concerning the sustainable management of Indonesia's mangrove resources are generally well-known and well-understood. What is required is a strategy and series of actions which take account the constraints to achieving the objectives of sustainable mangrove management, and provide appropriate solutions for achieving those objectives (UNEP/GEF/LPP Mangrove, 2002). A fundamental distinction needs to be made between the types of strategy and action plans being considered in Indonesia. In the first place there is a National Strategy, which deals primarily with national objectives and policies concerning the mangrove resource, and appropriate strategic actions that must be taken by the central coordinating and line agencies concerned with the management of mangroves. This general strategy provides the rationale and guidelines for the formulation of more specific provincial strategies and action plans (UNEP/GEF/LPP Mangrove, 2002).

Mangrove management activities involve cross-sectoral land-use planning exercises that are an integral part of the provincial and local spatial planning activities coordinated by the regional development planning boards. An important distinction for mangroves is that there should be a specifically designed management plan for clearly defined areas of the coastal zone that include mangroves, which is incorporated into the more general spatial plans. This decision-making framework will includes roles of the central, provincial and district governments.

It must be stressed that it is the provincial, district (*kabupaten*: sometimes also translated as "regency") and sub-district (*kecamatan*) agencies which will implement the mangrove strategy and action plans. Thus, their full involvement in devising appropriate strategic actions and more detailed management plans for areas of mangroves, and other coastal resource under their jurisdiction, is crucial to success in the sustainable management of those resources.

The priority actions must be ranked or prioritised in some way, and the agency or agencies best-qualified to undertake each action must be identified. Those actions requiring immediate implementation are referred to as key strategic actions, and are the trigger mechanisms for implementing the national and the provincial strategies. Without these key actions, steady attrition of the mangrove resource through its conversion to unsustainable alternative uses will continue, and the current institutional and legal uncertainty regarding the use of mangroves will remain unchanged (UNEP/GEF/LPP Mangrove, 2002).

To meet the mangrove management and preservation goals outlined in the National Strategy and Action Plan for Mangrove Management in Indonesia, several key strategic actions have been identified. The reader is referred to the National Strategy for more details about these and other necessary actions identified for implementation throughout Indonesia, as well as the agencies responsible for implementation and follow-up actions. The key actions are summarised below (UNEP/GEF/LPP Mangrove, 2002):

- **Key strategic ecological actions**
  1. *Objective*: To define more precisely the location, area and condition of the mangrove resource in Indonesia.
     Action: Implementation of a nationwide country study of mangroves.

  2. *Objective*: To assist the integration of data on mangroves and other coastal resources generated by different agencies.
     Action: Prepare provincial strategic action and mangrove management plans for the preservation and sustainable use of mangroves, and integrate with a provincial coastal and marine management strategy.

  3. *Objective*: To protect and conserve a significant proportion of the one-million-plus hectares of undisturbed mangroves in Indonesian New Guinea.
     Action: Inclusion of the mangrove forest in Lorentz National Park and declaration of this conservation area as a World Heritage Site.

- **Key strategic institutional actions**
  1. *Objective*: To establish an effective body to coordinate the formulation, implementation and monitoring of a strategy and action plan for the sustainable management of mangroves under the concept of coastal zone resource management.
     Action: The amalgamation of the National Committee on Mangrove Ecosystems and Coastal Zone Management with a recently formed National Wetlands Committee to form a committee with the prime objective of planning integrated sustainable resource management in the coastal zone. Mangroves, seagrasses and coral reefs are different coastal zone resources that would be handled by separate resource Sub-Committees or Working Groups.

- **Key strategic socio-economic actions**
  1. *Objective*: To improve knowledge and awareness of the values of mangroves among all levels of society, but particularly among decision makers and local people who live in and around mangrove forests.

Action: Initiation of national mangrove awareness programme in the media and in educational institutions.

2. *Objective*: To formulate an appropriate economic valuation system for mangroves (and other coastal resources) that takes into account the externalities present in any natural system, and applies these to the development of sustainable management plans for mangroves that satisfy the guiding principles of protection, conservation and sustainable development.
   Action: Establish a Mangrove Evaluation Sub-Committee, or Working Group in the National Committee, to address these issues and act as a "clearing house" for proposed methods of measuring externalities and developing management plans.

- **Key strategic legal actions**
  1. *Objective*: To strengthen the understanding, application and enforcement of the Spatial Planning Act (Law No. 24 of 1992) with respect to coastal zone planning.
     Action: Organise a national workshop on the application of the Spatial Planning Act with special reference to the coastal zone in general and mangroves in particular.

  2. *Objective*: To achieve legal recognition of the importance of the coastal zone in national development, the interdependence of natural resources in the coastal zone, and the need for integrated planning of the sustainable management of those resources.
     Action: The coastal environment should receive special legal recognition through the issuance of a Presidential Decree that fosters an integrated approach to coastal issues, including the management of mangroves.

4.2 Proposed national study of mangroves

A nationwide study of mangroves in Indonesia has been proposed in the National Strategy for Mangrove Management in Indonesia. The primary objective of the country study would be to make an inventory of Indonesia's remaining mangrove resources, aimed at determining the following (UNEP/GEF/LPP Mangrove, 2002):

- Area of mangrove forest in each province.
- Species composition of the mangroves in each province.
- Approximate volume of mangrove timber in each province.
- Major threats to the mangrove resource in each province.
- Condition and trend of the mangrove forest in each province.
- Official status of the mangrove resources in each province (protected forest, production forest, and so on).

These data would be entered into the Department of Forestry's GIS system and made available for use in compiling provincial and district coastal resource management plans.

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An overview of mangrove restoration efforts in Pakistan

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Abstract

Mangrove ecosystems exist in the transition zone between land and sea, characterized by tidal inundation and low oxygen levels necessitating morphological and physiological adaptations by the species surviving in this zone. Globally, 92 species of mangrove plants have been reported, of which 50 occur in South Asia.

Mangroves are highly productive tropical ecosystems which supply multiple goods and services of a provisioning, regulating, supporting and cultural nature. These include the production of woody plants, food, spawning grounds, habitat for marine and terrestrial animals, and protection of shorelines from storm damage and erosion.

In the coastal zone of Pakistan, the Indus Delta accounts for 97% of the country's remaining mangrove cover. The other 3% is found in scattered patches along the Baluchistan coast. Mangroves are a highly dynamic and fragile ecosystem. They are being depleted at an alarming rate by both natural and anthropogenic forces. The severest threat faced by mangroves in Pakistan is the declining inflows of fresh water from the Indus River, which may undermine their long-term sustainability.

In Pakistan, mangrove cover has declined rapidly over the past few decades, reportedly falling from 600,000 ha in 1932 to 86,000 ha in 2005. The most recent estimates, based on a remote sensing study by the Sindh Forest Department (SFD), indicate a slight rise in mangrove cover to about 100,000 ha. This trend seems to be due to increasing awareness and advocacy on the importance of mangroves by government and non-governmental organizations at various levels. The increasing attention has led to greater advocacy, resulting in supportive legislative reform and an increase in investment by government and donor agencies in conserving this important ecosystem.

This paper analyses trends in the management of mangroves in Pakistan, focusing on the key lessons from Pakistan's experiences with mangrove restoration and management. It also highlights the linkages between livelihoods and mangrove conservation in Pakistan, with a particular emphasis on the coastal economy, food security and coastal protection.

Keywords: mangroves, ecosystems, environmental protection, restoration, Pakistan

1. Introduction

The 990-km coastline of Pakistan is shared by its two coastal provinces of Sindh (230 km) and Baluchistan (760 km), divided respectively into the physiographical regions of the Indus Delta and the Karachi coasts, and the Lasbella and the Makran coasts.

The Indus Delta is the most prominent feature of the Sindh coast. The present delta is located at the head of the Arabian Sea, between Korangi Creek and the Rann of Kutch. It has seventeen major creeks and several smaller creeks and extensive mudflats. The Baluchistan coast extends from the mouth of the Hub River in the east to the middle of Gwater Bay in the west. The Lasbella coastal belt lies between the Hub River in the east and the Hingol River in the west, bordering Sonmiani Bay. The Makran coast forms the western part of

Makran, extending to the border at Jiwani. The two coasts have different climatic and physical characteristics: the Sindh coast is influenced by the tail end of the southwest monsoon; the Baluchistan coast has a Mediterranean climate.

1.1 Natural resources of the Pakistan coast

The coast of Pakistan is blessed with a wide variety of natural resources, such as mangrove forests, coastal and inland fisheries, and marine and terrestrial wildlife, including large numbers of migrating waterbirds. These resources provide livelihood opportunities for coastal communities and contribute to the country's economic growth.

1.2 Mangrove forests

Mangroves are among the few plant species globally which are adapted to the harsh environmental conditions found in coastal and estuarine areas. Pakistan is fortunate to have mangroves forests along its coastline, as these constitute an important natural resource for the livelihoods of coastal communities and for coastal protection.

Mangrove forests in Pakistan mainly occur in the estuarine areas of the Indus Delta along the Arabian Sea coast in the south of Sindh Province. The Indus Delta is home to one of the largest arid land mangrove forests in the world. The actual area under dense mangrove vegetation has declined tremendously as a result of several stresses. Nasir and Ali (1972, cited by IUCN Pakistan, 2005) reported eight species of mangroves along the Sindh coast: *Avicennia marina*, *Rhizophora mucronata*, *Ceriops tagal*, *Ceriops roxburgiana*, *Rhizophora apiculata*, *Aegiceras corniculatum*, *Sonneratia caseolaris*, and *Bruguiera conjugata*. Of these, *A. marina* is the dominant mangrove species in Pakistan. Miani Hor is home to *R. mucronata* and *C. tagal*; these species are also found in Daboo and Khai creeks in the Indus Delta. In Pakar and Daboo creeks near Shah Bunder, *A. corniculatum* can be found, but it has almost disappeared from elsewhere in the delta. Three species, *Bruguiera gymnorrhiza*, *C. tagal* and *A. marina,* have disappeared from the Hub River Delta over time as a result of habitat loss (Champion *et al*., 1965, cited by IUCN Pakistan, 2005), and species such as *Ceriops decandra*, *R. apiculata* and *S. caseolaris* can no longer be confirmed (Nasir and Ali, 1972, cited by IUCN Pakistan, 2005). *A. marina*, the dominant species, accounts for about 99.9% of the mangrove forest cover along the coastline thanks to its high salt tolerance and ability to survive in stressful conditions.

Baluchistan harbours a few pockets of mangroves in the deltaic swamps of seasonal rivers such as the Hub, Porali, Hingol and Dasht, which drain into the Arabian Sea at Kalmat Khor, Miani Hor, and Gwater Bay. Mangrove forest dominated by *A. marina* covers only a small area of about 7,340 ha in Baluchistan Province.

1.3 Factors responsible for degradation of mangroves in Pakistan

Historically, Pakistan's mangrove forests were treated not as productive assets but as open-access wastelands by managers, planners and policy makers. As a result, they have been widely destroyed and degraded, mainly to meet increased demand for timber, fuel and fodder, and to provide grazing land for thousands of camels from the Sindh hinterland. A steady decline in freshwater flows and associated sediment loads has also contributed to the degradation of mangroves.

Over the past two decades, however, the status and conservation of Pakistan's mangroves have received more attention, and serious efforts are now being made to restore and protect them. These efforts are described below.

2. Materials and methods

The analysis in this paper is based mainly on a review of secondary literature produced by various agencies involved in restoration of mangroves in Pakistan, including the Sindh Forest Department (SFD), Sindh Coastal Development Authority, IUCN Pakistan, WWF Pakistan, and other local organizations. In addition, relevant published literature available online was also accessed and reviewed. The methodological approach followed three steps:

2.1 Analysis of mangrove ecosystem management

Information collected from existing management plans and baseline studies of mangrove ecosystems was used to assess the shift in approach from conventional forestry focusing on commercial management of riverine forests and irrigated plantations, to management of mangrove ecosystems emphasising their protective functions and services. The analysis also covered a shift in management approach from traditional "top-down" decision-making to "bottom-up" and "participatory" decision-making.

2.2 Analysis of mangrove restoration efforts

This analysis aimed to determine trends in mangrove reforestation efforts and the nature of engagement by a growing number of stakeholder agencies in mangrove protection, rehabilitation, awareness and advocacy. Pakistan has a long experience of mangrove restoration using innovative planting techniques, used also for mangrove restoration in Middle Eastern countries. The impact of mangrove rehabilitation efforts by different agencies was analyzed to demonstrate changing trends in mangrove cover in Pakistan. The mangrove cover analysis was based on remote sensing studies carried out by agencies such as the Space and Upper Atmosphere Research Organization (SUPARCO), SFD, WWF Pakistan and IUCN Pakistan.

The analysis of policy and legislative reform concerning mangrove forests was based on a review of official gazette notifications issued by government.

2.3 Analysis of livelihood aspects

The livelihood aspects of mangroves were analyzed in relation to the importance of mangrove ecosystems for coastal communities and the protective role played by mangroves in mitigating the impacts of natural disasters. Using data on historical and recent trends in extreme events in coastal areas of Pakistan, this paper highlights the need for integrating mangrove conservation into disaster risk management plans for Pakistan's coastal zone.

3. Results and discussion

The management of mangrove ecosystems in Pakistan has seen a shift in approach over the past century. After being largely overlooked by conventional forest management until the late 1970s, mangroves have drawn increasing attention for their management and conservation from the mid-1980s to the present day. This shift and its implications are discussed in the following sections.

3.1 Paradigm shift from conventional forest management

The forest types of southern Pakistan are characterized by an arid climate with scanty and sporadic rainfall. Three prominent types influence the landscape of the region: riverine forests on the flood plains of the Indus River; the mangroves of the Indus Delta; and plantations raised along irrigation canals.

The available literature indicates that, for many years, conventional forest management focused on commercial objectives, with resources devoted to managing and exploiting riverine forests and irrigated plantations. As mangroves had less immediate commercial importance, they were legally classed as protected forests.

This situation prevailed until the mid-1980s, when the first serious effort to conserve mangroves was made. During this time, a management plan for mangroves was prepared and field activities for mangrove restoration were initiated by SFD and later by IUCN Pakistan. A 20-year mangrove forest management plan was prepared for Sindh after a thorough assessment of the mangrove stock at different densities and other conditions. This was the first serious attempt at the scientific management of mangrove forests, and constituted an active shift in focus towards the protective functions of these forests. It also led to the establishment of a separate Coastal Forest Division headed by a Divisional Forest Officer with adequate subordinate staff.

The analysis also reveals that certain policy decisions concerning the management of water resources in the Indus River in Pakistan led to mangroves occupying a pivotal position in the advocacy campaign run by some civil society organizations, who have constantly advocated for regular inflows of fresh water into the Indus Delta to maintain a sustainable and healthy mangrove ecosystem. The advocacy campaign gained particular momentum after the signing of the Water Apportionment Accord of 1991 by Pakistan's four provinces (which remains in force today).

At the same time, there has been an obvious improvement in awareness and understanding of the values of mangroves both globally and within Pakistan. Nationally, these values have been assessed by various mangrove valuation studies conducted by IUCN Pakistan, WWF Pakistan and others. These estimate the per hectare value of mangroves in Pakistan to exceed US$8,000 (Baig and Iftikhar, 2010). As a result, over the past two decades mangrove restoration has assumed greater importance at all levels from the local to the regional.

The changes in management approach in Sindh have been influenced by changing global perceptions of forestry as being about people, not just about trees. This has led to a focus on forestry as being essential for social and ecological needs rather than simply commercial gains, and a greater emphasis on forest conservation and forest-based rural development by donors and international NGOs. This shift in emphasis to social forestry can justifiably be called a paradigm shift, since it involved changes in conventional assumptions about forests and their governance, thus leading to an increasing investment in the conservation of mangroves by different agencies.

3.2 Analysis of mangrove restoration efforts

Mangroves are a highly productive ecosystem supplying numerous goods and services. Growing appreciation of the value of these goods and services, and the negative impacts of mangrove loss on coastal livelihoods and environments, has led to urgent steps being taken to restore mangrove habitat structure and functions. In Pakistan, these efforts have taken into account three basic principles:

- **Stakeholder involvement**: Ecosystem management is more about people than anything else. This approach has been built into mangrove projects through participatory planning, decision-making and implementation.
- **Ecological approach**: This approach embraces modern ecological concepts such as the interdependent nature of natural resources and human actions, the dynamic nature of ecosystems, the delineation of ecosystems based primarily on ecological processes, and the need to characterise ecosystems at multiple scales. This approach has been followed in most mangrove restoration projects in Pakistan.
- **Management based on sound scientific principles**: The quality of policy and ecosystem management decisions depends heavily on the quality and quantity of available information and science. This requires not only sound science, but also the right science, i.e. knowledge and understanding of how major ecosystems function, how they can support and tolerate human use, and how policies and management decisions affect resource use and recovery. Coupled with scientific information, restoration strategies make extensive use of local knowledge in identifying planting sites, collecting seed, and choosing suitable mangrove species.

An analysis of development projects linked to mangroves in the past two decades indicates that government, international and local NGOs, and small grassroots organizations have all supported integrated development and management of mangroves. Recently, regional initiatives such as MFF have also contributed to restoration of mangroves in Pakistan (Table 1).

Since 1985, about 80,000 ha of mangroves have been replanted or rehabilitated along the Sindh and Baluchistan coasts. The Indus Delta has dominated mangrove restoration activities. These efforts have helped to stabilise mangrove populations, and also led to the reintroduction of *R. mucronata* to the Indus Delta in the mid-1980s using seed collected from Sonmiani in Baluchistan. *R. mucronata* probably disappeared from the Indus Delta in the 1970s, but is now being planted on a large scale using seed collected from the trees originally planted in the 1980s.

A major leap in large-scale mangrove restoration in the Indus Delta is foreseen with two major initiatives due to start in 2012. Both will be financed by the government of Sindh; one will be implemented by SFD and the other by IUCN Pakistan. Together, these two initiatives plan to restore 100,000 ha of mangroves in the Indus Delta over the next seven years.

The Indus Delta also holds a world record for mangrove planting, with 541,176 saplings planted in one day on 15 July 2009 by a force of 300. This record drew significant media attention nationally and internationally. Such events have helped greatly in drawing policy support for mangrove conservation in Pakistan.

Table 1 Mangrove projects launched in the Indus Delta

Agency	Period	Planted area (ha)
IUCN/SFD	1985	3,000
SFD/World Bank	1993–1999	17,100
SFD/IUCN	1993–1999	150
SFD/Government of Sindh	2000–2006	16,000
SFD/Government of Pakistan	2003–2008	5,000
Sindh Coastal Development Authority/Government of Sindh	2003–2008	8,000
SFD/Government of Sindh	2003–2008	10,000
WWF	2003–2008	100
UNDP/Sonmiani Development Organisation	2004–2006	300
WWF/Royal Netherlands Embassy	2007–2011	1,500
IUCN/Royal Netherlands Embassy	2007–2013	1,200
Sindh Coastal Development Authority/ADB [a]	2006–2013	8,000
SFD/Government of Sindh [a]	2009–2014	5,000
SFD/Government of Sindh [a]	2011–2017	50,000
IUCN	2010	150
SFD/IUCN [a]	2011–2017	50,000
IUCN/Pakistan International Bulk Terminal [a]	2012–2014	500
MFF [a]	2011–2012	900

[a] Ongoing projects.

A growing trend in mangrove restoration can also be observed along the Baluchistan coast, thanks largely to donor-funded initiatives implemented by IUCN Pakistan. Reportedly, these initiatives have also introduced mangroves at some newly identified sites along the Baluchistan coast to protect coastal towns against coastal erosion and address the problem of shifting sand dunes.

Some of the more notable achievements of all these initiatives include:

- Re-introduction of *R. mucronata* in the Indus Delta.
- Introduction of various techniques for mangrove restoration.
- Introduction of participatory approaches for mangrove conservation.
- Diagnostic studies on socio-ecological aspects of mangroves.
- Mangrove valuation studies.
- Awareness and advocacy on mangrove conservation.

3.3 Community involvement in mangrove restoration

Over time, the global shift from conventional top-down forest management to participatory management has gained ground in Pakistan. Community participation has been encouraged by NGOs, and initiatives coupling strong community mobilization with incentives have produced good results in areas such as Keti Bunder and Sandspit on the Sindh coast. These results include:

- Coastal communities have developed linkages with the agencies working on mangrove plantation and restoration.
- A sense of ownership has been developed for mangrove planting and restoration.
- Coastal communities have become aware of the importance of mangrove restoration.
- Communities are themselves now able to identify suitable land for mangrove planting.
- Communities have also come to appreciate that mangroves are the best defence against tidal surges.

3.4 Plantation techniques used in Pakistan

Pakistan has experimented with various plantation techniques for restoring mangroves and, through experience, has developed some effective site-specific approaches. The techniques commonly used in the Indus Delta are discussed below.

3.4.1 Direct sowing through propagules/seeds

This is the commonest and most successful technique used in Pakistan. It uses mature propagules or seeds collected from the field and sown directly into the soil. The technique has been used for all mangrove species found in Pakistan. For example, *R. mucronata* and *C. tagal* can be planted by putting one-third of the pointed length of a propagule into the soil and leaving the rest above the ground. In general, a small pit is made for planting *Avicennia* and seeds are sown inside as well as outside the pit. Two or more seeds are sown in the same pit to ensure germination success. Seeds are sown directly into the soil using finger pressure.

3.4.2 Wildlings

Wildlings are naturally germinated, 1–2 month old saplings extracted with a ball of earth using an auger and transplanted in the planting site. This technique is used mainly to plant *A. marina*. In some cases, *Avicennia* seed is broadcast in plots near planting sites to produce wildlings for later planting. In these cases, wildlings are normally used to fill gaps and replace dead plants when both natural seed and nursery stock are unavailable. If done properly, wildling planting gives good results.

3.4.3 Planting nursery stock

Mangrove nurseries can be established at suitable sites in the intertidal zone near plantation areas using polythene bags. They are used mainly to supply supplemental stock for planting and restocking failures when natural seed is unavailable. All mangrove species in Pakistan have been raised successfully in nurseries. Field planting is done using corers or augers to dig a planting pit. Nursery seedlings are usually ready to plant at three months.

3.4.4 Broadcasting

This technique is normally used for planting in riverine forests along the Indus River. However, it has also been used experimentally in the Indus Delta. Its main purpose is to increase planting density and restock gaps.

Based on the experience in Pakistan, adopting a planting technique consistent with site conditions is recommended. In high-lying areas, trenches may be dug for planting to ensure plants are sufficiently inundated. In low-lying mudflats, direct sowing of *Avicennia* spp. is normally most successful; in higher mudflats, direct sowing of both *Avicennia* and *Rhizophora* propagules or seeds has been shown to give good results.

3.5 Use of GIS to monitor changes in mangrove cover

Pakistan has long experience of using GIS to monitor changes in mangrove cover. The first-ever analysis of mangrove cover in Pakistan based on remote sensing and GIS technologies was conducted in the late 1980s using Landsat images. This study revealed changes in mangrove cover based on density classes, and categorized mangrove cover into dense, medium and sparse classes.

Since then, GIS has been widely adopted for mangrove cover assessment by the Ministry of Environment, WWF Pakistan, the Pakistan Forest Institute Peshawar, SUPARCO, IUCN Pakistan and the Sindh Coastal Development Authority. All of these organisations are now equipped with facilities and trained analysts for GIS-based temporal analysis of forest cover. GIS techniques are also being used in site selection, monitoring and impact assessment of mangrove restoration.

An analysis of mangrove cover changes and the impact of restoration efforts in the Indus Delta reveal a small increase in mangrove cover during the past decade. According to a recent study conducted by SFD, in 2010 mangrove cover reached about 108,000 ha (Figure 1).

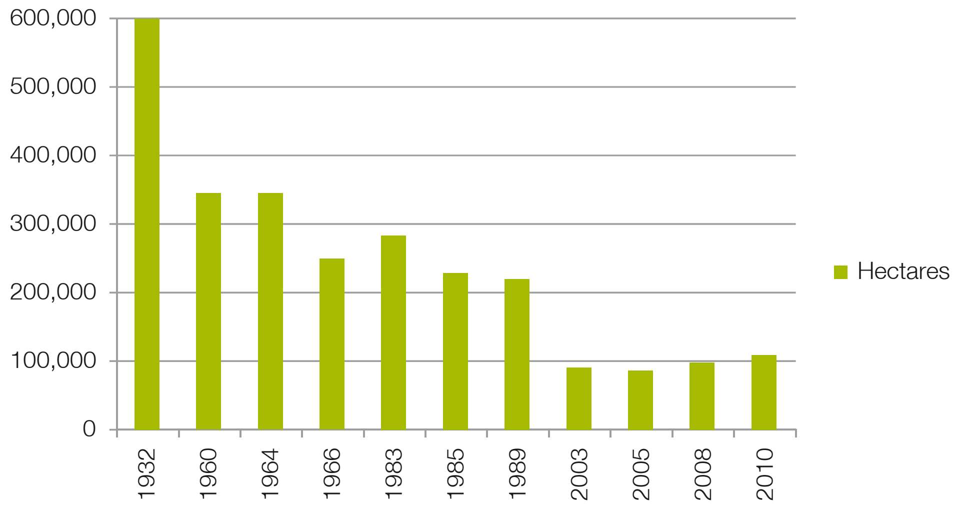

Figure 1 Mangrove cover trend analysis

3.6 Analysis of changes in mangrove-related legislation

The legal basis for protecting and conserving mangroves has seen various changes over the past 50 years. Initially notified as Protected Forest in the late 1950s, almost half of the area of mangroves in the Indus Delta was put under the control and oversight of SFD. Later, 64,400 ha of these protected forests were transferred from SFD to the Port Qasim Authority for port operations. A small part of the mangrove area remained under the administrative control of the Karachi Port Trust, but lacked any formal legal status (Table 2).

Table 2 Legal status of mangroves in Pakistan

Stakeholder	Area (ha)	Status
Sindh Forest Department	280,580	Protected Forest
Port Qasim Authority	64,405	Protected Forest
Sindh Board of Revenue	260,000	Wasteland
Karachi Port Trust and Defence Housing Authority	2,000	No legal status
Total mangrove area	606,985	–

Owing to ignorance of their ecological significance, the remaining mangroves were classified as wasteland and put under the administrative control of the Board of Revenue. This may have been one of the main factors leading to large-scale degradation of mangroves in Pakistan, as without legal protection the mangroves became open-access resources. The absence of effective legal protection and administrative weaknesses encouraged encroachment of mangroves in urban areas of Karachi and deforestation of mangroves in rural areas. Arguably, this indifferent attitude towards mangroves persisted for most of the ensuing few decades.

The past two decades have seen growing concern for environmental and natural resources conservation in Pakistan, including mangrove conservation. This attitudinal shift can be traced to the catalytic role played by international and local civil society organizations in creating awareness of and advocating for environmental issues. Natural disasters in coastal areas of Pakistan and South Asia more widely, such as tsunamis and storms, have also played an important role in drawing the attention of policy makers to conserving mangroves. The outcome of these changes is that all remaining mangrove areas in Sindh Province were re-notified as Protected Forests in November 2010 and put under the control of SFD. Furthermore, legislative reforms concerning mangroves and participatory management of mangroves and other forest types have been incorporated into a recent review of the Provincial Forest Act 1927 and put before the provincial legislative assembly of Sindh. This shift in policy and management is indicative of a growing realization among policy makers that mangrove ecosystems are important to the coastal economy and coastal protection, and is expected to have further positive impacts on mangrove conservation in Pakistan.

3.7 Livelihood aspects of mangrove restoration in Pakistan

Pakistan's mangroves provide a number of valuable goods and services, including supporting the fisheries sector by serving as breeding grounds for shrimp and fish species. About 200 fish species found in the Indus Delta are reported to provide livelihoods for local communities. Some studies indicate that mangrove ecosystems contribute to annual production of fish and shrimp ranging in value from US$750 to US$16,750 per hectare, indicating their potential connection in marine fisheries production (Rönnbäck, 1999). Mangroves are also an importance source of fuelwood for local communities and fodder for livestock.

The role of mangroves in disaster protection has received global attention. From the perspective of local communities, they offer protection against tidal surges and provide a defensive shield against cyclones and tsunamis. Historical records indicate that Pakistan's coast has long suffered from natural disasters. The oldest records date back to the earthquake of

November 325 BC near the Indus Delta/Kutch region. This caused a tsunami that destroyed a large Macedonian fleet (Lisitzin, 1974; Murty and Bapast, 1999, cited by Zaigham, 2012). Reportedly, Alexander the Great was passing through the region at that time. Other large earthquakes have included the following (Oldham, 1883; Zaigham, 2001, cited by Zaigham, 2012):

- 893–894 AD: Debal, lower Sindh. Several towns destroyed and 150,000 killed.
- 2 May 1668: Shah Bunder, lower Sindh. About 50,000 killed.
- 16 June 1819: Allahbund, Sindh. About 3,200 killed.

Pakistan also experienced an 8.7 magnitude earthquake off the Makran coast in 1945, which caused a huge tsunami in the Arabian Sea and killed more than 4,000 people. Deadly storms occurred along the Karachi coast in 1965, causing 10,000 casualties. Recently, cyclone 2A killed 6,200 people after making landfall at Shah Bunder on 20 May 1999.

Observations indicate that the frequency of cyclones and earthquakes in Pakistan has increased over time. From 1971 to 2001 the Sindh coast witnessed 14 cyclones (Memon, 2012). From 2001 to 2011, eight cyclones were recorded along the Pakistan coast. Two recent high-intensity cyclones, Yemyin and Phet, narrowly missed the Sindh coast yet still managed to cause considerable damage. Given these threats, conserving mangroves is essential to enhance the resilience of local communities against the impacts and challenges of extreme events.

4. Conclusions

The long-term restoration of mangrove ecosystems demands a multi-faceted approach, comprising replanting, management planning, and the development of planting capacity and awareness among relevant agencies and coastal populations.

Pakistan is seriously engaged in managing and developing its natural resources, especially its mangroves. These coastal forests provide valuable ecosystem services and also supply coastal communities with important natural resources.

The management of mangrove forests has seen a shift from neglect to active protection, and from a top-down approach to a bottom-up, participatory approach reflecting recognition of the many local, national and regional values of mangroves. These shifts have led to the evolution of various techniques for mangrove restoration, used successfully to rehabilitate degraded areas and stabilise mangrove populations, particularly in the Indus Delta, which harbours most of the mangroves found in Pakistan. Policy shifts have resulted in greater legislative support for mangrove conservation and its integration into disaster risk management strategies. Although these policy changes are relatively recent, increasing investment by government and other agencies in mangrove conservation reflects confidence in Pakistan's regulatory framework and augurs well for the sustainability of the country's mangrove restoration programme.

Pakistan's long experience of restoring its mangroves offers some useful lessons for other countries in Asia to adapt and follow.

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A collaborative approach between tourism and coastal communities: a present-day need and opportunity for mangrove management and conservation in Sri Lanka

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Abstract

Conservation of mangroves is a primary responsibility of mankind as a contribution to society, the environment and related ecosystems. In this regard Sri Lanka has taken many initiatives, a leading example being the restoration of 2004 tsunami-hit mangroves in lagoons in the east, west and south of the island. The involvement of communities, experts and nongovernmental organisations in this endeavour was commendable. However, the lack of continuous economic benefits to the neighbouring communities has challenged the long-term sustainability of mangrove rehabilitation efforts in many areas. External intervention and resources, over a considerable period, seems essential to conserve and restore the original flora. Considering current trends, introduction of tourism with visitor facilities for research, study and ecotourism activities will be an opportunity to generate additional or alternative income for mangrove stakeholders. When mangroves are used as a resource base to generate substantial economic benefits from activities such as operating eco-lodges, mangrove tours and other mangrove ecotourism activities, the stakeholders will be motivated to protect their resource base while using it sustainably.

In the study area in Kalpitiya, tourism was the primary source of income for 51.8% of the community and a secondary source of income for 28.5%; the tourist activities were mostly associated with mangrove environments. The study also revealed that mangrove areas generate many non-economic benefits such as providing an environment and nesting sites for birds, enabling the existence and continuity of wetland ecosystems, and protection of rare, site-specific faunal species. Protection against coastal hazards such as erosion and tsunamis, and providing a green cover were also noted. Moreover, due to the high tourism demand and visitor interest in nature and related ecosystems, a sustainable independent system capable of generating continuous economic benefits to the community through tourist facilitation could be developed. In turn, the sensitive and important mangrove habitats that are mostly found in lagoons, estuaries and wetlands can be protected sustainably by an independent tourism-centered system and its neighbouring stakeholders.

Keywords: mangroves, nature conservation, tourism, economic benefits, Sri Lanka

1. Introduction

Mangrove is a type of forest growing along tidal mudflats and shallow coastal water areas extending along rivers and streams where water is generally brackish. The mangrove ecosystem is dominated by mangrove trees as the primary producer interacting with associated aquatic fauna, and social and physical factors of the coastal environment. Table 1 below details the varying distribution of mangrove species in countries and regions.

Mangroves possess characteristics that collectively make them structurally and functionally unique. Morphological and ecophysiological characteristics and adaptations of mangrove trees include aerial roots, viviparous embryos, tidal dispersal of propagules, rapid rates of canopy production, frequent absence of an understorey, absence of growth rings, wood with narrow, densely distributed vessels, highly efficient nutrient retention mechanisms, and the ability to cope with salt and to maintain water and carbon balance (Alongi, 1998).

Being the only woody halophytes living at the confluence of land and sea, mangroves traditionally have been used heavily for food, timber, fuel and medicine, and currently occupy about 181,000 km^2 of tropical and subtropical coastline (Alongi, 2002).

Table 1 Distribution of mangrove species diversity

Country/Region	No. of species recorded
Australia	47
Indo-Malaysia	51
East Africa	11
West Africa	8
East America	11
West America	12
Sri Lanka	20

Source: Alongi (2002); pers. comm.

Mangrove plant communities are a comprehensive economic and non-economic contributor to mankind. They are a valuable ecological and economic resource, being an important nursery and breeding site for birds, fish, crustaceans, shellfish, reptiles and mammals (Melana *et al*., 2000; Alongi, 2002). Mangroves are a renewable source of wood, accumulation sites for sediments, contaminants, carbon and nutrients, and protect coastal communities against coastal erosion (Liyanage, 2010). Natural hazards such as storms, cyclones and most recently the Indian Ocean tsunami have repeatedly shown the value of mangroves and the need to prevent unregulated, destruction and extraction by man (Melana *et al*., 2000). Among the main reasons for the destruction of mangroves are urban development, aquaculture, mining and the overexploitation of mangroves for timber, fish, crustaceans and shellfish. Over the next 30 years, unrestricted clear felling, further development of aquaculture and the continuing overexploitation of fisheries will be the greatest threats. Lesser threats will include alteration of hydrology, pollution and climate change. The loss of mangrove biodiversity is, and will continue to be, a severe problem, as even pristine mangroves are species-poor compared with other tropical ecosystems (Alongi, 2002).

Mangrove conservation and restoration are often viewed with suspicion in terms of long-term sustainability, due to a lack of awareness, knowledge and the absence of systemic tangible benefits at the community level. The scarcity of land for human needs, which continues to exert pressure on mangrove and wetlands, is a major challenge. There is a pressing need to develop alternative conservation approaches that link mangrove conservation and restoration with other forms of coastal industry development, especially tourism, as a means to ensure mangroves' future sustainability. If mangrove forests continue to be exploited at current rates without addressing the need for sustainable management, they will be largely gone by about 2030. The future of mangroves depends on the development of technological and ecological advances in multi-species genetics and forestry modelling; the greatest hope for the future of mangroves is for a reduction in human population growth (Alongi, 2002).

1.1 Tourism towards environment

World tourism is the single largest industry; it generates almost one billion international tourist arrivals and about US$450 trillion in receipts globally, and is growing at around 3.5%–4%

annually, the highest growth rate for a single industry. These facts show the significance and size of the tourism industry in the world economy. Furthermore, the positive relationship between tourism demand and economic development in developed countries ensures that this industry will maintain its growth in the future (UNWTO, 2011).

The potential demand for nature tourism is enormous. UNWTO (2004) showed that nature-related tourism represents about 20% of total tourist arrivals globally, and is growing at 10%–30% annually, thus doubling the size of the nature tourism subsector every three to four years. Wight (2001) estimated that some 40% of all tourists travel with a view to seeing some form of wilderness during their trip. Ecotourism comprises about 10% of total tourism demand, and is growing at 7% annually, which is much faster than the overall growth of world tourism, estimated at about 4.1% per year (WTTC, 2010). The above numbers suggest that if tourism demand in 2015 is 1.561 billion arrivals, as forecast by WTTC (2010), approximately 312 million tourists will engage in nature-based facilities and activities.

1.2 Sustainable tourism and mangrove conservation

Sustainable tourism development requires the informed participation of all relevant stakeholders, as well as strong political leadership to ensure wide participation and consensus-building. Achieving sustainable tourism is a continuous process that requires constant monitoring of impacts, and introducing necessary preventive or corrective measures whenever necessary. Sustainable tourism calls for maintaining a high level of tourist satisfaction and ensuring a meaningful experience for tourists, raising their awareness about sustainability issues, and promoting the uptake of sustainable tourism practices. Sustainable tourism depends on the three interconnected impacts of environmental, socio-cultural and economic issues (UNEP, 2002).

The mangrove environment provides a comprehensive natural resource base as a foundation to attract tourists. The sustainability concept is widely discussed at present in all tourism initiatives. Coastal tourism resource bases, particularly vulnerable and sensitive mangrove ecosystems, which are distributed within limited areas in countries, need special attention to ensure their sustainability. Using sustainability concepts as a tool and vehicle for careful use of the coastal ecosystem, tourism has the potential to help conserve mangroves and interrelated ecosystems by providing economic gains to immediate stakeholders to ensure the wider non-economic benefits of mangroves (Ratnayake, 2007; Liyanage, 2010).

In summary, mangroves are a unique ecosystem that contributes direct economic benefits and major non-economic benefits to society. However, it appears that many stakeholders show little regard for this important ecosystem. Introducing tourism will bring economic benefits to the community and other associated stakeholders that will bring home the importance and value of mangroves for their livelihood, and motivate them to protect mangroves. This study aims to ascertain the economic and non-economic benefits (both direct and indirect) generated by mangroves.

2. Materials and methods

Data required to compile an overview of mangrove restoration areas, their geographical distribution and the local and locational values of the present mangrove ecosystem and social systems were collected. The overview also reflects the contribution by MFF and other conservation initiatives to restore or reinstate disturbed sensitive areas in the country damaged by natural hazards, and records their present status. The study pays specific attention to communities' knowledge (both general and scientific) about the surrounding mangrove forests and their associated ecosystem and biodiversity. The study also investigated the direct benefits that will gain positive responses and support from the neighbouring coastal community, when tourism initiatives for restoration and conservation are successfully concluded.

The research mainly focuses on how to assess independently which restoration and conservation initiatives are sustainable, for the next generation of the society (by 2030). The final aim of the study is to identify what kind of tourism (tourists, facilities and activities), and what type of nature research and education, are necessary and acceptable to support livelihood development systems in areas where mangroves are most at risk.

3. Results

The 20 species of mangrove found in Sri Lanka fall into four groups based on the frequency of occurrence. The four most common genera are *Avicennia*, *Rhizophora*, *Bruguiera*, and *Sonneratia*. Ten common species, three rare species and three very rare species are recorded. Table 2 shows the distribution of mangrove areas by coastal district.

Table 2 Extent of mangrove in coastal districts in Sri Lanka (ha)

Puttalam	3,210	Gampaha	313
Jaffna	2,276	Galle	238
Trincomalee	2,043	Ampara	100
Batticaloa	1,303	Colombo	39
Kilinochchi	770	Kalutara	12
Hambantota	576	Matara	7
Mullaitivu	428	Total	11,315

Source: Forest Department, Sri Lanka.

Mangrove restoration has taken place in all coastal districts affected by the Indian Ocean tsunami in 2004. Restoration commenced in the southern and eastern regions and later extended to northern and western regions. MFF small and medium grants made a substantial contribution towards this process. Necessary support from experts and organisations such as the Coast Conservation Department and Forest Department has also been obtained. Further research is called for on the damage caused by the tsunami and its future impacts; appropriate mangrove species; and replanting methods, locations and timing.

Ecological and economic benefits of, and threats to, mangrove forests surfaced in the study. Services provided by mangrove forests are:

- Nursery grounds for fish, shrimp and crabs.
- Harvesting grounds for crabs, shrimp and some fish species.
- Production of leaf litter and detritus – valuable food resources for animal life in estuaries and coastal waters.

- Protects coastal areas and communities from storm surges, waves, tidal currents, tsunamis and other natural hazards.
- Produces organic biomass and reduces organic pollution near the shoreline.
- Serves as recreational grounds for birdwatching and observation of other wildlife.
- Provides wood and timber for low-cost housing, firewood and charcoal.

Threats faced by mangrove forests are:

- Conversion to fishponds and salt beds.
- Reclaiming for various developments.
- Indiscriminate extraction of firewood and wood.
- Dumping of solid waste.
- Tsunamis, tidal waves, soil erosion.

Proposed solutions are:

- Establishment of nurseries, and management and research centres.
- Plantation of mangroves with appropriate species based on scientific findings.
- Introduction of alternative means of mangrove-based income generation, such as ecotourism, for coastal communities.

The community's perception of current economic benefits from tourism in mangrove restoration areas in Kalpitiya was assessed using a random sample amounting to 10% of the population. Situated in North-Western Province, Kalpitiya is the largest open lagoon in Sri Lanka, and is surrounded by many mangrove-covered islands. At present, the government is developing tourist facilities to promote formal tourism in a selected group of islands and mangrove forests.

The results presented in Table 3 show the community's high level of dependence on tourism. It is the principal source of income for half the community (51.8%) and the secondary source for another 28.5%. However, less than 20% are aware of the environmental value of mangroves, and almost 75% extract firewood from mangrove forests. These numbers illustrate the gravity of the threat facing mangroves. The community is largely engaged in providing *ad hoc* facilities to tourists, especially domestic tourists. They are using coastal resources for economic gain, but sadly are unaware of the value of these resources, nor do they seem to care. Only 11.7% claim they do not harm this valuable ecosystem.

About 27% of the households earned their entire household income from the tourism industry. Around 11% earned about half their household income, and another 23% some part of their income, from tourism. About 39% do not derive any income from the tourism industry.

Overall, the community's knowledge about mangroves was limited. Only 7% had a high level of awareness, and the rest knew little or nothing about mangroves. However, their willingness to learn about mangroves and readiness to co-operate are important for future development and should be appreciated. Most of those sampled (77.4%) agreed to learn about mangrove ecosystems to enable their participation in tourism and ecotourism initiatives.

Table 3 Socio-economic characteristics of the Kalpitiya area community

Characteristic	No. of households	Proportion (%)
Primary source of family income		
Tourism related	71	51.8
Non-tourism related	66	48.2
Total	137	100.0
Secondary source of family income		
Nil	75	54.7
Tourism related	39	28.5
Non-tourism related	23	16.8
Contribution of tourism to total family income		
Nil	53	38.7
100%	38	27.7
About 50%	15	10.9
Less than 50%	31	22.6
Total	137	100.0
Level of awareness of the environmental value of mangrove		
Nil	86	62.7
Very poor	17	12.4
Limited	27	19.7
High: mangrove protection is essential	7	5.0
Total	137	100.0
Wish to improve awareness about mangroves	106	77.4
How the community presently utilizes mangroves		
Fire wood	81	59.1
Does not utilize mangrove	16	11.7
Firewood and other uses	34	24.8
Uses other than firewood	6	4.4
Total	137	100.0
Future plans relating to mangroves		
To start a tourism business	67	48.9
To add more tourism facilities	31	22.6

The community is unhappy about current tourism practices, which are mostly *ad hoc* activities, but are willing to work with the tourism authorities to improve them. The majority (62%) have a positive attitude towards tourism and ecotourism, which they regard as a worthwhile activity. Their comments show that they believe that tourism and ecotourism will develop and will be sustainable in their area.

Global tourism shows continuous growth; nature-interested travellers and ecotourists are important contributors to this trend. Countries with high-nature-value landscapes and biodiversity can cater to such tourists. Sri Lanka being a tropical country as well as an island has comparative advantage in this market segment (Table 4).

Table 4 Global tourist arrivals and estimated numbers of ecotourists and travellers interested in nature (in millions)

Year	2006	2007	2008	2009	2010	2011 [a]
A. Tourist arrivals	782	898	924	880	935	1046
B. Nature-interested travellers [b] (20% of A)	156.6	179.6	184.8	176.0	187.0	209.2
C. Ecotourists [b] (avg. 7% of B)	10.9	12.6	13.0	12.3	13.1	14.6

[a] Projections. [b] Estimates. *Sources*: UNWTO (2011); Ratnayake (2007).

In line with international trends and peace in the country, international tourist arrivals have started growing quickly (46% in 2010 and 31% in 2011) in Sri Lanka (Table 5).

Table 5 Monthly and annual tourist arrivals to Sri Lanka

Month	2010	2011	2012	Average growth (%)
January	50,757	74,197	85,874	15.7
February	57,300	65,797	83,549	27.0
March	52,352	75,130	91,102	21.3
April	38,300	63,835	69,591	9.0
May	35,213	48,943	–	–
June	44,730	53,636	–	–
July	63,339	83,786	–	–
August	55,898	72,463	–	–
September	47,339	60,219	–	–
October	52,370	69,563	–	–
November	72,251	90,889	–	–
December	84,627	97,517	–	–
Annual total [a]	654,476	855,975	330,116 [b]	–
Annual growth (%)	46.1	30.8	18.3	–

[a] 454,475 in 2009. [b] By April 2012. *Sources*: SLTDA (2011, 2012).

3.1 Environmental and economic benefits of tourism

Tourism development increases the demand for quality accommodation, food and beverage, and other ancillary facilities. Moreover, visitors now look for specific places to visit, gain knowledge during the tour, respect nature and help maintain its balance. They are demanding diversified tourism products with high quality standards and services, pristine locations, and knowledge on the valuable ecosystems encountered during their travels.

The main positive economic impacts of tourism stem from foreign exchange earnings, contributions to government revenues, and generation of employment and business opportunities. Tourism expenditures and the export and import of related goods and services generate income for the host economy and can stimulate the investment necessary to finance growth in other economic sectors. Tourism can also contribute to environmental protection, conservation and restoration of biological diversity, and the sustainable use of natural resources. The need to protect valuable pristine sites and natural areas can lead to the creation of new non-conventional tourist destinations, activities and facilities.

Sri Lanka has about 36 lagoons and estuaries distributed across the country. Almost all of these areas are either on or near present tourist routes. Even in the north and east of the country, which are emerging areas for tourism, the remaining mangrove forests are located close to potential tourist routes.

Development of visitor facilities for awareness, education, accommodation, research, study and publication, with basic infrastructure, will provide unique value to nature-loving visitors and people living in those areas. Networking these facilities, both within the country and among other countries with similar resource bases and visitor facilities, will also strengthen their marketing.

To capitalise on potential and international visitor interest, appropriate visitor facilities, knowledge gathering and research centres, activities within and in neighbouring areas, and nature friendly accommodation in close proximity to mangrove areas, should be available. These facilities can generate additional income for the communities living close to mangrove habitats.

As a model, three home stay units were developed close to Kalpitiya Lagoon, and 12 mangrove tour assistants and 17 lagoon tour assistants were identified. Annual projected income (using the lowest estimates) for each unit (with 30 nature lodges for tourists) is presented in Table 6.

Table 6 Income projections for home stay units near Kalpitiya Lagoon

Estimates	Occupancy	Room rate US$30/day	Boat ride US$30/trip
Potential	15 days/month for 6 months; 8 days/month for other 6 months = 138 days/year		2 trips per day, for 15 days per month, for 6 months each year
Income		138 days x US$30 = US$4,140	2 trips x 15 days x 6 months x US$30 = US$5,400
Total cost		30% = US$1,242	30% = US$1,620
Profit or additional income per annum		US$2,898	US$ 3,780

Hypothetical projections show the financial benefits of tourism. Communities will be able to earn more income by providing camping, research, nature activities, and study tours (Table 7).

Based on tourism initiatives in mangrove areas and lagoons, there will be non-economic benefits such as a protected environment for breeding and nesting of birds, protection of habitats for specific rare fauna and flora species, and maintenance of wetland ecosystem services. Use of mangroves for firewood adversely affects all non-economic benefits; it can also lead to more serious environmental issues in the long run. Most community members who extract firewood from mangrove forests are unaware of the possible environmental problems. Financial difficulties drive them to use firewood for cooking. This suggests that alternative sources of income may indirectly protect mangroves and associated ecosystems.

Table 7 Proposed tourism facility development models for mangrove areas

Model (options)	I	II	III	IV
Visitor day activities	Nature walk/ trekking	Boating/ birdwatching	Observation and recording	Nature walk/ boating
Accommodation	Home stay	Camping	Ecolodge	–
Knowledge centre	Nature information centre	Nature library	Nature research centre	Nature information centre
Visitor activities 1	Reading/video	Reference/ recording	Reference/ data collection	Tourist information
Restoration	Nursery work	Replanting	Restoration/ replanting	Land preparation
Monitoring	Watering/fertilising	Plants aftercare	Plants aftercare	–
Visitor activities 2	Village walk	Fishing	Assist in cultivating	Visit attractions
Visitor activities 3	Study cultural aspects	Round tour	Excursions to other areas	–

Controlling the number of facility units in a given area, and number of visitors at any given time of the day, will increase the financial returns to the community without harming the resource base. Income generation based on mangrove resources will provide the necessary motivation to protect the mangroves with minimal intervention. Linked with effective management methods, this will be sustainable in the long run and will ensure the environmental benefits of mangrove forests without any disruption.

4. Discussion

Clearly, mangrove environments have a very high potential to attract the positive attention of the tourism sector, due to their natural biodiversity and the diversity of the associated ecosystems. The diversity of mangrove communities and their geographical locations offer considerable potential for the development of research centres, eco-friendly accommodation, nature trails, birdwatching, game fishing, observation platforms and interpretation services by local people. Nature-based activities could include replanting mangroves jointly with visitors, and research projects conducted by visitors in collaboration with local youth. These activities could open up a variety of avenues and opportunities for income generation for the communities living around mangrove habitats.

Initial inputs and support are required to train local personnel, and technical inputs are needed to create awareness among local people to facilitate introducing tourism initiatives. Once the initiatives are in place, and communities begin to generate alternative incomes using mangroves as a resource base, they will start protecting mangroves motivated by income and respect for mangrove resources. The community will have opportunities to generate income by organizing tourism programmes to mangrove areas and by providing facilities to tourists. The capacity of mangroves to generate alternative incomes from domestic and international tourism will increase when facilities are provided for nature-based activities. As additional income begins to flow in, the community will gradually move towards conserving sensitive mangrove areas. They will soon realize that keeping mangroves is more profitable than cutting mangroves. Hence, long-term sustainability of the conservation initiatives can be ensured. This model can be replicated in any area or country after a careful assessment of the area targeted.

5. Conclusions and recommendations

Introducing new activities to sensitive environments must be linked to careful studies, systematic management methods, and strict guidelines for stakeholders. So it is necessary to:

a. Carry out comprehensive studies on the resource base and its sensitivity to different levels of intervention, i.e. carrying capacities in the long run.
b. Identify areas that have to be conserved with no intervention. In other areas identify appropriate tourism facilities and activities e.g. introduce one of the proposed models.
c. Assess the level of community awareness and the assistance that will be needed to form community business centres in the identified areas.
d. Identify training needs such as capacity building and skills development for providing tourism activities and facilities.
e. Effectively manage the services developed with due care for the sensitive resource base.
f. Assist with technical and financial (borrowing) support to develop tourism facilities.
g. Use ecotourism as a tool for the conservation of mangroves while generating income.
h. Extend marketing support by linking with other similar products found locally and internationally, at least during the first two years in order to establish market sustainability.
i. Set up a mechanism to monitor interventions and take corrective action to support sustainable conservation of mangroves.

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Mangrove restoration efforts in Sri Lanka

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Abstract

In Sri Lanka, mangroves have been associated with 22 brackish water bodies; their estimated total extent is between 4,000–12,000 ha. Mangroves are scattered in different climatic zones and are associated with rare plant and animal species. Mangroves provide many benefits to coastal populations in terms of economic goods and ecological services, such as fisheries, ecotourism, building materials, aquaculture, medicines, and as a natural wastewater treatment system, and habitat for birds and mammals.

The main reasons for loss and degradation of mangroves in Sri Lanka have been identified as extraction of timber, conversion of mangrove lands for agriculture and salt production, coastal industrialization and urbanization, and for coastal aquaculture. After the 2004 tsunami disaster, the central government and some NGOs realized the significance of this mangrove cover that serves as a natural barrier against the wave storms. They initiated projects for restoration and replanting at selected locations.

The sustainability of these mangroves restoration projects and their achievements were evaluated through a study of published literature, project reports, research papers and presentations relating to these mangrove rehabilitation efforts. On-site observations, questionnaires for, and interviews with, the community, and discussions with project leaders were also carried out.

Six restoration/replanting project sites at Rekawa, Negombo and Puttalam Lagoons, and in Madu Ganga area were inspected; their level of success varied. In Rekawa Lagoon, replantation had commenced in 2007; of the 15,000 seedlings planted just 200 survive today. The project failed as the seedlings utilized were not suited to the environmental conditions at the site. The Negombo Lagoon projects, started in 2005 and 2007, were 70% successful, with 85,000 survivors out of the 125,000 seedlings planted. These projects provide many benefits both to the environment and the community. In Puttalam, replantation projects commenced in 2005 and 2010; 160,000 seedlings of *Rhizophora* sp. were planted over 15 hectares. They were 65% successful and the plants are now 3–4 m tall. The Madu Ganga area replantation, started in 2005, failed; only 50–70 survivors out of 10,000 seedlings planted. The failure was ascribed to low salinity levels and excessive growth of sea weeds at the site.

Almost all the villagers around the successful mangrove replantation sites are engaged in fishery activities. Most are now aware of the significance of mangroves and the prospects are excellent for conserving mangroves for the benefit of future generations. The mangrove vegetation here controls shoreline erosion and also traps sediments.

Reasons for the failure of some replantation projects, as revealed by the survey, can be summarized as follows: mangrove seedlings used were not suited to the environmental conditions, poor habitat selection, improper planting methods (e.g. planting at a substrate depth outside the natural range for mangroves in that area), lack of monitoring after planting, and indirectly, the decision makers' lack of knowledge/enthusiasm on the ecological role of mangroves.

Some recommendations towards improving and conserving the mangroves cover are: building awareness among people – schoolchildren and officials of government departments and

NGOs; improving coordination among institutions; introducing a system to share knowledge and data; in-depth studies on mangrove habitats to determine suitable species for different climatic areas, and facilitating small grants for community-based mangrove rehabilitation projects.

Keywords: mangroves, restoration, lagoons, biodiversity, wetlands, Sri Lanka

1. Introduction

Mangroves, wetlands rich in biodiversity, are subject to severe depredation worldwide. In Sri Lanka, mangroves are associated with 22 brackish waterbodies such as lagoons and estuaries, and are estimated to cover 4,000–12,000 ha. The largest mangrove system, around 3,385 ha in extent, is located in Puttalam Lagoon. Other large mangrove areas are found in Batticaloa and Trincomalee districts. Mangroves are found in different climatic zones and are associated with rare plant and animal species. Fishing in these lagoons and estuaries provides a livelihood for over 120,000 coastal people. Mangroves provide many benefits to coastal populations in terms of economic goods and ecological services, such as fisheries, ecotourism, building materials, aquaculture, medicines, a natural wastewater treatment system, and habitats for birds and mammals.

Ecologically, tropical mangrove forests are important in maintaining and building the soil, as a reservoir in the tertiary assimilation of waste, and in the global cycles of carbon dioxide/nitrogen/sulphur. Mangroves play a significant role in coastal stabilization and promoting land accretion, fixation of mud banks, and the dissipation of wind, tidal and wave energy.

Mangrove utilization falls into two categories. First, the use of the mangrove ecosystem as a whole or its conversion to other uses; and second, the use of products from the mangrove ecosystem. A relatively recent commercial use of mangroves is for recreation and ecotourism.

The main reasons for loss and degradation of mangroves in Sri Lanka have been identified as increasing population density, conversion of mangrove lands for agriculture and salt production, firewood and timber extraction, and coastal industrialization and urbanization. Many mangrove habitats have been heavily exploited and are no longer found in large areas in many locations. Over the past two decades, the mangrove vegetation in many lagoons and estuaries in Sri Lanka, especially on the north-western coast, has been rapidly cleared to make way for commercial aquaculture of shrimp for the booming export market. Wherever mangrove forests have been cleared, the yields of coastal fisheries have fallen drastically because mangroves are the breeding grounds of many economically important fish species. The loss of mangroves removes a life-supporting resource, not just for the fish populations but also for the coastal population.

After the 2004 Indian Ocean tsunami, the central government and some NGOs realized the importance of mangroves as a natural barrier against storm waves, and launched projects to restore the damaged mangroves. The objective of this study was to evaluate the progress and achievements of six selected projects initiated mostly around five years ago, with a view to understanding the possible reasons for their success or failure, as the case may be.

2. Materials and methods

2.1 Study sites

2.1.1 Rekawa Lagoon

Rekawa Lagoon is located about 200 km south of Colombo in Tangalle, in Hambantota District. The lagoon, about 250 ha in extent, with its wide basin and narrow meandering channel, is the dominant feature of the area. Mangrove and scrub forest (about 200 ha) surround the lagoon, which is bounded on the seaward side by a broad sandy beach approximately 10-km long. Landward of the lagoon is a large tract of paddy fields (about 500 ha), mostly abandoned due to high salinity. The Rekawa Lagoon study site has nearly 5,400 people living in 1,200 families. About half of the population is engaged in sea and lagoon fishing, and the other half in agriculture.

Rekawa Lagoon is shallow with the water depth averaging 1.4 m. Fringing mangroves such as *Rhizophora mucronata* and *Bruguiera gymnorrhiza* make up only a small portion of the mangrove forest system and form only a narrow band around the shoreline. Less-dominant mangrove species mixed with other vegetation grow inland from the fringing mangroves and form an additional band around the lagoon.

Freshwater inflows to the lagoon have been impeded by numerous irrigation structures built to supply agricultural land along the three main rivers flowing into the lagoon. Several causeways near the lagoon mouth impede the flow of sea water and shrimp and fish recruitment to the lagoon. These changes have affected the overall productivity of the lagoon fish and shrimp industry, and the water quality of the lagoon.

2.1.2 Negombo Lagoon

Negombo Lagoon, located about 35 km north of Colombo, is a large estuarine lagoon in Gampaha district, in south-west Sri Lanka. The lagoon is fed by number of small rivers and a canal. It is linked to the sea by a narrow channel to the north near Negombo town. It is surrounded by a densely populated region containing paddy fields, coconut plantations and grassland. The lagoon has extensive mangrove swamps and attracts a wide variety of waterbirds including cormorants, herons, egrets, gulls, terns and other shorebirds. Most of the people in the area are engaged in lagoon fishing and the shrimp industry. Mangrove cover is declining rapidly owing to land clearing for large-scale shrimp aquaculture.

2.1.3 Puttalam Lagoon

Puttalam Lagoon has the largest mangrove area (3,385 ha) in Sri Lanka. Coastal communities depend on the lagoon fishery and mangrove forests for their survival. Mangroves are heavily exploited by coastal communities for fuelwood, timber for buildings, stains for nets and sails, timber for fencing, and so on. Mangroves are disappearing from many areas of Puttalam Lagoon as a result of land clearing for large-scale shrimp aquaculture and agriculture. In addition, large areas of mangrove forest in Puttalam Lagoon have been destroyed to construct houses, hotels, factories and boat landing areas. Therefore, mangrove forests in the lagoon are under the serious threat of extinction due to overexploitation by coastal communities, aquaculturists and land developers (Kapurusinghe, 2011). In Puttalam district, where the most extensive and rare mangrove species exist, more than 3,000 ha of mangrove lands were converted to industrial shrimp farms under government patronage.

2.1.4 Madu Ganga

The Madu Ganga lakes are located on the south-western coast of Sri Lanka. These twin lakes, with surface areas of 915 ha and 390 ha, are connected by a narrow channel 3-km long. Madu Ganga has a unique biodiversity, consisting of ten major vegetation types including the predominant mangroves and marshlands. Together these comprise 303 species of plants belonging to 95 families, including 19 endemic and nationally threatened species, and nine invasive alien species. Due to the great variety of plants, a large number of invertebrates, reptiles (including snakes), birds, amphibians and mammals can be found around the lakes. The mixture of vegetation types and the 21 small and large islands within the twin lakes have made these two wetlands an ideal habitat for 111 bird species (Gattenlöhner *et al*., 2007). Pollution from pesticides, sewage, agricultural chemicals and industrial effluents are gradually becoming major threats. Many fisher folk communities bordering the lakes and the sea have lost their means of livelihood since the 2004 Indian Ocean tsunami.

2.2 Methodology

Background information was gathered through a study of the published literature, project reports, research papers and presentations relating to these mangrove rehabilitation efforts. Socio-economic data were collected from villages near the mangrove planting areas through discussions and questionnaires. Questionnaires were distributed among 20 individuals in the villages close to each site to collect qualitative data such as perceptions of ecological and economic values. Five water quality parameters were measured on-site during February 2012, using portable multi-parameter (Thermo Scientific) test kits provided by the Marine Environment Protection Authority. The value of each parameter, at each site, is the mean of measurements of five water samples. Plantation performance was assessed from discussions with project leaders and participants, photographic records, and on-site observations.

3. Results

Tables 1, 2 and 3 opposite detail, respectively, percentage survival of mangrove seedlings at selected replanting/restoration sites; the values of five water quality parameters at each site; and a measure of the increase of ecological and economic values due to replanting.

4. Discussion

Varied degrees of success were observed at the six mangrove replanting and restoration project sites. In Rekawa Lagoon, the new planting programme established in 2007 was unsuccessful because the natural environmental conditions were unsuitable for the seedlings used. Repeated attempts to establish seedlings failed. The salinity level was too low in Rekawa Lagoon. It is also known that restoration efforts generally fail where people live in close proximity to mangrove sites, as in this case. However, in this village, women's groups actively participate in mangrove restoration and conservation efforts. Also, they conduct community awareness and development programmes. Most people here are aware of the importance of mangrove forests and the benefits they provide.

At the Negombo Lagoon sites, the replanting of mangroves was 65–80% successful and has generated benefits for both the environment and the local community. The environmental conditions here are suitable for the growth of mangroves, and the ecological and economical values of the area have increased as a result of to these restoration efforts.

Table 1 Species and number of seedlings planted, and number of surviving plants

	Rekawa Lagoon	Madu Ganga	Negombo-Molawatta	Negombo-Kurana	Puttalam-Kalpitiya	Puttalam-Anawasala
Start year	2007	2005	2005	2007	2005	2010
Species	*Rhizophora* sp. *Bruguiera gymnorrhiza*	*Rhizophora mucronata*	*R. mucronata*	*R. mucronata*	*R. mucronata*	*R. mucronata*
No. of seedlings	15,000	10,000	100,000	25,000	150,000	10,000
Survival rate (%)	1.34	0.6	65	80	60	90

Table 2 Water quality at the six study sites

Parameter	Rekawa Lagoon	Madu Ganga	Negombo-Molawatta	Negombo-Kurana	Puttalam-Kalpitiya	Puttalam-Anawasala
Temperature (ºC)	29.24	31.65	26.9	25	29.3	30.1
DO (mg/l)	8.05	4.67	5.44	6.06	6.31	6.05
Conductivity (mc/cm)	25.32	28.51	18.79	19.39	19.29	19.12
pH	8.16	7.47	8.63	10.1	7.8	8.3
Salinity (ppm)	4.71	17.67	28.3	29.1	29.2	30.5

Table 3 Positive answers for increased ecological and economic values after replanting

	Rekawa Lagoon	Madu Ganga	Negombo-Molawatta	Negombo-Kurana	Puttalam-Kalpitiya	Puttalam-Anawasala
Increase in ecological values	4	2	14	14	16	15
Increase in economic values	4	2	14	15	16	15

Note: 20 people responded to the questionnaire.

At Puttalam Lagoon, the mangrove restoration project at Kalpitiya began in 2005 with community participation. The goal of this project is to initiate a long-term community-based conservation and management programme to increase the extent of tropical mangrove forests and local biodiversity in the lagoon. The project has been 60% successful; the mangrove plants are growing well and are now 3–4 m tall. The mangrove species selected for planting (*R. mucronata*) is well adapted to the environment and ecosystem, and this accounts for the success of the project. The ecological and economical values of the area have increased. In the Puttalam Lagoon project at Anawasala, 10,000 seedlings of *R. mucronata* were established in 2010. This effort was also successful and the plants are now about 1.5-m tall. The Puttalam Lagoon communities' awareness of mangrove forests and their benefits is at a higher level than that of the Rekawa and Madu Ganga communities.

At Madu Ganga, the replantation programme in 2005 failed; only around 60 of the 10,000 seedlings planted survive. This failure can be ascribed to the low salinity levels in the area, which not only had a direct negative effect on the mangrove seedlings, but also promoted an excessive growth of seaweed that smothered the seedlings. The Madu Ganga communities' awareness of mangrove forests and their benefits are at a lower level than that of the Rekawa, Negombo and Puttalam communities.

5. Conclusions and recommendations

The failure of mangrove restoration projects can be ascribed to:

- Inadequate monitoring of seedlings after planting.
- Poor habitat selection without adequate site assessment.
- Faulty selection of mangrove species for replanting.
- Improper planting of mangrove seedlings at a substrate depth beyond the natural range for mangroves in the area.
- Poor coordination among the institutions involved.
- Decision makers' inadequate knowledge of the ecological role of the mangroves.
- For economic reasons, mangrove planting is often limited to just one or two species.

In every area where mangrove replanting was successful, the villagers are engaged in fishery activities and their main income is from fishing. In the past, mangrove forests were destroyed to extract timber. In general, however, most villagers in the study sites are now aware of the importance of mangrove forests and the chances of successful and sustainable conservation of mangroves are higher. To enhance the success of mangrove restoration projects, it is recommended to:

- Build awareness of the importance of mangroves amongst villagers, schoolchildren, and government and NGO officials in an efficient manner.
- Improve coordination among institutions and introduce a system to share knowledge and available data.
- Conduct more research on mangrove habitats and related marine ecology.
- Facilitate small grants for community-based rehabilitation projects.
- Introduce, raise awareness of and adopt Ecological Mangrove Restoration (EMR) methods.
- Acquire knowledge of the processes essential to developing and supporting the productivity of the ecosystem as a whole, rather than its parts.
- In turn, this knowledge needs to be supported by appropriate technology and suitable legislation.

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Status of mangrove plantations in the living delta: an overview of the coastal afforestation experience of Bangladesh

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Abstract

Bangladesh is a largely deltaic country lying at the northern end of the Bay of Bengal, at the foot of the Himalayan Ganges. It slopes gently towards the sea, from an elevation of less than 1.5 m to 0.2 m above mean sea level. The country's coastal belt lies in the tropical zone between latitude 21°–23° north and longitude 89°–93° east, and is densely populated. The Bay of Bengal is particularly prone to the formation of tropical cyclones, experiencing about 10% of the tropical cyclones that form worldwide. The countries surrounding the Bay suffer most in terms of loss of life and property from cyclones, with more than 40% of the world's total deaths annually due to cyclones suffered by Bangladesh alone. A large number of cyclone casualties are caused by the associated storm surges.

To address the threat from extreme weather events, Bangladesh launched a coastal afforestation programme in 1960–1961 to create a protective belt around its coast and islands. This included mangrove planting, which began in the intertidal zone outside the coastal embankment in 1966. Bangladesh is a pioneer in coastal afforestation in terms of the scale of this programme and also its positive outcomes. In many areas, small-scale planting in unstable environments showed early success and was enthusiastically adopted by foresters. This success led to the objectives of the plantation programme being expanded beyond mitigating the effects of cyclones and storm surges.

Four types of changes – rapid accretion, sand smothering, sediment winnowing and erosion – adversely affect mangrove plantations in Bangladesh. From independence to 1992, a total area of 672.2 km^2 was eroded and 939.3 km^2 accreted, giving a net gain of 13.4 km^2 of new land every year. The mangrove afforestation programme was carried out in a very unstable environment, so there was always the risk of some plantations being lost in the time it takes for trees to reach maturity. Bangladesh foresters pioneered the field of mangrove afforestation by raising 1,773 km^2 of mangrove plantations over the past five decades along the coast and in offshore areas, mostly in the central part of the country's coastal zone. From 1961 to 2010, 23% of this plantation area was eroded and 10% encroached, but 67% survived as sustainable plantations.

Considerable variations in the level of salinity, inundation of the forest floor, rate of sedimentation and soil texture occur along the coastal belt of Bangladesh. These factors not only influence the growth of different species but also their survival. Different species also vary in their silvicultural requirements. Except for *Nypa fruticans*, the maximum mangrove species seedling time is from June to October.

With a view to using mangrove plantations as a weapon against the impact of climate-change-induced sea level rise, the value of mangroves can hardly be underestimated, especially their role in protecting coastal areas against cyclones and storm surges. Bangladesh's long, virtually barren shoreline is exposed to wind and wave action. So there is a need to build a "bioshield" of mangroves to protect coastal communities against extreme weather events.

Keywords: mangroves, afforestation, cyclones, climatic changes, Bangladesh

1. Introduction

1.1 The geography of Bangladesh's coastal zone

The coastal zone of Bangladesh is densely populated, except for extensive areas of natural mangrove forest in the Sundarbans Forest Reserve and the district of Chittagong. Most of the country's long coastline was without tree cover until regular mangrove afforestation began in 1966. Exposed to direct wind and wave action, the lives and property of the coastal population were constantly at risk. A permanent greenbelt along the coast and around islands would, it was believed, considerably reduce the losses caused by frequent cyclones and tidal surges. With this purpose in view, a massive mangrove plantation programme was launched and is still underway in Bangladesh. This mangrove planting was an innovation in conventional forestry practices, raising doubts about its feasibility in the minds of many, but it has since proved its worth.

Bangladesh is a largely deltaic country lying at the northern end of the Bay of Bengal, at the foot of the Himalayan Ganges. It slopes gently towards the sea, from an elevation of less than 1.5 m to 0.2 m above mean sea level (Ali, 1992). The country's coastal zone lies in the tropical zone between latitude 21°–23° north and longitude 89°–93° east. Its coastline extends about 710 km along the Bay of Bengal from the mouth of the Teknaf River in the south-east to the mouth of the Raimangal River in the west. The coastal zone comprises a total of 19 districts in Khulna, Barisal, Chittagong and Dhaka divisions.

The mean temperature in coastal areas ranges from 19°C in winter to 29°C in summer. Annual rainfall varies from about 3,000 mm in the west, down to 2,300 mm in the centre, and as high as 4,000 mm in the east. About 80% of total annual rainfall occurs during the monsoon in July–September. Virtually no rain falls during the dry winter months from December to February. The Bay of Bengal is particularly prone to the formation of tropical cyclones, experiencing about 10% of the tropical cyclones that form worldwide. The countries surrounding the Bay suffer most in terms of loss of life and property from cyclones, with more than 40% of the world's total deaths annually due to cyclones suffered by Bangladesh alone. A significant number of cyclone casualties are caused by the associated storm surges – in Bangladesh the proportion is about 90% (Tarafdar, 1977). Cyclones are most common before and after the monsoon period, with the greatest number in May and October.

The soils of Bangladesh's coastal zone are formed mostly from recent (Quaternary) sediments deposited by various rivers. The nutrient properties of coastal soils are more-or-less uniform along the coastline (Table 1). They have a loamy texture with a high clay content. Silt is the dominant component followed by clay and sand. The pH values range from 7.5 to 8.3, indicating slight to moderate alkalinity. There is a trend of constant pH with depth in most of the seasons. The organic carbon content of the soils is low to medium, ranging from 0.5% to 2.5%. It is higher at the soil surface and decreases gradually with depth. The action of tides and waves prevents the formation of a rich organic topsoil. Total nitrogen content ranges from 0.05% to 0.2% with a mean value of 0.09% (Khan *et al.*, 1998). Despite their comparatively low organic matter content, coastal soils are rich in mineral nutrients and are moderately fertile (Hassan, 2000).

Table 1 General characteristics of coastal soils in Bangladesh

	Western coast (Patuakhali, Bhola)	Eastern coast (Noakhali, Chittagong)	South-eastern coast (Chittagong, Cox's Bazar)
Texture [a]	Sil to Sicl	Sil to Sicl	Sil to Sicl
pH	7.5–8.1	8.0–8.3	7.5–8.0
Electrical conductivity (dSm^{-1})			
Wet season	1.5–2.5	3.0–4.5	Not available
Dry season	3.0–7.5	5.5–12.0	Not available
Salinity	Slight to Moderate	Slight to Moderate	Slight to Moderate
Organic carbon (%)	0.5–1.8	0.5–2.5	0.6–2.0
Total nitrogen (%)	0.05–0.15	0.08–0.20	0.05–0.15
Nitrogen (ppm)	65–125	60–150	50–120
Phosphorus (ppm)	15–20	15–20	10–15
Potassium (ppm)	200–300	200–250	150–250
Sulphur (ppm)	150–250	150–250	200–300

[a] Sil = Sandy loam; Sicl = Silty clay loam.

Sources: Hassan (1987); Chaudhuri and Choudhury (1994); Karim (1994); Khan *et al*. (1998).

Erosion and accretion occur continuously along the coast of Bangladesh. Permanent delta-building activity is reported to be minor, however (Jabbar, 1984). The net gain in land area between 1972 and 1991 was 268 km^2, i.e. 13 km^2 per year (see Table 2). Data on erosion and accretion in the Meghna estuary during the 220 years from 1776–1996 indicate a loss of 1,969 km^2 of land and a gain of 3,881 km^2, producing a net gain of 2,187 km^2 or about 10 km^2 per year (Anon, 1997). The rate at which new land is raised above sea level in the Ganges Delta suggests a mean increase of more than 35 km^2 per year in 1970–80 (McConchie, 1990a). Although accretion is occurring along the central coast, particularly on Bhola Island, erosion is taking place at an alarming rate on some of the inhabited islands. For example, Sandwip Island has been reduced to 250 km^2 from 650 km^2 by continuous erosion over the past 200 years. The process of sedimentation creates problems in drainage and navigation, but also helps in land building. Both erosion and accretion will remain active on a large scale along the greater part of the coast, leading inevitably to further dramatic changes and major effects on land resources.

Bangladesh has an exceptional hydrological setting. Three major rivers – the Ganges, Brahmaputra and Meghna – drain a catchment area extending across Bhutan, Nepal, India, Bangladesh and China. The total area of this drainage basin is about 1.5 million km^2, of which about 62% is in India, 18% in China, 8% in Nepal, 4% in Bhutan and 8% in Bangladesh. Ninety per cent of the water from this basin flows into the Bay of Bengal through the lower Meghna estuary in Bangladesh. This outflow is second only to that of the Amazon River system in South America. In both breadth and annual volume, the Padma River–lower Meghna River system is the third largest in the world. In its lower 100 km, the combined water flow of the Ganges, Brahmaputra and Meghna rivers is two and a half times the volume of the Mississippi River.

Delta-building activity in Bangladesh is driven mainly by sediment discharged by the Ganges, Brahmaputra and Meghna Rivers, plus many smaller rivers. Deltas are the most rapidly chang-

Table 2 Accretion and erosion in the coastal areas of Bangladesh, 1972–1991

Area	Erosion (km²)	Accretion (km²)	Loss/gain (km²)
Sundarbans	74.73	14.45	*–60.28*
Bhola area	69.63	329.49	*–259.86*
Noakhali-Chittagong	494.39	587.04	+92.65
Cox's Bazar	33.43	8.88	+24.55
Total	672.18	939.86	+267.68 (13.38/yr)

Source: BUET/BIDS (1993).

ing setting on Earth. Here, rivers deposit large volumes of sediments in the nearshore zone as their current velocity decreases. These sediments are then reworked and redistributed by wave and tide action to form bars (*chars*), mud banks or islands; or they accrete along mainland beaches. Among the factors determining the rapidity of delta formation are the rate of river discharge, volume of sediment load, currents, wave action and tidal range. This process is further complicated by the impact of high-energy episodic events such as floods, storms and cyclones, which can cause rapid and unpredictable large-scale morphological changes (McConchie, 1990a).

In Bangladesh, the discharges of the large rivers and many smaller rivers have combined to produce the largest delta on Earth. The deltaic sediments are more than 5-km deep, and extend over 100-km offshore along much of the coastline. It has been estimated that the total volume of sediments carried by the rivers flowing through Bangladesh is about 2.5 billion tons annually (Holeman, 1968). How much of this sediment is deposited on the coast is uncertain, however. In wetter years, it may increase to about two billion tons. A sediment load of 1.5 to 2.5 billion tons per year would be enough to cover about 200,000 ha to a depth of one metre, assuming it were fully deposited and stabilized. Most of the sediment is deposited beyond the continental shelf, however, and only a small portion contributes to delta-building.

1.2 History of coastal afforestation

The first experiments with mangrove afforestation began in China in the late 1950s. In Bangladesh, a coastal afforestation programme was launched in 1960–1961 to address extreme climatic events such as cyclones. Creation of a shelterbelt along the coastline was seen as the most practical and affordable way of protecting the lives and property of the coastal population against natural disasters and extreme weather events.

As already noted, cyclones and tidal surges commonly cause serious losses of life and property in Bangladesh's coastal zone. During the 1960s, the coastal zone experienced severe cyclones and tidal surges. Available cyclone records for the area begin as early as 1984, but at least eight severe cyclones hit before then in the period from 1960 to 1970 alone. The observed protective role played by natural mangroves in the Sundarbans led the Bangladesh Forest Department to try to establish mangrove plantations. Planting activities began in 1966 in the intertidal zone outside the protective coastal embankment. Limited planting in unstable environments showed promise in many areas and was enthusiastically adopted by foresters. The programme gained momentum with funding from the World Bank in 1978, and has since grown to be the largest such mangrove afforestation effort in the world. Administratively, the plantation programme is executed by four Coastal Afforestation Divisions, each division having several Range offices and Beat offices along the coastline and islands of Bangladesh.

The primary objective of establishing mangrove plantations in coastal areas was to mitigate the disastrous effects of cyclones and storm surges. The early success of the plantation programme resulted in the adoption of several additional objectives. At present, the objectives of the coastal afforestation programme are to:

- Protect the lives and property of the coastal population against cyclones and tidal surges.
- Conserve and stabilize newly accreted lands, and accelerate further accretion with the ultimate aim of transferring a large part of this land to agriculture.
- Produce timber for fuelwood and industrial use.
- Inject urgently needed resources into the national economy (i.e. timber and new land).
- Create employment opportunities for remote rural communities.
- Develop suitable habitats for wildlife, fish and other estuarine and marine fauna.

The overall objective of this paper is to describe the coastal afforestation experience of Bangladesh, focusing in particular on site suitability, survival, and the growth performance of the mangrove plantations established so far.

2. Materials and methods

This paper is based on a review of secondary information, including reports, books, journals and other relevant documents. A content analysis methodology was used to identify the outcomes and learning from the coastal afforestation carried out so far by the Forest Department. The primary selection of data sources was based on a set of keywords, including site selection, suitability, growth and survival of plants, mangrove species for plantation, history of afforestation, and so on. The author also drew on his experience as a former Chief Conservator of Forests to identify and recommend ways forward for coastal afforestation in Bangladesh.

3. Results

3.1 Site selection

The existing shrub and tree vegetation along the coastline of Bangladesh is typically scanty and scattered. Denser, naturally occurring vegetation is only found in areas with natural mangrove forests, such as the Sundarbans. As the long coastline is virtually barren and exposed to wind and wave action, a need exists to establish tree cover using artificial regeneration. However, the open nature of the coast, and the various physical processes that shape it, also pose a major challenge to establishing plantations.

Proper selection of sites is vital for ensuring successful plantations. Geomorphological changes in coastal areas can be rapid and unpredictable, making it difficult to identify suitable sites correctly. Wind action in some places can cause a shifting of soils, particularly sands. McConchie (1990a) identifies four processes affecting mangrove plantations in Bangladesh: rapid accretion, sand smothering, sediment winnowing, and erosion. Dalmacio *et al*. (1991) identify some practical considerations in site selection. Figure 1 illustrates some of these site characteristics determining suitability for planting or sowing.

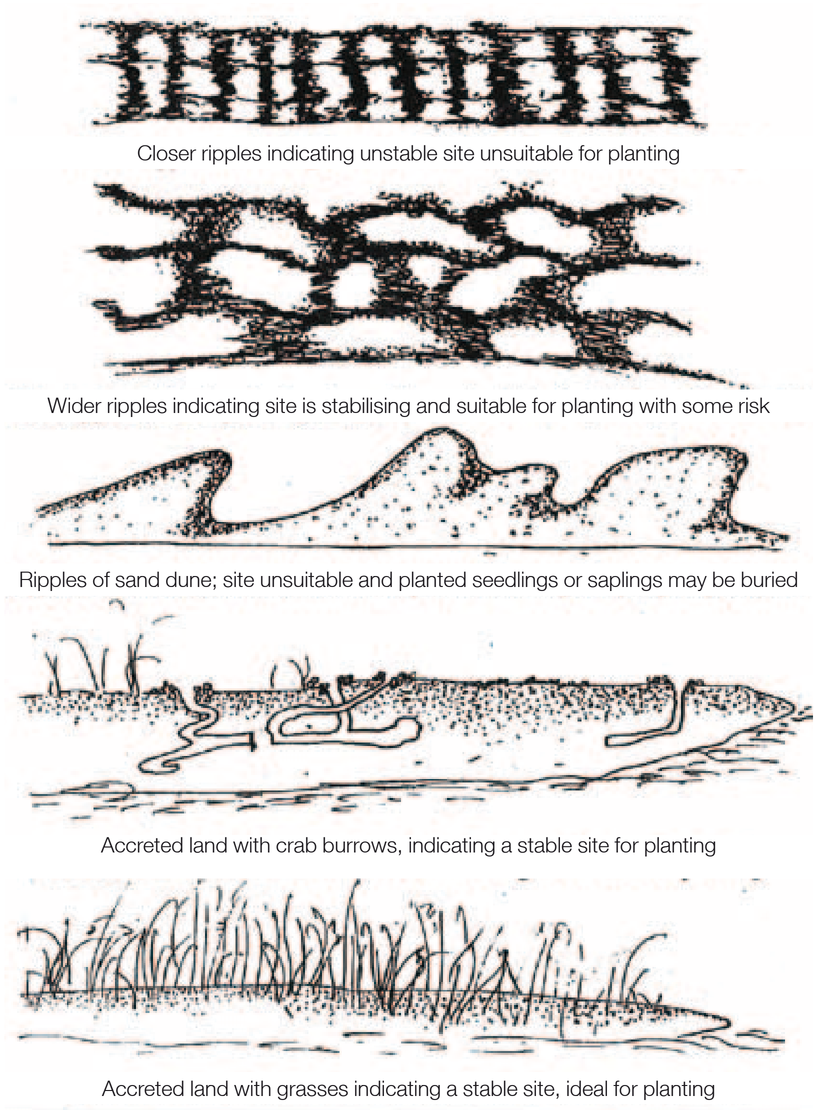

Figure 1 Different soil surface types and their suitability for mangrove planting. *Source*: Khan (1990; cited by Siddiqi, 2001).

As mangrove afforestation is carried out in unstable environments, there is always a risk that some planting will be lost during the time it takes for trees to reach maturity. The experience of field staff is a key factor in identifying suitable sites.

3.2 Survival of mangrove plants

The Bangladesh Forest Department initiated the artificial regeneration of mangrove species in the country and has pioneered the various afforestation techniques used along the coast. These have allowed Bangladesh's foresters to raise about 177,000 ha of new mangrove cover over the past five decades, mostly in the central coastal zone. Table 3 details the achievements of the planting programme up to 2010. It shows that a significant proportion of new planting has been lost to erosion and human encroachment.

Table 3 Coastal mangrove plantations, 1961–2010

Forest Department Division	Total plantation (km²)	Failed plantation (%)			Net plantation (%)
		Eroded	Encroached	Total	
Noakhali	705	21	14	35	65
Bhola	371	33	5	38	62
Patuakhali	243	9	1	10	90
Chittagong	454	25	14	39	61
Total	1,773	23	10	33	67

Source: Ahmad (2011).

3.3 Growth of mangrove plants

Considerable variations in inundation of the forest floor, rates of sedimentation and soil texture occur along the coastal zone of Bangladesh. These factors influence not only the growth of different mangrove species but also their survival. Different species also have different silvicultural requirements. Taken together, these factors mean that some species perform well and can be planted widely, whereas others do less well and have a necessarily restricted distribution. Table 4 details mangrove seeding times, and Table 5 below details the performance of various species in different locations as documented by Siddiqi and Khan (1990).

Table 4 Timing of seeding in selected mangrove species.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sonneratia apetala							■	■	■			
Sonneratia caseolaris										■		
Avicennia officinalis								■				
Avicennia alba							■	■				
Avicennia marina							■	■				
Excoecaria agallocha							■	■				
Heritiera fomes						■	■					
Xylocarpus mekongensis						■	■					
Xylocarpus granatum						■	■					
Cynometra ramiflora						■	■					
Aegiceras corniculatum							■	■				
Lumnitzera racemosa								■				
Nypa fruticans		■	■	■								
Phoenix paludosa							■	■				
Bruguiera sexangula						■	■					
Ceriops decandra						■	■					
Rhizophora mucronata							■	■	■			

Source: Siddiqi (1993).

4. Discussion

Stable ground is mostly suitable and risk-free for establishing plantations. The coastal environment is highly unstable, however. Unpredictable and often rapid geomorphological changes affect coastal plantations in various ways. Even established plantations may be eroded away or buried by heavy sediment deposition or sand dune movement (McConchie, 1990a, 1990b). Thus geomorphological changes play a major role in the success or failure of a plantation.

Table 5 Growth performance of mangrove species along the coast of Bangladesh

Species	Location	Age (yr)	Mean ht (m)	MAI of ht (m)	Mean dbh (cm)	MAI of dbh (cm)
Sonneratia apetala	Patherghata	11	12.00	1.09	12.99	1.18
	Char Kashem 3	10	10.50	1.05	11.88	1.19
	Char Kurki 4	11	12.71	1.05	12.74	1.16
	Char Osman 6	11	10.65	1.16	11.38	1.03
	Bogachatter 7	13	8.34	0.96	10.08	0.78
	Hali Shahar 9	11	9.47	0.64	13.57	1.23
Sonneratia caseolaris	Galachipa 3	11	10.76	0.86	21.11	1.92
	Char Islam 4	9	5.60	0.97	15.31	1.70
Avicennia officinalis	Char Kashem 3	12	6.89	0.62	12.22	0.94
	Char Kurki 4	13	8.42	0.53	16.09	1.24
	Char Osman 6	14	9.30	0.65	14.99	1.07
	Bogachatter 7	11	5.30	0.66	10.59	0.96
	Bandar 8	13	4.41	0.48	8.82	0.68
	Hali Shahar 9	9	3.70	0.34	4.16	0.46
Avicennia marina	Bogachatter 7	11	5.82	0.41	13.21	1.12
	Hali Shahar 9	9	3.21	0.53	4.02	0.45
	Grokghata 10	10	5.23	0.36	7.79	0.77
Avicennia alba	Bandar 8	13	4.16	0.52	5.56	0.80
	Grokghata 10	10	4.67	0.32	6.68	0.67
Bruguiera sexangula	Char Hare 2	10	2.25	0.47	1.31	0.13
	Char Kashem 3	12	2.76	0.23	2.82	0.24
	Char Kurki 4	13	4.07	0.23	5.38	0.45
	Dhal Char 5	11	4.19	0.31	4.50	0.41
	Char Osman 6	10	3.54	0.38	3.12	0.31
	Bogachatter 7	12	1.76	0.35	0.70	0.06
	Bandar 8	13	2.89	0.22	1.93	0.15
	Hali Shahar 9	10	1.42	0.14	0.78	0.08
	Char Kurki 4	12	7.40	0.62	11.14	0.93
	Dhal Char 5	11	7.67	0.70	9.70	0.88
	Char Osman 6	14	7.32	0.52	9.62	0.50
	Bogachatter 7	14	3.77	0.27	7.00	0.50
Ceriops decandra	Dhal Char 5	9	1.23	0.13	–	–
	Bogachatter 7	12	1.38	0.11	–	–
	Bandar 8	12	1.41	0.12	–	–
Xylocarpus mekongensis	Char Kashem 3	11	3.75	0.34	3.32	0.30

Note: ht = height; dbh = diameter at breast height; MAI = mean annual increment.
Source: Adapted from Siddiqi and Khan (1990).

An optimum rate of silt deposition is likely to stimulate the growth of planted mangrove trees (Imam, 1984). Maximum rates of plant growth have been noted on sites with 20–25 cm of silt deposition (Ahmad, 2011) during the dry season. The rate of silt deposition along the coastline is not uniform, however. In several plantation areas, the rate is so high that the planted seedlings or established saplings are partially or completely buried. Older plantations may survive heavy deposition, but young plantations are highly susceptible to excessive silt deposition.

In some localities, accretion rates of up to one metre a year have been observed. Howlader (1999) reports silt deposition of up to three metres in only 9–10 months at some sites. As accretion progresses, however, the shoreline shifts and tidal waters approach plantation sites more slowly and gently, gradually bringing smaller amounts of silt.

In many cases, the afforestation efforts of the Forest Department have been thwarted by the encroachment of settlers seeking new land after losing their old lands to erosion. Creative solutions have to be found to balance, on one hand, the need for stabilisation and water and soil conservation on newly formed lands, with, on the other, the need to settle what may be termed environmental "refugees". An improved land management system is needed for the period between the emergence of the land and its handing over to the Forest Department, and the subsequent transfer of the land to the Ministry of Land.

A key feature of such a management system would be the application of social forestry principles to the planting and conserving of mangrove forests. If people can be persuaded that mangroves are important for their future livelihoods because they help to stabilise new land, and at the same time have value for their present livelihoods (through a stream of income from benefit-sharing arrangements), illegal encroachment could be reduced or even stopped altogether. At the same time, alternative means of livelihoods could be developed to reduce the pressure on mangroves.

Expanding the area of mangrove plantations is a prime weapon against the predicted impacts of climate change, including accelerated sea level rises and an increase in the peak intensity of tropical cyclones by up to 5–10%, which together will lead to enhanced storm surges and coastal flooding. As the climate changes, cyclones may penetrate further inland and cyclone High Risk Areas (HRAs) are likely to increase in size. Currently, about 8.3 million people live in HRAs in Bangladesh. This could increase to 15 million by the 2020s and over 20 million by the 2050s, driven by the combined effect of population growth and the expansion of HRAs (Ahmad, 2011).

Given the importance of afforestation in coping with the effects of climate change, it is essential that knowledge and information are widely distributed to the coastal population, as well as to Forest Department staff and concerned NGOs. Large-scale campaigns and training programmes should be developed, focusing on the role that forests can play in strategies to address climate change. Officials working on social forestry can play a crucial role in the efforts to reach and involve coastal communities. Transfers of Forest Department staff from coastal to other areas, and the flux of new staff in coastal areas, make it essential to provide flexible training opportunities. Staff newly posted to the coastal zone should receive training on topics and skills tailored to coastal issues and conditions. At the same time, coastal personnel require frequent refresher courses in new knowledge and technologies.

Erosion in coastal areas leaves many people homeless, forcing them to move elsewhere to find land and livelihoods. The raised lands formed by sedimentation in mangrove plantation areas are an attractive target for these environmental refugees. To date, little consideration has been given to sustainable land management because of the pressures of human encroachment and agricultural practices. Technically in breach of the law, but driven by need, settlers do not stop to consider that protecting the plantations will enhance their safety against future natural disasters. So illegal encroachment continues, with over 600 ha of plantations affected in Noakhali Coastal Afforestation Division alone in recent years (Canonizado, 1999).

Newly accreted lands gradually become unsuitable for mangroves, requiring replanting with other tree species to stabilise them fully for protective purposes. At this point a compromise is needed between the coastal forestry practices of the Forest Department and the genuine need for cultivable land among the landless. This land can be used for crops such as rice, pulses and vegetables, although its productivity is low. Given the opportunity, however, people seem to be willing to raise tree crops in addition to agricultural ones if they receive support and a fair share of the benefits. Nandy and Paul (2001) suggest that such lands could be effectively managed through partnerships between settlers and the Forest Department. They believe that providing rights to land in some form, and the necessary support, would encourage settlers to take responsibility for ensuring the sustainability of newly accreted areas.

Although participatory forestry appears to be a strong alternative, it should be used with caution in coastal lands. The reclaimed land cannot be allowed to disappear or be degraded at any cost. There may be influential persons behind the landless people using them to grab government land. The primary objective of the mangrove afforestation programme, that is, to maintain a protective wall against cyclones and tidal surges, must be ensured. Long-term studies should be undertaken to formulate a pragmatic model of participatory forest management appropriate to raised coastal lands.

As an extension to the coastal afforestation programme, the government of Bangladesh is implementing a project to reduce the vulnerability of communities in five coastal districts most susceptible to the effects of climate change. In partnership with the United Nations Development Programme (UNDP), the government is working to enhance community resilience and introduce new options for income generation. The project has adopted a successful community-based adaptation intervention known as the “Forest, Fish and Fruit” (FFF) model (see Nandy and Ahammad, this publication). This model adds a new dimension to the programme by creating additional sources of income and establishing a “green shield” surrounding some of Bangladesh’s most vulnerable communities (UNDP, 2011).

5. Conclusions and recommendations

Coastal afforestation can protect vulnerable coastal communities from tropical cyclones and storm surges by reducing the risk of casualties, loss of property and environmental damage. The experience of past climate-induced disasters, including cyclones Sidr, Nargis and Aila, has shown that resilience to cyclones and storm surges is greater where mangrove greenbelts, coastal forests and other buffer ecosystems exist. Mangroves can mitigate or reduce the impacts of these natural disasters.

Bangladesh’s coastal afforestation programme comprises a number of stages that could involve communities, group farmers and contractual farmers. These include seed collection, site selection, preparation of the nursery bed, seed sowing, and nursery maintenance for at least six months.

Highly endangered coastal habitats are effective in sequestering carbon and locking it away in soils. Habitats such as mangroves, seagrass beds and salt marshes sequester as much as 50 times more carbon in their soil per hectare than tropical forests (Pidgeon, 2009).

Coastal forests also have a huge potential for satisfying a land-hungry country like Bangladesh. Coastal afforestation accelerates the process of land stabilization, and by creating new forest resources it enriches biodiversity and natural resources. People living in the coastal zone have been adapting to a dynamically changing environment for centuries. Climate change poses an additional challenge as the changes are likely to be substantial and will happen over a relatively short period of time. The exact implications of climate change for Bangladesh are still unclear. Yet, despite this uncertainty, policies must be developed and implemented on a delta-wide basis to prepare the country for any future changes.

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Mangrove conservation and restoration in the Indian Sundarbans

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[2] IUCN Large Grant project, Sundarban Biosphere Reserve, West Bengal, India

Abstract

The Sundarbans, the largest single block of mangrove forest in the world, is shared between India (about 37%) and Bangladesh (about 63%). The Indian part of the Sundarbans covers 9,630 km² between latitude 21°13' and 22°40' north, and longitude 88°03' and 89°07' east. Of this, 4,200 km² is exclusively mangrove forest with a high faunal and floral diversity. The Indian Sundarbans has been declared a World Heritage Site and a Biosphere Reserve by UNESCO. It also has a pioneer Tiger Reserve and includes one National Park and three Wildlife Sanctuaries.

The Sundarbans area experienced a neotectonic shift sometime in the 16th century resulting in unequal flow of fresh water, with a greater share of water flowing to its eastern part (currently in Bangladesh). This has greatly influenced mangrove distribution and growth. Human influence in the Sundarbans began when the British East India Company started regular reclamation of swamps by clearing of large tracts of mangroves to earn revenue, and the first regular settlements were established from 1830 onwards. Currently, over 4.2 million people live on the fringes of the Indian Sundarbans, resulting in high anthropogenic pressures on the mangroves and their resources. In recent years, climate change, regulation of freshwater flow, illicit mangrove felling, poaching and unplanned embankments for settlements have emerged as the main threats to the ecosystem. The central part of the Indian Sundarbans receives almost no fresh water because of heavy siltation and clogging of the Bidyadhari channel. Seawater intrusion has further affected the growth of dominant mangrove species such as the freshwater-loving *Heritiera fomes*. The influence of salinity and effects of climate change, though not well-understood, appear to be promoting the invasion of alien species in some parts of the Sundarbans. Human pressures and ecosystem changes are combining to threaten the population of endangered Royal Bengal tigers (*Panthera tigris tigris*), one of the iconic species of the Sundarbans.

Current efforts to restore cleared or degraded mangroves in the Sundarbans include the large-scale mangrove afforestation programme conducted by the West Bengal State Forest Department on mudflats, degraded areas and embankments. The Forest Department has also initiated efforts to improve relations with local communities by forming Joint Forest Management Committees (JFMCs), which include Forest Protection Committees and Eco-development Committees.

Keywords: mangroves, restoration, nature conservation, deltas, Sundarbans, India

1. Introduction

Mangrove forests are one of the most productive and taxonomically diverse wetlands on Earth. They consist of a diverse group of salt-tolerant, mainly arboreal, flowering plants that grow primarily in tropical and subtropical regions (Ellison and Stoddart, 1991). Estimates of mangrove area vary from several million ha to 15 million ha worldwide (FAO/UNEP, 1981). A recent estimate puts the total area at about 14,653,000 ha (Wilkie and Fortuna, 2003).

Mangroves are marine tidal forests which thrive around the mouths of large rivers and in sheltered bays in tropical countries where annual rainfall is fairly high. Mangrove plants include trees, shrubs, ferns and palms. These plants are found on riverbanks and along coastlines, being unusually adapted to anaerobic conditions in both seawater and freshwater environments. They produce pneumatophores, or respiratory roots, which project above the mud and water to absorb oxygen. Mangrove ecosystems act as a buffer zone between the land and sea, protecting the coast against erosion by wind, waves and water currents. They help to stabilize banks and coastlines and provide habitats for many types of animals.

The Sundarbans ecosystem is the world's largest mangrove forest, spread across India and Bangladesh on the Bay of Bengal. The entire area is covered by a complex network of streams, rivers, tidal creeks and channels, bringing fresh water from the perennial rivers and seawater to create a dynamic and biodiverse ecosystem – home to about 70% of all species of mangroves in the world (Chaffey *et al*., 1985). A total of 84 species of flora have been recorded in the mangrove forests of the Indian Sundarbans, 34 of which are true mangroves.

Human settlements in the Sundarbans, and the lives and livelihoods of their inhabitants, are integrated into this dynamic ecosystem. In many parts of the world, however, mangrove deforestation contributes to declining fisheries, degradation of clean water supplies, salinization of coastal soils, erosion and land subsidence, as well as the release of carbon dioxide into the atmosphere. Recently, the phenomenon of climate change has generated interest in understanding the carbon cycle of mangrove forests. These and other factors have made the conservation and restoration of mangroves a high priority.

The biodiversity, ecology and conservation issues affecting the Sundarbans both in India and Bangladesh have been discussed in several publications (Das and Siddiqi, 1985; Mitra *et al*., 2004; Gopal and Chauhan, 2006). In this paper, the current management practices in mangrove conservation and restoration in the Sundarbans are described, and the results from stakeholder interviews and analyses are presented.

2. The Indian Sundarbans

The Indian Sundarbans deltaic complex has been formed by alluvial deposits carried down by several major river systems. The main source is the Ganges River, specifically its distributary the Hooghly River. Geologically, the Sundarbans is of comparatively recent origin (Chaudhuri and Choudhury, 1994). Until a few thousand years ago, the whole area was under the sea. The deposition of debris and formation of the Sundarbans delta occurred recently with the change of the main course of the River Ganges from the Bhagirathi to Padma towards the east between the 12th and 15th centuries AD. This was the result of a neotectonic movement in the Bengal basin which gave it an easterly tilt. During the 16th century, the flow of the Ganges shifted almost entirely eastwards into Padma River (now in Bangladesh), and the Matla/Bidyadhari rivers, which had formed a network of creeks in the delta, were completely cut off from their freshwater sources.

According to Naskar and Mandal (1999), there are 40 species of major mangroves, 32 species of minor mangroves, and 30 species of back mangroves and associates. These are grouped into 39 families, 60 genera and 83 species. Among the important mangrove families are the Rhizophoraceae, Avicenniaceae, Meliaceae, Sonneratiaceae, Sterculiaceae and

Myrsinaceae. The mangrove forest is a dynamic ecosystem in a continuous state of erosion and accretion, leading to subsidence or erosion of existing banks and the appearance of new lands and mudflats. Mangrove succession starts with the appearance of the pioneer wild rice species *Porteresia coarctata*, known locally as *dhani ghas*, on newly accreted mudflats. With the passage of time, this species traps propagules of *Avicennia* and *Sonneratia* spp. which grow well on firm, freshly silted mudflats. Once the land is consolidated, goran (*Ceriops* spp.) and genwa (*Excoecaria agallocha*) colonise the area. The date palm or hental (*Phoenix paludosa*) is the climax species which develops on high land where it grows gregariously.

Not all parts of the Sundarbans are vegetated. There are some saline blanks which have been identified with the help of satellite images. These are high lands where water does not reach even during full tides. The extent of such blanks is very limited, however. They are generally devoid of any vegetation, although some show signs of primary succession and others support either scrubby growth of *Ceriops decandra* or scanty growth of *E. agallocha* and *P. paludosa*.

3. Anthropogenic pressures in the Indian Sundarbans

The Sundarbans is being subjected to various anthropogenic and natural processes affecting the distribution, quality and diversity of its mangroves. A census in 2000 found the total population of the area to be over 4.2 million, most living in extreme poverty. People inhabit the reclaimed area of the Sundarbans, where the water is saline and unsuitable for human or agricultural use. The ground (potable) water is found at depths of 300–400 m and its exploitation is costly. Exposure to storms and cyclones, which generally occur in the pre-monsoon period, further increases the vulnerability of poor village communities.

The Sundarbans has extremely poor infrastructure, so travel from one village to another is usually by small boat. This inaccessibility acts as a serious constraint to the development of the region. Because of a lack of irrigation, farmers cannot grow more than a single crop during the year. During the lean periods, people make their living by fishing and also by collecting firewood, honey and beeswax from the forest. The Royal Bengal tiger (*Panthera tigris tigris*) may confront people when they foray into the forest, resulting in injury and even death. Anthropogenic pressure on the ecosystem, especially the reclamation of land for agriculture, led to the extinction of swamp deer (*Cervus devaucelli*), hog deer (*Axis porcinus*) and barking deer (*Muntiacus muntjak*) by the end of the 19th century. The Javan rhino (*Rhinoceros sondaicus*) and the wild buffalo (*Bubalus bubalis*) have also become extinct from the region.

The Sundarbans differs from many other forests in the world in its highly inaccessible terrain, with islands criss-crossed by creeks and inundated twice daily at high tide. The islands in the Sundarbans are also dangerous due to the presence of the Royal Bengal tiger, which is known for its propensity to treat any humans on the islands as its natural prey. The behaviour of the tiger is also unique because of its almost amphibious nature and the fact that it preys on people within the confines of the forest, but wisely does not harm humans in the villages if it strays there.

Consultations with stakeholders (local communities, researchers and NGOs) to identify important anthropogenic factors influencing the ecosystem have revealed that human-wildlife conflict is considered the biggest threat, followed by climate change, salinity changes, shrimp seed collection by local people, other livelihood pressures on natural resources, and pollution (Table 1). Any threat to the Sundarbans is also a threat to the mangroves. The rise in human-wildlife conflicts may result in a hostile attitude among local communities towards the mangrove ecosystem, leading to its degradation beyond restoration limits. Climate change and its associated sea level rise affects the erosion pattern of coastal mangrove islands in the Sundarbans. Salinity is affected by climate change and the availability of fresh water from upstream river sources, which in turn affect the growth, distribution and diversity of mangroves. A lack of employment has led to the large-scale involvement of local people, especially women and children, in collecting tiger shrimp (*Penaeus monodon*) seed for shrimp farms. This practice adversely affects the regeneration of mangroves on riverbanks as the dragnets used for collection destroy regenerating mangroves. Collection also adversely affects the aquatic biodiversity of the Sundarbans and creates many socio-economic problems.

Table 1 Results of a survey to identify factors considered threats by local communities, NGOs, forest officials and researchers

Factor	Threat (%)
Human-wildlife conflict	24.4
Climate change	19.9
Salinity change	18.8
Shrimp seed collection	11.5
Pressure of natural resources	16.6
Environment and water pollution	8.8

Source: Vyas (2012).

The stakeholder consultation further revealed that 98% of people believe that tigers protect the Sundarbans, otherwise the mangroves would have been cleared for the want of land in this densely populated landscape. Local communities also believe (97% of respondents) that mangroves protect them from tropical cyclones. This has great significance, especially after Cyclone Aila in 1999, which caused massive damage to the area (Mitra *et al*., 2011). All respondents believe that the Sundarbans is important to protecting livelihoods and villages; this indicates a high level of awareness among local communities and is a positive indicator for the future security of the Sundarbans. However, the survey also indicated how serious the livelihood pressures are on the mangroves, as tigers have killed more fishers entering the Sundarbans without a boat licence certificate than the authorised number of certificate holders (Vyas, pers. comm.).

4. Restoration and afforestation programmes

The Sundarban Biosphere Reserve (SBR) has developed a two-pronged strategy for conserving and restoring mangroves in the Indian Sundarbans: a) preventative management to ensure that degradation is minimized; and b) ameliorative management to restore degraded mangroves and bring newly accreted mudflats under mangrove cover before they are encroached. Many mangrove nurseries have been established in different part of the Sundarbans to provide high-quality propagules for planting. An independent monitoring mechanism has also been established to assess the success of the afforestation programmes.

Since the declaration of the SBR in 1989, a total of 17,000 ha of mangrove plantations has been established on mudflats, in degraded mangrove forests, and on river embankments (Table 2).

Table 2 Mangrove plantations established in the Sundarban Biosphere Reserve since 1989

Year	Total area (ha)	Average survival (%) of 1-year-old plantation [a]	Average survival (%) [b]
1989	655	79	66
1990	350	85	71
1991	775	75	75
1992	882	80	81
1993	865	83	58
1994	948	78	73
1995	493	84	76
1996	530	86	–
1997	612	83	76
1998	930	73	96
1999	960	93	94
2000	1,020	91	–
2001	1,146	92	–
2002	770	68	–
2003	750	68	–
2004	830	81	–
2005	760	83	–
2006	800	86	–
2007	800	90	–
2008	400	–	–
2009	500	89	–
2010	1,220	92	–
2011	265	–	–
Total	17,288	–	–

Sources: [a] Monitoring Wing, Forest Department, Government of West Bengal. Monitoring of 1-year-old plantations.
[b] Review report on plantation programme (1989–2000), State Level Steering Committee on Sundarbans mangroves and Sundarban Biosphere Reserve; survey in 2001.

The planting technique involves cutting trenches at 4-m intervals along the river line and digging pits (30 cm x 30 cm x 30 cm) between the trenches in August–September. Dibbling of 2,500 seeds is done at a spacing of 4 m x 1 m, and afterwards 2,500 propagules are planted at a spacing of 4 m x 1 m. The species planted are mainly *Xylocarpus granatum* (dhundul), *Sonneratia apetala* (keora) and *Heritiera minor* (sundari) as potted seedlings; and *Rhizophora apiculata* (garjan), *Bruguiera gymnorrhiza* (kankra) and *Nypa fruticans* (golpata) as propagules. Seeds of *Avicennia* spp. (baen), *E. agallocha* and *Ceriops* spp. are mainly dibbled in the trenches after they are filled with loose mud by tidal waters. During the first year of the plantations, guards are engaged to protect the sites from prawn seed collectors, whose drag-nets often uproot the seedlings. The guards also help to fill in trenches damaged by wave action. From the second year onwards, guards are engaged to protect the plantation from illicit tree felling and other damage. Mangrove plantations are not maintained after the first two years.

This afforestation programme is monitored by the independent monitoring wing of the government of West Bengal's Forest Directorate every year. In addition, the GIS cell of the Forest Department also monitors changes in mudflats and erosion patterns.

Although there exist saline blanks in various parts of the Sundarbans, no efforts have been made to bring these degraded mangrove areas under restoration. This is because such a programme would involve risks to human life from the presence of tigers in these forests. It has also been observed that these small openings of salt-rich degraded mangroves create an edge effect, and provide habitat for certain wildlife species.

Commercial exploitation of mangroves in the Indian Sundarbans, known as coupe operation, was stopped in 2001. Before this date, 1,000 ha were commercially exploited every year, after which the felled areas were left to regenerate naturally. This practice was stopped as it was observed that, owing to poor implementation of the felling rules, some restricted mangrove species such as *X. granatum*, *S. apetala*, *H. minor*, *R. apiculata*, *B. gymnorrhiza* and *N. fruticans* were being rapidly depleted. The normal supervision of the coupe operation was not possible in the Indian Sundarbans owing to the threat from tigers. Between 1985 and 2001, tigers reportedly killed 24 people during coupe operations and injured many others. Hence they were always treated as a barrier to commercial mangrove felling operations in the Sundarbans (Curtis, 1933).

The SBR's two-pronged protective management strategy is achieved by intensive patrolling, especially along international borders. A total of over 20 permanent and temporary camps equipped with boats, radio transmitters and firearms have been set up in the Indian Sundarbans to protect its mangroves.

No ecosystem can be conserved without the active involvement of local communities and sharing benefits with them. A large section of the surrounding population depends on the natural resources of the Sundarbans for its livelihood, mainly fishing and honey collection. These people used to be in regular conflict with the law enforcement authorities. The strained relationship between the Forest Department and local communities has seen large-scale poaching of mangroves and wildlife, and retaliatory killing of tigers and other wildlife that stray out of the forest into villages. In 1996, the SBR initiated a Joint Forest Management (JFM) programme to involve the local communities in management. To date, 65 Joint Forest Management Committees (JFMCs, also known as Forest Protection or Eco-development Committees) have been formed with over 35,000 members protecting 64,000 ha of forest. The local communities are entitled to collect non-timber forest products freely and to a 25% share of the revenues from ecotourism. A large scale eco-development programme has been launched in the SBR to support alternative livelihood activities for poor mangrove resource users. These include establishing self-help groups for various income-generating activities, rainwater harvesting for irrigation and drinking, installation of solar lights, and construction of village roads, jetties and deep tube wells.

The impact of the JFM programme has been well-documented. Since 2001, no tiger or other wildlife has been killed in retaliation by local people. In fact, over 40 tigers and 500 other endangered animals have been rescued by villagers in the past decade (Table 3). The illicit felling of mangroves has fallen sharply, thus helping to prevent degradation. Recently, the SBR began implementation of an MFF Large Grant project entitled "Alternative livelihood options for vulnerable mangrove resource users in Sundarban Biosphere Reserve, West Bengal". This project is expected to study various aspects of alternative livelihoods issues in the Sundarbans from different stakeholders' perspectives.

Table 3 Stray tigers rescued with people's cooperation in Sundarban Biosphere Reserve, 2002–2010

	2002–03	2003–04	2004–05	2005–06	2006–07	2007–08	2008–09	2009–10
No. of tigers rescued	11	4	4	1	1	2	3	14

Source: Forest Department, Government of West Bengal.

5. Conclusions

The Sundarbans is a dynamic ecosystem. Newly accreted mudflats are a common phenomenon requiring afforestation. Because of hostile weather conditions and tidal erosion, large areas need a greenbelt of protective mangroves – in total, 3,500 km of embankments with villages need to be protected against tidal erosion. As a result of changes in salinity and reduced freshwater inflows in the Indian Sundarbans, a number of species are becoming locally extinct (Banerjee *et al*., 2010). These include the Sundari tree (*Heritiera fomes*), from which the Sundarbans derives its name. The West Bengal Forest Department is undertaking an extensive mangrove conservation and restoration programme in the Sundarbans, including mangrove plantation and nursery maintenance. Non-mangrove plants are also grown to meet local needs and so reduce human pressure on mangroves. Since the establishment of the SBR, over 17,000 ha of mangrove forests have been successfully grown and maintained. These measures are helping to stabilise mudflats, restore the mangrove ecosystem, and conserve threatened species.

The Sundarbans supports the world's single largest population of tigers, which have adapted to an almost amphibious life, swimming long distances and feeding on fishes, crabs and monitor lizards. The soils of the Sundarbans are constantly being changed, moulded and shaped by the action of the tides. The Sundarbans play a major role as nursery for a diversity of marine organisms and as a buffer against cyclones which are a unique and natural process. The mangroves in the Sundarbans are not only dominant as fringing mangroves along the creeks and backwaters, but also grow along the sides of rivers in muddy as well as in flat sandy areas (UNESCO, n.d.).

An average of 45 people were killed annually by tigers between 1975 and 1982. This has caused certain conflicts with local people who use the adjacent Tiger Reserve for collection of honey and firewood and for fishing. The legal protection provided to the Sundarbans on the Indian side is adequate. The Indian Forest Act 1927, with its amendments, Forest Conservation Act 1980, Wildlife Protection Act 1972, and Environment Protection Act 1986, are being implemented effectively, with rules and regulation regarding environmental pollution strictly enforced. The existing laws are sufficiently strict in respect of the protection and conservation of the Sundarbans on the Indian side (UNESCO, n.d.).

With the existing infrastructure, the Forest Department is making its best efforts, although there is a need to maintain and enhance the level of financial and human resources to effectively manage the Sundarbans. This includes an ecosystem approach that integrates the management of the existing protected areas with other key activities occurring in the Sundarbans, including fisheries and tourism. There is a need to develop alternate livelihood options for the local population to eliminate the dependence of people on the Sundarbans ecosystem for sustenance. Maintenance of participatory approaches in planning and management of the Sundarbans is needed to reinforce the support and commitment from local communities and NGOs to the conservation and management of the Sundarbans. Research and monitoring activities also require adequate resources (UNESCO, n.d.).

Due to emerging challenges such as increasing salinity, the impact of climate change and population growth, there is a need for high-quality, management-oriented research and supplementary livelihood programmes to address the needs of local communities. Dealing with the issue of alien invasive species needs to be prioritised before it becomes a serious threat. Developing synergy among various stakeholders may be an effective strategy to address the conservation and restoration issues of mangroves in the Indian Sundarbans (UNESCO, n.d.).

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Session II

Lessons Learned from Mangrove Rehabilitation Projects

Lessons learned from the programme *Let's Plant Mangroves*: a case study from villages in Banten and Central Java provinces, Indonesia

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Abstract

Degradation of the mangrove ecosystem in the northern coastal area of Central Java is very serious, more than 70% of the mangroves are in a severely damaged condition, or around 4,826 ha out of a total mangrove area of around 6,798 ha according to statistics of the Ministry of Marine Affairs and Fisheries (MMAF) in 2011. This condition has been caused by land use conversion, cutting of mangrove trees for milkfish and shrimp ponds, industrialization, oil pollution, and charcoal production. Degradation of mangroves can cause coastal erosion, seawater intrusion, and land subsidence. As one of the efforts to restore mangroves which have been degraded, the Directorate of Coastal and Ocean Affairs of MMAF developed a programme for mangrove rehabilitation called *Let's Plant Mangroves*. This programme has been implemented since 2009 and 420,000 mangrove seedlings have been planted covering an area of 42 ha (in seven villages in four provinces).

Besides replanting mangroves, there were other activities like environmental education, a student competition, training in alternative income generation and mangrove rehabilitation, integrated coastal management training, and a campaign on environmental awareness. A lot of benefits accrued to the local communities, and after two years of implementing the programme there were positive impacts from recovery of the mangrove ecosystem. They have practiced how to develop a seedling nursery to supply mangrove seedling needs for other programmes in different locations. By this activity, local community groups received some supplementary income. Members of the groups are increasing every year. A housewives' group applied what they learned from the training and they can produce different mangrove products and milkfish post-harvest processing. The younger generation is more aware of environmental rehabilitation; it is important to create this awareness at an early stage, so they can give advice to their parents and become involved in protecting the environment.

The methodology used in this study included: i) analysis of data, interviewing to local community and local government; ii) monitoring, learning and evaluation (MLE) regarding relevance and quality of design, efficiency and effectiveness of implementation to date, livelihoods and future impact, potential for sustainability, weaknesses, and summary of key observations and recommendations; iii) writing of lessons learned; and iv) suggestions for replication of the programme. The information sources used were demographic data, livelihood and income data before and after the programme was implemented, a questionnaire, and MLE documents.

Based on evaluation of case studies in three villages, two of them, namely Depok village and Mangunharjo village, were considered successful in bringing benefits to the local communities. They were able to increase their income from processing mangrove products and post-harvest processing, develop a nursery for mangrove seedlings and establish an environmental inspection group. In addition, after the mangrove seedlings grow up, nursery grounds can be recovered and the coastline can be protected from wave attack. The results in Tanjung Pasir village were less successful, with many seedlings dying. These failures and successes should both be used as lessons to help replicate the programme in other locations. For example, soil type and hydrological conditions must be considered when planting mangroves.

Keywords: mangroves, environmental degradation, restoration, evaluation, Indonesia

1. Introduction

1.1 Background to the problem

Java is the principal island of Indonesia's five main islands (Sumatera, Java, Kalimantan, Sulawesi and Papua). The north coast of Java is divided into five provinces: Banten, Jakarta, West Java, Central Java, and East Java. The northern coastal areas of Java are generally in a degraded condition. Coastal erosion, land-use changes and the loss and degradation of mangroves have all contributed to declining environmental quality. More than 70% of the mangrove forests in this area are severely damaged: of the total mangrove cover of 6,798 ha, about 4,826 ha are degraded (Directorate of Coastal and Ocean Affairs, 2011a, 2011b, 2011c, 2011d). The reasons for this include land conversion, cutting of mangrove trees for milkfish and shrimp ponds, industrialization, oil pollution and charcoal production. Degradation of the mangroves has led in turn to coastal erosion, seawater intrusion and land subsidence.

The length of the coastline in Central Java Province is 493 km. Degradation of the coastline is severe. Coastal erosion has reached around 6,567 ha in 13 regencies (Directorate of Coastal and Ocean Affairs, 2011e). This condition is threatening the lives of local people and some villages have been evacuated because of the coastal erosion; for example Bedono village in Demak and Tanggul Tlare village in Jepara.

Responding to this situation, the Directorate of Coastal and Marine Affairs has since 2009 implemented a programme called *Let's Plant Mangroves*. Some 420,000 mangrove seedlings have been planted across 42 ha in seven villages in four provinces. This programme is intended not only to rehabilitate mangroves, but also to raise awareness about the importance of preserving and caring for mangrove ecosystems.

In fiscal year 2010, programme activities were implemented in Tanjung Pasir village (Banten Province) and Depok village (Central Java Province), and in Mangunharjo village in Semarang City in 2011. In Tanjung Pasir village, 40,000 mangrove seedlings were planted; in Depok 60,000; and in Mangunharjo 40,000.

The aims of the *Let's Plant Mangroves* programme include: i) long-term recovery of the coastal area through replanting of mangroves; ii) raising the awareness of all levels of society about the importance of mangrove ecosystems; iii) encouraging communities to participate in efforts to improve the coastal environment through their own mangrove planting; iv) increasing public participation in the rehabilitation of mangrove ecosystems to create a coastal greenbelt; and v) giving support and imparting skills to local communities through the introduction of potential income-generating initiatives.

Public awareness of the importance of the mangrove ecosystem is still low, and for that reason people still think it would be more profitable economically to replace mangrove forests with pond-based aquaculture. The real challenge today is changes in land use from mangrove habitat to aquaculture or fishponds. This phenomenon has caused the carrying capacity of the mangrove areas to decline, reducing their ability to protect coastal areas from environmental stresses such as coastal erosion and seawater intrusion. To increase environmental awareness among the local community, environmental education is needed, especially during children's early school years, to provide a complete understanding of the importance of environmental sustainability. Basic education can provide theory in the classroom and also engage students in field activities to preserve the environment through local action. The *Let's Plant Mangroves* programme provides a direct example to students of real and immediate action that can be taken to rehabilitate damaged mangrove ecosystems.

The present study was conducted to observe the effectiveness of the program's implementation to date, and to assess its shortcomings. The results are expected to provide valuable inputs and lessons for the future implementation of this programme in other locations.

1.2 Problem statement

The main problem identified is mangrove degradation in the coastal area of the three villages in the study. It was hypothesized that the causes of this problem are largely: i) land use conversion and cutting of mangroves; ii) low of awareness within the local community about the mangrove ecosystem and coastal environment; iii) low sustainability of action in protecting the mangrove ecosystem; and iv) low household incomes.

1.3 Objective

The objective and outputs of the *Let's Plant Mangroves* programme are that an effective coastal environmental co-management regime is established through: i) empowered coastal local communities and school students, and functional coastal environmental co-management institutions; ii) reduced environmental destruction of coastal ecosystems in selected areas through practical action to replant mangroves; iii) introduction of sustainable income-generating activities to coastal communities; and iv) replication of the programme in other locations using a learning approach.

1.4 Social and economic context

1.4.1 Tanjung Pasir village

Tanjung Pasir is located about 17 km north of Jakarta in Teluk Naga district (Tangerang regency, Banten Province). The district of Teluk Naga has an area of 564 ha and sits at an elevation of 0–3 m above sea level. The average annual precipitation is 150–200 mm. In 2010, the total population of Tanjung Pasir village was 9,168 people (4,693 males or 51.2%, and 4,475 females or 48.8%, distributed in 2,424 families) (Table 1).

Table 1 Total population of Tanjung Pasir village

Sub-village	Community association	Population			Families
		Male	Female	Total	
I	01 s/d 05	864	813	1,677	439
II	01 s/d 05	942	889	1,831	512
III	01 s/d 07	1,057	1,006	2,063	568
IV	01 s/d 04	806	810	1,616	391
V	01 s/d 03	380	371	751	191
VI	01 s/d 03	644	586	1,230	323
Total	–	4,693	4,475	9,168	2,424
Proportion (%)	–	51.2	48.8	100	–

Source: Directorate of Coastal and Ocean Affairs (2011e).

The education level of the population based on available data can be explained as follows: playgroup level, 50 people; elementary school level, 1,107 people; junior high school level, 497 people; senior high school level, 259 people; academy level, 20 people; and bachelor level, five people.

The livelihoods of the Tanjung Pasir working population are divided into: fishers, 1,759; government employees, 17; security workers, 15; private sector employees and entrepreneurs, 165; farmers, 365; and farm workers, 158.

The local community's understanding of natural resources and environmental issues is still low. Their thinking is short-term, focusing on exploitation of natural resources such as cutting of the mangrove forest and converting it to fishponds and aquaculture production.

Tanjung Pasir villagers can be classified among the the rural poor, as they are only able to meet their basic consumption needs. Based on interview data, the daily income of fishers is around IDR 30,000–50,000 (US$3.33–5.55). Not all fishers have a boat and fishing gear. Those who do not work as labourers for a local fishing boat skipper. Assuming an average of 20 days fishing in a month, their monthly income is still only IDR 600,000–1,000,000 (US$66–111).

The potential uses of natural resources include fishponds, marine tourism and fisheries. Marine tourism is related to island ecotourism, as there is a port leading to the Thousand Islands region. Fishers catch about 5–30 kg/day, depending on the season, weather and type of boats and fishing gear used; their catch is sold to the local fish auction.

1.4.2 Depok village

Depok village is located about 22-km south of Pekalongan City. It is one of the resort areas in Pekalongan district, Central Java Province. Some areas are occupied by fishponds or other types of aquaculture. Most of the livelihoods of its inhabitants are based on fishing and shrimp farming, with an average education level of junior high school. The village population is around 15,000 people.

About 15 years ago, the coastal area of the village was still covered by mangrove vegetation. However, because the community's perspective was predominantly short-term and income-oriented, they cut the mangroves and converted the area into milkfish and shrimp ponds.

The environmental problems facing the village today are: i) coastal erosion affecting around 200 m of land; ii) low education and low environmental awareness; iii) cutting mangroves for shrimp ponds; and iv) waste pollution from tourism.

1.4.3 Mangunhardjo village

This village is located in Semarang City and has a total population of 7,429 people. The education level is as follows: elementary school, 1,609 people; junior high school, 1,039 people; senior high school, 1,237 people; academy educated, 171 people; and bachelor degree, 128 people. The livelihoods of villagers are divided into: fishers, 156; farmers, 175; farm labourers, 154; traders and entrepreneurs, 39; general labourers, 296; government employees, 53; pensioners, 21; and others, including the service sector, 3,394. Fishponds cover an area of 192 ha in the village (Bappeda Semarang City, 2010).

1.5 The *Let's Plant Mangroves* programme

As one of its efforts to restore the degraded areas of mangrove, the Directorate of Coastal and Ocean Affairs of Indonesia's Ministry of Marine Affairs and Fisheries (MMAF) developed a programme for mangrove rehabilitation called *Let's Plant Mangroves*. This has been implemented since 2009, and has led to 420,000 mangrove seedlings being planted on 42 ha in seven villages in four provinces. The programme has involved local communities in planting, maintenance and filling gaps where plants have died. Beside mangrove planting, other programme activities include: i) training in new livelihood opportunities through alternative income-generating activities and post-harvest processing; ii) raising public awareness to protect and conserve the coastal environment; iii) environmental competitions for youths, students and community members; and iv) exhibitions on conserving the mangrove ecosystem.

The programme locations and the dates on which activities started are: i) Pantai Indah Kapuk, Jakarta (2009); ii) Depok village, Central Java (2010); iii) Tanjung Pasir village, Banten (2010); iv) Ambon City, Maluku (2010); v) Mangunharjo village, Semarang City, Central Java (2011); and vi) Wonorejo village, Central Java.

2. Materials and methods

The methodology for conducting this study included:

- Data analysis and interviews with local community members and local government representatives.
- Application of a monitoring, learning and evaluation (MLE) approach based on the following criteria:
  - Relevance and quality of design
  - Efficiency and effectiveness of implementation to date
  - Climate change and gender equality considerations
  - Livelihoods and future impact
  - Potential for sustainability
  - Weaknesses
  - Summary of key observations and recommendations
- Compiling lessons learned and developing suggestions for replication of the programme.

3. Results

3.1 Data analysis and interviews

An analysis of primary and secondary data on the implementation of the *Let's Plant Mangroves* programme yielded the following findings:

1. **Replanting of mangroves**. A high proportion of the mangrove seedlings planted in Depok village survived (about 90%, or more than 54,000 seedlings). Similar success was achieved in Mangunharjo village (90% survival, or around 36,000 seedlings), but, conversely, in Tanjung Pasir village almost all the seedlings died.

2. **Training of local community**. In Depok, project participants who received training were able to adopt new livelihood activities including mangrove syrup production, fish meal production, and mangrove *batik*-making.

3. **Environmental awareness**. The local community began to understand the importance of mangroves, and in some cases planted mangroves by themselves. In Depok village, local community groups actively discussed and took part in planting of mangroves.

4. **Income generating**. Beside fishing and fishpond farming, the local community in Depok began implementing alternative livelihood options using the skills they gained from programme training.

Interviews using a questionnaire were conducted to obtain information from the local community. In Depok village, seven people were interviewed from the selected community groups. The questions included:

1. Do you think the *Let's Plant Mangroves* programme is beneficial for the coastal environment in your area?
   All the people responded that the programme is useful.
2. How did the local community participate to support this programme?
   All the people stated that they were involved in the programme.
3. What is your livelihood?
   Three people answered fishponds farmer; three answered enterpreneurer; and one person answered fisher.
4. Does this programme need to be continued?
   Six people answered that the programme should be continued; one did not answer.
5. What is the condition of the planted mangroves?
   Five people answered good, one person answered not too good, one person did not answer.
6. What do you think of the benefits gained from *Let's Plant Mangroves*?
   All replied that the programme is producing a lot of benefits.
7. Have you any suggestions for the programme in the future?
   Three people answered that they need a greenbelt along the coastline.
8. What are the weaknesses of the programme?
   One person answered that it would be better if mangroves were planted along the coastline, one person answered that some seedlings did not survive, five people did not answer.
9. What is your expectation for rehabilitation of mangroves in your village?
   One person answered that it is important to find solutions to shrimp and milkfish mortality. Another person mentioned the importance of a greenbelt for environmental rehabilitation, and one person stated that the mangrove seedlings planted must be tended. Four people did not answer.

In Tanjung Pasir village, four people were interviewed from the selected local community groups. The questions included:

1. Do you think the *Let's Plant Mangroves* programme is beneficial for the coastal environment in your area?
   Two persons stated that the programme is useful, one person thought that it is not useful and one person responded that he did not know the programme well.
2. How did the local community participate in supporting the programme?
   All respondents stated that they are involved in the programme.
3. What is your livelihood?
   They all replied that they work as fishers.
4. Does this programme need to be continued?
   They all replied to say that the programme needs to continued.
5. What is the condition of the mangroves that have been planted?
   Four people answered that many mangrove seedlings have died.
6. What do you think of the benefits gained from *Let's Plant Mangroves*?
   All replied that the programme is producing a lot of benefits.
7. Have you any suggestions for the programme in the future?
   Two people suggested that *Avicennia* spp. should be planted, one person mentioned that he needed more training, and one person stated that he needed a fishing net.
8. What are the weaknesses of the programme?
   All people stated that maintenance is needed if the mangrove seedlings are to survive.
9. What is your expectation for rehabilitation of mangroves in your village?
   Three people stated that they expect wider-scale planting of mangroves.

3.2 Monitoring, learning and evaluation

Based on the interviews and the analysis of primary and secondary data on the implementation of *Let's Plant Mangroves*, the programme can be judged as important for rehabilitation of coastal areas, and should be continued (Table 2 below).

4. Discussion

Based on the above assessment, various aspects of the *Let's Plant Mangroves* programme can be evaluated.

4.1 Replanting of mangroves

For replanting of mangrove, the activities need to be carried out in stages:

- Procurement of mangrove propagules. Mangrove seedlings were collected by local community members from a nearby location and taken to develop in the nursery. Local group members collected mangrove propagules of *Rhizophora mucronata* or *Avicennia* sp. in the early stage of the programme. The criteria for selecting mangrove propagules are

Table 2 Summary of score sheet in Depok, Tanjung Pasir and Mangunharjo villages (evaluated by Arief Marsudiharjo, Prayogi and Weka Mahardi).

Tick box and summary score	Depok village			Tanjung Pasir village			Mangunharjo village		
	Arief	Prayogi	Weka	Arief	Prayogi	Weka	Arief	Prayogi	Weka
Relevance and quality of design	B	B	B	B	B	C	B	B	B
Efficiency of implementation	B	B	B	C	C	C	B	B	B
Climate change and gender considerations	B	B	B	C	C	C	B	B	B
Effectiveness to date	B	B	B	C	C	C	B	C	C
Likelihood of future impact	B	B	B	C	C	C	B	B	B
Potential for sustainability	B	B	B	C	C	C	B	B	B
Overall rank	B	B	B	C	C	C	B	B	B

Note: A = Very good: fulfills the purpose; B = Good: generally fulfills the purpose; C = Adequate: needs some improvement; D = Poor: must be improved.

that they should be of prime quality, 50–70 cm long, with a cotyledon at least 2 cm wide. Group members were also involved in filling polythene bags with soil media, constructing a nursery, clearing land for planting, etc. These activities involved 20–30 people.

- Requirements for a nursery location are: inundated by water at least during high tide each day; near to the planting area; and accessible – it should be near a road or settlement. Each month, the nursery should be maintained by clearing any grass growth. The criteria for mangrove seedlings grown in the nursery and used in rehabilitation are: i) four months old; ii) at least six leaves have developed; iii) substratum in polythene bag is mud or soil from mangrove areas; and iv) 75 cm tall with a dark-green leaf colour.

- Making marker sticks. Bamboo sticks 80 cm long and 5 cm wide, painted red at their top end, are used as markers (one stick per seedling). The sticks can be used during monitoring when counting the number of planted mangroves that have survived.

- Planting location. Mangrove seedlings are planted in pond areas or along the coast at a density of 1,000 seedlings/ha. Land clearing is needed before planting of mangrove seedlings. The local community is involved in this activity, which takes 3–7 days.

- For adapting to natural conditions, shade nets are used in the roof of the nursery. After the seedlings are ready to plant, they are removed from the nursery and transported to the planting location by motorbike or bicycle. It takes 2–3 days for all mangrove seedlings to be transported to each pond at the mangrove planting area.

- Mangrove seedlings are planted in a hole made using a stick. The planting activity involves group members in the local community.

- Monitoring conducted six months after planting using a census method revealed a survival rate of 95% in Depok village and Mangunharjo village, with good growth (seedlings were 0.5–1 m high and had eight leaves). However, in Tanjung Pasir village almost all the seedlings had died.

4.2 Training

Training was held in Depok village in 2010 for 40 participants drawn from all stakeholder groups involved in coastal management in Pekalongan City. After training, the participants can teach other village members to improve their skills and increase their incomes.

4.3 Competition related to environmental preservation

In Mangunharjo, *Let's Plant Mangroves* organized a competition for children, involving both speaking and drawing contests. This competition proved effective in raising the environmental awareness of the participating students and local people.

5. Conclusions and recommendations

The programme *Let's Plant Mangroves* consists of several valuable components, including: i) replanting of mangroves; ii) public awareness campaigns on environmental conservation; iii) training to increase skills to support alternative livelihoods and post-harvest processing; and iv) competitions for young people in environmental conservation. Several recommendations can be made based on the programme's results to date:

- Synergies should be sought between local government and central government in managing mangrove rehabilitation.
- The involvement of communities in managing programme activities should be maintained.
- Follow-up activities need to be organised so that programme achievements will be sustained after the programme ends.
- The programme budget should be planned and managed more effectively to maximise benefits for participating communities.
- Results of project activities need to be documented and could be used in a best practice manual or guidebook.

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Restoration of deteriorated wetlands in Kumana (Yala East) National Park, Sri Lanka: a pilot project on mangrove restoration

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Abstract

Kumana (Yala East) National Park on the south-east coast of Sri Lanka's Eastern Province (6º30' to 6º42' N, 81º04' to 81º15' E) is reputed for the diversity and abundance of its avifauna. The park provides food, shelter and roosting sites for large numbers of migratory waterfowl and waders, and is a breeding site for several thousands of resident aquatic birds of more than 33 species. In view of its importance, the park has been recognized as a Ramsar wetland of international importance.

In recent years, a slight reduction in the numbers of waders, waterfowl and other aquatic birds has been noted in the Kumana wetlands. Recent observations point to increased competition for nesting and roosting sites during the breeding and migratory seasons, indicating that available mangrove resources are limited.

The 2004 Indian Ocean tsunami caused substantial damage to the mangroves of Kumana National Park. Natural regeneration has been extremely slow and inadequate. For this reason, a pilot project was carried out to determine the feasibility of restoring mangroves in the main bird feeding, roosting and breeding sites in the park, namely the Bagura and Kumana wetlands, both of which are fringed by mangroves. Two trial plots of mangroves were established in the selected wetlands in early September 2011. Two species of mangroves, *Sonneratia caseolaris* (low salinity species) and *Rhizophora mucronata* (high salinity species), were selected for planting. Healthy plants from a nursery run by a community-based organization (CBO) associated with the Department of Wildlife Conservation (DWLC) were used in the trials.

At the time of transplanting in the field the mangrove plants averaged 12 cm in height and three leaves per plant. At the trial plot in Bagura wetland, a total of 2,048 *R. mucronata* saplings were established in 30 cm x 30 cm x 30 cm plots with community participation. This plot was assessed after six months in March 2012. Results were promising, with 1,889 plants found to be surviving (92.2% survival rate). Interestingly, 53.5% of the plants were well-established without any signs of damage, which is quite high for a dynamic habitat where severe conditions prevail, especially high herbivore pressure. A total of 793 plants were damaged, 60% by grazing (as revealed by their appearance). Direct observations indicated that wild buffalo are the main culprit. Of the 472 herbivore-damaged plants, over 90% were regenerating. After six months, the average height of undamaged plants at Bagura was 19.6 cm (an increase of 38.8%). Preliminary data from the trial plot of *S. caseolaris* in Kumana wetland indicate that, six months after planting, the mortality rate is less than 10% and growth rates are much higher than those of *R. mucronata*.

Preliminary results from the trial plots suggest that restoration of mangroves in the Kumana National Park is feasible. Provided conditions remain favourable, it should be possible to restore ecosystem characteristics that support birds, the primary attraction of the park.

There is great potential for nature-based tourism and ecotourism in Kumana National Park, owing to its rich birdlife and scenic beauty. In this respect, it is important to implement further

management strategies for restoring deteriorated habitats in the park's wetland ecosystems to support its avifaunal population.

Keywords: mangroves, restoration, Ramsar wetland, aquatic birds, Kumana National Park, Sri Lanka

1. Introduction

Kumana (Yala East) National Park lies on the south-east coast of Sri Lanka's Eastern Province (6º 30' to 6º42' N, 81º04' to 81º15' E) and is reputed for its avifaunal richness and abundance. In view of its avifauna the park has been listed as a Ramsar wetland of international importance since October 2010. Sri Lanka's Department of Wildlife Conservation (DWLC) is responsible for managing this protected area and the adjacent Panama-Kudumbigala Sanctuary, which is also a part of the Kumana Ramsar site. Kumana NP is an important habitat for numerous waterbirds, including the vulnerable Lesser Adjutant (*Leptoptilus javanicus*) (DWLC website; Miller *et al*., 2010).

The diverse ecosystems of the park, dominated by wetlands, provide feeding and roosting sites that attract large flocks of migratory waterfowl and waders. The park is a regular breeding site for more than 33 species of waterbirds. Every year several thousands of resident aquatic birds and migratory waders and waterfowl are attracted to the park, making it a key destination for birdwatchers and an internationally important site with great scope for nature-based tourism and ecotourism (DWLC website; Miller *et al*., 2010). As its prime attraction throughout the year, birds are the flagship species of Kumana NP. Therefore, aligning management to support birds should be a major management goal of the park.

The dominant vegetation types of the park comprise semi-arid thorn-scrub with areas of dense forest, grasslands, wetlands and mangroves. The latter provide crucial feeding, roosting and breeding habitats for aquatic birds, including numerous migratory waterfowl and waders (DWLC website). The 2004 Indian Ocean tsunami that hit the eastern coast, causing physical damage and changing hydrological regimes, also caused major damage to the mangroves along the coast, including the mangrove ecosystems of Kumana NP (Bambaradeniya *et al*., 2005; IWMI, 2005; UNEP and MENR, 2005).

Mangroves are woody shrubs and trees that are salt and flood tolerant and hence dominate intertidal areas of lagoons, estuaries and sheltered bays along tropical and subtropical coastlines (Pinto, 1986; Tomlinson, 1986; Ball, 2002; Jayatissa *et al*., 2002). These tidal forests are of enormous ecological and economic importance (Tomlinson 1986; Bandaranayake, 1998, 2002). Despite the importance of mangroves in providing ecosystem goods and services, they are disappearing in an escalating manner (Pinto, 1986; Alongi, 2002). Hence the conservation and restoration of mangrove ecosystems deserve high priority (Jayatissa and Wickramasinghe, 2006; Jayasekare *et al*., 2010). Restoration of mangroves in Kumana should get the same attention.

During recent years, a slight reduction in the numbers of nesting birds in Kumana wetlands has been evident. Also, recent observations on breeding of birds at the Kumana wetland of the park indicate an increased competition for nesting sites (P. N. Dayawansa, pers. comm.). Mangrove vegetation is an obligatory resource for aquatic birds; to display breeding behaviour patterns, roosting, taking hide and ambush, etc. (Nisbet, 1968; Jayson, 2001).

Mangrove vegetation that serves as nesting sites and habitat for waterbirds, seems to be a limited resource during their peak breeding season that regularly commences in the month of May. Ecosystem characters such as complex structure, diversity, linkages and resilience of mangrove ecosystems depend heavily on the availability of mangrove vegetation (Jayson, 2001; Jayasekare *et al*., 2010). Availability of food resources for numerous species of wildlife too is indirectly influenced by mangrove vegetation (Tomlinson, 1986; Cannicci *et al*., 2008). Therefore, it is necessary to restore the affected areas with suitable species of mangroves to facilitate recovery of the ecosystem.

A preliminary project was started in September 2011 to determine the feasibility of restoring mangroves at reputed bird breeding sites in the park, namely Bagura and Kumana wetlands, both of which are fringed by mangrove vegetation.

2. Materials and methods

The pilot project was carried out from September 2011 (commencement of replanting) to March 2012 (initial gathering of data on population dynamics). However, the study of population dynamics is a long-term study. It will involve the collection of ecological data every six months for a period of three years and annual monitoring thereafter, and is to be carried out with the involvement of local community, including schoolchildren.

Planting the wrong species in the wrong place is a major reason for failure of mangrove rehabilitation projects (Lewis, 2005). Therefore, selection of mangrove species for restoration was based on published guidelines (Jayatissa and Wickramasinghe, 2006), and a survey of mangroves species in Kumana before and after the 2004 Indian Ocean tsunami. As soil salinity is a primary factor controlling the survival and growth of mangrove seedlings (Jayatissa and Wickramasinghe, 2006), salinity tolerance was also considered. Two species of mangroves, namely, *Sonneratia caseolaris*, a low-salinity loving species, and *Rhizophora mucronata*, a high-salinity loving species, were selected for restoration. *Sonneratia* is the preferred species for constructing bird nests and *Rhizophora* for roosting.

The Bagura and Kumana wetlands were selected as study sites in view of their avifaunal significance. Bagura wetland is regularly used throughout the year as a roosting site by many waterbirds, whereas Kumana wetland is frequented by breeding waterbirds, especially in the peak breeding season starting in May. Both wetlands are excellent feeding sites for all species of waterbirds. The status and distribution of mangrove vegetation before the 2004 Indian Ocean tsunami was obtained by personal communication with experts, and the current situation was assessed by carrying out a ground survey in the area.

Nursery plants of *Sonneratia* and *Rhizophora* raised in polythene bags were obtained from a community-based organisation (CBO) in Rekawa in Southern Province associated with DWLC. The polythene bags were 5 cm in diameter and 15 cm in height and the potting mixture was a 1:1:1 mix of sieved loam soil, sand and organic matter (degraded mangrove litter). Seedlings were irrigated with fresh water and, when well-established, were transferred from the CBO nursery in Rekawa to Kumana. Healthy plants were selected and acclimatized for a period of three months at Kumana NP before planting out in the trial site. The planting pits were 30 cm x 30 cm x 30 cm, and at the time of transplanting the height of the plants averaged 12 cm, with three leaves per plant.

Two trial plots were established, one each in Bagura and Kumana wetlands, in early September 2011. A total of 2,048 *Rhizophora* plants were planted at Bagura and 1,500 *Sonneratia* plants at Kumana, and protected with branches to avoid predation by herbivores. The Bagura trial assessments were made six months after planting in early March 2012, and the Kumana trial plot is currently being assessed.

3. Results

3.1 Bagura wetland trial

In early March 2012 (six months after planting), 1,889 plants of the 2,048 planted out were surviving and 159 plants had died, i.e. 92.2% survival and 7.8% mortality of plants over the six-month period. A mortality rate of 7.8% may be considered nominal for a harsh natural habitat. Of the 1,889 survivors, 1,096 plants were well-established without any signs of damage, which is quite satisfactory for a dynamic habitat where severe conditions prevail, especially with high pressure from herbivores. Of the 793 plants damaged, 59.5% suffered from browsing as indicated by their appearance. Direct observations indicated that wild buffalo are the main source of browsing pressure. Over 90% of the 472 herbivore-damaged plants were found to be regenerating.

After six months, the average height of undamaged plants was 19.6 cm – an increase of 7.6 cm (or 38.8%) over six months, which is quite rapid in such dynamic habitats. The number leaves per plant varied from five to nine after six months.

3.2 Kumana wetland trial

An evaluation is currently underway. Preliminary results indicate that the survival rate is more than 90%, and that the growth rate of *Sonneratia* is faster than *Rhizophora*.

4. Discussion

The progress of the trial plantings of *R. mucronata* and *S. caseolaris* at Bagura and Kumana wetlands respectively has been encouraging. These results suggest that replanting mangroves in Kumana NP, and thus restoring ecosystem characteristics that support birds, the primary attraction of the park, is eminently feasible. Accomplishing this will undoubtedly support the rich birdlife of the park and help maintain the quality of the park as a breeding site for waterbirds, and retain its Ramsar status. In the long run, establishment of mangrove vegetation in the wetlands will facilitate restoration of ecosystem characters of major wetlands affected by the 2004 Indian Ocean tsunami.

Jayathissa and Wickramasinghe (2006) reported that many attempts to restore mangroves have failed completely, as they were poorly planned and managed. As already noted, planting the wrong species in the wrong place is a major reason for many failures (Lewis, 2005). Salinity of the habitat appears to be a primary factor controlling the survival and growth of mangrove plants. Taking this into consideration, appropriate species were selected based on salinity distribution: two species of mangroves, namely the low-salinity loving *S. caseolaris* and high-salinity loving *R. mucronata*, were selected for restoration. The initial success of the current project can be ascribed to the appropriate selection of species for replanting and use of healthy plant material.

Herbivore pressure is by far the biggest contributor to the 7.8% mortality of plants at Bagura wetland. This factor is difficult to control as buffalo are abundant in the area. However, the community members involved in restoration were advised to avoid buffalo trails while replanting mangroves, and to use branches to protect the plants from the animals. No attempt was made to fence the replanted blocks as this is not a realistic option in wetland areas.

The height of saplings increased from the initial 12 cm to 19.6 cm after six months, despite the harsh conditions that prevail in such habitats. Although this relatively slow growth rate (1.27 cm per month) may well be frustrating, according to Jayatissa and Wickramasinghe (2006) such slow growth at the initial stages is common in natural regeneration of mangroves. An important hurdle in a hostile environment is the initial survival and establishment of the plants, which is always challenging. Once established better productivity can be expected. A systematic monitoring programme should be put in place to follow progress and ensure success.

Community involvement was assured by sourcing nursery plants from a CBO associated with DWLC. Community involvement was further assured by using local community labour to replant mangroves, which also made the project more cost-effective. Community members were made aware of the significance of the project by educating them about mangroves, their significance and conservation.

The implementation plan of the current project built in the involvement of the community through participation. Community participation will bring about desirable attitudinal changes in the local community, in addition to the project's major objective of environment restoration.

Nature-based tourism is on the increase throughout Sri Lanka and Kumana National Park is an ideal location for this type of tourism. Also, there is a great potential for ecotourism among adjacent hamlets such as Panama, the doorway to Kumana NP. In light of this, it is important that management strategies should be directed towards restoring deteriorated habitats of the wetland ecosystems and conserving the avifauna of the park.

5. Conclusions and recommendations

The initial success of a mangrove restoration programme depends on appropriate selection of the site and mangrove species, and how the programme is implemented. Involvement of the community at all stages of the project will bring additional benefits. Continuous assessment and monitoring of the progress of the transplants are critical to ensure the success of a restoration programme.

The results of the trial plantings at Bagura and Kumana clearly indicate that restoration should be extended to other deteriorated habitats associated with the wetlands of Kumana

National Park with proper appraisal and further involvement of the community, for instance by establishing community nurseries in adjacent villages.

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Afforestation of coastal mudflats in Gujarat, India

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Abstract
India registered an increase of about 24 km² in its mangrove cover between 2009 and 2011. The greatest increase (12 km²) was reported from Gujarat, and is attributed to the state's strong mangrove conservation and afforestation efforts. Gujarat has 66% of the country's coastal wetlands, suggesting an extensive range of potential sites where mangrove plantations could be established. This calls for a long-term afforestation strategy. To this end, in 2010 Gujarat launched an ambitious mangrove afforestation programme aimed at establishing about 100–120 km² of mangroves a year. In addition, recognizing that a holistic approach is required for long-term conservation of mangroves, Gujarat has conducted a number of area-specific research studies on mangrove reproductive and pollination biology, the status of natural regeneration, and the preferred substratum and inundation conditions of different mangrove species. This work has established that mangrove plant associates and faunal components play an important role in the overall functioning of mangrove ecosystems.

Based on these findings, and instead of only raising mangrove plantations, a mangrove habitat development plan has been developed for the intertidal mudflats of South Gujarat. This plan takes into account the substratum conditions, inundation conditions, natural zoning of mangroves in the area, and existing mangrove species. The plan also includes an inventory of all the potential mudflats more than 1 km² in area. Each mudflat has been given a permanent identity by means of a Potential Area Number (PAN). Mudflat-specific treatment plans have also been developed, identifying the mangrove species and mangrove associates that can be established in the different zones and sub-zones of each mudflat. These plans will promote biodiversity, whereas the location-specific permanent identification numbers will facilitate long-term monitoring. Following these criteria, treatment plans have been developed for 70 mudflats covering about 810 km² across seven coastal districts of Gujarat. Implementation of the mangrove habitat development plan began in 2011–2012.

Keywords: mangroves, afforestation, mudflats, sediment properties, tidal range, Gujarat, India

1. Introduction
The state of Gujarat contains the second largest area of mangroves (1,058 km²) in India (total mangrove area: 4,662.56 km²). The state's mangrove cover has shown an increasing trend from 1987 to 2011 (Forest Survey of India, 2011). This cover is unevenly distributed across 13 coastal districts forming four mangrove regions: Kachchh (Kori creek), Gulf of Kachchh, Saurashtra and South Gujarat (see Table 1 below).

The species diversity of mangroves in Gujarat is relatively low. A total of 15 mangrove species have been recorded from the state (Pandey and Pandey, 2009). However, a survey of the diversity and regeneration of mangroves in South Gujarat in 2009 by the GEER (Gujarat Ecological Education and Research) Foundation found a remarkable floristic diversity and rich growth of mangroves in this area. The study identified a number of new mangrove areas, as well as potential mangrove areas in the southern districts of Navsari and Valsad. Subsequently, the state started establishing mangrove plantations in these districts. As the mangrove afforestation programme has developed, it has been felt necessary to identify potential mudflats where investment may be encouraged for mangrove afforestation and

Table 1 Distribution of mangroves in Gujarat

Mangrove region	Districts	Mangrove area (km²)	Proportion (%)
Kachchh	Kachchh	778	73.53
Gulf of Kachchh	Jamnagar and Rajkot districts and areas under Marine National Park and Sanctuary	161	15.22
Saurashtra	Amreli, Junagadh	2	0.19
South Gujarat	Bhavnagar, Ahmedabad, Anand, Vadodara, Bharuch and Surat, Navsari and Valsad	117	11.06
Total		1,058	100

Source: Forest Survey of India (2011).

habitat development. To this end, the Gujarat Department of Forests and Environment sanctioned a special project under its climate change programme to identify coastal mudflats in South Gujarat where mangrove restoration or afforestation could be carried out.

2. Materials and methods

The intertidal areas of seven districts in south Gujarat – Valsad, Navsari, Surat, Bharuch, Anand, Ahmedabad and Bhavnagar – were surveyed for their potential to support mangroves. For this task, IRS LISS-III satellite imagery from 2008–09 was used to identify coastal mudflats of more than 100 ha for ground verification. Where possible, mudflats of less than 100 ha were grouped together for ground verification. Small patches of mudflat which could not be combined were omitted from this exercise.

A total of 90 potential areas was delineated, each of which was verified on the ground for its potential to support mangroves. For each mudflat, details of the existing vegetation (mangrove and mangrove associates), land use, sediment and tidal conditions, and vulnerability to natural and anthropogenic pressures, were collected and used to prepare a mudflat treatment plan for each potential area. Figure 1 and Table 2 summarise this methodology.

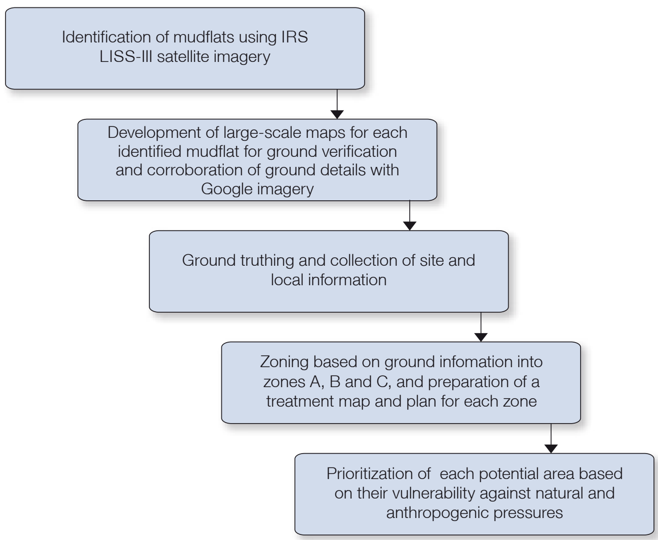

Figure 1 Schematic representation of methodology. *Source*: Pandey *et al*. (2012).

Table 2 Probable coastal areas and potential areas of seven districts of South Gujarat

District	Number of identified coastal areas (>100 ha)	Number of potential areas after ground verification
Valsad	12	6
Navsari	16	9
Surat	14	11
Bharuch	19	16
Anand	8	8
Ahmedabad	11	9
Bhavnagar	10	11
Total	90	70

2.1 Referencing of potential areas

Every potential area was given a unique index number, or Potential Area Number (PAN), for referencing purposes.

2.2 Zoning of potential areas

Mangrove habitats show distinct zoning as one moves from the high-tide line towards the land. Depending on the local substratum and inundation conditions, various mangrove species occupy specific zones in the mangrove habitat. Each potential area was categorized into three zones based on substratum and inundation conditions: A, B and/or C (Table 3).

Table 3 Soil and inundation features of zones A, B and C influencing potential for mangrove restoration or afforestation

Zone A	Zone B	Zone C
▸ Regularly inundated (more than 7 days out of 15-day tidal cycle) ▸ Substratum is soft clay ▸ Located near or along a creek ▸ Direct mangrove plantation is possible	▸ Inundated on 4–6 days out of 15-day tidal cycle ▸ Substratum is relatively harder (hard clay or mixed type) ▸ Creeks in the nearby areas ▸ Mangrove plantation is possible after channelling	▸ Inundated on fewer than 4 days out of 15-day tidal cycle ▸ Substratum is harder ▸ Mangrove associates may be planted

Source: Pandey *et al*. (2012).

2.3 Vulnerability assessment

Each potential area was assessed for natural and anthropogenic pressures. Anthropogenic pressures included illicit tree felling, livestock grazing, sand mining and pollution. The potential areas were categorized into high, moderate or low vulnerability to anthropogenic pressures on the basis of these factors. In general, any potential area with three or more such factors was treated as highly vulnerable to anthropogenic pressures. Potential areas with one or two factors were treated, respectively, as low or moderately vulnerable to anthropogenic pressures. Natural pressures were assessed in terms of susceptibility to soil erosion, proximity to the shoreline and absence of biological or mechanical shields. As with the anthropogenic pressures, potential areas with all three factors were generally treated as highly vulnerable to natural pressures, whereas those with one or two were treated, respectively, as low or moderately vulnerable. The opinions of local communities and Forest Department field staff were also sought while deciding the vulnerability category for each potential area.

3. Results

Ground truthing revealed that 70 of the 90 surveyed mudflats had potential for mangrove restoration or afforestation. These potential areas were sheltered mudflats; the other 20 were either sandy beaches or exposed areas, so were not considered further.

3.1 Distribution of the potential areas by district

Among the seven coastal districts surveyed, the highest number of potential areas was reported from Bharuch (16), followed by Surat and Bhavnagar with 11 each. Valsad, Navsari, Anand and Ahmedabad were found to have 6, 9, 8 and 9 potential areas, respectively. The reference numbers of each potential area and their classification by zone in each district are provided in Table 4.

Table 4 Zoning and reference numbers of potential areas by district

	Potential area (ha) in different zones				Potential Area Number
District	A	B	C	Total	(PAN)
Valsad	785.61	705.18	153.40	1,644.19	PAN 1 to PAN 6
Navsari	490.96	4,833.88	2,980.65	8,305.49	PAN 7 to PAN 15
Surat	1,512.94	4,489.81	567.69	6,570.44	PAN 16 to PAN 26
Bharuch	8,410.04	5,895.29	879.66	15,184.99	PAN 27 to PAN 42
Anand	4,283	9,976.50	3,591.49	17,850.99	PAN 43 to PAN 50
Ahmedabad	756.59	7,310.06	12,827.97	20,894.62	PAN 51 to PAN 59
Bhavnagar	4,541.92	5,526.28	541.22	10,609.42	PAN 60 to PAN 70
Total	20,781.06	38,737	21,542.08	81,060.14	–

Ahmedabad has the largest potential area for mangrove restoration or afforestation, followed by Anand, Bharuch, Bhavnagar, Navsari, Surat and Valsad. The areas located in Bharuch district were found to be most suitable for mangrove restoration and afforestation with direct planting (Zone A), whereas Anand district has the most suitable areas for mangrove restoration and afforestation after channel development (Zone B). Ahmedabad district was found to be most suitable for planting mangrove associate species (Zone C).

3.2 Mangrove and mangrove associates reported from potential areas

A total of 13 mangrove species (*Avicennia marina*, *Avicennia alba*, *Avicennia officinalis*, *Acanthus ilicifolius*, *Aegiceras corniculatum*, *Ceriops tagal*, *Bruguiera cylindrica*, *Bruguiera gymnorrhiza*, *Excoecaria agallocha*, *Lumnitzera racemosa*, *Sonneratia apetala*, *Rhizophora mucronata*, *Xylocarpus* sp.) were reported from potential areas in South Gujarat. Except for *Xylocarpus* sp., all have been recorded in natural mangrove habitats in Gujarat (Pandey and Pandey, 2009, 2010). Further, the maximum number of mangrove species was reported from the potential areas of Valsad. In the case of Bharuch, Anand, Ahmedabad and Bhavnagar, only *A. marina* was reported. Moving from south to north (Valsad to Anand), the number of species of mangroves and mangrove associates decreases. Table 5 summarises the diversity of mangrove and mangrove associate species in the districts (see also annexes 1–3).

Table 5 Floristic diversity of mangroves and mangrove associates in South Gujarat

District	Number of mangroves	Number of mangrove associates
Valsad	11	38
Navsari	3	30
Surat	8 (6 natural + 2 planted)	23
Bharuch	1	13
Anand	1	6
Ahmedabad	1	8
Bhavnagar	1	9

3.3 Potential area development plan for mangrove restoration

Detailed maps identifying waterbodies, area and location of zones A, B and C, and geo-references (for example approach roads) were prepared for each potential area. One such map from Valsad district is given in Figure 2. These maps were prepared on the basis of the details of substratum, inundation conditions, suitability of various species of mangroves and mangrove associates for mangrove restoration in the potential area. The plant species recommended for each zone are listed in annexes 1–3.

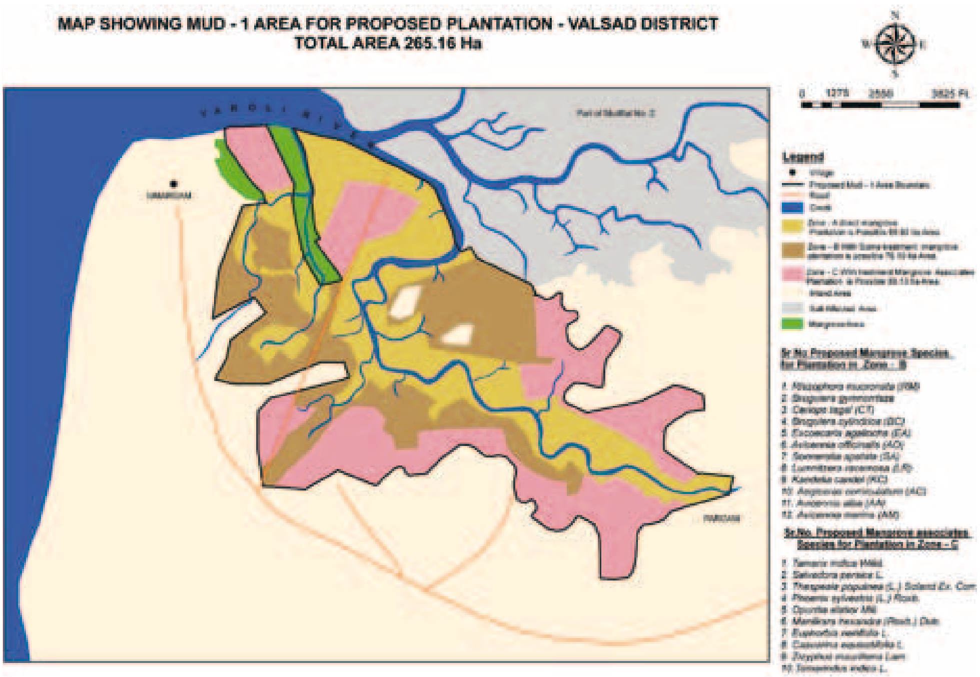

Figure 2 Map of a potential area: PAN 1 of Valsad. *Source*: Pandey *et al*. (2012).

3.4 Vulnerability index of potential areas

The potential areas of each district were further categorized into different vulnerability classes (Table 6). Bhavnagar district recorded the highest number of potential areas vulnerable to anthropogenic pressures, followed by Navsari. It is important to note that Anand district did not have any potential areas that could be classified as highly vulnerable. Considering natural

Table 6 Vulnerability index of potential areas in South Gujarat

District	Number of potential areas	Number of potential areas vulnerable to					
		Anthropogenic pressures			Natural pressures		
		High	Moderate	Low	High	Moderate	Low
Valsad	6	1	3	2	Nil	Nil	6
Navsari	9	6	3	Nil	5	Nil	4
Surat	11	4	3	4	5	Nil	6
Bharuch	16	4	6	6	14	Nil	2
Anand	8	Nil	1	7	2	Nil	6
Ahmedabad	9	4	2	3	1	Nil	8
Bhavnagar	11	8	Nil	3	11	Nil	Nil

pressures, Bharuch district has the highest number of most vulnerable potential areas, followed by Bhavnagar, Navsari and Surat.

4. Conclusions

Mangrove conservation and restoration in degraded or potential afforestation areas are essential for the ecological security of the coastline and socio-economic wellbeing of local coastal communities. However, an informed and scientific approach is needed that accounts for all relevant biotic and abiotic factors influencing the area under question. This paper outlines a holistic approach to restoring and developing mangrove habitats on suitable mudflats. This approach also incorporates suitable mangrove associates along with the mangrove species in an effort to augment the biodiversity of the area, thus improving the structure and functioning of the ecosystem, and improving the sustainability of restoration and afforestation efforts. This diversified approach would also improve the ecological and socio-economic functions of the mangrove habitats. The work developed in Gujarat also provides a model for effective planning, implementation and monitoring of mangrove restoration programmes covering scattered and isolated mudflats. This model combines remote sensing with ground truthing in such a way that field-based information is given precedence, resulting in more realistic and site-specific planning. The methodology, as well as the planning and monitoring model, has wide-ranging regional and global applicability.

As mentioned earlier, Gujarat has a mangrove area of 1,058 km^2. This study has identified an additional area of over 810 km^2 with potential for mangrove restoration or afforestation. However, the study covered only the intertidal regions of seven of the 14 coastal districts of Gujarat, and, based on its findings and implications, a similar exercise has been launched for the other seven districts. It is estimated that 1,500–2,000 km^2 may potentially be available in the state for further development as mangrove habitats. Six of the 16 identified potential areas in Bharuch district have already been adopted for mangrove restoration or afforestation under the government of India's Green India Mission.

Acknowledgements

The seeds of this study were sown during an MFF-funded small grants project on the floristic diversity of mangroves in Gujarat, and the authors thank MFF for this. We express our gratitude to the government of Gujarat for sponsoring this project. We are also thankful to the GEER Foundation, especially Mr Bipin Khokhariya, Kamlesh, Sheenath, Rakesh Patel, Mukesh Mali, Bhargav Brahmbhatt and Mehul Joshi, for their support and contribution to this study. Thanks are due to the GIS Centre, Vadodara, Gujarat Forest Department, for developing the final maps, and to the officials and staff of the Gujarat Forest Department for facilitating the field work which made this study possible, and for using its outputs to improve strategies for mangrove restoration.

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Annex 1 List of mangroves and mangrove associates reported from potential areas

No.	Scientific name	Type	Growth form
1	*Acanthus ilicifolius* L.	Mangrove	Tree
2	*Aegiceras corniculatum* (L.) Blanco	Mangrove	Tree
3	*Avicennia alba* Bl.	Mangrove	Tree
4	*Avicennia marina* (Forsk.) Vierh	Mangrove	Tree
5	*Avicennia officinalis* L.	Mangrove	Tree
6	*Bruguiera cylindrica* (L.) Bl.	Mangrove	Tree
7	*Bruguiera gymnorrhiza*	Mangrove	Tree
8	*Ceriops tagal* (Perr.) Robinson	Mangrove	Tree
9	*Excoecaria agallocha* L.	Mangrove	Tree
10	*Lumnitzera racemosa* Willd.	Mangrove	Shrub
11	*Rhizophora mucronata* Lamk.	Mangrove	Shrub
12	*Sonneratia apetala* Buch.- Ham.	Mangrove	Tree
13	*Xylocarpus* sp.	Mangrove (Planted)	Shrub
14	*Adansonia digitata* L.	Mangrove Associate	Tree
15	*Aeluropus lagopoides* (L.) Trin. ex Thw.	Mangrove Associate	Herb
16	*Azadirachta indica* A. Juss.	Mangrove Associate	Tree
17	*Caesalpinia crista* L.	Mangrove Associate	Climber
18	*Calotropis procera* (Ait.) R.Br.	Mangrove Associate	Shrub
19	*Capparis sepiaria* L.	Mangrove Associate	Shrub
20	*Carissa congesta* Wt.Icon.	Mangrove Associate	Shrub
21	*Casuarina equisetifolia* L.	Mangrove Associate	Tree

No.	Scientific name	Type	Growth form
22	*Clerodendrum inerme* (L.) Gaertn. F.	Mangrove Associate	Shrub
23	*Cressa cretica* L.	Mangrove Associate	Herb
24	*Cyprus* sp.	Mangrove Associate	Herb
25	*Derris indica* (Lamk.) Bennet.	Mangrove Associate	Tree
26	*Derris scandens* Benth.	Mangrove Associate	Climber
27	*Derris trifoliata* Benth.	Mangrove Associate	Climber
28	*Eragrostis* sp.	Mangrove Associate	Climber
29	*Erythrina viregata* L.	Mangrove Associate	Herb
30	*Euphorbia neriifolia* L.	Mangrove Associate	Tree
31	*Hygrophila auriculata* (Schum.) Heiene	Mangrove Associate	Herb
32	*Hyphaene indica* Becc.	Mangrove Associate	Tree
33	*Ipomoea fistulosa* Mart. ex Choisy	Mangrove Associate	Climber
34	*Ipomoea pes-caprae* (L.) R. Brown	Mangrove Associate	Climber
35	*Ixora pavetta* Andr.	Mangrove Associate	Tree
36	*Lantana camara* var. *aculata* (L.) Mold.	Mangrove Associate	Shrub
37	*Manilkara hexandra* (Roxb.) Dub.	Mangrove Associate	Tree
38	*Maytenussen egalensis* (Lam.) Excell.	Mangrove Associate	Shrub
39	*Moringa oleifera* Lam.	Mangrove Associate	Tree
40	*Nauracanthus sphaerostachyus* (Nees) Dalz.	Mangrove Associate	Herb
41	*Opuntia elatior* Mill.	Mangrove Associate	Shrub
42	*Pentatropis capensis* (Linn.f.) Bullock	Mangrove Associate	Climber
43	*Phoenix sylvestris* (L.) Roxb.	Mangrove Associate	Tree
44	*Porteresia coarctata* (Roxb.) Tateoka.	Mangrove Associate	Herb-grass
45	*Prosopis juliflora* (Sw.) D.C.	Mangrove Associate	Tree
46	*Salvadora persica* L.	Mangrove Associate	Tree
47	*Selicornia brachiata*	Mangrove Associate	Herb
48	*Sesbania sesban*	Mangrove Associate	Shrub
49	*Sesuvium portulacastrum* (L.) L.	Mangrove Associate	Herb
50	*Sida acuta* L.	Mangrove Associate	Herb
51	*Suaeda monoica* Forssk. Ex. Gmel.	Mangrove Associate	Shrub
52	*Suaeda nudiflora* Roxb.	Mangrove Associate	Herb
53	*Tamarindus indica* L.	Mangrove Associate	Tree
54	*Tamarix indica* Willd.	Mangrove Associate	Shrub
55	*Thespesia populnea* (L.) Soland. Ex Corr.	Mangrove Associate	Tree
56	*Zizyphus mauritiana* Lam.	Mangrove Associate	Tree
57	*Zizyphus nummularia* (Brum.f.) W.& A.	Mangrove Associate	Shrub

Annex 2 List of mangroves and mangrove associates suggested for Zone A and Zone B

No.	Zone A	Zone B
1	*Acanthus ilicifolius*	*Acanthus ilicifolius*
2	*Aegiceras corniculatum*	*Aegiceras corniculatum*

No.	Zone A	Zone B
3	*Avicennia alba*	*Avicennia alba*
4	*Avicennia officinalis*	*Avicennia marina*
5	*Bruguiera cylindrica*	*Avicennia officinalis*
6	*Bruguiera gymnorrhiza*	*Bruguiera cylindrica*
7	*Ceriops decandra*	*Bruguiera gymnorrhiza*
8	*Ceriops tagal*	*Ceriops tagal*
9	*Excoecaria agallocha*	*Kandelia candel*
10	*Kandelia candel*	*Lumnitzera racemosa*
11	*Lumnitzera racemosa*	*Rhizophora mucronata*
12	*Rhizophora mucronata*	*Sonneratia apetala*
13	*Sonneratia apetala*	*Suaeda maritima*
14	*Porteresia coarctata*	*Porteresia coarctata*

Annex 3 List of plant species suggested for Zone C

No.	Non-mangrove	Substrata	Growth form	Spacing
1	*Tamarix indica*	More sandy + clay	Shrub	3 m x 3 m
2	*Salvadora persica*	Hard clay	Tree	5 m x 5 m
3	*Thespesia populnea*	Hard clay and soft clay	Tree	5 m x 5 m
4	*Phoenix sylvestris*	Hard clay	Tree	5 m x 5 m
5	*Opuntia elatior*	Hard clay	Shrub	3 m x 3 m
6	*Manilkara hexandra*	Hard clay	Tree	5 m x 5 m
7	*Euphorbia neriifolia*	Hard clay	Shrub	3 m x 3 m
8	*Casuarina equisetifolia*	Sandy	Tree	5 m x 5 m
9	*Zizyphus mauritiana*	Hard clay	Tree	5 m x 5 m
10	*Tamarindus indica*	Hard clay	Tree	5 m x 5 m
11	*Cocos nucifera*	More sandy + clay	Tree	5 m x 5 m
12	*Pongamia pinnata*	Hard clay	Tree	5 m x 5 m
13	*Borassus flabellifer*	Sandy	Tree	5 m x 5 m
14	*Anacardium occidentale*	Hard clay	Tree	5 m x 5 m
15	*Azadirachta indica*	Hard clay	Tree	5 m x 5 m
16	*Bambusa arundinacea*	Hard clay	Tree	5 m x 5 m
17	*Adansoina digitata*	Hard clay	Tree	5 m x 5 m
18	*Clerodendrum inerme*	Hard clay	Shrub	3 m x 3 m
19	*Caesalpinia crista*	Hard clay	Climber	5 m x 5 m
20	*Suaeda maritima*	Hard clay	Shrub	3 m x 3 m
21	*Suaeda monoica*	Hard clay	Herb	2 m x 2 m
22	*Suaeda nudiflora*	Hard clay	Herb	2 m x 2 m
23	*Salicornia brachiata*	Hard clay	Herb	2 m x 2 m
24	*Porteresia coarctata*	Soft pure clay	Herb-grass	2 m x 2 m
25	*Aeluropus lagopoides*	Hard clay	Herb-grass	2 m x 2 m
26	*Asparagus racemosus*	More sandy + clay	Climber	5 m x 5 m

Genesis and present status of restoration practices in saline blanks in India

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Abstract
Unvegetated areas, or saline blanks, are a common feature of mangrove wetlands in arid and semi-arid regions. They are characteristic of mangroves of Tamil Nadu and Andhra Pradesh, though the reasons for this are not clearly understood and, as a result, many attempts to restore these areas have yielded limited results.

Participatory research by the M. S. Swaminathan Research Foundation (MSSRF) has shown that the clear-felling system used in mangrove management in India from the early 20th century to the late 1970s was the main cause of degraded saline blanks. Clear-felling of mangrove trees in coupes exposed large areas of mangrove wetland to sunlight, causing evaporation of the water. Almost 80% of the water is lost in this way, increasing soil bulk density and changing the original flat topography of the area into a trough-shaped form. Tidal water entering these troughs during high tide became stagnant; its subsequent evaporation increased soil salinity to a level lethal to mangroves. As a result, no regeneration of mangrove plants occurred in clear-felled areas, and attempts to restore these areas by planting also failed.

Drawing on these findings, a simple and cost-effective restoration technique was developed and demonstrated with the participation of stakeholders including the State Forest Department and local communities. This technique involves a canal system with supply and feeder canals that allow tidal water to move freely in and out of the degraded area, thereby avoiding stagnation of saline water. This free and energy-neutral flushing by tidal water reduces soil and water salinity, increasing the moisture of the degraded areas and making them biophysically suitable for supporting mangroves. MSSRF and the State Forest Department of Tamil Nadu demonstrated this technique in Pichavaram in an area of about 10 ha. Stakeholders there raised three important questions: i) who will maintain the artificial canals created for tidal flushing; ii) how can mangrove restoration activities be scaled up; and iii) how can livelihood pressures such as felling of trees and grazing of animals be managed.

Answering these questions led to the development of a Joint Mangrove Management (JMM) programme, pilot tested in seven mangrove wetlands in the states of Tamil Nadu, Andhra Pradesh, Orissa and West Bengal by MSSRF, together with State Forest Departments and local communities. Between 1996 and 2004, a total of 33 villages in the four states and about 5,200 families participated in the testing, and more than 1,500 ha of mangroves were restored by planting 6.8 million mangrove saplings. The Ministry of Environment and Forests of India subsequently formed a sub-committee to review the restoration protocol and JMM approach. The sub-committee declared it the best approach currently available, and included it in the National Mangrove Action Plan. At present, State Forest Departments on the east coast of India and in Gujarat use the canal technique to restore degraded mangrove wetlands in suitable areas.

Keywords: mangroves, saline blanks, restoration, Pichavaram, India

1. Introduction
Saline blanks, also called salinas or salt flats, are common in arid and semi-arid mangroves (Macnae, 1968; Cintrón *et al*., 1978). They have also been recorded in many of the mangrove

wetlands of India (Balsco, 1975; Selvam *et al*., 2005). All of these saline blanks are hypersaline, with soil salinity exceeding 100 parts per thousand (ppt) in some areas (Cintrón *et al*., 1978; Gordon, 1988). An analysis of remote sensing data of the Muthupet mangroves in Tamil Nadu, which lie in the coastal, semi-arid zone of the north Tamil Nadu plains, showed that of the 12,000 ha of declared mangrove area, hypersaline blanks accounted for nearly 7,200 ha, or 60% (Selvam *et al*., 2002). Similarly, 55% of the Pichavaram mangroves, also located in the same zone, were found to be saline blanks with few mangroves. The management plan of the Muthupet and Pichavaram mangrove wetlands records that many unsuccessful attempts to vegetate these saline blanks have been made since the 1930s (Ahmed, 1937; Thangam, 1961).

Another problem is that local communities have not been given an opportunity to participate in the management and decision-making processes for these mangroves, as well as other mangroves in India. The combination of a lack of participation and hypersalinity has resulted in the mangroves of India, including those of Tamil Nadu, being in a highly degraded state. This was the situation when the M. S. Swaminathan Research Foundation (MSSRF) started its community-based mangrove management projects along the east coast of India, especially in the Pichavaram mangrove wetlands. This paper describes: a) the causes of the development of saline blanks; b) techniques to restore these blanks; c) joint mangrove management processes to scale up restoration programmes that were tested in mangroves along the east coast of India, with communities and State Forest Departments as partners; and d) the current status of restoration of Indian mangroves.

2. Materials and methods

The restoration of saline blanks in mangroves was divided in two phases. In Phase 1, MSSRF identified the causes of formation of saline blanks, and developed and demonstrated appropriate restoration techniques. This phase was implemented in the Pichavaram mangroves in Tamil Nadu. Phase 2 consisted of Joint Mangrove Management (JMM) programmes, pilot-tested with communities and State Forest Departments, in seven major mangrove wetlands located along the east coast of India.

2.1 Causes of saline blank formation and development of restoration methods

Participatory studies and scientific field investigations were used to identify the causes of saline blank formation in the Pichavaram mangroves. In the participatory studies, rapid rural appraisal and participatory rural appraisal were used to elucidate the views of the communities on the causes, and interviews were held with Forest Department officials. Following these, joint field visits were conducted with officials and community representatives, which revealed stagnation of tidal water in many parts of the Pichavaram mangroves. These were followed by a scientific study to assess the reasons for tidal water stagnation, in which the micro-topography of the forest floor was measured at 2-m intervals and visual observations made of tidal flushing patterns. Micro-topographic measurements were taken along nine randomly selected transects covering both saline blanks and healthy forest areas. The floral structure along these transects was also analysed using standard methods described by Cintrón and Novelli (1984). Soil and pore water salinity along the transects were measured using the method described by Gordon (1988). Based on these observations, a restoration technique was developed and tested in about 10 ha of saline blanks.

2.2 Joint Mangrove Management (JMM)

To scale up restoration activities, and also to give local communities a role in decision-making for mangrove management, JMM programmes were developed and pilot tested in mangrove wetlands in the states of Tamil Nadu, Andhra Pradesh, Orissa and West Bengal. A science-based, people-centred and process-oriented approach was followed in pilot testing of JMM to plan, restore and sustain mangrove wetlands.

3. Results and discussion

3.1 Causes of saline blank formation

The study of micro-topography, tidal flushing patterns, soil and pore water salinity, and plant community structure, in Pichavaram revealed the following differences between healthy mangroves and saline blanks:

- The micro-topography in healthy mangroves was smooth (Figure 1, top) and flushed by tidal water freely during high tide and low tide. No stagnation of tidal water was observed. In healthy areas, soil salinity was moderate, ranging from 12–51 ppt. Pore water salinity was between 22 and 64 ppt. Plant diversity was high.
- In saline blanks, the topography was trough-shaped (Figure 1, bottom), so tidal water entering these areas stagnated. Evaporation of the stagnant water led to a high soil salinity of 68–112 ppt, and a pore water salinity of 70–120 ppt. This hypersalinity prevented natural regeneration of mangroves.

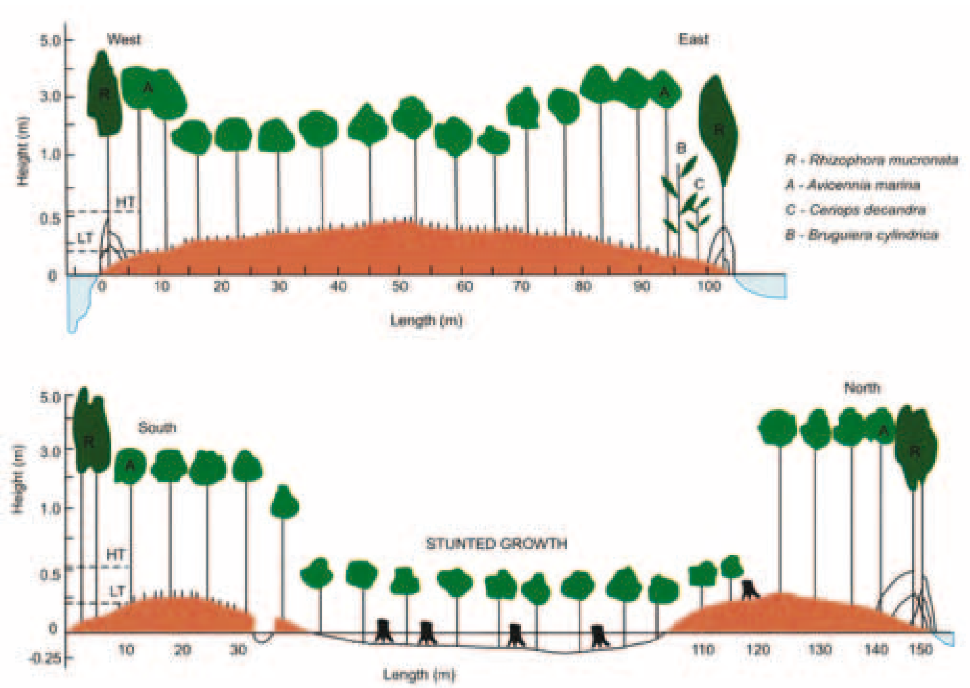

Figure 1 Smooth topography of healthy mangroves (top) and trough-shaped topography of saline blanks (bottom). The latter causes stagnation of tidal water leading to hypersalinity.

Further investigations revealed that past management practices were primarily responsible for the development of the trough-shaped hypersaline blanks. The Pichavaram mangrove wetland has been managed by the Forest Department since 1911. From 1935 to 1975, it was managed under a coupe-felling system, in which mature mangrove forests were clear-felled in coupes at regular intervals for timber, poles and firewood. About 500 ha of healthy mangrove forest was clear-felled in 20 coupes in Pichavaram between 1935 and 1975 (Venkatramani, 1951; Thangam, 1961; Venkatesan, 1972). Over several decades, this system triggered a chain reaction leading to mangrove degradation (Figure 2).

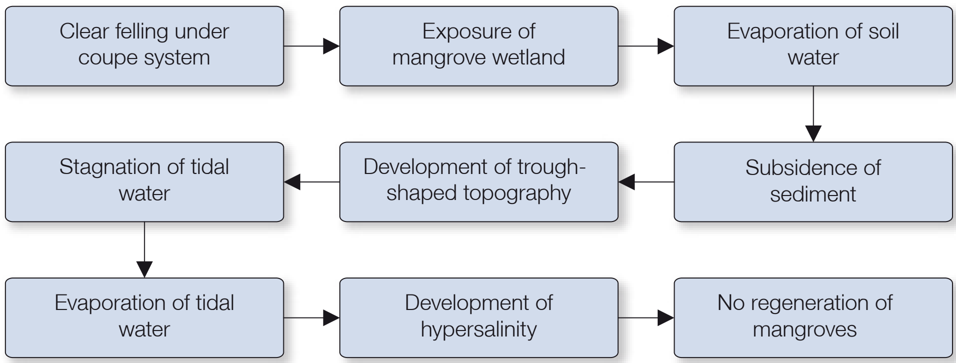

Figure 2 Flow chart of a chain reaction triggered by past mangrove management practices leading to degradation of mangrove wetlands

According to Allen (1984) and FAO (1994), subsidence of sediment is a common feature in wetland soils exposed to prolonged solar radiation. Stephens and Speir (1969) observed surface subsidence of mangrove sediments in the Florida Everglades, where peat soils that formed under mangroves were cleared for agricultural development.

3.2 Development of restoration technique for saline blanks

As detailed above, the stagnation of tidal water in the trough-shaped blanks and subsequent increase in salinity were mainly responsible for their degraded condition. It was hypothesized that, if provision was made for free movement of tidal water in and out of the trough-shaped areas, the saline blanks could be restored. To test this hypothesis, a 10-ha area of saline blanks was selected and, based on its topography, a canal system was designed and constructed. This consisted of a main canal and a number of feeder canals laid out in a "fishbone" pattern (Figure 3).

The main canal was connected to a nearby natural canal. It was observed that during high tide, tidal water entered the trough-shaped area and spread across the entire area through the feeder canals. At low tide the water drained out completely. As a result of this tidal flushing during both the summer and the monsoon seasons, soil and pore water salinity declined steeply and soil moisture increased.

Mangrove plants (*Rhizophora apiculata*, *Rhizophora mucronata* and *Avicennia marina*) were planted along the main and feeder canals at 1-m intervals. In the first year, the survival rate was about 80%; thereafter, the number of plants in the demonstration area increased because of the regeneration of propagules flushed into the site by tidal waters.

Figure 3 Fishbone canal system developed to facilitate free tidal flushing of saline blanks. Photo © MSSRF.

3.3 Development of JMM programmes

At the end of the successful demonstration at Pichavaram, three key questions surfaced:

1. Who will maintain the artificial canal system?
2. How to upscale restoration activities?
3. How to sustain the restored mangroves?

Answering these questions led to a community-based JMM programme, pilot tested in the Muthupet and Pichavaram mangroves of Tamil Nadu; the Krishna and Godavari mangroves of Andhra Pradesh; the Devi and Mahanadi mangroves of Orissa; and the Sundarbans of West Bengal.

In these areas, as a first step, mangrove user communities were identified and project villages selected based on the intensity of resource use, socio-economic conditions, and willingness to participate in JMM. After an intensive development process facilitated by MSSRF, a village-level institution, the Village Development and Mangrove Council (VDMC), was established in each village with a decision-making and an executive body. The decision-making or the general body consisted of a male and female representative from each participating family, and the executive body consisted of community leaders and members, and representatives of the State Forest Department, with equal representation of women and men. The capacity of these institutions was regularly improved through orientation workshops, training in participatory project management methods, exposure visits to successful participatory natural resource management projects, and technical training in restoration.

3.4 Micro-planning

Participatory rural appraisal and a socio-economic survey were used to identify the concerns of the communities and the State Forest Departments relating to mangrove conservation and management, and community and village development. Micro-plans were prepared and implemented to address these concerns. Funding for the plans was mobilized from a small grant project supported by the Mangroves for the Future Initiative, the State Forest Departments, financial institutions and government institutions.

3.5 Mangrove management unit and restoration

A mangrove management unit is defined as the part of a mangrove wetland traditionally used by a village community to meet its their basic needs. The communities, State Forest Departments and MSSRF jointly identified and demarcated suitable management units for project villages, and also designed the canal systems for restoration. Funds were provided to the VDMCs, who mobilized both women and men for constructing canals, collecting propagules and planting. The VDMCs also prepared plans for plantation maintenance in consultation with the Forest Departments. Different villages followed different methods to protect the plantations and nearby mangroves. The VDMCs were required to involve women in all activities and provide equal wages to women and men. This obligation was initially resisted by the men, but later accepted as a norm after persistent efforts by MSSRF.

3.6 Livelihood and poverty reduction

Apart from ensuring access to mangrove resources, particularly fishery resources, a number of livelihood-strengthening and poverty-reduction activities was implemented in the project villages. These played a critical role in sustaining people's interest in participatory mangrove management. For example, in one of the villages a primary school was started with project support; it has now grown into a middle school. This motivated parents to participate actively in the processes of mangrove management. In addition, a substantial sum was given to each VDMC as a corpus fund, to be used for making loans to its members. This avoided exploitation by money lenders. For livelihood augmentation, three different kinds of interventions were implemented:

1. Interventions that would enhance or strengthen the current livelihood activities.
2. Demonstrations of potential income-generating opportunities in a participatory mode, so that viable options could be taken up in the future.
3. Vocational skills training.

In the event, people proved more interested in interventions that enhanced or strengthened existing livelihood activities, rather than alternative livelihood or income-generating activities.

3.7 Outputs of JMM

- Established 33 VDMCs for joint mangrove management with about 5,240 mangrove user families as members.
- Restored 1,447 ha of degraded mangroves through these village-level institutions.
- Planted about 6.8 million mangrove saplings in the restored areas, of which 75–80% survived. A substantial increase in plant density due to natural regeneration was noted after one or two years in the restored areas.

- About 12,000 ha of flourishing mangrove forests were brought under JMM.
- Organised 194 self-help groups, comprising both women and men, and linked them to various government livelihood schemes.

Mangrove restoration activities generated 90 person-days of work per hectare; hence the JMM pilot projects generated 135,000 person-days of work in total. Even today, JMM is creating employment for rural communities as mangrove restoration activities are continuing.

3.8 Current status

The Ministry of Environment and Forests (MOEF) of India formed a sub-committee to evaluate the mangrove restoration technique and JMM programmes. The MOEF declared these as the best available approaches and included them in its National Mangrove Action Plan. As a result, actions to restore and conserve mangrove wetlands at the national and state level have increased, as reflected in the increased allocation of resources by the central government to state governments for mangrove restoration and management programmes.

Two of the pilot mangrove areas, Pichavaram in Tamil Nadu and Godavari in Andhra Pradesh, have been completely restored through replication of the JMM model by the respective State Forest Departments. A recent Forest Survey of India report indicates that the country's mangrove forest cover has increased by 616.56 km^2 over the past two decades, from 4,046 km^2 in 1987 to 4,662.56 km^2 in 2011 (FSI, 2011). The community-based JMM programme is reported to have played a catalytic role in this growth, not only by developing and demonstrating suitable models, but also by inducing changes in the programmes and policy of MOEF (FSI, 2011).

4. Conclusions and recommendations

As described above, a location-specific, science-based, community-centred and process-oriented approach is needed for sustainable management of mangroves and other coastal resources and ecosystems. Such an approach can be promoted through a multi-stakeholder community–NGO–government–private partnership. The concerns of the mangrove user community should be incorporated into the coastal and marine governance framework, by giving them opportunities to participate in decision-making and policy-making processes. This will create a "win-win" situation for all stakeholders in coastal resources management in India.

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Mangrove restoration and planting in micro-tidal barrier-built estuaries and lagoons in Asia – ideology versus sustainable ecosystem science?

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Abstract

This paper provides a preliminary synthesis of information on mangrove restoration and planting for some micro-tidal barrier-built estuaries and lagoons in Sri Lanka, Indonesia and India. Activities relating to mangrove restoration, planting and bioshields are compared and analyzed on the basis of the hypothesis that mangrove restoration and planting (and bioshields) cause long-term changes in micro-tidal barrier-built estuaries and lagoons that undermine their functional integrity as social-ecological systems by diminishing their fishery value, mainly through accelerated sediment entrapment. The hypothesis could be falsified by appropriate measurement of sedimentation rates and fishery yield.

The comparisons did not intend to recognize linear cause-effect relationships between mangrove restoration and planting, and sedimentation processes, since the systems are complex and fraught with many uncertainties within a diverse web of relationships. The aim was to determine if mangrove restoration and planting appear to support the hypothesis in a recognizable manner as a dominant relationship. The evidence supports the hypothesis. The incorporation of the precautionary principle into these activities is indicated. The results reveal:

- Mangroves and inappropriately sited bioshields are implicated in accelerated sedimentation and diminishment of the fishery in Rekawa Lagoon, although the economic value of mangroves was shown to be unrealistically high. The economic study was supported by an organization that funded mangrove planting and bioshields.

- Mangrove restoration and planting that accelerated in Negombo Lagoon under the UNDP/UNESCO Regional Mangrove Project in the 1980s, and gathered momentum under subsequent funding arrangements, contributed substantially to the acceleration of the sedimentation trend.

- Heavy sedimentation and stabilization by mangroves in Segara Anakan as demonstrated by historical records dating back to 1903 resulted in the diminishment of the fishery habitat by 50%. Major investment in restoration of the ecosystem appears to be failing since among others, further rehabilitation of mangroves may have been unwarranted.

- Mangrove restoration and planting, as well as inappropriately sited and technically incorrect bioshields, appear to have contributed to accelerated sedimentation. The investment in bioshields may be regarded as wasted public funds.

- Restoration of Chilika Lagoon since the 1990s under the Chilika Development Authority has been highly successful. Restoration apparently did not include any activities related to mangroves, although studies showed that they had been degraded and lost in the past. Hydrological restoration by itself restored fishery livelihoods and safeguarded biodiversity.

A large technical literature is available for mangrove restoration, planting and bioshields. Some material relates to these activities in micro-tidal barrier-built estuaries and lagoons. These entities are among the most threatened coastal ecosystems in Asia. Millions of coastal community households depend on their ecosystem services for livelihoods. Mangrove restoration and planting in micro-tidal barrier-built estuaries and lagoons currently appear to

be isolated from the diversity and complexity of the social-ecological relationships that drive change in these systems. An inter-disciplinary discourse is required at a regional level within the integrated coastal management context.

Keywords: mangroves, estuaries, lagoons, restoration, livelihoods, Sri Lanka

1. Introduction

Dynamic micro-tidal barrier-built estuaries belong in a class of complex coastal ecosystems occurring in Sri Lanka and other tropical Asian countries, including India, Indonesia and Viet Nam. Incorrectly termed lagoons, they range in size from India's Chilika Lagoon (about 1,000 km^2), the largest in Asia, to the more common size of tens to hundreds of square kilometres. They are critical for fishery-based livelihoods of coastal communities in developing countries. Micro-tidal lagoons are later stages in the geomorphological evolution of barrier-built estuaries, mainly by way of sediment entrapment from land drainage and naturally impeded tidal hydraulics (Day *et al*., 1989).

The fundamental ecological variables that determine the functionality and sustainability of micro-tidal barrier-built estuaries and lagoons are hydrological, and include the balance between sediment entrapment, stabilization and tidal flushing. This is the case simply because the natural destiny of barrier-built estuaries is disappearance by infilling (Perkins, 1974). Therefore, variables that accelerate sedimentation processes simultaneously hasten the transformation of these entities, from open waters supporting viable fishery habitats into mosaics of stabilized mud flats and creeks. In the tropics, mangroves exist in these entities, typically as fringing intertidal vegetation. Oceanography determines the nature of tidal influences, which may range from micro-tides to macro-tides. Tidal amplitude directly influences the extent of intertidal fringing mangroves. Watershed dynamics and sediment loads may contribute positively to mangroves, while concurrently impacting hydraulics in a negative way. Some of these counteracting processes could have a lesser impact in larger than in smaller water bodies. Each entity will be characterized by its particular ecological, social, cultural and institutional histories, which impart differing economic values and need to be assessed individually (Constanza, 2008). Therefore, the scientific prospects for mangrove restoration or assisted rehabilitation involving planting are linked to the scales, associated processes, and patterns that determine ecology (Wiens, 1989; Farnsworth, 1998).

Mangroves generally occur in eight biophysical settings (Cintrón and Shaeffer-Novelli, 1992). This paper refers to mangroves in drowned river valleys that originated during the Holocene Transgression, and subsequently evolved into barrier-built estuaries and lagoons. Although mangroves date to the Cretaceous, their present scale and form are more recent; they evolved from about 10,000 years BP when the eustatic sea level stabilized as observed today (Ellison *et al*.,1999). To simplify the diversity and complexity of environmental settings, Lugo (2002) used three levels in discussing mangrove conservation in the Caribbean and Latin America. This paper uses the same arrangement and refers mainly to regional mangrove ecosystems.

Mangrove "restoration" in developing countries usually takes the form of assisted rehabilitation in open access, common pool and common property resource systems that belong to the state (and this is what mangrove restoration refers to in the present paper). Mangroves planted as seedlings in these publicly owned spaces yield benefits when the vegetation reaches partial maturity after 10–15 years. In the interim, changes in initial conditions, negative externalities such as accelerated sedimentation, as well as the problem of "free rider" goods could come into play, resulting in social conflict (Ostrom, 1990). Who benefits and who loses thus becomes an important consideration. In those micro-tidal barrier-built estuaries that are relatively shallow, mangrove restoration results in land or wetland build-up unless water flow is maintained by design (for example, the fishbone channel mangrove planting technique in India; see Selvam, Ramasubramanian and Ravichandran, this publication). Who will own such land or wetland? Will ownership be determined through a clash of power where economically weaker coastal communities may lose?

The opportunity for generating benefits is linked to the scale on which restoration of mangroves occurs to compensate for degraded vegetation, and how it relates to essential hydrological processes, since water surface area, volume and flow are needed for fishery habitats and many other non-fishery uses. In the event that mangroves compete for "fish living space", should removal of mangroves be considered? The case study of Segara Anakan poses this question. In New Zealand, managing the spread of mangrove vegetation into estuaries is done through carefully planned removal (Schwarz, 2003). In Hawaii, introduced mangroves even warrant categorization as invasive plants for the purpose of conserving biodiversity, including control by defoliation (Convention on Biological Diversity, 2003).

This paper was designed as a contribution to the controversy pertaining to mangrove restoration and planting, and bioshields, that warrants discussion at a regional colloquium. Sri Lanka addressed the same subject at a previous inter-disciplinary colloquium combined with field assessments of mangrove restoration and planting (and bioshields) in micro-tidal estuaries and lagoons. It contributed towards a partial review of policy and recognition of safeguards. The purpose of this paper is to support MFF's Strategic Implementation Framework (2006), (mainly in regard to two of its Programmes of Work (PoWs):

- Improving the knowledge base for coastal planning, policy and management (PoW 1).
- Promoting adaptive coastal management programmes that include ongoing ecological and socio-economic assessments and monitoring (PoW 14).

Both of these PoWs enable learning and refinement of policies, associated project implementation processes, their governance, and indicator-based monitoring and evaluation. This paper flows from the author's close technical relationship with IUCN Sri Lanka as a contribution to adaptive management of mangrove restoration and planting (and bioshields) in micro-tidal barrier-built estuaries and lagoons. Adaptive management aims to identify uncertainties in the management of an ecosystem while using hypothesis-testing to further learning (Resilience Alliance, 2010).

Guidelines are available for mangrove restoration and planting, including a distinction between "restoration" and "planting" generally (Saenger and Sideek, 1993; Field, 1998; Lewis, 2005). Kathiresan (2003) explains mangrove-related sedimentation, and India's MFF National Strategy and Action Plan provide guidelines that are valuable for micro-tidal barrier built estuaries (MFF, n.d.). Other "Best Practice Guidelines for Mangrove Restoration" are available that ignore potential negative externalities including entrained sedimentation (IUCN, 2007). Therefore, it would be useful to synthesize available knowledge from a landscape perspective suited to ecosystem-based management of mangroves. This may enable convergence with the ecosystem approach to fisheries management (FAO, 2003; Cochrane and Doulman, 2005), which regards mangroves as integral parts of the fishery landscape.

Without safeguards, subdivision and conflict in hydrologically unified micro-tidal barrier-built estuaries and lagoons could occur. Those engaged in mangrove restoration and planting may claim territorial rights over parts of public property in which investments have been made (for example tourism interests), with ensuing conflicts. Additionally, in economic terms, a negative externality is involved when micro-tidal barrier-built estuaries and lagoons are considered as natural capital in the public domain. Those investing in mangrove restoration and planting are rarely dependent on their fishery resources for livelihood support. The risks to them are non-existent, since they may have already received payment for the activity, whereas the fishery-dependent resource users, arguably the poorest segment in most developing countries, must bear the full cost of adverse impacts arising in the longer term.

The paper presents an indicative synthesis of information from a concerned ecologist's perspective, to indicate some dimensions for discourse that relate both to ecosystem fragmentation and its socio-economic consequences. The author has the impression that core beliefs that drive mangrove restoration require expansion and diversification to make the activity responsive to the dynamic complexity of micro-tidal, barrier-built estuarine ecosystems. They are arguably the most vulnerable among coastal ecosystems, where millions of livelihoods depend upon their ecosystem services (Constanza, 2008). Perhaps an ecologist's concerns may resonate with similar thoughts of other participants at the colloquium to stimulate discourse on the spatial and temporal complexities of mangrove restoration that require examination in the context of integrated coastal management in Asia.

The author is conscious that the colloquium participants are predominantly mangrove specialists who believe in the "goodness" of mangroves. Anything that appears threatening to the interests of mangrove restoration may provoke cognitive dissonance, that is, an inability to deal with evidence that contradicts a belief. Therefore, it is necessary to state at the outset, in order to encourage empathy, that this paper only suggests an additional way of thinking about mangroves. Actions and consequences in complex ecosystems cannot be reduced to linear cause–effect relationships. Nevertheless, in the event that beliefs about complex systems have been too simple, it should be possible to demonstrate unintended consequences flowing from "good" activities, and to ask cogent questions about their scientific foundation (Merton, 1996). Colloquium participants then may choose to discuss the need for verification of key inferences, and whether conventional theory (existing beliefs) needs modification.

2. Materials and methods

This section provides material for assessing, indicatively, the "scientific foundation" of the existing practice of mangrove restoration, including planting and bioshields. The site information (see Tables 1, 2 and 3 below), selected from an array of published and unpublished material, is combined with the author's insights from field experience, to explore the hypothesis that, after mangrove restoration, long-term changes in micro-tidal barrier-built estuaries and lagoons undermine their functional integrity as social-ecological systems by diminishing their fishery value, mainly through accelerated sediment entrapment. This hypothesis can be validated or rejected by comparing sedimentation rates and fishery yields before and after mangrove restoration.

A case study approach is used to provide evidence in support of the hypothesis. Chilika Lagoon was selected since it is a micro-tidal barrier-built estuary where there has been no mangrove restoration. A caveat is required in regard to interpretation of the case studies, since an ecological perspective is applied predominantly, while also making an effort to bring in interdisciplinary considerations. In Indonesia, Segara Anakan is being studied in a socio-ecological context that should provide more incisive information (Taurusman *et al.*, 2010).

A case study approach to test hypotheses may appear inadequate to support inferences for complex social-ecological-political entities, according to the perceptions of some scientists who prefer to think in simple cause–effect, linear relationships (Holling, 1978; Ostrom, 2007). However, it is precisely the absence of cause–effect relationships in complex systems that frustrate purely technocratic approaches. There are too many variables involved to fully comprehend complex ecosystems, not to mention the impossibility of conducting the kind of controlled experiments that might yield scientifically credible answers. Therefore, in seeking to understand complex systems, systematic use of case studies is warranted (Ostrom, 2007; also see Bryant and Wilson, 1998; Wilson, 2009). They enable recognition of dominant ecological patterns and processes (Wiens, 1989), which would justify heuristic inferences (Kuhn, 1970).

The case studies share criteria that enable logical comparison (Table 1). They present scenarios across orders of magnitude to enable some understanding of the manner in which the impact of mangrove restoration is related to the scale of the total estuary system. Tables 2 and 3 provide sets of basic information. The latter enables sensitization to the magnitude of the natural capital involved. The proposed questions that may be addressed in the discourse are, Do the case studies warrant inter-disciplinary analysis of the hypothesis presented by the author? and, What are the meaningful regional approaches that may be useful?

3. Results and discussion

The case studies demonstrate that mangrove restoration/rehabilitation (and bioshields) are simply one set of land-use options, interacting with others. This is important to note, because for almost three decades, since initial efforts to promote mangrove conservation started in the mid-1980s (Vannucci, 1988a; 1998b), the prevalent inclination has been to view mangrove restoration in isolation instead of holistically. The controversy that prompted this colloquium indicates changing perceptions. Harmonization among land uses is necessary, preferably through integrated coastal management (ICM), where the goal is to improve the quality of life of human communities who depend on coastal resources while maintaining the biological diversity and productivity of coastal ecosystems. Thus ICM must integrate government with the community, science with management, and sectoral with public interests in preparing and implementing actions that combine investment in development with the conservation of

Table 1 Characteristics of the selected sites that enable meaningful comparison

Study site	Micro-tidal	Surface water area (ha)	Extent of mangroves	MR&P	Bioshields	Urbanization	Fishery livelihoods
Rekawa Lagoon [a]	Yes	278	100	Yes	Yes	Moderate	Marginal
Negombo Lagoon [b]	Yes	3,000	253	Yes	?	Intense	>3,000
Segara Anakan Lagoon [c]	Yes	2,600–3,000	>3,000	Yes	?	Intense	–
Batticaloa Lagoon [d]	Yes	15,000	650	Yes	Yes	Intense	>20,000
Chilika Lagoon [e]	Yes	100,000	?	No (?)	No (?)	Intense	>50,000

Sources: [a] http://pdf.usaid.gov/pdf_docs/PNADO964.pdf; Rekawa Special Area Management Coordinating Committee (1996). [b] Devendra (n.d.). [c] http://www2.adb.org/Documents/PCRs/INO/22043-INO-PCR.pdf. [d] http://www.neccdep.com/Studies/Final/Batticaloa/Study%20-%2005%20-%20NECCDEP.pdf. [e] Ghosh and Pattnaik (2006).

Table 2 Some basic parameters of the five selected estuaries and lagoons

Area (ha)	Mean tidal range	Salinity (ppt)	Nature of tidal inlet	Mangrove area (ha)	Basin area (km²)	Trapped sediment load (m³/yr)	Management status
Rekawa Lagoon (lagoon)							
278 [a]	<10 cm when inlet opens	<5	Opens briefly, assisted manually	70	<200	Not measured	Sporadic effort. Fishery livelihood diminished
Negombo Lagoon (barrier-built estuary)							
3,000	<40 cm	0–30	Open perenially	230	720	70,000	Sporadic efforts. Fishery livelihood endangered
Segara Anakan Lagoon (barrier-built estuary)							
3,225 [b]	<1.5 m	0–25	Open perennially following restoration	1,995 (as islands) 12,610 (intertidal)	835	2.6 million	Restoration by ADB, mangroves rehabilitated, fishery diminished
Batticaloa Lagoon (barrier-built estuary)							
15,000	10–40 cm when inlet opens	0–25	Closes seasonally	321	>800	Not measured	Sporadic effort. Fishery livelihood endangered
Chilika Lagoon (barrier-built estuary)							
100,000	<1.5 m	0–15	Open perennially following restoration	Nil / ? Mangroves existed in the past	4,300 (to be verified)	1.8 million	Restored tidal inlet and fishery; managed by Chilika Development Authority

Sources: [a] Ganewatte *et al*. (1995). [b] White *et al*. (1989).

Table 3 Some indicative fishery-related economic values of the five selected estuaries and lagoons

Population engaged in fishing	Estimated annual income (US$ m)	Daily income of fisher household (US$)	Average value of estuary or lagoon (US$/m²)	Value of investment in studies, restoration, management, etc. [a]
Rekawa Lagoon [b]				
144	0.71 (doubtful validity: see text)	>15	0.26	About US$100,000 (estimate)
Negombo Lagoon [c]				
3,000	4.8	< 3	0.16	About US$300,000 (estimate)
Segara Anakan Lagoon [d]				
?	?	?	?	US$78 million
Batticaloa Lagoon [e]				
20,000	12.2	2	0.08	About US$2 million (estimate)
Chilika Lagoon [f]				
50,000	?	?	?	US$12.7 million [g]

[a] Estimated and reported investment to enable comparison with value of fishery earnings.
[b] Ganewatte *et al*. (1995), Joseph and Kumara (2001), Ranasinghe and Kallesoe (2006).
[c] The unit value of a square metre is indicative of the minimum sedimented area around a mangrove plant.
[d] White *et al*. (1989), ADB (2006).
[e] Samarakoon and Samarawickrama (2012).
[f] Ramsar site. Ghosh and Patnaik (2006).
[g] Government of India and World Bank data, 1996–2004.

environmental qualities and functions” (GESAMP, 1996). Harmonization becomes possible where the “thinking” that drives particular land uses acquires clarity. The axiomatic “law of unintended consequences”, which draws on Merton’s (1936, 1996) insights and theoretical explanations, provides one option.

3.1. Sedimentation processes, mangrove restoration, planting and bioshields

Rekawa Lagoon and Chilika Lagoon constitute the extremes of the size range. Rekawa Lagoon, the smallest, is most vulnerable to changes in its hydromorphology (the relationship between the forces of water flow and sediment deposition and shaping). It is also associated with a historical legacy of obstructed environmental flows. Man-made impediments to the flow of water, for example water control structures, increasingly exposed the system to the impact of coastal processes (longshore drift and wave action), which resulted in closure of the tidal inlet, impeded tidal flushing, and accelerated sediment entrapment (Ganewatte *et al*., 1995). Chilika Lagoon, several orders of magnitude larger, likewise suffered the impact of coastal processes on tidal flushing. The tidal inlets of both systems were blocked by spits formed by longshore drift. This similarity demonstrates shared vulnerability to the dominance of coastal processes. Changes in the hydrological and hydraulic patterns influence this vulnerability.

Regardless of existing vulnerability, mangrove planting under the label of restoration and rehabilitation was promoted under the special area management planning process for Rekawa Lagoon, and subsequently by organizations dedicated to mangrove interests. Mangroves expanded by 100 ha in 10 years between 1984 and 1994 (IUCN/CEA, 2006), amounting to about 30% of total water area. None of the decision-making entities shared livelihood interests with the local communities based on the lagoon's fishery. Post-tsunami, mangrove restoration and planting was justified by economic studies (Ranasinghe and Kellesoe, 2006). However, the methodology was questionable and conclusions did not match the reality of the fisheries. A high value was assigned based on the assumption that marine fish catches were served by the nursery function of the lagoon. The authors chose to ignore that the tidal inlet of Rekawa Lagoon remains closed during most months of the year, unless breached manually. In 2009, independent validation (IUCN, 2011) revealed that the number of full-time fishers had decreased to about fifteen, and the catches consisted mainly of tilapia (*Oreochromis* sp.), and other freshwater varieties that rarely or never migrate to the sea. The lagoon fishers enthusiastically collected mangrove seedlings, for a payment, for mangrove planting since it was more profitable than fishing (IUCN, 2011). Persuading poor people in need of every form of income, through cash incentives, cannot be interpreted as sustainable development in their own interests (Sen, 1995; 1999). The costs of mangrove restoration stemming from negative externalities are borne by the same communities years after the project implementing entities depart.

In the case of Rekawa Lagoon, mangrove restoration and bioshields were brought into management in an unintegrated manner despite the existence of Coordinating Committee (Rekawa Special Area Management Coordinating Committee, 1996). Whoever came onto the scene with money to pay for seedling collection by the labour of local residents, could complete a mangrove restoration project, receive allocated funds and claim success. Selection of a planting site was indiscriminate since it had no relationship to any historical presence of mangroves that were subsequently degraded. The technical rationale for restoration was ignored (Erftemeijer and Lewis, 2000). The result of mangrove restoration was further acceleration of sedimentation, now combined with eutrophication and a diminished fishery.

In the case of Chilika Lagoon (Ghosh and Pattnaik, 2006) the integrated and participatory planning placed hydrological and hydraulic restoration at the top of the "restoration agenda". Physical interventions did not occur that could impede hydrology, and included interventions for removal of water reed spread (not mangroves). All management decisions were guided by enhanced governance. The intended consequences were demonstrated spectacularly in many ways including increases in fish catches and human well-being.

Both Negombo Lagoon and Segara Anakan Lagoon were vulnerable to sediment entrapment that impeded hydrology, hydraulics and hydromorphology. As both are an order of magnitude larger than Rekawa Lagoon, water surface area may have slowed the process of sediment entrapment and infilling, but could not avert it. Mangrove planting and rehabilitation in Negombo Lagoon and in Segara Anakan, although on different scales, accelerated the process of sedimentation. In the case of Negombo Lagoon, infilling by itself did not undermine the fishery entirely, since the tidal inlet was maintained by coastal engineering works. This allowed recruitment of larval and juvenile stages of fish and crustaceans into the water body where seagrasses contributed to the nursery function. Maintenance of the tidal inlet, however, was for the purpose of safeguarding free access for marine fishing craft to this most important of Sri Lanka's fishery anchorages (Samarakoon and Van Zon, 1991).

Segara Anakan had mangroves on an order of magnitude scale greater than in Negombo Lagoon. Sediment entrapment and mangrove spread (Table 4) were proportionately greater (White *et al.*, 1989). The total extent of expansion of mangroves into the water body between 1903 and 1996 was 3,540 ha, which reduced the fishery area by about half. The tidal inlet failed by the early 1980s, undermining the fishery within the estuary as well as the coastal shrimp stocks that depended on the estuary as a nursery. The ADB restoration programme started in the late 1980s (ADB, 2006). The fishery was partially restored by coastal engineering that opened the tidal inlet, which allowed larval and juvenile recruitment. The situation was seriously undermined when all the planned ADB interventions could not be concluded in an integrated manner. The river diversion project which was necessary for sediment deflection from the water area was abandoned before project completion. On the other hand, the "intertidal" mangrove rehabilitation of more than 1,000 ha was completed successfully. This led to an imbalance between the two inter-linked project components. Sediment inflows persisted while the large-scale mangrove rehabilitation was highly effective in trapping sediment downstream, stabilizing and converting it to marsh. At project conclusion the expectation was that the lagoon would transition inevitably to a marsh-tidal creek system (ADB, 2006).

Table 4 The rate of loss of total estuary and water areas in Segara Anakan, 1900–1984

			Water area loss (ha)	
Year	**Total area (ha)**	**Net water area (ha)**	**Total**	**Per year**
1900	6,898	6,675	–	–
1924	6,791	6,445	230	10
1940	6,645	6,049	396	25
1946	6,061	5,412	637	106
1961	5,444	4,737	675	45
1978	4,831	3,852	885	52
1980	4,680	3,636	214	107
1982	4,375	3,206	432	216
1983	4,313	2,959	247	247
1984	4,050	2,761	198	198

Source: White *et al*. (1989).

Comparable events in Negombo Lagoon, partially attributable to indiscriminate mangrove planting, occurred over a period of about 30 years (Nagabatla *et al.*, 2008) When eventually the opportunity for hydraulic restoration was provided by way of a project co-financed by ADB, the Coast Conservation Department (the project implementing agency) could not prevail to implement dredging. It was unable to overcome opposition from members of coastal communities who owned land abutting the area demarcated for dredging. These were the once "landless" poor who captured land from the lagoon by way of planting mangroves, now grouped as a land-owning political force (CCD, 2005; Samarakoon and Samarawickrama, 2012).

Some of the private properties that became a management problem in Negombo Lagoon in 2004 were created through mangrove planting dating back about 25 years to the time when the UNDP/UNESCO Regional Mangrove Project RAS/79/002 encouraged mangrove rehabilitation at the same locations. A relationship with hydraulics then was not foreseen by the proponents. It is notable, in the context of temporal "uncertainties" of complex ecosystems, that in 1986, during a field visit organized as a part of a regional symposium, prizes were awarded to school children in Negombo Lagoon under the slogan "Let us conserve mangroves", while in the background their parents engaged in housing expansion on degraded mangrove areas (Field, 1988). This reflects the reality of dynamics in micro-tidal barrier built estuaries and lagoons; the uncertainties are such that the "applauded present of 1986" would be buried with time, but rise to "bite back" in a different context.

Batticaloa Lagoon, an order of magnitude larger than Negombo Lagoon and Segara Anakan, was faced already with accelerated sedimentation stemming from development activities that fragmented the integrity of its hydrology and hydraulics (Santharooban and Manobavan, 2005; IUCN, 2011). Mangrove restoration and bioshield development constituted a layer of land uses that contributed to accelerated in-filling and fragmentation (Samarakoon and Samarawickama, 2012). The North-East Coastal Community Development Project, financed by ADB, engaged in substantial mangrove planting activities (termed restoration/rehabilitation) both before and after the 2004 Indian Ocean tsunami (JUGAS Ltd., 2010). Organizations involved with bioshields (also termed "greenbelts") chose to ignore technical guidelines available from some two decades previously (Soerianegara, 1988) and in the immediate aftermath of the Indian Ocean tsunami (FAO, 2007). Neglect of technical guidelines by funding organizations, as well as by subsidiary implementing environmental NGOs, was perhaps motivated more by the availability of money, post-tsunami, and the urgency of spending in order to access more, rather than by any empathy towards communities exposed to coastal hazards. This is akin to the phenomenon in the arena of post-tsunami relief and reconstruction in Sri Lanka that Stirrat (2006) termed "competitive humanitarianism".

Bioshields, when mature after 10–15 years, technically must possess the proper dimensions to be effective as windbreaks and to decrease the force of run-up of wind-driven, short period waves, for example 500-m wide and 1000-m long, with inter-plant spacing of a metre at maturity (FAO, 2007). Moreover, bioshields need to be at points along the coastline where wave run-up occurs, rather than inside sheltered waters such as barrier-built estuaries where waves are practically non-existent. The author's observations indicate that the bioshields planted in Batticaloa Lagoon did not adhere to these technical specifications.

Why were mangrove bioshields implemented in an aberrant form? The short answer is that mangroves do not exist naturally fronting coastlines in Sri Lanka. Therefore, it is not possible to nurture mangroves where bioshields actually belong. But funds were available for bioshields, and consequently recipients and funding organizations, driven by their immediate interests, planted mangroves opportunistically wherever they would grow and termed them "bioshields". Caution in this regard was emphasized in the MFF Sri Lanka National Strategy and Action Plan (IUCN, 2009).

Before implementing mangrove bioshields on a broad regional scale with global funding, Baird (2006) expressed concerns about greenbelts (another term for bioshields): “The crux of the issue for me as an ecologist is that bad science is being used to justify worse policy, with the potential for major social injustice. Hopefully, it is not too late to reverse this injustice before my profession becomes complicit in one of the great land grabs in post-colonial history”.

Chilika Lagoon’s hydrological restoration (see Tables 1 and 2 for a comparison of scale) demonstrates how management focused on the highest-order variables in an ecosystem can be effective (Holling, 1978), without being distracted by lower-order ones such as mangrove restoration and planting. This interpretation of Chilika Lagoon’s success should be considered in greater detail in terms of the political and socio-economic interests of planning and implementing partners. Nevertheless it is noteworthy that successful restoration in this largest Asian micro-tidal barrier-built estuary demonstrates both the significance of spatial scale as well as the strategic approach to restoration.

3.2. Perceptual causes of unintended consequences

This paper is a contribution to rethinking the way we view mangroves. The evidence in support of the hypothesis affirms the need for such a rethink. So it is necessary to ask the question, Why was mangrove planting, which clearly defied basic scientific principles, implemented in a way that appears to have harmed the functioning of these social-ecological systems? Partial answers can be derived from applying the axiomatic law of unintended consequences to the case studies from Sri Lanka (Table 5). The justifications for the interpretations may be taken up for discussion at the colloquium to assess their generalizability in Asia:

- **Ignorance**: Absence of adequate grasp of the geomorphological evolution of these entities and their hydromorphological destiny, while neglecting inter-disciplinary analysis before planning mangrove restoration, rehabilitation or bioshields.

- **Error**: Generalization of the “goodness” of the intention, irrespective of the physical and social contexts of the ecosystems. Successful and large-scale mangrove restoration had been carried out in other locations such as Bangladesh (Vannucci, 1988a, 1988b), therefore it was deemed appropriate across Asia. The author, having discussed problems of mangrove restoration in Negombo Lagoon with international experts, was aware of their reluctance to consider site-specific appropriateness. Metaphorically, mangrove planting in micro-tidal barrier-built estuaries is akin to performing organ transplants while allowing the patient to die. Error was also aggravated by disregard for existing technical guidelines.

- **Immediate interests**: Implementing mangrove planting simply because money was available, and more money would be forthcoming based upon the speed of completion of already funded activities, accompanied by disregard for monitoring, feedback and sustainability evaluations. Following the UNDP/UNESCO field visit to Negombo Lagoon in 1986, and the award of prizes for mangrove activities, many local community-based organizations and NGOs acquired funding from various sources, including international ones, to plant mangroves. The concerns of traditional lagoon fishers generally were rejected, since the NGOs with money had support from seedling collectors and planters.

- **Values**: The moral and ethical dilemmas of engaging in mangrove planting based on payments for services of community members, while undermining their long-term livelihood interest.

- **Self-fulfilling hypothesis**: In the 1980s, numerous academics became involved with the UNDP/UNESCO/NARESA Regional Mangrove Project (UNDP/UNESCO, 1988) implemented primarily on the west coast of Sri Lanka, which offered career rewards. Any provisional statements about mangroves soon became the guiding principle for reinforcing the positive ecological role of the vegetation and the correctness of mangrove restoration. Scientists set up experiments and carried out field surveys to support the "provisional statement", instead of seeking to test and reject it if necessary. However, it needs to be noted that scientists deny the "control" of the hypothesis over their actions since it is largely unconscious and often deniable.

Table 5 Comparison of how the law of unintended consequences influenced decision-making in three of the study sites

	Five attributes of the law of unintended consequences influencing decisions					
Study site	**Ignorance**	**Error**	**Immediate interest**	**Values**	**Self-fulfilling prophesy**	**Remarks**
Rekawa Lagoon	Yes	Yes	Yes	Yes/U	Yes/U	The dominant influence was that mangrove planting was in fashion (Vannucci, 1988b) and an assumption that the poorest fisher communities would benefit.
Negombo Lagoon	Yes	Yes	Yes	Yes/U	Yes/U	As above, combined with the inclination not to adequately understand the motivations and values of local communities enrolled into mangrove planting through incentives.
Batticaloa Lagoon	Yes	Yes	Yes	Yes/U	Yes/U	As above, combined also with a total disregard for existing technical guidelines. The power of funding agencies such as ADB, FAO in partnership with the Forest Department, or IUCN/MFF in partnership with the Ministry of Environment, was overwhelming.

Note: "Yes" indicates influence of a particular attribute in driving these activities. "U" means unclear. More than one attribute may have combined to influence thinking and decision-making.

3.3. Science and ideology

Marta Vannucci, when she was Chief Technical Advisor of the UNDP/UNESCO Mangrove Programme in Asia and the Pacific, declared, "The situation vis-à-vis mangroves has changed drastically over the last twenty years and mangroves are now in fashion" (Vannucci, 1988b). Fashion is a form of behaviour that generally is imposed by a dominant class in society. Fashion shares attributes with ideology, in that the latter "is a set of ideas proposed by the dominant class of a society to all members of the society (a "received consciousness" or product of socialization)" (Wikipedia, 2012a). The author's contention is that mangrove rehabilitation, as practiced today in micro-tidal barrier-built estuaries and lagoons, is driven more by ideology than by tested propositions (science).

4. Conclusions and recommendations

The supported hypothesis requires that serious consideration be given to fully incorporating the precautionary principle into planning mangrove restoration, rehabilitation or bioshield establishment, particularly by organizations such as MFF, which at present has a leadership role (hegemony) in mangrove matters. The precautionary principle states, "that if an action or policy has a suspected risk of causing harm to the public and to the environment, in the absence of scientific consensus that the action or policy is harmful, the burden of proof that it is not harmful falls on those taking the action" (Wikipedia, 2012b). This is already recognized in the Draft Code of Conduct for the Sustainable Management of Mangrove Ecosystems (Macintosh and Ashton, 2003).

Mangrove planting as practiced at present risks allegations that it embodies environmentally dangerous implications, namely, negative externalities, free riding on the commons, stimulating "creeping normalcy" (chronic disasters), contradicting the Millennium Development Goals that seek to reduce poverty, and a lack of accountability.

Mangrove conservation, restoration, planting, removal, non-restoration and bioshield establishment are all options for incorporation into sustainable management depending on the social-ecological history of particular geographic entities. Balanced incorporation of available options is possible within the framework of ICM.

Mangrove planting in micro-tidal barrier-built estuaries and lagoons appears to have been done in the past, and is continuing to be done now in Sri Lanka, with funds from various sources including the private sector, without adequate consideration of the complex ecosystem structure and hydraulic functioning of the parent ecosystem. The relevant literature and reports since 1990, as well as a colloquium report (IUCN, 2011; Samarakoon and Samarawickrama, 2012) reveal the diverse unintended consequences that have resulted. The lessons from experience appear to have been ignored by funding organizations in their haste to implement projects because of a combination of behavioural causes, including ignorance, error, immediate interest, inequity and self-fulfilling prophesy.

Misplaced bioshields planted in barrier-built estuaries and lagoons in Sri Lanka have exposed their fundamental technical errors, demonstrated through the "natural experiment" of the impact of a flood event; and therefore the investments are a waste of public funds.

The following recommendations would offer a practical solution to help ensure that these same errors and failures are not repeated in future:

- Convene a regional technical committee to produce draft guidelines for mangrove restoration and planting in general, giving specific consideration to the geomorphological settings of micro-tidal, drowned valley wetlands in which mangroves exist (Cintrón and Shaeffer-Novelli, 1992); the hierarchical arrangement of mangrove ecosystems (Lugo, 2002); site-specific social-ecological-political history; the landscape perspective; and recent technologies.

- Convene a regional sub-committee from the Asian countries in which MFF is active, and which have barrier-built estuaries and lagoons (i.e. India, Indonesia, Sri Lanka, Viet Nam), to produce guidelines congruent with the broader framework developed under the preceding recommendation, to ensure safeguards that incorporate the ecosystem approach to fisheries (FAO, 2003) and the precautionary principle, with due consideration also given to the emerging approaches to management of social-ecological systems (Ostrom, 2007).

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Session III

Guidelines for Good Practices in Mangrove Restoration and Rehabilitation

Mangrove rehabilitation through community involvement: establishing mangrove conservation awareness and education

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Abstract

Wildlife Clubs of Seychelles (WCS) is an NGO formed in 1994 to promote conservation in the Seychelles through environmental education. From July 2009 to December 2010, WCS undertook a wetlands education and rehabilitation project with financing from the MFF initiative. Project activities were organised at six different locations on the islands of Mahé and Praslin, and in Curieuse Marine National Park. The purpose of the project was to advocate for wetlands and mangrove ecosystems conservation, and to build capacity and understanding for wetland values and restoration through co-operative actions with children, the relevant national authorities, and local communities. To achieve this, schoolchildren, the general public and other stakeholders were involved in mangrove planting and rehabilitation activities at the six project sites. Four of these sites saw survival rates of between 10% and 40% in the planted seedlings. The Curieuse Marine National Park site had an 8% survival rate, and no seedlings survived at one rehabilitated site.

Most planting success can be attributed to the location chosen and the advice received from national mangrove experts on the best sites for rehabilitation. Only schoolchildren took part in planting activities at two of the project sites, whereas the others saw the participation of local community members, staff of a private hotel, and conservation officials. Compared with previous attempts, an increase was observed in the number of male WCS members participating in mangrove rehabilitation activities. Obviously, much work remains to be done to educate people about the importance and value of mangroves and wetland habitats in the Seychelles. A need still exists to raise awareness and provide training for youths, as well as local communities, in monitoring changes within wetland habitats. This is necessary to facilitate the rehabilitation of wetlands and to ensure community engagement in their conservation.

Keywords: mangroves, wetlands, rehabilitation, nature conservation, education, Seychelles

1. Introduction

The loss of mangroves leads to a number of threats to human safety and shoreline development, including erosion, flooding, storm waves and surges; reduced water quality and biodiversity; destruction in fisheries habitats and reduced catches; destruction of coastal habitats and reduction in revenue from tourism (Gilman *et al*., 2006). For these reasons, mangrove rehabilitation initiatives are usually undertaken to reduce these threats and increase resilience of mangrove habitats (Quarto and Lewis, 2003). However, in order for rehabilitation to be successful, there are a number of steps that need to be taken into consideration, including understanding the ecology of each species being planted, as well as any modifications to the original mangrove habitat, restoration of appropriate hydrological conditions, plus the actual planting technique (Lewis *et al*., 2006).

1.1 History of Seychelles mangroves

Before the arrival of settlers in 1744, the pirates visited the Seychelles islands, which were rich in marine and coastal biodiversity. Most of the coastal fringes were surrounded by mangrove swamps. The settlers that came after the pirates built roads along the coastline, and in some places the sea had access under the roads and thus the mangroves kept thriving. But in a large number of areas sea access was completely cut off, the remaining water stagnated and the animals died along with the mangroves. Overall, 90% of the original mangrove swamps around the country had been destroyed by the 1970s, making the protection and conservation of the remaining 10% all the more urgent (Gillham and White, 1973). Eventually mangroves started to be used by the people for timber, poles and firewood; *Rhizophora mucronata* was used as a dye to polish floors and in the early 20th century mangroves were exploited for commercial gains on some islands (Beaver, 1984). Today, most of the mangrove habitats in the Seychelles have been destroyed by development and land reclamation, except for a small area behind the reclaimed land in the north-east where the conditions created have been favourable for mangrove establishment (K. Beaver, pers. comm.).

1.2 Objectives

The mangrove restoration project undertaken by Wildlife Clubs of Seychelles (WCS) had the aim of bringing back the mangrove habitats to their original status, following removal of mangrove species around the islands due to development and natural hazards. It is hoped that through mangrove restoration, erosion of the coastal areas and the shoreline can be prevented.

There is a need for community education and awareness on the importance and function of mangroves, as many Seychellois do not completely understand the value of wetlands and the services they provide. Meanwhile, the Seychelles, consisting as it does of coastal islands vulnerable to the impacts of climate change, has a need to protect mangroves and other coastal wetlands that can help in protecting infrastructures and coastal developments from these impacts. Without proper understanding of the importance, value and role of mangrove, it is difficult for this to be achieved and for these resources to be used appropriately. Therefore, sensitization of Wildlife Club members as well as the local communities needs to be carried out, to ensure their engagement in wetland conservation actions.

2. Materials and methods

In order for the objectives to be met, a number of activities had to be carried out. These included developing leadership in coastal conservation in young people through recognition and training; increasing awareness and stakeholder input in mangrove conservation through participation; and implementing educational programmes and experience-based learning on mangroves and coastal management, including mangrove rehabilitation activities on two islands in the Republic of Seychelles.

2.1 Description of rehabilitated sites

Three districts around the main Mahé Island, as well as one site in the Curieuse Marine National Park, were chosen for rehabilitation:

- **Roche Caiman Site 1** was planted where no mangroves were growing, in a bare area with high wave activities. Seedlings were obtained from an established site and then transplanted to new site. Planting was carried out by WCS schoolchildren and 200 seedlings were planted.

- **Roche Caiman Site 2** was an area where mature mangrove trees were already growing a few metres from the shoreline and thus provided shelter for seedlings. Some seeds were obtained from Curieuse Island and grown in the club's nursery before transplanting. Seedlings were also planted by WCS schoolchildren as well as the Roche Caiman community. A total of 150 seedlings were planted.

- **Port Launay Site 1** was in an area that was not sheltered, where there was the establishment of mature mangrove trees; an area cleared for the construction of a concrete bridge giving access to the five-star resort adjacent to this Ramsar site. Seedlings were obtained from Port Launay mangrove area. Planting was carried out by WCS students and 100 seedlings were planted.

- **Port Launay Site 2** was in an area that was sheltered, among mature mangrove trees. Some seedlings were obtained from Providence while others were obtained from Port Launay. WCS schoolchildren planted the seedlings with the participation of the local community, Constance Ephelia Resort (a hotel located within the Port Launay Mangrove Ramsar Site), hotel staff and some tourists. A total of 800 seedlings were planted.

- **Mont Fleuri** rehabilitation was in a sheltered area, amidst other mature mangrove trees. WCS schoolchildren had the task of planting the seedlings and they were assisted by the Wetland Unit of the Department of the Environment, in charge of all management activities pertaining to the Seychelles wetlands. A total of 100 seedlings were planted.

- **Curieuse** mangrove seeds were planted in a sheltered area, where mangroves were not growing, but surrounded by mature mangrove trees. All seeds were obtained from Curieuse. WCS Praslin and La Digue schoolchildren and leaders, as well as staff from the Seychelles National Parks Authority and MFF representatives, participated in the planting process. This time, 600 seedlings were planted.

2.2 Conditions for rehabilitation

Roche Caiman Location 1 was rehabilitated using three species of mangrove seedlings, which increased diversity at this location when compared with the other five sites. There was no study conducted on current flow or structure of the soil, but the planting session was guided by the Wetlands Unit. Roche Caiman Location 2 was another area where no studies were conducted. However, advice was obtained from mangrove experts on where to plant the seedlings at Location 2. At Port Launay Location 1, again no studies were conducted, no advice was followed and planting took place without any expert input. Port Launay Location 2 saw the advice of experts being given on the best areas for planting the seedlings. Mont Fleuri was also an area where no study was conducted. However, the Wetland Unit of the Department of Environment participated in the planting of seedlings in that area, and in this way provided information on the best method to use when planting, and the best area for planting mangrove seedlings. Meanwhile, the Curieuse planting and rehabilitation activity saw the participation of Seychelles National Parks Authority researchers and staff, with expert knowledge being given to the planting team. Two species of mangroves were planted. However, the difference with Curieuse is that it was treated as an experiment to find out whether the two species used could grow in the area of Curieuse, where they are currently not growing.

2.3 Youth involvement and public participation

Youth involvement in the planting and rehabilitation activities was through the establishment of working groups, so that most WCS students formed part of a group and could participate in the activities. At the same time, while youths always show an interest in WCS activities and were eager to participate, there were generally more girls than boys who participated. With this rehabilitation project, WCS ensured that apart from actual planting of mangroves there were also clean-up activities, art works and educational exhibits, as well as presentations and community visits to improve on education and awareness. This meant that while girls were more taken with the learning activities and community visits, more boys got involved in the planting and other supporting activities including arts and exhibits. The WCS coordinators also worked closely with the Department of Community Development in order to get the local communities on board and enable them to participate in the rehabilitation activities. The media was an additional tool used, where information about the activities that were being carried out was provided, and the local public was encouraged to participate. At the same time, youths had the tasks of conducting community visits to encourage participation and to gather information about the public perception of their wetland habitats, their role towards such habitats and what they perceived as their responsibilities.

3. Results

At Roche Caiman Location 1, no mangroves survived from the 200 planted, while at Roche Caiman location 2, a total of 15 mangroves survived from 150 seedlings planted there. Port Launay location 1 had 26 of 100 mangrove seedlings surviving in the first year, while 320 out of the 800 planted seedlings survived at Port Launay Location 2. Mont Fleuri had 40 seedlings surviving from 100 planted and Curieuse had only 48 mangroves surviving from a total planted pool of 600. In summary, of the seedlings that were planted, one site had 0% success (Roche Caiman 1) while the others had 8% (Curieuse), 10% (Roche Caiman 2) and 26% (Port Launay 1). The other sites (Port Launay 2 and Mont Fleuri) had 40% survival rates.

Through the campaigns that were carried out, in at least three out of the six locations the general public took an interest in the rehabilitation activities and participated in the actual planting of mangrove seedlings. In addition, Port Launay Location 2 also had the participation of a private hotel and tourists.

4. Discussion, conclusions and recommendations

Mangrove rehabilitation should help in protecting coastlines from storms, and reducing salt intrusion into agricultural production areas, found along the coastal fringe, especially on Mahé Island (Hong, 2001). However, there is a need for proper management of rehabilitated areas to prevent mortality of such large numbers of mangrove seedlings as described above. Ongoing management is one of the main reasons why local communities should be part of the process, so that they can feel a sense of ownership of the rehabilitated areas, existing mangrove and wetland habitats; and in this way making it easier to engage them in its conservation and monitoring of progress (Hong, 2001). This was attempted in the mangrove rehabilitation activities of WCS in Seychelles. However, measuring the impact on awareness of the local communities through participation in such activities is difficult, though through their involvement the communities are now more eager and willing to engage in activities and projects that restore and conserve wetlands (Martin and Vel, 2011).

Different types of mangrove species require different parameters in terms of soil types, tidal inundation period, and salinity. They also have different capacities to withstand wave intensity and currents (Ravishankar and Ramasubramanian, 2004). The lower success rate at Curieuse and lack of success at Roche Caiman Location 1 can be attributed to the high wave impacts at those two locations. Those two locations are also sites where tidal inundation period is longer than any other sites so that mangroves were completely submerged for a long period of time when compared to the other sites. Furthermore, those two areas had no mangroves growing prior to planting, which could be an indication of the lack of suitability of those areas for mangrove survival (Page *et al*., 2003). Another factor that could be associated with the tidal inundation period and subsequent death of mangroves is the effect of sedimentation. This usually results in burial of aerial roots so that even as mangrove thrives at the initial stage of growth, they eventually die because of this smothering. High wave action and submergence for long periods can help bring about this process (Ellison, 1998).

Mont Fleuri, Roche Caiman Location 2 and Port Launay Location 2 were all areas that were relatively sheltered from strong wave action. Mature mangrove trees were also growing in these areas, indicating their suitability for mangrove growth. Although the planting sites at Port Launay Location 1 were not in a sheltered area, they were not exposed to the full impact of wave action. The presence of mature mangrove trees also showed that the area is suitable for mangrove growth, which accounts for the comparatively good survival rate of 26% at this site (Page *et al*., 2003). Another explanation for this limited success could be the type of mangrove that was planted in this location, compared with the other Port Launay rehabilitation area. Some mangroves can tolerate higher salinity, root burial or longer tidal inundation period, which means that they will thrive in the same environment that leads to death of other mangrove species (Ellison, 1998).

Overall, the mangrove rehabilitation activities undertaken at the six locations had a low success rate, with the highest recorded survival rate only 40%. A large part of this can be attributed to a lack of knowledge in the proper methods and techniques for planting mangroves, as well as a lack of proper criteria used in selecting sites for planting of mangrove seedlings. As there has not been a lot of work carried out on mangrove rehabilitation in the Seychelles, it is difficult to find people with the proper knowledge on when to collect seedlings for planting, handling of these seedlings, types of soils that different mangrove species are adapted to and the impacts of wave actions on the survival of seedlings. In short, there is very limited local knowledge on the parameters needed for successful rehabilitation of mangrove habitats (T. Vel, pers. comm.).

Data collection to measure growth was part of the rehabilitation project. This was an initiative that also involved the participation of the local community, so that they could take over the project, and thus feel a sense of ownership of the project, the rehabilitated site, and the mangrove wetlands in general. However, the project was not handed over to the community, upon completion of seedling planting activities, because of time constraints, and again lack of proper communication and coordination (T. Vel, pers. comm.). However, the local people who participated in the activities have indicated a desire to preserve their local wetlands, though they have also expressed disappointment at the lack of proper enforcement of legislation and lack of proper management of wetland areas. These people do, however, recognize the benefits of healthy wetlands and coastal ecosystems, increasing their willingness to contribute in the protection of wetland ecosystems (Martin and Vel, 2011).

Nonetheless, it is evident that a lot more work needs to be done in order to both increase the rehabilitation success of mangroves, while encouraging participation of the local communities in rehabilitation of mangrove habitats in their districts, as well as in monitoring changes in mangroves around their place of residence. At the same time, more education and awareness needs to be carried out to ensure that there is greater understanding of the importance of mangrove habitats and of their role in its conservation. Building a conservation ethic in new generations will allow local communities and leaders to understand the future benefits of mangrove conservation (Gilman *et al*., 2006).

In order for this to happen, there is a need for research work to be carried out on proper methods of monitoring mangrove parameters, so that baseline information can be gathered on these variables, allowing proper site selection process when it comes to rehabilitation (Krauss *et al*., 2008). Therefore, it is of vital importance to provide training to young people, community members and local research staff in conducting monitoring and assessments of relevant mangrove parameters; and to facilitate adaptive management, but also increase regional capacity in restoration and enhancement of mangrove wetlands. Youth involvement is very important for passing on information, monitoring techniques and awareness to other young people, teachers and parents in their community. Additional work also needs to be done to ensure gender balance in conservation initiatives so that all members of youth groups and communities feel a sense of ownership of these ecosystems (Payet and Agricole, 2006; Gilman *et al*., 2006).

As part of the priorities in addressing mangrove responses, resistance and resilience to climate change effects should be increased, through reduction and elimination of other stressors that degrade mangroves. This can be achieved through ongoing and proper education and awareness programmes aimed at the local communities (Gilman *et al*., 2006).

To this end, the Seychelles National Parks Authority has started a project to monitor, detect and quantify changes through time in the community structure and health of mangroves within the Curieuse Marine National Park. The aim is to provide baseline data for future studies and research work, while understanding the current conditions of mangrove species and habitats in the Seychelles. This will allow dissemination of information on mangrove ecosystems, increase education and awareness as well as provide training in rehabilitation and conservation of mangroves.

Furthermore, following another small grant facility project implemented by a local NGO, Sustainability for Seychelles (S4S), the Department of Environment, in collaboration with S4S and the Constance Ephelia Resort, is working on a management plan for mangroves at Port Launay. The aim here is to carry out monitoring activities so as to follow changes within the mangrove habitat, facilitate rehabilitation and engage community and youth involvement in monitoring and conservation of the mangrove habitat (K. Beaver, pers. comm.).

It should be noted that efforts are also being made to ensure countrywide support and participation in rehabilitation, through engaging the commitment of political figures, such as the Minister and Principal Secretary for Environment, in mangrove planting activities. WCS has been supported in their efforts through media coverage of its activities and dissemination to the general public, through support from the Ministry of Education for student involvement in projects, as well as through parents supporting their children's participation and their own personal involvement where required. It is these kinds of support and involvement that will lead the Seychelles people to a better understanding of the role of the wetlands, especially mangrove habitats, and help strengthen conservation and improve coastal management (T. Vel, pers. comm.).

It is important to keep in mind though that the cost of rehabilitation may sometimes be too high, which may make it more cost effective not to directly plant mangrove seedlings, but rather to take other steps that will create a favourable environment for mangroves to colonise the habitat (Lewis, 2001). This might not always happen, though, as some ecosystems have been altered to such a great extent that even assisted changes will not make a difference to colonisation. This is where actual planting is sought, but the result are not always what one might expect, and most replanted mangroves die. Again, proper research and monitoring of these areas should be carried out, with proper understanding of the biological parameters in which different mangrove species strive (Lewis *et al*., 2006).

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Local knowledge management for mangrove management

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Abstract
A range of threats to coastal areas in southern Thailand, in particular the mangrove charcoal-making concessions of 1968–1991, and the devastating Indian Ocean tsunami of 2004, has provided the main impetus for local communities' efforts to rehabilitate degraded mangrove areas. Merging local wisdom with external knowledge, community participation in mangrove rehabilitation has helped to dissolve conflicts and promote fairness within Thailand's coastal societies. It has also provided answers to the question of what benefits should be gained by communities from mangrove rehabilitation.

A study of learning and knowledge management for rehabilitating and managing mangroves in four coastal communities on Thailand's Andaman Sea coast found active processes of searching out, collecting, learning, applying and disseminating local knowledge. Activities such as selecting mangrove species, cultivating seedlings and saplings, and maintaining and protecting mangroves, all draw on a combination of existing local knowledge and external knowledge derived from self-learning in daily occupations and the transfer of know-how from local community experts.

Key factors affecting knowledge management in the communities are the efficiency of internal communication, the nature of people's occupations, and the capacity of community leaders. National policies and the activities of supportive organizations are also important influences. However, communities also want to develop their own capacity for systematically collecting, editing and presenting their knowledge, as well as developing new generations of leaders who will preserve community wisdom and its use in effective mangrove management.

Keywords: mangroves, rehabilitation, knowledge management, participatory approach, tsunamis, Thailand

1. Introduction
The communities living along the Andaman Sea coast in southern Thailand have strong traditional links to mangrove forests. Today, even though many have taken up rubber and fruit production as their main occupation, they still depend on coastal fisheries for supplemental income, particularly during the rainy season when rubber production is usually low.

The degradation of community mangrove resources during the charcoal concession period (1968–1991) affected traditional forest uses, but also led to some communities launching their own mangrove rehabilitation efforts. In 2004, the Indian Ocean tsunami caused significant damage to the remaining mangroves, though they in turn helped to protect coastal communities and reduce the damage to people's lives and property. The experience of the tsunami stimulated local concern for the integrity of mangroves and gave rise to many new mangrove rehabilitation initiatives in community areas. These have developed into a broad community-based mangrove management process supported by government and other organizations, which draws on local wisdom and external knowledge transferred for appropriate adaptation and merging with the local context (Department of Marine and Coastal Resources, 2008). Much of this community knowledge or local wisdom is still tacit, however, lacking organisation as a systematic, written body of knowledge, and is spread through informal mechanisms that can be difficult to access or are limited to specific groups. Without continuous transfer of knowledge, some knowledge has been lost with the passing of local gurus or experts (Luangmanee, 2002, cited by Simarak *et al*., 2006).

This study was initiated to study and analyze the community learning process and local knowledge management related to mangrove rehabilitation and management. Local approaches to knowledge management are believed to play an important role in the sustainability of community-based mangrove management.

2. Materials and methods

This study defines *local knowledge* as knowledge, ideas and beliefs accumulated in the community, derived from people's experiences and their adaption of external knowledge, used to live in harmony with the existing area and resources, and transferred from generation to generation. *Knowledge management* is defined as a process for supporting human and organizational development by improving knowledge creation, modification, application, sharing and learning. This study puts an emphasis on knowledge management for the purpose of sustainable management of mangrove resources, which includes rehabilitation, preservation and utilization of mangrove resources for a sustained supply of social, economic and environmental benefits. This aims to ensure maximum and long-lasting direct benefits for coastal livelihoods, fishery productivity, and the preservation of coastal ecosystems and the environment as a whole.

2.1 Study sites

Four communities in four locations along the Andaman Sea coast of Ranong and Phang Nga provinces in southern Thailand were selected: i) Baan Bang Hin in Kapur Bay, Kapur district, Ranong; ii) Baan Bang Kuay Nok in the Naka coastal area of Suk Samran district, Ranong; iii) Baan Bang Tib in Kuraburi district, Phang Nga; and iv) Baan Muang Mai on Kor Khao Island in Takua Pa district, Phang Nga.

2.2 Methodology

The study sought to characterise and understand community learning processes and knowledge management approaches using a combination of quantitative data (collected from a household questionnaire survey) and qualitative data (collected from in-depth interviews, focus group discussions, field observation and document review). Figure 1 opposite outlines the research process and key issues.

The quantitative component of the research focused on the heads or representatives of the households in the study communities. The sample size for the questionnaire survey was determined using Yamane's formula for a random sample (see Yamane, 1973), and the sample itself selected by a simple process of drawing lots. This procedure generated an overall survey sample of 501 households, distributed as follows:

- Baan Bang Hin: 180 households (total: 324).
- Baan Bang Kuay Nok: 154 households (total: 249).
- Baan Bang Tib: 129 households (total: 190).
- Baan Muang Mai: 38 households (total: 41 households).

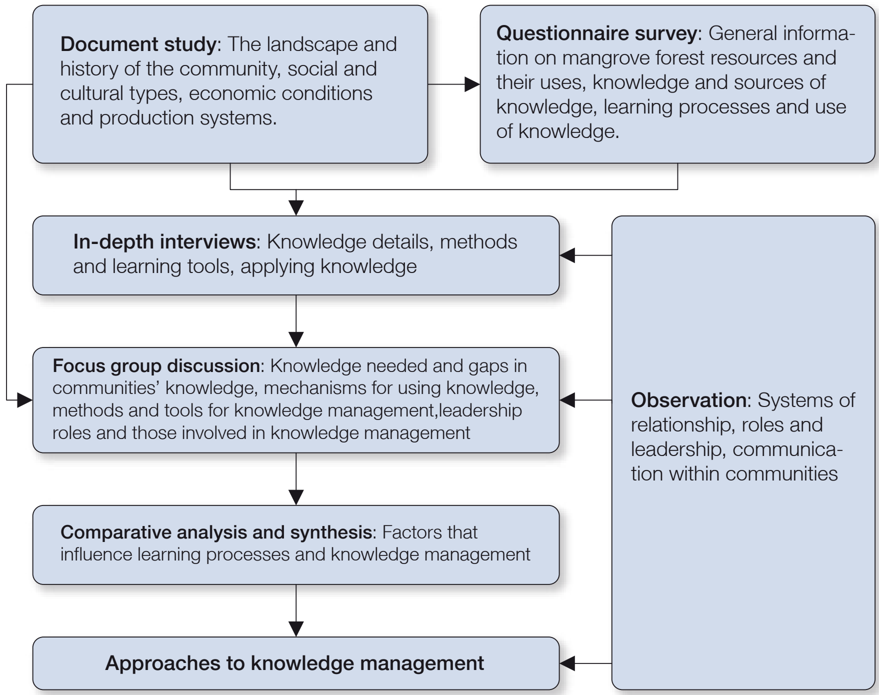

Figure 1 Research procedure, methods and issues

The qualitative component of the research focused on two groups of data providers: first, community leaders such as village heads, religious leaders, members of the local Tambon Administrative Organization (TAO) and mangrove conservation committee members; and second, local community experts with in-depth knowledge of mangrove resources. There was some overlap between the two groups, as local experts included coastal fishers, herbal medicine makers, community researchers, religious leaders, village heads, TAO members, and members of the community mangrove conservation committees.

3. Results

3.1 General description of study sites

The four study communities are sited in the coastal zone of the upper Andaman Sea. They are all small settlements, established close to coastal mangrove forests between 50 and 150 years ago. Most of their inhabitants are Muslim, except for Baan Muang Mai, which is predominantly Buddhist. The main occupations in order of importance are agriculture, coastal fisheries and external wage labour.

During the rainy season, villagers cannot collect much latex from their rubber plantations, so they turn to fishing as a supplemental occupation. Most of the coastal fishing sites are around nearby canals lined with mangroves that serve as a natural windbreak for fishers. The communities obtain direct benefits from the mangroves in the form of plants and aquatic animals that provide food sources. They also harvest aquatic species for sale, use Nypa palm (*Nypa fruticans*) to make thatching for housing, make herbal medicines from some mangrove plants, use mangrove wood to make tools, shelters and housing, and obtain income from tourism in mangrove forest areas.

The coastal zone in the study area is a narrow strip running from north to south and sloping from east to west. Some mangroves are scattered along the coastline, particularly around the islands (*koh*) and bays (*ao*), and also some canals. The width of the mangrove belt varies from 5 m to over 1,000 m in places. Although their distribution and abundance vary from site to site, the main mangrove species are Kong Kang Bai Lek (*Rhizophora apiculata*), Kong Kang Bai Yai (*Rhizophora mucronata*), Taboon Kaw (*Xylocarpus granatum*), Taboon Dam (*Xylocarpus moluccensis*), Jik Talay (*Barringtonia asiatica*), Nguak Pa Mor Krua (*Acanthus volubilis*), Prong Dang (*Ceriops tagal*), Samae Talay (*Avicennia marina*), Hwai Ling (*Flagellaria indica*), Peng Talay (*Phoenix paludosa*) and Nypa Palm (*N. fruticans*). Most of the mangroves in the study area are still regenerating after exploitation by charcoal concessions in areas with moderate to high fertility. Some areas were damaged by the 2004 Indian Ocean tsunami and are now covered with dense growths of Tob Tab (*Derris trifoliata*) and Nguak Pa Mor Dok Muang (*Acanthus ilicifolius*), which hinder replanting.

3.2 Local knowledge of mangrove management at study sites

Each community plays the central role in forest rehabilitation and management locally, with external organizations providing mainly support. Local wisdom derived from direct experience and learning is vital for mangrove rehabilitation and management, developed and adapted for each individual site as necessary. This knowledge can be divided into three categories: i) knowledge on the mangrove ecosystem; ii) knowledge on mangrove rehabilitation and conservation; and iii) knowledge on utilizing mangrove resources. The questionnaire survey found that each community has a variety of knowledge, with some exceptions mostly in site-specific issues:

- **Knowledge that communities share in common** is mostly about the mangrove ecosystem and the uses of mangrove resources, because each mangrove area has a similar composition. The main body of knowledge relates to plant and aquatic species, the tidal system, and basic utilization of mangroves through coastal fisheries, edible food plants and herbal medicines.

- **Site-specific knowledge** that communities have covers mangrove rehabilitation and conservation, and mangrove utilization. Different communities have experienced and learned from different issues depending on their involvement in external actions such as supporting government units in clearing mangroves, monitoring of mangroves by officials and researchers, receiving a national award, and taking part in local research grants on various coastal and mangrove-related topics. Baan Muang Mai on Kor Khao Island has also had opportunities to learn from developing communal mangrove-based tourism.

- **Knowledge gaps or additional knowledge** required by the communities were highlighted by the questionnaire survey as follows:
  - Mangrove cultivation technique for windbreaks (85%).
  - Sustainable utilization of mangrove resources (76%).
  - Ecotourism management (35%).
  - Increasing the abundance of aquatic life and development of aquatic life banks (32%).
  - Strengthening community groups and organizations (25%).

Focus group discussions with community leaders and local experts revealed that most wanted more knowledge on sustainable mangrove utilization to provide economic incentives for community members, and on strengthening community groups and organizations.

3.3 Community learning processes in mangrove management

The learning process related to mangrove rehabilitation and management in the study communities is primarily a self-learning process that draws on local expert knowledge and external sources:

- **Self-learning about mangroves**: Most respondents (85%) who fish in the mangroves reported that learning from experience was more important to them than transferred learning from community experts. However, most of the respondents (65%) who fish beyond the mangroves mentioned that they learned about mangroves from community experts during exchange forums, or by participating in various activities.

- **Local communication and transfer of know-how** within communities from the local experts to community members takes place through monthly village meetings, Friday prayer services, mangrove reforestation events, youth training events, village radio broadcasts, and small group or individual discussions. Both monthly village meetings and Friday prayers provide a constant communication channel with a definite schedule in the Muslim communities. Moreover, Friday prayers offer an opportunity to reinforce learning through related Islamic concepts communicated by Kut Ba or religious chanting. However, the small size and clustered pattern of households in the study communities, which allow frequent informal gatherings, mean that group and one-on-one discussions are a key channel of communication.

- In addition, **some exchanges and learning about mangroves take place through external channels**, as many communities have received support from the local government Mangrove Resources Development Station since the end of mangrove charcoal concessions in 1997. Since then, other external agencies and organizations have also provided support to the communities. Hence most communities have had good opportunities to gain experience and explore new ideas through workshops and site visits, as well as visits by guest lecturers and external experts. Some communities have also received national awards or recognition from other communities for their participatory mangrove management practices, resulting in further opportunities to share knowledge and experience during site visits and other related events.

3.4 Mechanisms and tools for local knowledge management

Community groups, external organizations and various activities organized in the community all play a part in applying knowledge and skills in mangrove management. Many communities also manage their knowledge through a variety of common and specific ways. These can be categorized into internal and external mechanisms (see Table 1 below).

Mangrove resources rehabilitation activities are an important and widely used tool in local knowledge management. This tool can be used to apply both internal and external knowl-

Table1 Mechanisms for local knowledge management

	Roles	Found in
Internal mechanisms		
Coastal fishers	Personal/individual knowledge management through searching, learning and adapting in their daily occupation.	Every community
Groupings within the community	Groupings of community leaders, coastal fishers and others in conservation groups, occupational groups and other groups to learn, integrate and adapt their internal knowledge with external knowledge.	Every community
Religious leaders	Transfer of Islamic concepts related to the importance of natural resources through Kut Ba, the religious chanting at Friday prayer services.	All communities except Baan Muang Mai
Local school	Encourage all students to participate regularly in community activities, and use community mangroves as a learning centre by inviting local and external experts to share and transfer their knowledge and experiences about mangroves to students.	Only Baan Bang Tib
Herbal medicine-makers	Transfer their knowledge to those interested in herbal medicine, both local villagers and outsiders. Even though herbal medicine has become less popular as a treatment, they are still a living source of knowledge on mangroves.	Only Baan Bang Tib
A team of community researchers	Study internal knowledge in communities, bring in other external knowledge, and initiate a new body of knowledge derived from a participatory research process.	Baan Bang Kuay Nok and Baan Bang Tib
External mechanisms		
Tambon Administrative Organization (TAO)	Support community mangrove rehabilitation activities and organise forums for knowledge exchange among communities.	Only Baan Bang Tib
Mangrove Resources Development Station	Apply knowledge through rehabilitation activities and monitoring, and also support knowledge transfer and exchange through various meetings and activities.	Baan Bang Hin and Baan Bang Tib
Non-profit organizations	Support community-level knowledge management and new learning through community leaders' capacity development, adapting and transferring knowledge within the community, and also connecting local knowledge with external sources.	All communities except Baan Bang Hin
Community networking	Promote new learning and knowledge transfer through site visits, meetings and other collaborative activities. Some communities have developed wide networks through external awards and recognition, and their practices have become widely known and accepted.	Baan Bang Kuay Nok and Baan Bang Tib

edge, and also to support knowledge transfer among community members through demonstration and actual practice from community and external experts. Moreover, rehabilitation activities are relatively easy to implement and do not require much resources.

Knowledge exchange activities have often been found to be a useful tool for initiating and sharing knowledge in the form of monthly meetings and small group discussions within communities, seminars and workshops outside the community, and study tours or case studies for other communities and stakeholders supported mainly by government units or non-profit organizations. Furthermore, participatory development planning activities are also useful for sharing and transferring knowledge since they involve surveying, fact-finding, and applying and communicating knowledge.

3.5 Factors affecting the learning process and knowledge application

The factors influencing community learning processes and knowledge management were assessed through a SWOT analysis of strengths, weaknesses, opportunities and threats (Table 2). Data from in-depth interviews and field observation were merged into the SWOT analysis as they revealed additional factors affecting community learning and the application of knowledge.

Table 2 SWOT analysis of the community learning process

Strengths	Weaknesses
+ The community leader is respected and makes sacrifices. + Strong family relationships. + Clustered settlement pattern promotes regular interaction and discussion. + Knowledge can be communicated and transferred directly to younger generations. + Religion and education are inter-linked in the community. + Continual learning activities in the community, such as village meetings and religious ceremonies.	– The community leader has high confidence but there is a lack of development of a new generation of leaders. – Communal conflicts. – New, separate settlement by immigrants. – Lack of communication mechanisms and activity in community. – The new generation has been educated outside the community. – Lack of transfer of fishing and herbal medicine knowledge to younger generations. – Lack of skills in gathering and compiling data. – Negative attitude towards government departments.
Opportunities	**Threats**
+ External agencies encourage and support sustainable community development. + Various easily accessible and understandable communication channels. + Policy support for learning resources in the community and development of the local curriculum. + Management of coastal resources through people's participation.	– Tourism and large development projects may affect mangrove forests and cause negative social change. – Local government staff are limited to implementing the policies of their agency.

Internal factors are vital for promoting the learning process and applying knowledge in communities, particularly the efficiency of local communication channels and the nature of local occupations or other relevant activities, as most new knowledge is derived from adapting to practical challenges in fisheries and mangrove conservation. Inter-generational transfer of knowledge has also proved important, as has regular internal communication that helps all villagers stay informed. Leadership and intra-communal relationships are fluid and change over time, but in general they still help to expand the scope and application of new knowledge.

The influence of external factors is also important in the learning process and local knowledge management. Tourism is an external factor that can also become an opportunity for community members to apply their mangrove knowledge in providing tours, information and other services to visitors. National policy can also help by creating a role and mandate for government officials to collect and disseminate knowledge on mangrove management.

4. Discussion

Knowledge about mangroves: The study communities have a diverse knowledge about mangroves, covering the mangrove ecosystem, rehabilitation and maintenance of mangroves, and how to utilize mangrove resources. Most of this knowledge covers common issues, except for some specific external learning drawn from systematized knowledge such as research into specific aquatic species, or from managing mangroves at a learning centre. This diverse knowledge derives from the action of different internal or external factors influencing each community, for example dealing with government officials, tackling illegal fishing by outsiders, or coping with the influx of visitors to areas that are a tourist attraction.

Learning process and local knowledge management: Most villagers learn themselves from occupations related to mangroves, such as fishing, or learn from local experts in their communities. Some villagers also gain knowledge from outside experts and published documents at meetings, workshops and visits outside their communities sponsored by external agencies. These include exchange programmes in which one community with substantial local expertise and a variety of knowledge transfer mechanisms provides a learning centre for other communities with mangrove forests. Most communities also share similar patterns of disseminating and sharing knowledge through monthly village meetings, reforestation activities, youth camps, and group discussions. In Muslim communities, Islamic concepts and rituals, for example the chanting at Friday prayers, strongly influence ideas and their transfer. Furthermore, some communities have also built a strong reputation and are widely recognised as “best practice and learning centre” sites, a designation which creates more opportunities to share learning with other best-practice communities in other coastal regions of Thailand.

Communities have their own mechanisms and tools for knowledge management, including groups and organizations such as coastal fishers or herbal medicine makers who have developed specialised knowledge and practices, or a team of community researchers who bring a systematic process of learning and knowledge dissemination, or local conservation groups which organize regular communal activities. In Baan Bang Tib, the religious leaders and teachers have transferred a variety of knowledge, influencing both internal and external learning processes. The communities’ external mechanisms have become more evident with changes in national policy as there are now government units working continuously to support communities in the study sites. Activities organised by non-profit organisations to build community capacities after the devastating Indian Ocean tsunami of 2004 have been another important mechanism of support.

Key factors affecting the learning process and local knowledge management include the nature and quality of community leadership. Strong leaders can have both positive and negative impacts (for example, if they are over-confident and do not invest time in developing new young leaders). Natural and man-made threats can also have both positive and negative impacts depending on a community's readiness and perspective, particularly if it decides to treat a critical situation as an opportunity to organise collaborative action. Other important external factors include the nature of assistance from external agencies, and the content of national policy, as they offer an opportunity to initiate a clear participatory resources management process. However, further obstacles may be created if some government officials cannot perform their duties in line with national policy priorities.

5. Conclusions and recommendations

The study communities need to develop their capacities in systematically collecting, editing and presenting their knowledge by collaborating with local academic or regional technical institutes to develop a local knowledge base and school curriculum related to mangrove ecosystems, coastal fisheries and mangrove products. Religious concepts related to natural resources management clearly have a major impact on attitudes and behaviours, and should be a specific focus of any further comparative studies. Knowledge exchange should focus on issues specific to one community rather than common issues, as this will increase the overall sum of knowledge. Lastly more attention should be paid to learning about and developing communities' communication channels.

Communities should put greater emphasis on developing new young leaders to maintain local knowledge and use it in mangrove management. This is particularly important in the context of climate change, which is expected to impact mangrove and coastal resources disproportionately through higher sea levels, changes in water volume and quality, and accelerated coastal erosion.

The relevant agencies should encourage youths and communities to be proud of their local knowledge, and help them to compile and record tacit knowledge for disseminating, scaling-up, adapting for expansion, and transferring to younger generations. Support for local knowledge management related to mangrove resources should aim to present and disseminate this knowledge to the public in easy-to-understand and adaptable formats.

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Active vs passive restoration of mangroves: developing models for sustainable rejuvenation of mangrove ecosystems used for shrimp farming in North-Western Province of Sri Lanka

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Abstract

A narrow coastal belt of 120 km in Puttalam district of Sri Lanka's North-Western Province is where more than 90% of the island's shrimp farms are located. But the industry is increasingly constrained by disease and environment-related problems, and, as a result, many farms are now being abandoned. Most shrimp farms have been constructed by clearing prime mangrove and associated coastal ecosystems. The present study, conducted during 2010 in Puttalam district, aimed at assessing the current status of the shrimp culture industry, identifying sensitive areas for restoration, and finally developing models for each identified location for restoration. Information about the shrimp farms, such as their size, present status (functional/abandoned), current vegetation characteristics of the farm and the surrounding area (density and diversity), type of vegetation prior to shrimp farm construction, distance to ecologically sensitive areas, type of ownership of land, as well as current mangrove restoration projects in the vicinity, were collected. This was done by visiting all the farms and also by interviewing service providers to shrimp farms, officers of farmer associations, community leaders and relevant government officials. Maps were prepared using Google Earth.

The results indicated that the total area taken up for shrimp farming in the project area was 2,534.5 ha. Of the 814 farms in the area, 290 were abandoned, accounting for 1,531.7 ha. The highest percentages of abandoned farms were in Mundal (78.1%) and Kalpitiya (78%), both prominent mangrove areas in Sri Lanka. Results also revealed that most of the large-scale farms had been abandoned, whereas the majority of operational farms were small-scale ones. The study also revealed a gradual natural restoration in sites where shrimp farms had been abandoned, where they were in close proximity to existing mangrove patches. *Excoecaria agallocha* and *Suaeda monoica* were the dominant species in the established secondary vegetation. Comparison of such areas with actively restored areas indicated a higher diversity in the former. Long-term leasing of land, as well as the recent trend to convert large abandoned farms into salterns, hinder restoration efforts. Models developed for the ecological restoration of abandoned shrimp farms are described: passive restoration is recommended, with only active protection of the area from further encroachment, clearing and development. Since small-scale farmers run most of the active shrimp farms today, involving them in restoration activities with mangrove planting, and transferring of rights of such restored areas to the local community, are vital.

Keywords: mangroves, restoration, shrimp culture, participatory approach, Sri Lanka

1. Introduction

1.1 Shrimp farming in Sri Lanka

Shrimp farming has been identified as one of the main non-traditional foreign exchange earners in Sri Lanka, and a source of direct and indirect employment in North-Western Province (Corea *et al*., 1995). Shrimp farming was started in Sri Lanka in the early 1980s by a few multinational companies, but developed slowly. The first commercial production entered the market in 1984 in very small quantities (Jayasinghe and Macintosh, 1993). During the period from 1992 to 1996, the industry saw a rapid and uncontrolled expansion driven by high economic returns. Small-scale farms of around 0.4 ha each were developed in clusters, mainly encroaching on lagoon reservations and ecologically sensitive areas belonging to the government (Senarath, 1998).

In the initial stages of shrimp farming in Sri Lanka, the farms were located in agricultural land, wetlands, and in bare lands. The proportion of farms on salt marshes and mangroves was around 30% during the early stages of development (ADB/NACA, 1997). But, with the rapid expansion, more wetlands were converted either legally or illegally for shrimp culture, and about 65% of farms were located on wetlands by 1996.

Land conversion into shrimp farms on the salt marshes was widespread as these areas could be converted to ponds with relative ease, and the adjoining mangroves were indirectly affected by high pollution, edaphic changes and other manipulations (Corea *et al*., 1998). In the latter part of the development of this industry, more and more farms were developed on salt marshes and mangroves, mostly on state-owned land. As a result, the land value of mangroves and salt marshes increased tremendously, discouraging their reclamation for other uses or for restoration. In addition, with increasing land values, the illegal land owners have used all measures to retain their lands instead of handing them back to the government. Hence clear ownership of land along the shrimp-farming belt has become a complicated political issue.

1.2 Rejuvenating ecosystems in the shrimp-farming belt

Shrimp farming is now constrained by the frequent outbreak of diseases (Anh *et al*., 2010) stemming from over-stocking, pond construction in unsuitable areas, self-pollution, reduction in environmental capacity, destruction of ecologically sensitive habitats, siltation of waterways, conversion of pyritic soil in intertidal areas, and sand-bar formation at natural outfalls that restrict tidal exchange (Corea *et al*., 1995; Jayasinghe and Orlina, 2004). Continual crop failure has resulted in culture ponds being abandoned in large numbers, leaving a large area for potential restoration (FAO, 2005).

Interactions between shrimp aquaculture and coastal wetlands have received considerable attention as the majority of the farms are located in mangrove and salt marsh habitats. The environmental services and ecological functions (both direct and indirect) of these ecosystems were underestimated when allocating land for coastal aquaculture (Dewalt *et al*., 1996; Hai and Yakupitiyage, 2005; Sousa *et al*., 2006; Arquitt and Johnstone, 2008).

Mangrove ecosystems demonstrate close links between vegetation assemblages and geomorphologically defined habitats (Li and Lee, 1997; Alongi, 2008). Mangrove species distribution is influenced by several environmental gradients which respond, either directly or indirectly, to particular landform patterns and physical processes. In addition, vegetation can change through time as landforms accrete or erode.

Specific characteristics enhance the establishment of mangroves, such as availability of an extensive and suitable intertidal zone (as found on low gradient or macro-tidal coasts in the tropics) with an abundant supply of fine-grained sediment. The growth becomes lush under high rainfall or abundant freshwater supply through run-off or river discharge (Woodroffe, 1992). Mangroves can grow on a wide variety of substrata, including sand, volcanic lava or carbonate sediments found in low-energy, muddy shorelines, particularly in tropical deltas (Clark, 1998). Sediments are important for the establishment and continuity of mangroves, whether natural or planted, and some can be allochthonous such as terrigenous mud, brought in from outside the ecosystem. Mangroves can themselves create autochthonous sediments by contributing to organic peat derived largely from the roots of mangroves in carbonate areas, where there the supply of terrestrial sediments is limited as they are often calcareous skeletal or reef substrates or calcareous mud. Understanding these characteristics is important for their restoration (Field, 1998). Ecological restoration of abandoned areas will improve environmental sustainability of the shrimp farming areas by re-establishing previous natural habitats and their original functions, benefiting not only biodiversity and ecological integrity, but also all the land-use practices in the region, including shrimp farming itself. Yet, to initiate such an effort in the shrimp farming belt of North-Western Province, a status assessment is a priority.

The main objectives of the present study, therefore, were to review the present status of shrimp farming; to identify the distribution of shrimp farms and estimate the extent of abandoned shrimp-farming areas; and to identify models for ecological restoration, with a view to providing options and interventions for enhancing environmental sustainability and economic productivity, especially in mangrove ecosystems.

2. Materials and methods

2.1 Area of study

The area covered by the study included the Puttalam Estuary and its surrounding coastal wetlands, Mundal Lagoon and associated wetlands, the northern and southern portions of the Dutch Canal, and associated areas in North-Western Province. The Puttalam Estuary is a hypersaline water body. Seasonal salinity variation is high and depends mainly on the rainfall. This estuary, along with Dutch Bay, is the second-largest brackish waterbody in Sri Lanka. The lower reaches of the estuary, where shrimp farming is concentrated, is divided into two sections, Puttalam basin and Eththale Estuary, which together are about 30-km long and 3–12 km wide with a mean depth of about 1.5 m. The salinities recorded in this area are relatively high (Arulananthan *et al*., 1995).

The northern portion of the Dutch Canal connects to the Puttalam Estuary at Palaviya and to Mundal Lagoon at Mangala Eliya, and is about 18 km in length. The southern portion of the Dutch Canal connects to the Deduru Oya at Chilaw and the southern tip of Mundal Lagoon at Pulichchikulam, and is about 19 km in length. The total area of Mundal Lagoon is 3,080 ha, whereas the Puttalam Estuary is 15,064 ha. Together, they form one of the most important man-made (canal) and natural (estuary and lagoon) aquatic systems in Sri Lanka, and one of the country’s most important mangrove ecosystems (Arulananthan *et al*., 1995; Wijeratne *et al*., 1995).

The southern stretch of the Dutch Canal sees a considerable influx of fresh water through seven rivers. The Anavilundawa Sanctuary, Sri Lanka’s second Ramsar wetland, is located in this area. Mundal Lagoon is separated from the adjoining sea by a low ridge of sand dunes and barrier flats. The lagoon is about 12 km in length and 4-km wide. It is also shallow, with a recorded maximum depth of around 2 m.

2.2 Sampling and data collection procedures

Sri Lanka's National Aquaculture Development Authority (NAQDA) has declared five shrimp-farming administrative zones in North-Western Province: Chilaw, Arachchikattuwa, Mundal, Kalpitiya and Puttalam. The present study activities were concentrated in the Arachchikattuwa, Mundal, Kalpitiya and Puttalam zones. Each shrimp-farming zone is subdivided into sub-zones – of the 32 sub-zones in total, 23 were covered by the study (see annex on page 189).

The presidents and secretaries of the shrimp farmer societies were interviewed to collect data on the number of farms active in the area, the number of farms abandoned (not in operation during the previous three years), and the area of active and abandoned farms. The collected data were fed into downloaded maps of the respective areas using Google Earth. The prepared maps were taken back to the farmer societies and feed distributors for verification, and finally ground truthing was done for cases where the respondents' classifications did not match. Data were summarised by sub-zones and zones, and the total number of active and abandoned farms and the area under each category were calculated. Data on ownership – actual owner, rented (from private party/ government), state land, illegal encroachment – were also compiled. After the maps were verified, data were collected on past rehabilitation programmes from a desk-based study and interviews. Ground truthing was done by visiting the sites. A desk-based study was also made of the locations of important ecosystems in the area using available literature and maps. Data were collected from the regional offices of the Forest Department and the Department of Wildlife Conservation on actual and proposed protected areas in the study area. The gathered information was compiled and each area visited to verify its current status.

Line transects and quadrat (1 m x 1 m) sampling were conducted to determine the density and diversity of flora in areas of ecological importance. The number of sampling points and the length of transects varied between sites and was determined according to the length, shape and the topography of the sites. Abandoned farms were visited and their diversity was measured within ponds, dykes and inlet canals using the same methodology.

Results were used to propose models for restoration reflecting the diversity, land ownership and willingness of shrimp farmers to engage in mangrove and other ecosystem restoration.

3. Results

3.1 Current status of shrimp farming in North-Western Province

Shrimp farming in the project area extends over 2,534.55 ha. Of the 814 farms in the area, 290 have been abandoned, accounting for 1,531.74 ha. Although these represent only 35% of all farms, they account for a large proportion of the area (more than 60%) because they are mostly large-scale farms with pond areas of 1.2–2 ha. The highest number of abandoned farms (191) is in zone 3, covering 939.27 ha, followed by zone 2 (48 farms, 247.66 ha) (Table 1).

Table 1 Operational status of shrimp farms by zone, 2010

Zone	Sub-zone	Total farm area (ha)	Operational area (ha)	Farm numbers		Area abandoned (ha)
				Total	Operational	
5	Palaviya/ Poorvasakuda	13.76	2.43	2	1	11.33
5	Sewwanthivu	98.34	53.82	25	13	44.52
5	Manathivu	49.78	30.55	10	5	19.22
5	Anaikutti & Mee Oya	135.17	70.42	26	10	64.75
5	Wadathamunai	62.32	30.76	7	7	31.57
5	Wanathavillu	27.92	2.43	4	2	25.50
4	Karambe, Eththale, Mampuri, Palliwasathurai, Kandakuliya	209.22	61.51	28	13	147.71
3	Poonapitiya, Watawana, Kothantivu	185.35	131.12	65	43	54.23
3	Mangala Eliya & Kiriyankalliya	225.01	50.59	136	85	174.42
3	Madurankuliya South	791.57	80.94	154	36	710.63
	Madurankuliya Sembatta		0			0
	Pulidiwayal		0			0
2	Bangadeniya, Karukkupani	116.95	116.95	15	9	0
2	Kusala, Kottage, Kuda Wairankattuwa	133.95	133.95	29	26	0
2	Wairankattuwa	106.84	106.84	26	14	0
2	Bogahawetiya (Nagul Eliya, Doopatha)	19.02	19.02	7	5	0
2	Muthupanthiya	44.52	110	65	65	0
2	Pinkattiya	152.16	357	100	98	0
2	Pulichchikulam	93.89	190	48	25	0
2	Udappu, Andimunai	68.80	170	67	67	0

3.2 Floral diversity and density of abandoned shrimp farms and restoration models

Although most of the abandoned shrimp farms were in zone 3, these are mainly state-owned lands held under long-term leases. As a result, the leaseholders did not agree to support restoration of their abandoned shrimp farms. Therefore, models were developed for areas with true potential for restoration and where the community was supportive, and for sites with an urgent need for restoration, such as those adjacent to protected areas and mangrove or salt marsh patches identified as important for conservation.

A total of 33 plant species were identified in abandoned shrimp farms and associated areas. These consisted of 12 species of core mangroves and 22 mangrove and salt marsh associates, as well as flora in dry shrub land and cultivated land (coconut plantations and paddy fields). (Table 2).

Table 2 Flora identified in shrimp farms and associated areas

Core mangrove species	Associates and other plant species	
Acanthus ilicifolius	*Dolichandrone spathacea*	*Salicornia brachiata*
Avicennia marina	*Suaeda maritima*	*Potamogeton* spp.
Avicennia officinalis	*Suaeda monoica*	*Arthrocnemum* spp.
Lumnitzera racemosa	*Derris trifoliata*	*Oryza sativa*
Excoecaria agallocha	*Derris* spp.	*Azadirachta indica*
Aegiceras corniculata	*Pongamia pinnata*	*Lantana camera*
Bruguiera cylindrica	*Pemphis acidula*	*Phragmtis* spp.
Bruguiera gymnorrhiza	*Hibiscus tiliaceus*	*Phoenix pusilla*
Ceriops tagal	*Thespesia populnea*	*Cissus quadrangularis*
Rhizophora apiculata	*Clerodendrum inerme*	*Salvadora persica*
Rhizophora mucronata	*Premna obtusifolia*	
Heritiera littoralis	*Acrostichum aureum*	

In undisturbed abandoned shrimp farms of over three years, *E. agallocha* (0.18 ± 0.09 plants/m^2), *S. monoica* (0.13 ± 0.10 plants/m^2) and *S. persica* (0.08 ± 0.03 plants/m^2) were the dominant flora. Young plants of *Rhizophora* spp. (0.03 ± 0.01 plants/m^2) dominated the undisturbed inlets with water. Saplings of *Avicennia* spp. (23 ± 12 plants/m^2) were the most abundant type of sapling in the sampled areas. In disturbed abandoned shrimp farms, *E. agallocha* (0.23 ± 0.14 plants/m^2) dominated. A total of 19 species were recorded in abandoned shrimp farms.

In actively replanted areas along the western flank of Puttalam Lagoon, *R. apiculata* was dominant, mainly along the edges of the lagoon. Evidence of attempts to replant species such as *Avicennia* spp. was observed, but only a few of the plants had survived.

Disturbed abandoned shrimp farms which were previously salt mash ecosystems were dominated by *S. monoica* (0.18 ± 0.06 plants/m^2) and *S. brachiata* (23 ± 19 plants/m^2). Relatively undisturbed abandoned shrimp farms which were previously salt marsh ecosystems were dominated by *S. brachiata* (29 ± 9 plants/m^2) and other salt marsh flora, with the typical salt marsh structure. However, most of the abandoned shrimp farms in the salt marshes had been converted to coconut plantations and salterns, especially in the Puttalam area.

Four restoration models were developed for: Anavilundawa and Pinkattiya (adjacent to Anavilundawa Ramsar sanctuary); Seguwanthivu, Manathivu and Anaikutti (presence of relatively undisturbed mangrove and salt marsh vegetation); Muthupanthiya (presence of large abandoned farms adjacent to a mangrove patch extending up to the Dutch Canal); and Uddapuwa and Pulichchikulam. The model developed for Uddapuwa and Pulichchikulam is not discussed here as the communities were not in favour of replanting when it was suggested to them.

3.2.1 Model developed for the Anavilundawa, Pinkattiya area

This area has large numbers of small operational farms, as well as a few large abandoned farms. The proposed mangrove restoration aims to improve natural biodiversity and plant density. Accordingly, the species recommended for planting are *A. marina*, *A. officinalis*, *R. mucronata*, *R. apiculata*, *L. racemosa*, *A. corniculata* and *E. agallocha*, which are naturally present in this area. Resilient species should be planted first at a higher density that takes into account natural mortality rates. The prevailing winds in this area are mainly from the north-east and south-west; it is therefore recommended that shrimp farm bunds (dykes) facing the prominent wind direction are kept intact to prevent wind erosion. They should be removed or levelled off once the plants are established and the top layer of soil secured. At the same time, it is proposed that farmers operating active shrimp farms are involved in replanting their inlets and outlets, as Hai and Yakupitiyage (2005) have indicated the benefits of *Rhizophora* spp. to shrimp.

Acquiring the abandoned land for restoration by the government (e.g. Department of Wildlife Conservation) or by community-based organizations (CBOs) is also recommended. Once restored, the ownership should be transferred to, or the area maintained by, a relevant body that can provide adequate protection to the area, while sharing some of the benefits with local stakeholders.

The model anticipates that species such as *A. corniculata*, *A. ilicifolius* and *E. agallocha* can also establish themselves naturally from existing mangrove patches.

Table 3 Proposed budget per 2-ha unit for restoration model in Anavilundawa, Pinkattiya

Item	Cost (LKR [a])
Land acquisition	250,000 [b]
Expenditure for acquisition procedures	7,500
Land preparation (involves bund removal and restoration of hydrology)	10,000 [c]
Purchase of planting materials	
A. marina (205 plants) [d]	3,075
Rhizophora spp. (1,111 plants) [e]	16,665
Transport and planting cost	5,000
Incentive for aftercare [f]	
6 months	10,000
12 months	10,000
24 months	10,000
48 months	10,000

Note: This model is prepared assuming that all 46 ha of abandoned land is taken up by government, NGOs, or in government-NGO partnerships, for restoration and managed with community involvement.

[a] Sri Lanka rupee (1 USD = 130 LKR).
[b] LKR 62,500 per 0.5 ha.
[c] Restoration cost per 2-ha plot in the acquired land.
[d] 25 m x 5 m spacing.
[e] 32 m x 2 m spacing.
[f] A percentage should be deducted from the proposed incentives if more than 25% of plants die.

3.2.2 Model developed for Seguwanthivu, Manathivu and Anaikutti area

The existing mangrove patches in this area are small and scattered. To improve the ecological services they provide, they need to be enriched with vegetation and connected through plant corridors where possible. The species recommended for replanting are *Avicennia* spp. (5 m x 5 m spacing), the most prominent true mangroves of this area, and *Rhizophora* spp. (4 m x 4 m spacing), with the same conditions and incentives mentioned in the preceding section. Since some abandoned farms have been converted to salterns, the implementation of a well-formulated policy and action plan for salt pan development in the area by the Provincial Environmental Authority is needed. This would include updating the current lists of mangrove patches, surveying the land, demarcating the boundaries, preparing management plans, posting officials and providing sufficient infrastructure, and establishing co-management committees. Since this area is sparsely populated, rejuvenation of mangroves could be taken up directly by state authorities.

3.2.3 Model developed for Muthupanthiya

The models developed for Anavilundawa and Pinkattiya area could be adopted for this area since the same mangrove patch extends to here, and the same incentives could be provided to local inhabitants.

The model proposes strict implementation of existing environmental regulations, such as those provided in the Forest Ordinance, Fauna and Flora Protection Ordinance, and the Environmental Act of North-Western Province, with regard to the restoration of natural vegetation. Where possible, immediate land acquisition should commence within islands for the purpose of restoration. It is also proposed that land should not be given out from islands for shrimp farming or any other development activity in future. It was noted that people tend to clear the vegetation, not only in the farm area, but also along the prevailing wind direction to facilitate increased dissolved oxygen within their ponds. This activity adds to the damage caused to the mangrove vegetation in the vicinity of shrimp farms. The model proposes promoting ecotourism by the local communities, which will lead to coupled tourism between Anavilundawa Ramsar sanctuary and Muthupanthiya and Pinkattiya mangrove ecosystems and islands. This will indirectly protect the ecosystems in this area.

4. Discussion, conclusions and recommendations

It has been observed that in many locations in Southeast Asia, abandoned shrimp ponds have shown at least a partial return to mangrove forest through natural recolonization (Lewis, 2005). During the present study, several abandoned shrimp farms were found where partial recolonization was evident. In areas not disturbed by freshwater influx, recolonization by salt marsh species was found to be more rapid than by true mangrove and mangrove associate species, but such sites are rare mainly because of conversion into salterns.

A period of about five years after shrimp farming ends may allow sufficient time for shallow extensive culture ponds to be recolonized by mangroves, provided the local hydrology or the tidal regime is restored and the surrounding social and institutional conditions are favourable (Lieth, 2008). Favourable social conditions can be achieved by partial handover of ownership to stakeholders (Primavera *et al*., 2011). The importance of clarifying the aims of mangrove rehabilitation programmes and integrating such aims with the welfare of the local communities is vital, and this has been stressed by others for mangrove ecosystem sustainability (Field, 1998). This includes species choice (Datta *et al*., 2012), site choice and a good knowledge of the actual uses of mangroves (Walton, 2006). A lack of such knowledge hinders effective restoration, and it is vital that future research addresses these gaps.

In the identified areas, mangrove reforestation could be done with minimal technical input, but the lessons of past replanting activities need to be considered carefully. Drawbacks seen in past replanting included a lack of community incentives, as well as the use of the wrong species in the wrong season and in the wrong locations (for example *Avicennia* spp. replanted in Puttalam Lagoon in deep-water areas, where the survival rate was zero).

The current study also documented the rapid expansion of salterns in the area, which could represent another silent wave of mangrove and salt marsh destruction. Although no environmental impact assessment is needed for such conversions on a small scale, the cumulative effects of several conversions could damage both aquatic and terrestrial habitats.

Large-scale abandoned farms are threatened by the current interest among small-scale farmers in dividing them into small farms and acquire them on leases. Some abandoned large farms are within the boundary of the Anavilundawa Ramsar sanctuary; hence the relevant authorities need to maintain vigilance.

The current study also highlighted the possibility of restoring mangroves in shrimp farm inlets and outlets not considered previously as potential areas for restoration. For this to be successful, however, the perception among shrimp farmers that such restoration is fruitless must be addressed through awareness raising and active demonstration of benefits. Individualistic, self-interested behaviour is the motivation for participation decisions (Barbier, 2008) and is achieved through dialogue with stakeholders.

The occurrence of invasive species such as *L. camara* in abandoned farms is another reason for restoring these habitats, as such species could spread from disturbed lands to forest patches.

Lastly, human factors critically influence the success of forest restoration (Walters, 1997), so the restoration of abandoned shrimp farms should be harmonised with local resource extraction and land tenure patterns. Different social groups should be actively mobilised, and encouraged to use their skills and knowledge for mangrove replanting. Political will, backed by appropriate policies, will help to ensure effective restoration.

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Annex Shrimp farming zones and sub-zones

Zone	Sub-zones	
Zone 1 Chilaw	Thalwila Madampe Thoduwawa/Iranawila Kakkapalliya	Ambakandawila Marawala/Suduwella Wattakkalliya/Jayabima
Zone 2 Arachchikattuwa	Bangadeniya Kusala/Kottage Wairankattuwa Bogahawetiya	Nagul Eliya/Muthupanthiya Pinkattiya Udappuwa Pulichchikulam
Zone 3 Mundal	Punapitiya/Watawana Koththanthiv Keeriyankalliya Mundal/Mangala Eliya	Madurankuliya South Madurankuliya/Sembatta Pulidiwayal
Zone 4 Kalpitiya	Karamba Mampuriya/Eththale Palliwasathurai/Kiriyankalliya	
Zone 5 Puttalam	Palaviya/Poorvasakuda Sewwanthivu Manathivu Aneikutti/Malayamadu	Mee Oya Wadathamunei/Samagipura Wanathawillu

Restoration and return of mangroves and fisheries in abandoned aquaculture farms

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Abstract

More than 92% of the global aquaculture production in 2007 (56.7 million tonnes) was produced in Asia. Aquaculture in Asia, including that of India, is characterized by small-scale, family-operated farms and constitutes one of the important sources of income and employment for rural coastal communities. However, in recent years, coastal aquaculture has suffered setbacks in terms of production, value and area. For example, in India shrimp production which was around 1.06 million tonnes in 2007–08 fell to 0.76 million tonnes in 2008–09. Monoculture, disease, poor seed quality, excessive use of artificial feed, increased input costs and decreased market value are considered as important factors accounting for this decline in aquaculture production. Above all, poor environmental management and a lack of different activities to diversify livelihoods within aquaculture farming are also responsible for the current status of coastal aquaculture in India; and the social impact of decline in prawn farming has been enormous. Many of the farmers, who converted their agriculture land into aquaculture farms, are currently getting no income either from agriculture or from aquaculture; many of these families now migrate either temporarily or permanently in search of employment and livelihood to nearby urban areas. In this situation, the projected Integrated Mangrove Fishery Farming System (IMFFS), wherein cultivation of mangroves, halophytes and culture of fish, crabs and prawns are integrated, provides a tangible solution to make coastal aquaculture sustainable, while also strengthening resilience of the coastal communities. This also provides opportunity to integrate livelihoods with mangrove bioshields and to promote ecologically sensitive alternative land-use practices.

In IMFFS, which has been demonstrated with the participation of the local community, government agencies and shrimp farmers, aquaculture ponds are designed to provide space for growing saline-tolerant vegetation including mangroves and halophytes. Space for planting is created by constructing bunds inside the pond in a zigzag manner, or as small mounds (mitochondrial in shape). These bunds and mounds are created by digging the soil from the bottom of the pond. This makes the pond deeper and below the tidal level. As a result, tidal water fills the pond by gravitation during high tide and drains out during low tide. The tidal inlet and outlet are designed in such a way that nearly one metre of water remains in the pond as standing water. Further, the ponds are designed in such a way that nearly 30–35% of the space is left for planting mangroves and halophytes, while the remaining 65–70% is left for holding sea water for fish culture. Three species of mangroves and two halophytes are planted along the inner bunds, mounds and outer bunds of the ponds. The survival and growth rate of mangroves and halophytes are almost equal to the growth rate observed in natural conditions. Regarding fish culture, experiments conducted to culture sea bass in these ponds indicated that this can generate an income of about US$1,500 in a period of eight months from a one hectare pond. Further experiments are ongoing to utilize this system for polyculture of mullet and shrimp. The IMFFS is also a good farming system for culturing of mud crabs since the well-developed root system of mangroves provides these crabs with a refuge, while detritus generated from mangrove litter provides them with food.

Keywords: mangroves, halophytes, aquaculture, shrimp culture, India

1. Introduction

Livelihood security of the coastal communities and ecological security of the coastal zones become vulnerable due to high population density, urbanization, industrial development, high rate of coastal environmental degradation and frequent occurrence of cyclones and storms. More than 100 million people depend on natural coastal resources to sustain themselves; an extremely vulnerable existence. This vulnerability is likely to be further aggravated by increases in sea level due to climate change. An estimate indicates that the predicted sea level rise would lead to the inundation of approximately 5,700 km^2 of coastal lands in the coastal states of India, and that nearly seven million coastal families could be directly affected (Aggarwal and Lal, 2001).

One of the major land-use changes predicted is conversion of saline-affected agriculture lands into aquaculture farms. However, the current situation of aquaculture warrants a more responsible and sustainable aquaculture system and practice. Development and demonstration of new approaches such as seawater-based integrated agro-aqua farming systems would not only ensure livelihood security of the poor coastal families and ecological security of the coastal areas, but also enhance adaptive capacity of coastal communities to sea level rise and climate change.

2. Materials and methods

The Integrated Mangrove Fishery Farming System (IMFFS) is being demonstrated by the M. S. Swaminathan Research Foundation (MSSRF) in the coastal areas of Tamil Nadu and Andhra Pradesh in India with the participation of private aquaculture farmers and fishing communities. Meetings were held in each target village with traditional leaders, youth and women groups, and members of other village-level institutions to introduce the concept of IMFFS. Following this, a committee consisting of three men and three women was set up in each village, and two workshops were organized for all committee members to discuss the status of aquaculture in the region, and also the conceptual framework of IMFFS and its sustainability. In consultation with local communities, private aquaculture farmers, representatives of the Fisheries Department and Revenue Department, and local engineers, several protocols of the IMFFS models were designed and developed; two were eventually chosen for implementation (Figures 1 and 2).

In both models, the ponds were designed to provide 30% of the available space for planting mangroves and halophytes, and the remaining 70% for holding sea water for fish culture. In Model 1, the inner bunds (built as an extension of the outer bunds), were created to provide space for mangrove plantations. Bunds/mounds were created with soil excavated from the pond floor. With this deepening, the pond becomes tidally fed by gravity, with water entering the pond during high tide and draining out during low tide. The tidal water inlet and outlet were constructed to retain 90–120 cm of standing water in the pond for fish culture. In Model 2, the inner bunds were replaced by mud mounds. The peripheral bunds and the mounds accommodated the mangrove plantations.

Pond water was refreshed daily as per the tidal inflows, thus eliminating the need for an aerator to oxygenize the water. The movement of water also brings in a healthy supply of food into the ponds, thus removing the need for artificial feed.

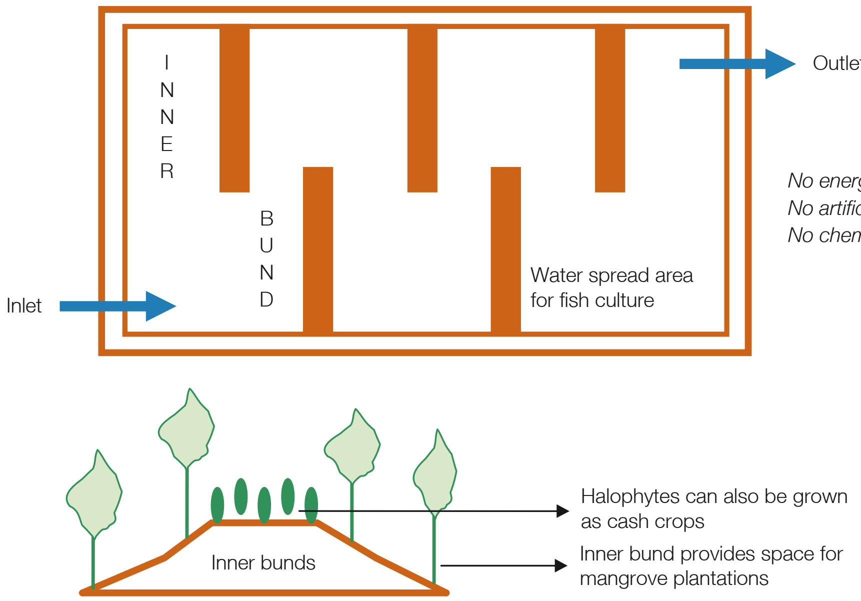

Figure 1 Design for a seawater-based integrated agro-aqua farming system with inner bunds

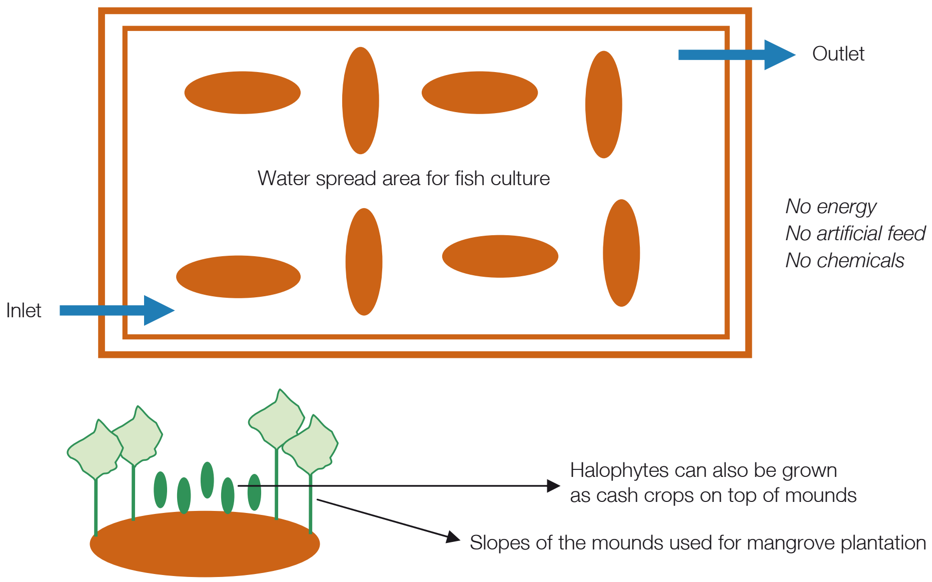

Figure 2 Design for a seawater-based integrated agro-aqua farm with earth mounds

In February 2008, 1,723 *Rhizophora mucronata* saplings, and 1,327 *Avicennia marina* saplings were planted in a one-hectare pond. The *R. mucronata* saplings were planted in two rows along the lower edge of the bunds, whereas the *A. marina* saplings were planted about two metres above the *R. mucronata* plantation. Both *R. mucronata* and *A. marina* were planted at one-metre intervals in the row. Data on height, number of branches, and number of leaves, their length and breath, length of internodes between two leaves, number of stilt roots formed in *R. mucronata*, and number of aerial roots originated in *A. marina*, were collected every three months. Survival rates were recorded once a month.

In a one-hectare IMFFS farm, sea bass (*Lates calcarifer*) was cultured by stocking 1,000 juveniles, collected from the estuarine waters and grown for eight months. The weight of the wild juveniles was between 15 g and 30 g. During the growing out period no artificial feed or other chemicals were added to the system. The daily tides ensured water changes, which not only helped keep the water clean but also brought food in the form of juvenile fishes of various species, including tilapia.

3. Results

3.1 Mangrove plantation

The survival of *R. mucronata* plantation was around 65% in the first year, and the dead ones were replaced with nursery-raised saplings during the second year. Low survival of *R. mucronata* was due to an attack of sap-sucking scale insects of the Coccidae family, which severely affected the leaves of the plants. It was controlled by spraying a 5% solution of neem oil. *A. marina* showed 89% survival in the first year. During the second year and subsequent period no mortality was observed in both plantations. *R. mucronata* reached an average height of 119 cm at the end of two years whereas *A. marina* reached 81 cm. Other growth parameters are given in Table 1.

Table 1 Growth performance of *R. mucronata* and *A. marina* in a one-hectare IMFFS farm

	R. mucronata		*A. marina*	
	1 year	**2 year**	**1 year**	**2 year**
Plant height (cm)	74.8	119.2	33.6	81.2
Number of leaves/plant	36	108	23.4	82
Leaf length (cm)	12.1	14.7	4.5	5.4
Leaf breadth (cm)	5.3	6.1	1.6	2.6
Internodal length (cm)	4.2	5.2	3.4	4.9
Number of branches/plant	4.2	15	2.5	12
Number of stilt roots/plant	4	16	0	14

3.2 Fish culture

The survival rate of the sea bass was about 20% at the end of the 8 month period of farming. After this period, about 155 kg of sea bass, 10 kg of eel, 25 kg of mullet, 5 kg of shrimp (*Penaeus monodon*) and 5 kg of mangrove crab (*Scylla* spp.) were harvested (Table 2). Besides sea bass, other fish, shrimp and crab species entered the IMFFS farm with tidal waters.

Table 2 Harvest of fish cultured in a one-hectare IMFFS farm after eight months

	No. of juveniles released	**Average size of juveniles (g)**	**Quantity harvested (kg)**	**Average price per kg**	**Value (INR)** [a]
Sea bass	1,000	25	155	220	34,100
Eel	–	–	10	50	500
Mullet	–	–	25	40	1,000
Shrimp	–	–	5	200	1,000
Crab	–	–	12	200	2,400
Total	–	–	207	–	39,000

[a] Indian rupees.

3.3 Crab culture

After the fish harvest, the mangrove crab *Scylla* was reared in the same IMFFS farm. About 400 juveniles collected from the mangrove wetlands were released into this pond. They were harvested after a 4 month growth period (Table 3). Clearly, productivity in terms of biomass and income from the fish farm will be more than from the mangrove farm. Considering the period of farming, the productivity and income from crab farming are more than from sea bass farming.

Table 3 Harvest of crab cultured in a one-hectare IMFFS fish farm after four months

	No. of juveniles released	Average size of juveniles (g)	Quantity harvested (kg)	Average price per kg	Value (INR)[a]
Scylla	400	50–100	83	250	20,750
Sea bass	–	–	15	180	2,700
Eel	–	–	8	60	420
Mullet	–	–	15	30	450
Other fish species	–	–	15	25	375
Shrimp	–	–	2	175	350
Total	–	–	138	–	25,045

[a] Indian rupees.

4. Discussion

In India, in the late 1980s, brackish water shrimp farming emerged as an important fishery sector that earned foreign exchange. It is characterized by small-scale family-operated farms. Currently, more than 150,000 farmers are growing prawns in about 160,000 ha of brackish water areas on the east and west coasts of the country. Ninety-one percent of the shrimp farmers in the country have a holding of less than 2 ha, 6% between 2 and 5 ha, and the remaining 3% have an area of 5 ha and above (Yadava, 2002). Until the mid-1990s, the culture system adopted was semi-intensive, and prawn production grew at a rate of 8.4% per year. However, after outbreaks of viral diseases, coastal aquaculture suffered setbacks in terms of production, leading to the abandoning of farming across large areas.

To evolve a low-input, eco-friendly, integrated farming model, the Integrated Mangrove Fishery Farming System (IMFFS) was initiated, where mangroves, halophytes and fishes are raised together to make coastal aquaculture sustainable. The results clearly indicate that in IMFFS farms, mangrove species can be successfully grown while accruing profits from fish and crab culture.

Integrating mangroves in fish farms began many years ago with the Indonesian *tambak* system, where mangroves were planted to provide firewood, fertilizers and protection from wave action (Schuster, 1952). The *gei vai* ponds in Hong Kong (Lee, 1992), mangrove-shrimp ponds in Viet Nam (Binh, 1994; Johnston *et al*., 2000), aqua-silviculture in the Philippines (Baconguis,1991), and *tambak tumpang sari* or *lambak empang parit* in Indonesia (FitzGerald, 2002), are traditional models that integrate mangroves and fish culture. According to Primavera (1998), in these various models, mangroves and other trees are planted on a central platform occupying 60–80% of the total area, while a peripheral canal is maintained for growing fishes and shrimps. The present IMFFS farm is different in that more space is kept for fish and shrimp culture to make the system economically viable.

Integrated mangrove fishery farming is an environmentally friendly and energy-efficient system of farming, where no artificial chemicals are used, and the water is refreshed through tidal currents. This results in a sustainable farm, rather than semi-intensive and/or intensive coastal aquaculture farms, which rely on external energy and inputs in the form of artificial feeds, chemicals, water changes, and so on. According to Kautsky *et al*. (2000), semi-intensive and intensive shrimp pond farming have had a limited life due to their environmental impacts. The productivity and profitability of the integrated farm can be further enhanced through introducing hatchery-produced shrimp larvae, mangrove crabs and high-value fish species in the ponds (FitzGerald, 2002). Sukardjo (1989) showed that the traditional Javan integrated mangrove farming system of *tambak tumpang sari* increased food supplies and contributed significantly to the socio-economic well-being of the coastal rural population.

5. Conclusions and recommendations

In tropical countries, brackish water aquaculture is being practiced in areas where mangroves are present. The development of aquaculture farms in the mangrove areas is one of the main reasons for the reduction of the global extent of mangroves. Integrated mangrove fishery farming brings back mangroves which provide both ecological security and livelihood security for the coastal community. It also provides sustainability to coastal aquaculture farming. The IMFFS approach has a huge potential for rehabilitating abandoned shrimp farms in the coastal belt, both at the national level and in the global arena. After a period of 3 to 4 years, IMFFS becomes more suitable for crab culture, since the mangrove root systems provide shelter, and detritus from mangrove leaves provides food for commercially valuable crabs such as *Scylla* spp. The mangrove root system will provide a natural environment for the crabs to hide, feed and grow. Polyculture of fishes, shrimps, crabs, mussels, blood clams and seaweed can also be taken up in the IMFFS farms to enhance productivity and income.

IMFFS has great potential to enhance the adaption capacity of coastal communities to sea level rise and climate change, since the model addresses both livelihood security of disadvantaged coastal families and ecological security of coastal areas through their rehabilitation. Furthermore, it has the potential for policy interventions relating to rural development, coastal aquaculture, and building adaption capacity to climate change.

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Benefit sharing and clam seed production in Xuan Thuy National Park, Viet Nam

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Abstract

Xuan Thuy National Park is a Ramsar site located in Viet Nam's Red River Delta. It is of high economic importance: thousands of shrimp farmers, clam seed producers and clam collectors depend on its mangroves and mudflats. Since its designation as a Ramsar site in 1989, the park has been almost completely converted to shrimp production as a result of demand for natural resources. Although the area under mangroves has recovered as a result of mangrove planting on new mudflats, the park's core zone remains a *de facto* open access area. The park's management board can neither officially accept the presence of people in the core zone, nor strictly follow national laws that forbid human use of the core zone. In an effort to defuse competition and conflict over these resources, the management board has piloted a benefit-sharing agreement for households involved in highly profitable clam seed production. The other signatories are the local government and management board. According to the park's analysis, the agreement has generated significant revenue to support local welfare services but has failed to address over-harvesting of clam seed.

Keywords: mangroves, clam culture, economic benefits, Xuan Thuy National Park, Viet Nam

1. Introduction

Established in 1989, Xuan Thuy National Park was the first Ramsar site in Southeast Asia (and the fiftieth worldwide). Located in Nam Dinh Province and with a legal area of 12,000 ha, the park contains some of the last remnants of the coastal ecosystems of the Red River Delta. The park is internationally significant as a migratory bird habitat, notably for the globally threatened black-faced spoonbill (*Platalea minor*). There are 46,000 households living next to the park, half of which depend on the extraction of aquatic products from the park. The park therefore makes a major contribution to the local economy. In 2004, the park was recognized by UNESCO as a core zone of the Red River Biosphere Reserve.

Xuan Thuy has undergone significant changes in land cover and use. A study using a time-series of satellite images shows that the area of mangroves increased from 14,000 ha in 1975 to 16,000 ha in 1986, before falling to 6,000 ha in 1992 and recovering to 13,000 ha in 2002. These changes resulted from government support in the early 1990s for converting mangrove "wastelands" to shrimp ponds and subsequent internationally funded replanting efforts. The net effect is that the mangrove core zone has migrated seaward as the park has accreted sediment deposited by the Red River. This has formed Lu Island, which lies parallel to the coast.

The Ramsar Convention stipulates the sustainable and wise use of wetland resources to promote the biodiversity values of wetland areas. In this respect, Xuan Thuy National Park offers a mixed story. National regulations prohibit any kind of use in the core zone. In practice, for many years the park management has been unable to stop local people entering the core zone to collect clams, clam seeds, and other aquatic products. This pressure reflects the high economic value of these products and the fact that ultimate authority over the park's resources rests with the Nam Dinh Provincial People's Committee (PC), not the park management board.

The past decade has seen a substantial increase in the quantity and value of the aquatic products that local people collect from the park. The average revenue from clam culture alone is VND 10–20 billion (US$0.5–1 million) per year. This increase has put more pressure on the park and its natural resources. Every day, thousands of people enter the core zone to collect aquatic products. This is not only against the law, but in the absence of any form of management regime it has also resulted in conflicts, some of which have turned violent. The challenge for the park management is how to manage both the collection and the distribution of these benefits without any precedent or institutional structure.

2. Materials and methods

In 2005, Xuan Thuy National Park funded a project to develop a co-management mechanism governing the sustainable and wise use of natural clam seed in the park for the benefit of the local people. (Other regulations are in place for the clam culture beds.) The following steps were carried out: surveying the livelihoods of local communities; assessing the park's natural clam seed resources; and organizing consultations with local communities, local authorities and scientists.

This project has institutionalized local partnerships and addressed problems ignored by the existing legal documents. For example, how to use wetland resources wisely? What are the specific rights and responsibilities of the management board, clam seed collectors, and commune authorities?

Wise use is based on the following principles: aquatic resources are highly productive with a high capacity for regeneration; reasonable exploitation can both generate income and sustain the resource over the long term; and wise use of aquatic resources can be put into practice by proper planning, use of technology, and cooperation between institutions.

In terms of the rights and responsibilities of stakeholders:

- **Clam seed collectors** are allowed to lease mudflats from the park, access credit and technical know-how, and participate in formulating regulations and monitoring implementation. The collectors pay VND 0.5–3 million/ha/year (US$25–150/ha/year) depending on the quality of the mudflat. Every year during the April-to-July clam seed collecting season, the mudflats are allocated to households on short-term leases. Clam seed collectors can use only manual (not mechanized) collection devices, and are not allowed to convert any natural habitats, use destructive fishing practices, pollute the environment, hunt, or sub-contract the collection area. The total area of clam seed beds is 1,000 ha, including 700 ha in the Red River estuary and 300 ha at Lu Island. In a good year, these can provide seed for up to 1,300 ha of clam culture with seed also sold to other provinces.

- **Local authorities** are responsible for protecting the park's natural resources and providing technical and financial support to the community. In return, they receive a portion of the revenue from the leases, which is then spent on local welfare.

- The **park management board** is in charge of managing and monitoring the co-management agreement.

3. Results

In August 2006, the Nam Dinh Provincial PC approved the pilot project on managing clam seed at the mouth of the Red River inside the park. The management board, which comprises representatives from Giao Thuy district, Giao An and Giao Thien communes, and the park, implemented the pilot project from 2006 to 2010. The park management board has concentrated on making sure that clam seed collection does not damage the park's biodiversity.

The clam management board, which is chaired by the Giao Thuy District PC, holds local meetings and consults with the District Party Committee on project implementation. A management agreement has been prepared. The two Commune PCs have disseminated information about the project. As a result, the awareness and attitude of local people toward conservation have improved significantly. The Commune PCs have also issued legal documents to ensure that aquatic resources are harvested sustainably.

Every year, at the end of the clam seed collection season, the clam resource management board requests the Commune PCs to submit progress reports. The revenue from leasing the mudflats has contributed to the commune's budgets, and has been used to invest in improved public services. Table 1 summarizes the revenues of both communes.

Table 1 Commune revenues from benefit-sharing agreement, 2006–2010

	Number of households	Area (ha)	Revenues	
			VND [a]	US$
Giao Thien Commune				
2007	24	260	420,070,000	26,419
2008	20	170	111,240,000	6,621
2009	11	150	188,000,000	10,162
2010	13	150	96,000,000	4,638
Total	–	–	815,310,000	47,841
Giao An Commune				
2006	215	450	400,000,000	26,667
2007	240	450	385,000,000	24,214
2008	235	450	410,000,000	24,405
2009	245	400	370,000,000	20,000
2010	210	400	312,000,000	15,072
Total	–	–	1,887,000,000	110,358

[a] Viet Nam dong.

4. Discussion

When designing the pilot project, the park underestimated the impacts of seed collection. In fact, clam seed production has fallen substantially over the past few years, as reflected in the decline in area of leased mudflats and revenues since 2007 in Giao Thien Commune shown in Table 1. This decline can be traced to the following causes:

- Very few mother clams remain in the clam collection area to deliver seeds to the clam seed beds via longshore currents, because clam collectors gain no direct benefit from limiting their harvest.

- Households collect clam seeds when they are too small (initially the seeds were the size of sand grains; now a magnifying glass is needed to see them). If this trend continues, the clam seeds will become commercially extinct.
- Possible changes in ocean currents and the status of the mudflats, which have become less favourable to clam seed development.

The current agreement does not set sustainable harvesting limits. In effect, the agreement is a benefit-sharing arrangement put in place to avoid social conflicts rather than a sustainable management agreement that regulates harvesting. So the focus is on dividing up the proceeds rather than ensuring a sustainable yield.

According to the policy approved by Nam Dinh Provincial PC, this revenue is allocated as follows: 80% to a local welfare fund, 15% to an environmental protection fund, and 5% to the park to cover the operating expenses of the clam management board. However, given the limited revenue and availability of other funding, the park has returned its share of the revenue to the communes.

5. Conclusions and recommendations

The pilot project succeeded in establishing strong multi-stakeholder cooperation to ensure a fair distribution of the benefits from clam seed production in Xuan Thuy National Park. The project increased local incomes, provided additional revenue to commune budgets, and reduced the scope for conflict. Environmental protection clubs have been formed that testify to the degree of community support for the co-management agreement.

In February 2012, based partly on the Xuan Thuy experience, Viet Nam's Prime Minister issued Decision 126 on piloting benefit-sharing in the management, protection, and sustainable development of protected areas. The park was chosen as one of two sites to implement the decision. In line with the decision, the park will carry out the following five components:

1. Sustainable use of clam seed beds resources in frequently flooded areas in the Red River estuary and around Lu and Ngan Islands.
2. Sustainable local community use of aquatic resources inside the mangrove forests in the core zone of the park.
3. Community-based mangrove management model in the park's buffer zone in Giao An, Giao Lac and Giao Xuan Communes.
4. Sustainable use of the clam culture areas while still protecting the important bird areas in the ecological restoration zone on Lu Island.
5. Sustainable collection of medical plants in the *Casuarina* forests on Lu Island.

In October 2011, the park received an MFF small grant to implement component 2 of Decision 126. A UNDP/GEF project is supporting component 3; the Viet Nam Conservation Fund may support the other three components.

Despite the challenges, the park management board is confident of its ability to implement the Prime Minister's benefit-sharing decision with the support of ministries, local authorities, and international organizations. If successful, the park will demonstrate Viet Nam's commitment to meet the Ramsar requirement for "wise use" and strengthen Xuan Thuy's importance as a core zone of the Red River Biosphere Reserve.

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Mangrove planting, community participation and integrated management in Soc Trang Province, Viet Nam

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Abstract

The highly dynamic coastline of Soc Trang Province in the Mekong Delta of Viet Nam is in most parts protected from erosion, storms and flooding by a narrow belt of mangroves. This protection function is threatened by the unsustainable use of natural resources in the coastal zone. This situation will be exacerbated by the impacts of climate change, particularly by the increased intensity and frequency of storms, floods and rising sea levels. The GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit) project "Management of Natural Resources in the Coastal Zone of Soc Trang Province, Viet Nam" makes a contribution to addressing this issue by protecting and sustainably utilising the coastal wetlands for the benefit of the local population through mangrove rehabilitation and management with an emphasis on resilience to climate change. Lessons learned from five years of mangrove planting, protection and management can be summarised in five statements:

1. Planting mangroves alone is of little use. Newly planted mangroves must be protected from human impacts such as destructive fishing or resource collection methods. This has been achieved by participatory involvement of local communities through co-management. Co-management is an effective way of maintaining and enhancing the protection function of the mangrove forest belt and, at the same time, providing livelihoods for poor local people. Payment for ecosystem services from a clam cooperative on the sandbanks in front of the mangrove forest contributes to the sustainability of co-management.

2. Site-specific, appropriate solutions are needed. This covers selection of suitable species, site selection for planting different species, appropriate planting techniques, and selection of the best planting times. Testing of new planting techniques which mimic successful natural regeneration will help to address the uncertainty about the impacts of climate change. Mangroves can only be planted in erosion sites after fences and wave breakers have reduced the erosion and stimulated sedimentation. The impact of wave breakers on shoreline dynamics must be predicted using numerical current and erosion modelling.

3. Looking at the *status quo* is not enough. Historic information contributes to a better understanding of coastal dynamics. It also allows the selection of species for rehabilitation which grew naturally in a given site before human interventions.

4. Integrated coastal area management is needed. Parts of the coastal zone cannot be effectively managed using an isolated, sectoral approach. Mangrove planting, protection and management must form part of an integrated approach.

5. Raising the awareness of and communicating with all stakeholders is a prerequisite for successful mangrove and integrated coastal area management.

Keywords: mangroves, participatory approach, integrated coastal zone management, climatic changes, Viet Nam

1. Introduction

The Mekong Delta of Viet Nam plays an important role as the "rice bowl" for the whole country (Nguyen, 1994). The expansion of shrimp farming in the Mekong Delta has contributed to economic growth and poverty reduction, but has also led to concerns about environmental and social impacts (Phan and Hoang, 1993; de Graaf and Xuan, 1998; Páez-Osuna, 2001;

Primavera, 2006). The lack of an integrated approach to the management, sustainable utilization and protection of the coastal zone and economic interests in shrimp farming has led to the unsustainable use of natural resources, thereby threatening the mangrove forest belt's protective function. This threat will be exacerbated by the impacts of climate change through the predicted increase in intensity and frequency of storms, floods and sea level rise (Carew-Reid, 2007; IPCC, 2007; MoNRE, 2009; MRC, 2009).

Soc Trang Province is one of 13 provinces in the Mekong Delta region and is located south of the Hau River, the southernmost arm of the Mekong River. The province covers a total area of 331,176 ha, of which about 62% is used for agriculture, just over 3% for forestry and more than 16% for aquaculture. The population of the province is just over 1,285 million, of which about 29% are Khmer and 6% are ethnic Chinese (2008 figures from Soc Trang Statistics Office, 2010).

The 72 km coastline of Soc Trang is characterised by a dynamic process of accretion and erosion created by the discharge regime of the Mekong River, the tidal regime of the Vietnamese East Sea (South China Sea), and the coastal longshore currents driven by the prevailing monsoon winds (Chu *et al*., 1999; Lu and Siew, 2006; Nguyen, 2009). In some areas, a loss of land due to erosion of up to 30 m per year has been recorded, while in other areas land creation through accretion processes can reach up to 64 m per year (Joffre, 2010; Pham, 2011).

The project "Management of Natural Resources in the Coastal Zone of Soc Trang Province, Viet Nam", funded by the German Federal Ministry of Economic Cooperation and Development and implemented by GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit), aims to protect and sustainably use the coastal wetlands for the benefit of the local population through mangrove rehabilitation and management with an emphasis on resilience to climate change. The project started in 2007, and after five years of implementation the key lessons learnt from mangrove planting, protection and management can be summarised into five statements: i) planting mangroves alone is of little use; ii) solutions must be site specific and appropriate; iii) looking at the *status quo* is not enough; iv) whatever is done must be part of an integrated approach to coastal area management; and v) raising awareness of all stakeholders and communicating with them is a prerequisite for successful mangrove management as part of an integrated coastal area management approach.

2. Material and methods

A systematic assessment of past experiences with mangrove planting and rehabilitation, and an analysis of the reasons for success or failure, were carried out. Records from mangrove plantings since 1993 were compared with the results from field surveys (mangrove survival and growth rates) carried out in 2008. Additional information was obtained from a mangrove cover change analysis using topographic maps from 1965, SPOT satellite images from 1995, Landsat ETM images from 2001 and QuickBird satellite images from 2006/7 (Pham, 2011). The analysis of the effectiveness of mangrove protection and management was based on interviews with local people and staff from local authorities (Joffre and Luu, 2007; Pham, 2011). Historic topographic maps dating to 1889, plus aerial photos from archives and libraries in Aix-en-Provence, Paris (France) and Ho Chi Minh City (Viet Nam) were compared with the results from Pham (2011), and information from key informants with long-term knowledge of the area, for an analysis of changes in the coastline and mangrove forest cover (Joffre, 2010).

Two mangrove planting trials mimicking natural regeneration were established: i) small-scale planting of high numbers of seedlings close to established trees and shrubs; and ii) planting in canopy gaps created in even-aged plantations.

In October 2009, seedlings of *Ceriops tagal* and *Rhizophora apiculata* were planted in 24 plots of between 26 and 36 m^2 in area at the seaward edges of 2–6 m high mangrove forest dominated by *Avicennia marina*. The planting densities ranged from 8 to 40 seedlings/m^2 (Meinardi, 2010). Additional planting of *A. marina* was carried out in June 2010 with densities of 4–20 seedlings/m^2. In August 2011, all plots were enlarged to 100 m^2 and *A. marina*, *Bruguiera cylindrica* and *C. tagal* were planted in varying species compositions and densities of 5, 10 and 20 seedlings/m^2.

Canopy gaps were created in a 13-year-old *Rhizophora* plantation with an average tree height of 6–8 m. The gaps ranged in size from 7–45 m^2. The species *C. tagal* and *R. apiculata* were planted in nine of these gaps at densities ranging from 21–46 seedlings/m^2 in October 2009. Nine gaps were left for natural regeneration to occur and three plots were marked as control without felling any trees (Meinardi, 2010). In August 2011 all plots were increased in size to 12–54 m^2 and *A. marina*, *C. tagal* and *R. apiculata* were planted at densities ranging from 5–14 seedlings/m^2.

To monitor mangrove species, data on number, height, knots and diameter are recorded in randomly placed sampling plots as described in Pham *et al*. (2011). The resource use monitoring programme compares indices, thus avoiding the need for expensive baseline data. The indices are the amount of resources harvested, and the effort required for the harvest of a defined quantity. The resources harvested and units are: juvenile and sesarmid crabs (number of crabs), long snails and blood cockles (kilogrammes); goby fry (grammes); mudskippers (number); sea snake and rats (number) and dry wood (*tac**). The data are recorded using time as a measure of effort. The recoding is done by the local resource users, who do not use watches to record the time they spend collecting resources; they record only short or long collecting trips. As collection time normally does not exceed four hours, a period of one hour is used to calculate effort for a short trip and three hours for a long trip.

A two-dimensional depth-averaged numerical hydrodynamic model was developed for the design of wave-breaking barriers using the open source software RMA·KALYPSO (Schrage *et al*., 2009). The numerical wave model SWAN was coupled with the hydrodynamic model to obtain the wave parameters for different scenarios. The results of the hydrodynamic modelling were then used in the morphodynamic model GENESIS (Hanson and Kraus, 1989) to compute the most effective position and dimensions of erosion protection measures. Physical tests in a wave flume were carried out to determine the most effective design of the actual structure of the wave-breaking barriers (Albers, 2011; Albers and von Lieberman, 2011).

* A *tac* is a pile of cut wood 0.3 m x 1 m x 1 m in size.

3. Results and discussion

This section focuses on the key lessons learned from five years of mangrove planting, protection and management.

3.1 Planting mangroves alone is of little use – they must also be managed effectively

Techniques for mangrove forest restoration have been described by many authors and comprehensive overviews can be found in Kairo *et al*. (2001), Lewis (2005, 2009) and Kathiresan (n.d.). These authors emphasise the importance of identifying the main objectives of a restoration programme. Furthermore, selection of species must be based on a sound understanding of their autecology and community ecology, hydrological patterns, tidal amplitude, soil conditions, salinity and morphodynamics (erosion, accretion). Mangrove species can also be selected based on the species that occur naturally in the site. Based on this, the appropriate species need to be selected for each site, and must be planted using appropriate planting techniques at suitable times. The nursery technique is another important factor which will contribute to the restoration's success (Melana *et al*., 2000; Hoang and Pham, 2010). To ensure that newly planted mangrove forests can grow undisturbed and eventually fulfil their protective function, they must not only be planted as described above, but must also be protected from human impacts such as destructive fishing methods, logging and encroachment. In some specific sites, they must also be protected from waves (see section 3.2).

In the case of the coastal zone of Soc Trang, where the main objective of restoring mangroves is to protect the coast against tidal waters, erosion and storms, mangrove restoration has been carried out since 1993 (Pham, 2011). Between 2000 and 2007, mangrove protection and management in Soc Trang was done using forest protection contracts and forest land allocation along the coast. Land was allocated to farmers (around 4 ha per household) and protection contracts made with payments of VND 50,000 (about US$3 based on the average exchange rate in 2007) per hectare per year (Pham, 2011).

The effectiveness of this approach to mangrove management was analysed by Joffre and Luu (2007) and Pham (2011). They concluded that individual household-based forest protection contracts did not result in effective protection and management of mangrove forests. In fact, the opposite was the case: the amount paid per hectare per year was not enough to actively engage people in forest protection activities. Instead, it encouraged them to make their own income by cutting the forest for fuelwood instead of protecting it. The experience with forest protection contracts clearly shows that mangrove protection and management, which rely on individual ownership of small plots of forest, does not work in a situation where a highly dynamic coast is only protected by a narrow belt of mangroves. This has also been confirmed by the director of the Forest Protection Sub-department of the neighbouring province of Bac Lieu (pers. comm.).

The project therefore decided to pilot a form of mangrove management where larger areas of forests are managed jointly through a co-management agreement between the local communities and local authorities. Co-management has been used successfully for management of natural resources worldwide and a comprehensive overview is provided by Borrini-Feyerabend *et al*. (2004, 2007).

3.1.1 Mangrove co-management – a pilot study in Au Tho B village

Co-management is based on participatory negotiation, joint decision-making, a degree of power-sharing, and fair distribution of benefits among all stakeholders (Borrini-Feyerabend *et al*., 2004). Co-management in the context of protection and sustainable natural resource management in mangrove forests of the Mekong Delta can be described as a partnership agreement in which a resource user group gets the right to use natural resources sustainably on a defined area of state-owned land (Protection Forest), while being held responsible for the management and protection of those resources. All stakeholders share the responsibility and authority for the management of a given area and a defined set of natural resources. Resource users and local authorities jointly negotiate a formal agreement on their respective management roles, responsibilities and rights.

The co-management process can be described in three main phases: organising for the partnership; negotiating co-management plans and agreements; and implementing and revising the plans and agreements: "learning-by-doing" (Borrini-Feyerabend *et al*., 2007). For mangrove co-management in Soc Trang, these phases were divided into smaller steps and implemented within the framework of key principles:

- Obtain acceptance from all stakeholders for the piloting of co-management.
- Carry out surveys on natural resource use and socio-economy of the pilot site.
- Follow a four-step process of: consultation and organisation; negotiation and agreement; implementation; and monitoring and evaluation.
- During this process, four principles must be applied: integrated coastal area management, participation, zonation and monitoring.

The key elements of co-management can be summarised as participation, an agreement and a pluralistic governance body (Borrini-Feyerabend, 2011).

This paper will provide a brief overview of the co-management process in Soc Trang, co-management implementation, main impacts and sustainability. A more detailed description of the co-management process is given in Lloyd (2010) and Schmitt (2011).

The co-management process in Soc Trang started in mid-2007 with capacity building of local authorities at the provincial and district levels. Understanding and acceptance of co-management by all key stakeholders is a prerequisite for starting the participatory process. The importance of political support at the provincial and district levels has also been highlighted by Marschke and Kim (2003). A pilot site was selected after key stakeholders agreed to test co-management. The village of Au Tho B was selected because it has a lot of poor, landless people from ethnic minority groups who rely on the collection of natural resources from the mangrove forests for their livelihood. The next steps were surveys of the natural resources use and socio-economy in Au Tho B.

The actual participatory process started with consultations. This involved many meetings with villagers and staff from local authorities to introduce the co-management concept, identify resource users and to get acceptance from all stakeholders at the local level. Then the user group membership and leadership were organised, and in January 2009 the resource user group was established formally under Decree 151* consisting of 240 households (by 2012 the number had increased to 289). The next step in the co-management process was negotiation between the resource user group and the local authorities about acceptable ways to jointly and sustainably manage the natural resources within the mangrove forest area of Au Tho B, and at the same time protect the integrity of the mangrove belt. In September 2009, after 12 negotiation meetings, a resource use agreement was signed between the resource user group and the local Commune People's Committee. During the negotiations, the project carried out capacity-building activities by providing training for leaders from the resource users and staff of local authorities.

The "Regulations on the Rights in Forest Protection and Natural Resource Use by the Co-management Group in the Coastal Area of Au Tho B Village, Vinh Hai Commune" (the agreement) have the objective "to enable co-management practice to protect the forest and rationally and sustainably use natural resources within the Au Tho B coastal area". The agreement contains seven chapters: Objectives; Where and to Whom this Regulation Applies; General Provisions; Natural Resource Management; Rewards and Penalties; Report Schedule; and Implementing Provisions. Article 10 of the agreement covers regulations on what can and cannot be done in each zone. It specifies the 'six w's': who can do what, where, when, how and how much (for details see annex on page 221).

Environmental awareness-raising, understanding of the agreement and effective communication between stakeholders, are important prerequisites for the successful implementation of co-management (see section 3.5). They are also essential activities which must continue as part of the implementation of co-management.

A pluralistic governance body for joint decision-making is also essential for the effective implementation of co-management. For Au Tho B, a co-management board was established with members from the resource user group, local authorities (village and commune level), the technical department responsible for mangrove management and the farmers' and women's unions. The board is responsible for overall steering and conflict resolution. It also uses lessons learned during implementation and the analysis of monitoring data to revise the agreement and zonation plan. A first review of the agreement was carried out after 20 months of implementation.

In Au Tho B, a participatory resource use monitoring programme has been put in place, carried out by the resource users with the aim of monitoring the sustainability of the resource harvest. Information based on the analysis of monitoring data will enable the co-management group and board to make informed decisions for adaptive management and protection of the mangrove forest. The monitoring programme has been designed so that it can ensure sustainability through simple and easy data collection protocols, easy data entry using mobile phones and data storage, analysis and report production with a user-friendly custom-made database programme. This can also ensure that the results of the monitoring are reported regularly to all key stakeholders.

* Decree 151/2007/ND-CP of 10 October 2007 on the Organisation and Operation of Cooperative Groups.

Whatever is done during the implementation of co-management, four principles must apply: integrated management (see also section 3.4), participation, zonation and monitoring. The co-management process must be undertaken in a participatory manner involving all stakeholders. The mangrove forest under co-management in Au Tho B covers 94.5 ha. This area is large enough to be divided into zones in which different management regimes are applied. Zoning allows areas to be set aside for particular activities such as protection of key habitats, nursery areas/breeding sites and resource use. The zones must be identified jointly during the negotiation step and specific rules are attached to each of the zones. In Au Tho B, four zones have been defined (Figure 1). Monitoring is one of the key principles of the co-management process and at the same time part of the four-step process described above.

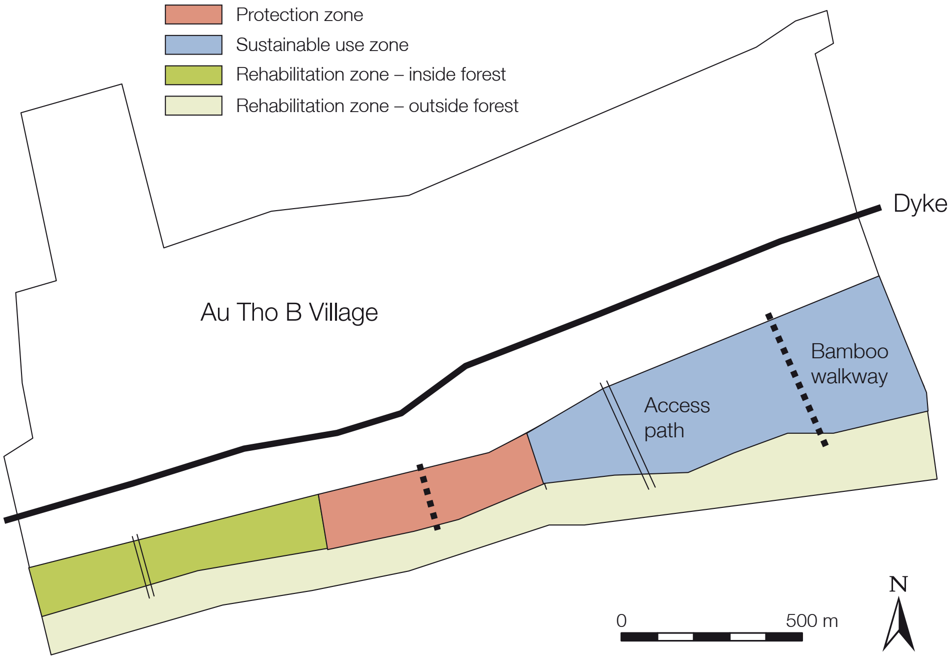

Figure 1 Mangrove management zones in Au Tho B Village, Soc Trang, Viet Nam

An actor-centred Method for Impact Assessment of Programmes and Projects (MAPP) was devised by the German Development Institute (Neubert, 2010). This method was tested successfully in Soc Trang (Eucker, 2009). MAPP will be used again for an impact assessment at the end of the project period. Therefore, for the time being, we have to rely on proxy indicators, which are statements by the people who have been implementing co-management on a daily basis for almost three years:

- **Co-management is an effective way of maintaining and enhancing the protection function of the mangrove forest belt**. During an interview by a film team from BBC World News a woman said, "*Now I have to go less far to collect resources*". This is a clear indication that the application of resource use rules and regulations, in terms of access (zonation, time restrictions, number of people) and the use of fishing tools, has led to an increase in the abundance of aquatic resources and an improvement in the structure and integrity of the mangrove forest. Effective protection of mangrove forests, with the exclusion of resource use in a protection zone, leads to an increase in aquatic resources, as has been shown by Laegdsgaard and Johnson (1995), Mumby *et al*. (2004) and Mumby (2006). This is also supported by Kihia *et al*. (2010), who concluded that lower litter fall occurs in mangrove forests with evidence of human disturbance.

- **Co-management provides livelihoods for poor local people**. During the same BBC interview, a villager said "*Since we started co-management we are very happy because our daily income has increased; we benefit now from about VND 50,000–60,000 per day*". The main source of income is from sales of goby fry, crabs, blood cockles and snails – and again the increase in income indicates that resources are more abundant.

- **Co-management contributes to better governance**. During a different interview, one villager said "*Before we were afraid of forest rangers, now we are working together – and there are fewer outsiders entering our area*". This clearly indicates improvements in collaboration between local people and local authorities. It also indicates an increase in the sense of resource ownership by the resource users, which results in improved and more effective protection of resources (Erdman *et al*., 2004).

A participatory monitoring programme has been developed with the aim to monitor the sustainability of the resource harvest. A first analysis of resource-use monitoring data has already provided a good indication of the sustainability of the harvest. Figure 2 shows a comparison of two indices for the collection of juvenile crabs for a period of 17 months. The number of crabs harvested fluctuates according to a seasonal pattern (February to July is the low season for crab collection, Joffre and Luu, 2007). Although the monitoring period is relatively short, based on the comparison of these indices over time, one can already conclude that there is enough natural regeneration to support the current harvest volume sustainably.

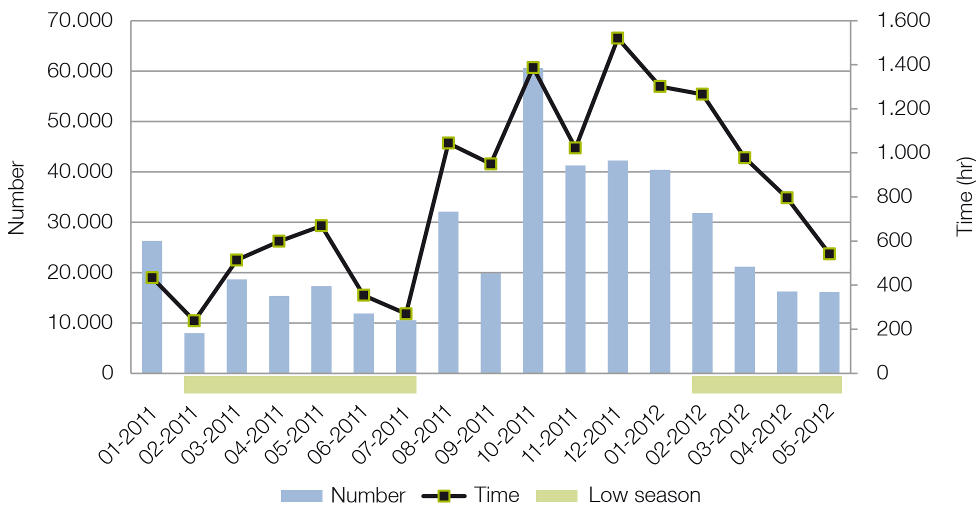

Figure 2 Collection of juvenile crabs in Au Tho B Village

Figure 2 shows that the amount harvested follows a seasonal pattern and does not indicate any decline due to overexploitation. The effort needed for collection, in terms of time spent, closely follows this seasonal pattern and there is no indication that the effort increases over time for the collection of a fixed amount of crabs. This supports the indication that there is no overexploitation, that the natural regeneration is sufficient to support the current harvest volume and, therefore, that the resource collection is sustainable.

Besides the sustainability of the resource harvest, the financial sustainability of mangrove co-management must also be considered. Although it carries recurring expenses, in contrast to community forestry, for example, it does not provide the members of the user group with the opportunity to earn high incomes from the sale of timber, a part of which could be used to defray those expenses. It must be emphasised again that, in sites where there is only a narrow belt of mangroves along a dynamic coastline, the primary aim of mangrove co-management is mangrove protection. The sustainable collection of aquatic resources and dry wood for local livelihood enhancement is a secondary aim.

For the sustainability of mangrove co-management, it is essential to ensure that recurring expenses (for example to carry out meetings, maintain communication between stakeholders and enter monitoring data) do not need to be paid by the co-management group. The project has therefore started to pilot a payment for ecosystem services scheme with the aim of covering the operational costs of co-management sustainably.

The sandbanks in front of the mangrove forests of Au Tho B are habitat for clams (lyrate Asiatic hard clam, *Meretrix lyrata*) of high commercial value. These clams are currently exploited in an unsustainable way because of open access to the resource. The project has supported the establishment of a clam cooperative with the aim of sustainable commercial utilisation of clams and increase of income along the aquatic value chain through Marine Stewardship Council certification. The clam cooperative will benefit from ecosystem services provided by well-managed and protected mangrove forests, which provide food, habitat and nursery grounds for aquatic life. The importance of mangroves for food security and income has been highlighted by Hamilton and Snedaker (1984), who concluded that up to 80% of fish catches are directly or indirectly dependent on mangroves; Schatz (1991), who concluded one hectare of healthy mangrove forest produces about 1.08 tonnes of fish per year; and Aburto-Oropeza *et al*. (2008), who showed a positive correlation between fisheries landings in the Gulf of California and the local abundance of mangroves.

After extensive consultation processes involving the clam cooperative, the co-management group and local, district and provincial authorities, all stakeholders agreed that the clam cooperative will gain financial benefits from a well-managed and protected mangrove forest. The fact that local people recognise the ecosystem services provided by mangroves has also been shown by Warren-Rhodes *et al*. (2011) for rural communities in the Solomon Islands. Based on the recognition of the ecosystem services provided by mangroves, the clam cooperative agreed to a direct payment for these services to the co-management group which protects and sustainably manages the mangroves. The clam cooperative included a clause in their statute that they will pay for the operational costs of mangrove co-management on a reimbursement basis against proof of expenses. Implementation of this payment for ecosystem services will start at the end of 2012 and will contribute to the sustainability of co-management by involving the private sector.

3.2 Site-specific and appropriate solutions are needed

Although this lesson seems obvious, there are still many situations in which decisions are not based on the most appropriate solution. Lessons from national and international best practice examples, and from an analysis of the successes and failures of mangrove rehabilitation in Soc Trang between 1993 and 2007 (Pham, 2011), were used to produce a mangrove management tool box, consisting of three manuals: Mangrove Nursery (Hoang and Pham, 2010); Mangrove Planting and Management (Pham *et al.*, 2009) and Monitoring (Pham *et al.*, 2011). The mangrove planting and management manual not only highlights the importance of site-specific species selection and planting time, but also covers new planting techniques, which mimic successful natural regeneration through: i) small-scale planting of high numbers of seedlings close to established trees and shrubs, and ii) planting in canopy gaps created in even-aged plantations. The latter mimics the natural occurrence of canopy gaps and the natural regeneration found in such gaps (Duke, 2001).

Results of the monitoring carried out 4, 8 and 16 months after the dense planting at the seaward side of established trees and shrubs showed high survival and growth rates. For *C. tagal*, for example, no significant change in survival rate was recorded (P=0.24; 0.39 and 0.57) as well as an increase in height from an average of 11.2 cm in February 2010 to 44.5 cm after two years in February 2012. During the same period, *R. apiculata* increased in average height from 27.8–81.9 cm. The repeated planting also mimics nature and can ensure that a tapering forest edge is created towards the sea side. Results of the monitoring carried out 4, 8, 16 and 28 months after the planting in canopy gaps showed very low survival rates. Only 1% of *R. apiculata* plants were still alive 28 months after planting, in contrast to 7.7% of *C. tagal*. The average height after two years was about 39% less for *R. apiculata* and about 47% less for *C. tagal* compared with the plantings in the open sites described above.

The actual amount of light reaching the forest floor in the canopy gaps declined over time because of lateral growth of the crowns of the trees around the gaps. Therefore, limited availability of light may be the main factor for the low survival and slow growth rates. More analysis will be necessary to account for the impact of crabs, human disturbance and other environmental factors. An extension of the sizes of the gaps to 12–54 m^2 and additional planting in August 2011 did not improve the survival rate. Therefore, a gap size of around 50 m^2 may not be sufficient for successful regeneration. This is supported by an observation in a nearby natural gap with an area of about 81 m^2, which shows abundant and more vigorous regeneration than in the smaller gaps.

When testing approaches which mimic nature, it is important not to depend on a single solution, but to spread the risk by applying different strategies to address uncertainty. This is particularly important in the context of climate change. One example is mangrove planting in erosion sites, which requires solutions appropriate and specific to the situation of each site. Mangroves grow along sheltered coastlines and therefore can only be planted on erosion sites after barriers have reduced the erosion and stimulated sedimentation.

The coast of Soc Trang is protected from flooding by an earthen dyke, which in turn is protected from erosion by mangrove forests. The latter has been demonstrated by Mazda *et al.* (1997), who showed that a 1.5 km wide belt of six year old mangroves in the north of Viet

Nam reduced the height of incoming waves from 1 m to 5 cm, whereas in areas without mangroves the waves were reduced to only 75 cm. The financial implications of this have been elaborated by Brown *et al*. (2006), who concluded that US$1.1 million invested in mangrove rehabilitation in northern Viet Nam saved US$7.3 million annually in dyke maintenance.

In several places along the coast of Soc Trang the mangrove belt has been destroyed by erosion. Here the sea dyke is endangered. At such sites, coastal protection and climate change adaptation through mangrove rehabilitation is only possible after the wave energy has been reduced by physical barriers. The project has therefore put in place an erosion control model, which combines "hard" and "soft" solutions, i.e. breakwaters and mangroves. The placement and dimensions of the wave-breaking barriers have been designed based on a numerical model to ensure that they reduce erosion, stimulate sedimentation, and avoid down-drift erosion as much as possible. Wave-breakers and T-shaped bamboo fences yielded the best results, and have additional advantages due to the strength, availability and low cost of bamboo (Albers and von Lieberman, 2011; Albers, 2011; Albers 2012).

Co-management is also a site-specific solution. The steps and principles described in section 3.1.1 apply to all co-management sites, but each site is different in terms of its socio-economic conditions and natural resource use patterns, and this must be considered when developing the process. Whether or not co-management is appropriate for a given site also depends on biophysical and socio-economic conditions and resource-use patterns. For example, in localities where mangroves cover large areas in sheltered sites or inland from the sea dyke, other management regimes can be applied to manage the mangroves effectively, as has been documented for Malaysia by Kamaruzaman and Dahlan (2008) and for Viet Nam by Minh *et al*. (2001).

3.3 Looking at the *status quo* is not enough

The discharge regime of the Mekong River, the tidal regime and coastal longshore currents combine to create a dynamic process of accretion and erosion along the coastline of the Mekong Delta. This process has changed over time, influencing the shape of the coastline, erosion patterns and, in turn, mangrove cover. This has been demonstrated in two studies which aimed to understand changes to the coastline and mangrove forest cover of Soc Trang between 1904 and 2007 (Joffre, 2010; Pham, 2011).

These studies show that since 1904 the coastline and mangrove forests have changed substantially, including a sequence of deforestation and reforestation in some areas, changes in tree species composition and transformation of the coastline landscape from sand dunes to mangrove forests. These dynamics of the coastline and mangrove forest cover result from a combination of man-made factors such as deforestation for fuelwood, expansion of farming areas, impact of defoliants used during the Viet Nam War, followed by reforestation, which modified the original species composition, and natural factors such as accretion and erosion.

The use of a historical approach allows us to understand the sequence of changes that occurred in this area. It helps to provide a better understanding of the "original" ecosystems before human influences. Understanding the diversity of this coastal zone through its history will assist in the development of future adaptation measures to protect and manage it, such as choice of suitable species and site selection for reforestation. In short, historical information contributes to a better understanding of coastal dynamics (Joffre, 2010).

3.4 Integrated coastal area management

Mangroves form a narrow belt along most of the coastline of Soc Trang. This belt cannot be managed effectively through a sectoral approach, with only one sub-department looking at the mangroves in isolation from what happens on either side of the mangrove belt (i.e. the mudflats and sandbanks on the seaward side and the dyke, shrimp farms and agricultural areas on the landward side). Furthermore, Kairo *et al*. (2001) expressed the need for integrated management of mangrove forestry and fisheries. It is also essential to consider what happens along the entire coastline of the province – and beyond its boundaries – when planning and carrying out interventions, instead of just looking at individual spots in isolation along the coast. Therefore, mangrove management must be part of an integrated coastal area management (ICAM) approach. This is a holistic, cross-sectoral, multidisciplinary approach, requiring institutionalised co-ordination and cooperation of local authorities from all levels, and participation of all affected stakeholders.

Co-management and mangrove rehabilitation in erosion sites provide examples of this. The co-management of natural resources must be looked at from an ecosystem perspective, not purely a site-specific one. Co-management must consider what other land/resource uses or controls are present in the vicinity of the site itself, and their interactions with the co-management process. One example of this is the interaction with the clam cooperative on the sandbanks in front of the mangroves as described in section 3.1.1.

Mangrove rehabilitation in erosion sites cannot be carried out effectively by just looking at one specific erosion site. It is essential to consider interactions with other parts of the coast, i.e. look at the coastal zone as a whole, through numerical modelling, and to put different options in place depending on site-specific conditions.

An integrated, ecosystem-based approach is not only needed for planning and management, but must also be applied to knowledge and expertise. Local knowledge must be integrated with technical input from experts in relevant fields such as coastal engineering. This will result in a true holistic, cross-sectoral and multidisciplinary approach.

3.5 Awareness raising and communication

Mangrove rehabilitation, protection and management must be part of an integrated approach involving a wide range of stakeholders. These stakeholders can only participate effectively if they are aware of the importance of mangroves and the benefits and services they provide; and if they are informed about planning and management actions. This is supported by 15 years of research on co-management in fisheries and other coastal resources, which points to awareness and communication as conditions that affect the success of co-management (Pomeroy *et al*., 2001), as well as by findings from mangrove management in East Africa (Kairo *et al*., 2001).

The importance of raising awareness about environmental issues, understanding of the co-management agreement, and effective communication among stakeholders, as prerequisites for the successful implementation of co-management, have clearly been confirmed by the experience from Soc Trang.

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Annex Regulations on the rights in forest protection and natural resource use by the Co-management Group in the coastal area of Au Tho B Village, Vinh Hai Commune

Pursuant to the Law on Forest Protection and Development 2004. Within the framework of the project "Management of Natural Resources in the Coastal Zone of Soc Trang Province". Based on the Co-operation Contract signed by the Co-management Group of Natural Resource Users in Au Tho B Village and the Vinh Hai Commune People's Committee on 1 January 2009, and following a negotiation process with approval from local authorities and other relevant agencies, the Co-management Group of Natural Resources Users in Au Tho B Village (hereinafter referred to as the Co-Management group) has established and promulgated the following co-management regulations on forest protection and natural resource management in the coastal area of Au Tho B Village, Vinh Hai Commune:

CHAPTER 1 Objectives

Article 1. To enable co-management practice to protect the forest and rationally and sustainably use natural resources within the Au Tho B coastal area to achieve the vision contained in the Co-operation Contract dated 1 January 2009: "*The forest and fishery resources are well managed, protected, developed and reasonably used in accordance with the Law; there are no poor households, people have stable incomes and children attend higher school levels; and there is a clean and beautiful environment and less impact from natural disasters*".

Article 2. To strengthen co-operation between the Au Tho B resource users, local authorities and other related organisations to improve the standard of living for resource users in the Au Tho B Village coastal area.

CHAPTER 2 Where and to Whom this Regulation Applies

Article 3. These regulations apply to the existing and proposed mangrove forest areas (500 m into the mudflat area) which are contiguous to the area of Au Tho B Village, Vinh Hai Commune. The area is bounded to the west by Lac Hoa Commune and to the east by Au Tho A Village, Vinh Hai Commune.

Article 4. Natural resources mentioned in this regulation include fuelwood and aquatic products such as shrimps, crabs, fish, clams, cockles and others which are extracted from the mangrove forest and mudflats, and from the sea in the area of Au Tho B Village.

Article 5. Members of the Co-management Group, visitors from outside and Au Tho B Village community shall comply with this regulation.

CHAPTER 3 General Provisions

Article 6. The boundary for the area to which this regulation applies is clearly shown on the attached map and marked on the ground by people in Au Tho B Village under instructions from local authorities. Members and non-members of the Au Tho B Co-management Group shall only access the mudflats and sandbanks using the four existing access pathways marked on the map.

Article 7. Members of the Au Tho B Co-management Group shall be identified using membership cards. For members who are above or equal to 16 years old will be eligible to obtain blue cards. For children whose ages are from 7 to under 16 years old will be issued with green cards which their parents will be responsible for safe keeping. Only when parents allow their children to go to the forest should they give these green cards to their children.

The household head will take the responsibility to manage his/her family's membership cards. The cards cannot be given to another person to use. In case a person loses his/her card, the household head shall inform any person in charge and apply for a new one. Only members of the Co-management Group with their membership cards on them can enter the forest to collect dry wood and aquatic resources using the four existing access pathways, following the regulations in this document.

Article 8. All members of the Co-management Group shall have the duty to be involved in managing the natural resources of the Au Tho B coastal zone and monitoring and reporting all illegal activities inside the map area to local authorities.

CHAPTER 4 Natural Resource Management

Article 9. The area to which this regulation applies (refer the attached map) comprises 4 functional zones:

1. **Protection Zone**: is part of the mangrove forest which is setup for good protection of aquatic animals, providing them undisturbed habitats for natural breeding, ensuring biodiversity of the mangrove forest. This 12-ha area lies next to Sub-groups 3 and 4.
2. **Rehabilitation Zone (inside the forest)**: is part of the inner mangrove forest belt where the forest has lower density and has been replanted for the purpose of protection from breaking waves and habitat provision for aquatic animals. This 22-ha area lies next to Sub-group 4.
3. **Rehabilitation Zone (outside the forest)**: is newly-planted forest lying 90 m from the border of the inner mangrove forest towards the mudflats. This zone is set up to increase the forest width for the purpose of protection from breaking waves and habitat provision for aquatic animals. This 26.5-ha area runs parallel to Sub-groups 1, 2, 3 and 4.
4. **Sustainable Use Zone**: is part of the inner mangrove forest belt where trees are well-grown and the density is high. This 34-ha forest lies next to Sub-groups 1 and 2 and can continuously provide natural resources for people if used sustainably.

Article 10. Regulations on what can and cannot be done in each zone

Protection Zone		*Prohibited*: ▹ Entry of people without permission ▹ Any other activity not explicitly permitted
		Permitted: ▹ Patrolling (with permission) from time to time, ensuring no illegal activities are occurring
Rules for all zones (except the Protection Zone)		*Prohibited*: ▹ Entry of non-members of co-management group ▹ Carrying and use of axes, knives, saws, spades, hoes in the forest ▹ Activities which damage or destroy trees (including small trees) such as cutting or digging ▹ The use of chemicals and electric fishing devices ▹ Use of long nets ▹ Any other activity not explicitly permitted
		Permitted: ▹ Only members of co-management group can enter to collect resources ▹ Catching of sesarmid crabs, juvenile crabs, elongated gobies, mudskipper, snake, rat and cockles when the tide is low and mud is visible ▹ Using long hooks to catch crabs ▹ Using bamboo trapping basket (chum) for collecting mudskipper *Periophthalmus schlosseri* (*ca thoi loi*)
Rules for specific zones	**Rehabilitation Zone (inside the forest)**	*Permitted*: ▹ Catching sesarmid crabs, small crabs, sea snakes and snails when the tide is high or low ▹ Catching by hand or with round nets (diameter less than 50 cm) ▹ Collecting dry wood by hand in months 1, 3, 5, 7, 9, 11
	Rehabilitation Zone (outside the forest)	*Permitted*: ▹ Entering the forest when mud is clearly visible ▹ Catching by hand or with round nets (diameter less than 50 cm)
	Sustainable Use Zone	*Permitted*: ▹ Catching sesarmid crabs, small crabs, sea snakes, snails, juvenile elongated gobies when the tide is high or low ▹ Catching by hand or using round nets (diameter less than 80 cm) ▹ Collecting dry wood by hand in months 2, 3, 5, 6, 8, 9, 11, 12

Article 11. Monitoring of both natural resource use and activities occurring within the various zones must be continuously undertaken as follows:

a) When requested, each household member of the Co-management Group shall detail the time taken to collect resources and the amount of resources collected for a given time he/she enters the forest.
b) These records will be compiled and summarised by selected monitoring recorders and then given to the Group Head monthly for analysis.
c) Monitoring of activities occurring within the Au Tho B coastal area through observation shall be undertaken by Group members at all times when they are in the area.
d) The Protection Zone shall be monitored only by authorised members who are determined to patrol the zone by the instruction from local authorities.

e) In case of detecting illegal activities Group members shall follow the procedure outlined in Chapter 5 below.
f) Each Sub-group Leader shall have a book for recording detected illegal activities and suggested methods for prevention and shall inform the Group Head monthly.
g) In case of emergency, members should directly call the Village Head or Chairman of the Commune PC. After receiving such notice, the Commune PC will assign one staff to arrive on the scene as soon as possible (not later than 1 hour).

Article 12. Relevant agencies including the Village's People's Board, Civil Defence, Police, Communal Detachment, Vinh Hai Commune's People Committee, Forest Protection Office (District-level), Sub-Department of Fisheries and Border Military Station 642 shall provide favourable conditions for the Group's activities and closely collaborate with the Co-management Group to achieve the objective stated in Article 2.

CHAPTER 5 Enforcement

Article 13. In case of detecting illegal activities which damage the forest (such as cutting of forest and digging for worms) Group members shall immediately inform a Sub-group Leader or the Group Head. The Group Head or Sub-group Leader shall immediately inform local authorities of the illegal activities. The Group Head, Sub-group Leaders and members are allowed to make a record of illegal activities.

Article 14. In case of detecting illegal activities which do not damage the forest, though are contrary to these regulations, Group members shall:

a) For the first offence: inform and educate the violator of their offence.
b) For the second offence: immediately inform a Sub-group Leader or the Group Head.
c) For the third offence: immediately inform a Sub-group Leader or Group head who will report it to the local authorities.

CHAPTER 6 Rewards and Penalties

Article 15. Any member or non-member who detects violation of these regulations and timely reports the matter will be rewarded accordingly. Any serious violation of Law on Forest Protection and Development or Law on Fisheries shall be directly dealt with by local authorities regardless of the number of repetition.

Article 16. For illegal activities which do not damage the forest, though are contrary to these regulations, if the offender is a member of the Au Tho B Co-management Group:

a) For the first offence: the exhibit(s) will be confiscated and his/her membership card will be confiscated for 3 months and he/she will be subject to an educational lesson by the Group Head.
For the second offence: the exhibit(s) will be confiscated as well as all membership cards of the offender's family for 3 months.
For the third offence: the exhibit(s) will be confiscated and a meeting held to vote for terminating the offender's membership.

For subsequent offences (purposely), the exhibit(s) will be confiscated and the offender shall be dealt with by the local authorities.

b) If children under 16 years old repeat offences more than 4 times they will be dealt as if he/she was an adult.
c) Households who skip 3 consecutive group/sub-group meetings will be dismissed from the group.

Article 17. For illegal activities which do not damage the forest, though are contrary to these regulations, in case the offender is not a member of the Au Tho B Co-management Group:

a) For the first offence: the exhibit(s) may be confiscated and the offender will be subject to an educational lesson by the co-management member, Sub-group Leader, Group Head or Village Head.
b) For the second offence: Sub-group Leader or the Group Head who will provide a further educational lesson and may confiscate exhibit(s).
c) For the third offence: exhibits will be confiscated and the offender will be reported to the local authorities.

CHAPTER 7 Report Schedule

Article 18. Sub-group Leaders shall report all the Sub-group's activities as well as monitoring results to the Group Head monthly.

Article 19. The Group Head and the Village Head shall report to Vinh Hai Commune PC by documents every 2 months.

CHAPTER 8 Implementing Provisions

Article 20. The Co-management group and local authorities shall inform and propagate to members about these regulations. Members shall comply with and effectively implement these regulations.

Article 21. These regulations may be modified at any time during their implementation but only as agreed by the majority of the Co-management Group and shall only become effective when certified by the Vinh Hai Commune PC.

Article 22. These regulations were certified by the Vinh Hai Commune PC and took effect in May 2011.

Monitoring framework for replanted mangrove areas – sharing the experience from Pakistan

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Abstract

Almost 97% of the mangroves in Pakistan grow in estuarine areas, amid the intertwining creek system of the Indus River delta. The historical distribution of mangroves in the Indus Delta has been altered greatly by both human and natural forces. Deforestation and grazing, coupled with changes in hydrological regimes in the Indus River, are believed to be the main causes of mangrove degradation in the delta.

Over time, awareness has grown globally of the values of mangrove ecosystems and their contribution to coastal economies and coastal protection. Efforts to rehabilitate the degraded mangroves in Pakistan, which started about three decades ago, have gained momentum in recent years and now involve multiple agencies. However, in the absence of a transparent and accountable mechanism of monitoring and evaluation, this restoration work has drawn criticism from certain quarters in Pakistan as costly and ineffective.

Under the Sindh Coastal Community Development Project (SCCDP) being implemented in the Indus Delta, IUCN Pakistan has been tasked with third-party monitoring and evaluation of replanted mangrove areas. To this end, IUCN has successfully developed and implemented a simplified framework for physical monitoring and evaluation of replanting sites. Using a simple random sampling technique, replanted areas are surveyed annually to generate data on indicators identified in the monitoring framework, including plant survival, plant growth, species composition and natural regeneration. The resulting feedback has helped resource managers to develop adaptive measures for identifying suitable sites for mangrove planting, choosing appropriate species and planting approaches, and ensuring accountable performance from field staff.

It is assumed that improvements in performance indicators in future years will be due largely to the improved management measures adopted by SCCDP partners in response to the learning generated by monitoring and evaluation. Based on the experience from its use, the methodology developed for SCCDP is recommended for monitoring and evaluation of large-scale mangrove restoration works in similar conditions.

Keywords: mangroves, restoration, monitoring, deltas, Pakistan

1. Introduction

Almost 97% of the mangroves in Pakistan grow in estuarine areas, amid the intertwining creek system of the Indus River delta (IUCN Pakistan, 2005). The historical distribution of mangroves in the Indus Delta has been altered greatly by both human and natural forces. Deforestation and grazing, coupled with changes in hydrological regimes in the Indus River, are believed to be the main causes of mangrove degradation in the delta.

Over time, awareness has grown globally and in Pakistan of the multiple values of mangrove ecosystems. This has led to a greater emphasis on conservation of mangrove ecosystems in Asia, which has about 40% of the world's total area of mangroves (Spalding *et al*., 1997, cited by Mithapala, 2008).

The economic values of mangrove ecosystems have been widely studied in terms of their direct and indirect uses, leading to a growing consensus on the important contribution of mangroves to the productivity of coastal fisheries, livelihoods and coastal protection. Studies conducted in the Philippines, for example, reveal that one hectare of properly managed mangrove forest could yield up to 200 kg of molluscs, 25 kg of shrimp, 15 kg of crabmeat, 100 kg of fish, and 40 kg of sea cucumber annually (Porter, 1988, cited by WWF/IUCN, 1998). Other studies have indicated that mangroves and other coastal forests can potentially reduce the hydraulic impact of tsunamis by up to 80% and their flow speed by up to 70% (Harada and Imamura, 2003, cited by Forbes and Broadhead, 2007).

Natural disasters have been frequent in Asia in recent decades, with over 900 extreme events occurring since 1970 (Memon, 2010). Asia is home to more than 1.5 billion people, 600 million of whom are considered vulnerable to natural disasters because of their poverty (Memon, 2010) and resulting lack of resilience against external shocks. Concern is growing that climate change will increase the magnitude and frequency of natural disasters globally and regionally. In Asia, Pakistan has been ranked as one of the countries most at risk from natural disasters (NDMA, 2007).

Against this backdrop, the need to conserve mangrove ecosystems to protect the livelihoods of coastal communities and reduce their vulnerability to disasters has gained increasing acceptance in recent years. This has led to enhanced local and regional responses by government agencies and NGOs to conserve mangroves in Pakistan and further afield.

Efforts to restore Pakistan's degraded mangrove ecosystems began about three decades ago. They have gained momentum over time and now involve multiple agencies. Reportedly, thousands of hectares of degraded mangroves have been replanted in the Indus Delta, and thousands of hectares more have been targeted for restoration under ongoing and future schemes.

Defining quantifiable success indicators is considered essential to effective mangrove restoration (Lewis, 2009). In the past, however, no monitoring and evaluation (M&E) mechanisms were put in place to assess the success or failure of large-scale mangrove restoration efforts in Pakistan. Due to the absence of transparent and reliable M&E, the investment in replanting degraded mangrove areas has drawn criticism from certain quarters in Pakistan, with some remarking that restoration is like "draining money into the sea" (Sindh Forest Department, 1997).

Given this uncertainty, Pakistan has identified an overwhelming need for a reliable and cost-effective M&E methodology for restored mangrove areas, that will support quantitative and qualitative assessments of the impacts and cost-effectiveness of restoration.

A number of factors restrict the effective use of M&E for mangrove replanting in Pakistan. The restored areas lie in intertidal zones where accurate assessment of restoration is hampered by tidal patterns, remoteness, and a lack of surveyed reference points. Increased resources are required for frequent monitoring of large replanted areas. The use of remote sensing and GIS technologies has greatly facilitated the task of mangrove mapping, but such measures are costly, requiring experienced analysts and high-resolution data to support accurate assessments. In general, GIS-based applications are used mainly in mapping identified patches of mangroves, categorising them, and measuring spatial and temporal changes (Anon, 2008). Technological limitations and resource demands restrict the application of GIS and remote sensing techniques to detailed assessment of physical parameters affecting survival of replanted species, assessment of plant growth under different site conditions, and assessment of natural regeneration.

Taking these constraints into account, independent M&E was made an integral component of the Sindh Coastal Community Development Project (SCCDP), implemented by the Sindh Coastal Development Authority with financing from the Asian Development Bank. This has been the first-ever experience of using independent M&E in large-scale mangrove restoration work in Pakistan. IUCN Pakistan was tasked with carrying out M&E for the project, and to this end it has developed and successfully implemented a simplified methodology for assessing replanted mangrove areas.

The assessment methodology is based on the guidelines and indicators identified in the overall monitoring framework developed for SCCDP. The indicators include plant survival, species composition, plant growth, natural regeneration, and effectiveness of the planting approach and protection measures adopted by the Coastal Forestry Division (CFD). As far as frequency of M&E is concerned, some authors suggest ten assessments over a period of five years after initial planting (Lewis, 2009). However, since the project's target areas are extensive, this frequency was felt to be too cumbersome and costly. So IUCN has adopted an annual monitoring approach.

The objectives of M&E under SCCDP are to:

1. Assess the success or failure of replanted areas, and the quantity and quality of mangrove restoration work undertaken by CFD, and to report to the project executing agency.
2. Generate feedback on adopting corrective measures in the project's mangrove restoration component to enhance its overall outcomes.
3. Suggest a cost-effective and reliable method for future such assessments.

The results from this M&E approach have been well-received and highly appreciated by the project agencies. The feedback generated from monitoring has helped resource managers to implement adaptive measures for improving management of newly planted areas in terms of site selection, choice of species, and enhancing survival.

The objectives of this paper are to detail the M&E methodology developed by IUCN for newly planted mangrove areas under SCCDP, and to share the lessons from monitoring with other stakeholders involved in similar restoration work in Asia.

2. Materials and methods

2.1 Project area

The project area consists of 6,000 ha of newly planted mangroves in the Indus Delta, specifically the coastal areas of Thatta and Badin districts of Sindh Province.

The planting areas lie on completely and partially open mudflats in the creek system of the Indus Delta at Keti Bunder (24°08'58" N, 67°25'22" E) and Shah Bunder (24°03'40" N, 68°01'30" E). The mangrove planting was carried out by CFD between 2009 and 2011 (Table 1).

Table 1 Yearly planting areas at SCCDP project sites

	Actual area planted (ha)			
Name of site	**2009**	**2010**	**2011**	**Total area (ha)**
Keti Bunder	832.5	832.5	1,300	2,849
Shah Bunder	967.5	683.5	1,500	3,151
Total	1,800	1,400	2,800	6,000

Planting used direct sowing of *Rhizophora mucronata* propagules and *Avicennia marina* seeds collected from natural mangrove stands during the planting season (April–June for *Rhizophora* and July–September for *Avicennia*). Monitoring of the planted areas was scheduled annually in November–December when tides and weather allowed access to the newly planted mudflats.

2.2 Methods

The assessment followed a purpose-built methodology with the following key steps:

2.1.1 Choice of assessment approach

The ideal method for accurately assessing any replanted area is the whole population count. However, this is most useful when the subject population is small. When the population is large, it can be a costly as well as time-consuming method. To deal with large population sizes, sampling techniques are commonly used to make inferences about the target population from smaller subgroups.

Given the large extent of newly planted mangrove areas, simple random sampling (SRS) was adopted for assessing project progress. SRS is a widely used sampling approach that helps in making reliable inferences about a population from the data collected through the independently selected samples. It is a cost-effective and comparatively quick sampling approach (Wikipedia, 2012).

2.1.2 Recording of GPS coordinates

The first requirement for monitoring and evaluation of replanted areas was to record the GPS coordinates of newly planted areas and ensure their conformity with the pre-planting site maps developed by CFD. This was done through site visits during the various phases of the project.

2.1.3 Random selection of sample plots

The creek system in the Indus Delta has not been surveyed and lacks any known geographical reference points. In these circumstances, adopting a completely randomized sample selection approach is difficult. As in any other estuarine area, the major and minor creeks in the planted areas are usually inundated, so access to planted mudflats must be by boat.

Given these constraints, an innovative method of randomization using extreme ranges of GPS coordinates (east and north) encompassing the planted areas was used to generate a list of random coordinates for the required sample size.

Since the degrees of latitude and longitude encompassing the planted areas did not change, only minutes and seconds of east longitude and north latitude were used to select random sampling coordinates. This was done by calculating the range of both east and north coordinates separately, that is, by subtracting the lowest value of minutes and seconds from the highest value. The resulting product was then converted to seconds and used as a sampling frame to select the required number of random digits falling within this range. Random digits were generated for both east and north coordinates using the online random number generator at: http://www.graphpad.com/quickcalcs/randomn2.cfm. Each random number was converted to minutes and seconds and added to the lowest value of the respective coordinates. This procedure was repeated for both east and north coordinates, generating a set of random coordinates for each sample plot which was located in the field using a GPS receiver. This randomized approach avoided any sampling errors resulting from human bias in selecting sample sites, since none of the assessment team members had any prior idea of where the randomly selected sample plot would lie.

2.1.4 Preparation of field maps

Field maps were found to be very useful in locating sample plots in the field. They were prepared by marking the randomly generated coordinates for each sample plot using the online Google Earth service. With the help of field maps and local knowledge, sample plots were located in the field by traversing the target areas from the nearest possible creek edge with a GPS receiver (see section 2.1.6). Traversing long distances through mangroves should be avoided as far as possible, however, as it is time-consuming and tiring. Planning the shortest-possible traversal route before starting proved to be the most effective strategy for covering the sample plots.

2.1.5 Sample size

The sample size was selected on the basis of the area under consideration. A higher sampling intensity was adopted for the first year after planting, and a reduced intensity for subsequent annual assessments. Figure 1 below illustrates the number of sample plots from which data were collected over three years of monitoring.

The sampling intensity of newly planted areas was reasonably high during the first and second annual assessments, in which one sample plot represented 12 ha on the ground. A lower sampling intensity was adopted during the third year of assessment, in which each sample plot represented 35 ha (see Table 2 below).

2.1.6 Sample plot location

The list of randomly selected coordinates and field maps were used to locate the sample plots in the field with the help of a GPS receiver. A team member trained in using the receiver was assigned the task of locating sample plots by traversing the site from the nearest creek edge. The team member would move in the probable direction of the sample plot, keeping an eye on the changing GPS readings. The sample plot would be located at the point where

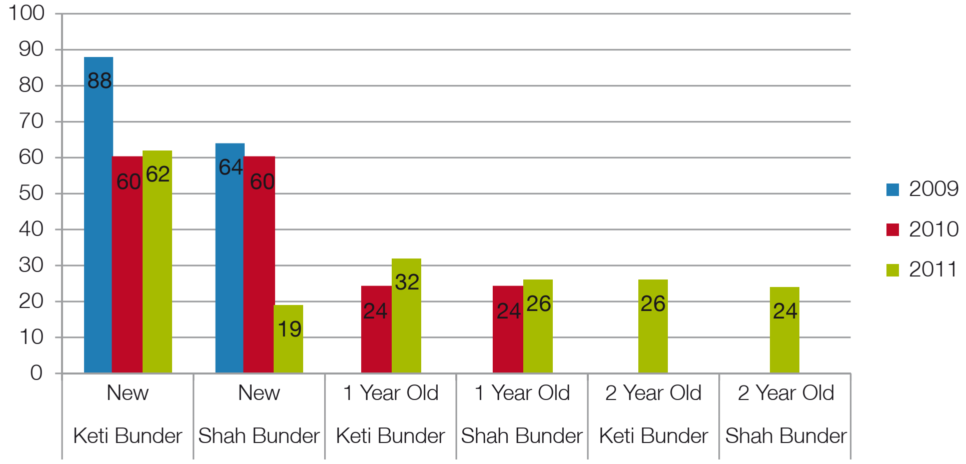

Figure 1 Number of selected sample plots

Table 2 Sample size and area covered

Year of assessment	Year of planting	Number of sample plots	Area covered by sample plot (ha)
2009	2009 (New)	152	12
2010	2010 (New)	120	12
	2009 (1 year old)	48	38
2011	2011 (New)	81	35
	2010 (1 year old)	58	24
	2009 (2 years old)	50	36

both the east and north GPS readings exactly matched the randomly chosen east and north coordinates of the plot marked on the field map. While the other team members surveyed the located sample plot, the team member with the GPS receiver would move in the probable direction of the next sample plot to locate it. This strategy was adopted to make efficient use of time and resources. Using this procedure, data were successfully collected from all of the randomly located sample plots.

2.1.7 Layout of sample plots

Sampling involved a variable sample plot approach using two different plot layouts. During assessments in the first and second years, 100 m long linear transects were laid out at each sample location (Figure 2). These transects were laid along the nearest row of planted saplings radiating in each cardinal compass direction from the marked GPS point. This meant that along each linear transect a minimum of 33 saplings, and a minimum of 132 saplings in total along four transects, would have a chance of being measured, if they were planted at the usual spacing of about 3 m x 3 m.

This approach was found to be exhausting and time-consuming, so during the third year of assessment 100m^2 square plots (10 m x 10 m) were used to collect data (Figure 3). To randomize this procedure, the plots were laid out by systematically measuring 10 m from the marked GPS point to the north, from there 10 m east, then 10 m south, and finally 10 m west (back towards the point of origin) to complete the square plot. The laying out of sample

Figure 2 Layout of linear transect. Photo © IUCN Pakistan.

Figure 3 Layout of square plot. Photo © IUCN Pakistan.

plots was simplified by using a 40 m long nylon rope marked with a knot at 10 m intervals. Four wooden pegs were used to stretch the rope to a distance of 10 metres in each cardinal compass direction. Once the team finished recording data in the plot, they shifted and dragged the two eastern points of the square plot in the opposite direction (to the west) to lay out and survey a second grid on the opposite side. This procedure was found to be much more convenient than the linear transect method.

2.1.8 Data collection and analysis

At each sample plot, data on the number of surviving and dead plants, species type and planting distance were recorded on purpose-made datasheets. To measure growth rate, the average height of plants and average number of leaves were also recorded. In addition, data on natural regeneration and naturally growing mangrove plants were also collected at each sample plot, as well as field observations on general topographical and biological conditions, extent of grazing, and soil conditions. The age of plants was considered equal, since they were planted during the same periods. The field data were supplemented with additional information on the planting approach and protection measures adopted by CFD to safeguard the planted areas. Photographs were also taken at each sample plot to record its ground position.

The field data were compiled into Microsoft Excel spreadsheets and analysed statistically to calculate various parameters including mean, variance and standard deviation, and to determine the statistical significance of the sample data. Significance was analysed by applying a t-test with a 0.05 significance level (95% confidence). Based on this analysis, conclusions were drawn about the mean survival rate at both the planted sites.

3. Results and discussion

3.1 Survival trends at planted Sites

The overall average survival rate of newly planted mangroves was found to be 80% at Keti Bunder and 73% at Shah Bunder. Figure 4 details annual survival rates at the two sites. Overall, a gradual reduction in the survival of newly planted areas was noticed in later years. Any increase in survival of the previous year's planting during the second year of assessment can be attributed to restocking by CFD.

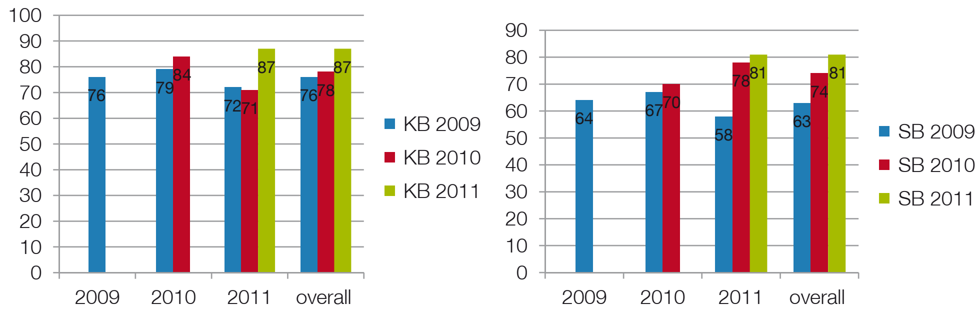

Figure 4 Survival trends in planted areas, Keti Bunder (left) and Shah Bunder (right)

The results indicate a significant improvement in the survival rate of mangrove areas planted in 2010 and 2011, attributable to the adoption of improved management measures by CFD in response to the feedback from M&E. This is reflected in the increase in survival rate of planted areas from 76% in 2009 to 87% in 2011 at Keti Bunder, and from 64% in 2009 to 81% in 2011 at Shah Bunder.

In particular, the feedback from M&E led to CFD adopting corrective measures to select potentially better sites for planting, choose appropriate mangrove species for planting consistent with site conditions, and carry out accountability checks on field staff. For example, M&E revealed that the survival rate of *R. mucronata* planted on low-lying open mudflats and creek frontages was lower than that planted on grassy mudflats and the interspaces of mudflats covered by sparse natural vegetation of *A. marina*, which provided nursing cover to the *Rhizophora* propagules. The rates of survival of *Rhizophora* in such areas were 80% and 78% at Keti Bunder and Shah Bunder, respectively.

It was also observed that open and low-lying mudflats were affected by rapidly receding tidal waves, which flushed away *Rhizophora* propagules, and by algal mats and barnacles which attacked the propagules, suppressing their growth and causing higher mortality (IUCN Pakistan, 2009).

3.2 Species composition

The results showed that *A. marina* was the dominant choice of species at Shah Bunder, constituting 61% of total planting, whereas *R. mucronata* was the main species at Keti Bunder, constituting 64% of planting (Figure 5). A monocultural approach dominated in planting, perhaps because of the relative ease of planting *Rhizophora* propagules, as well as the varying availability of seed of different mangrove species at different times of the year. The seed of *R. mucronata* becomes available earlier in the year, during April to June, whereas that of *A. marina* becomes available during late July to mid-September. The seed of two other mangrove species, *Ceriops tagal* and *Aegiceras corniculatum*, also becomes available during April to June, but the quantities produced can be too small to establish large-scale mixed mangrove plantations.

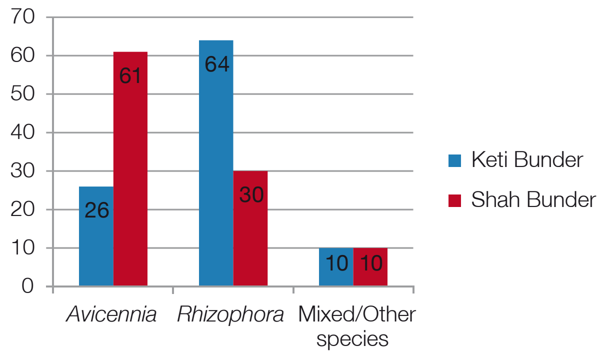

Figure 5 Species composition in planted areas

Furthermore, planting efforts by CFD over the past few decades have focused mainly on *R. mucronata* to enhance species diversity in the Indus Delta. Historically, eight mangrove species have occurred in the Indus Delta, four of which are now locally extinct. *A. marina* accounts for more than 95% of the remaining mangroves in the delta (IUCN Pakistan, 2005). As it is more salt-tolerant, it has been able to adapt to the hypersaline conditions now prevailing as a result of reduced inflows of fresh water to the delta. The other three species, *R. mucronata*, *C. tagal* and *A. corniculatum*, account for the remaining 5% of the delta's mangroves.

3.3 Plant growth

Although growth monitoring of mangrove species requires longer time-series data to determine growth rates accurately, some aspects of growth were observed during annual monitoring and evaluation. These included increases in height and leaf counts of *A. marina* and *R. mucronata*, as well observations on growth in different site conditions.

Overall, a more-or-less identical pattern of growth was observed at both sites, with localized growth variations related to site conditions. *A. marina* attained an average height of about 15 cm with six leaves at six months, and reached 45 cm at 30 months. *Rhizophora* propagules reached an average height of about 30 cm with six leaves at six months, and 50 cm with 12 leaves at 30 months after planting (Figure 6).

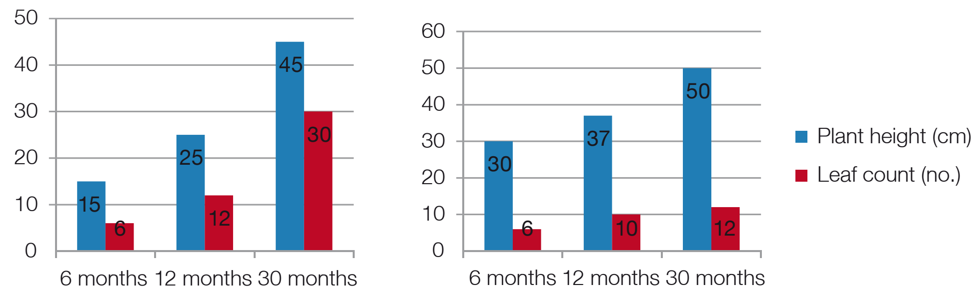

Figure 6 Observed growth pattern of *A. marina* (left) and *R. mucronata* (right)

Furthermore, at both sites, good plant growth was observed in mixed plantations of *Avicennia* and *Rhizophora* on grassy mudflats covered with *Arthrocnemum* and *Aeluropus* grasses. Replanting of *Rhizophora* on grassy mudflats yielded the highest survival rates and healthiest plant growth, compared with open mudflats devoid of vegetation. Hence, replanting of *Rhizophora* could be a preferred strategy for grassy mudflats. Planting on barren and low-lying mudflats should be avoided as *Rhizophora* is susceptible to damage from algal growth and barnacle attack. In these areas, direct seed sowing or planting with wildlings of *Avicennia* may be better. Moreover, mixed plantations of mangrove species should be preferred for their greater ecological benefits (Macintosh *et al*., 2002).

3.4 Natural regeneration

Natural regeneration increased steadily in the planted areas, owing to continued protection which allowed the germination of new seedlings and the recovery of *Avicennia* plants stunted by camel over-grazing.

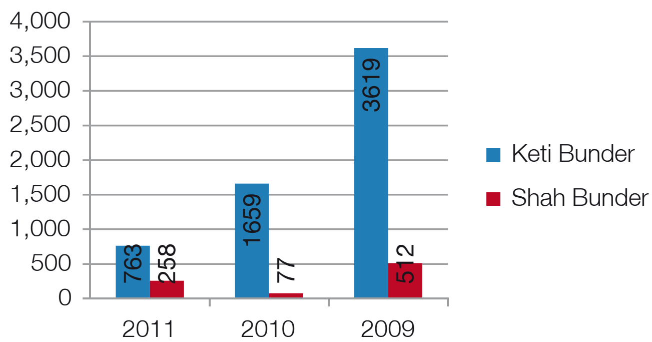

Figure 7 Natural regeneration in planted areas

Natural regeneration was more profuse at Keti Bunder than at Shah Bunder (Figure 7). About 763, 1659 and 3619 saplings/ha were recorded at Keti Bunder, against 258, 77 and 512 saplings/ha at Shah Bunder, in the areas planted in 2011, 2010 and 2009 respectively (IUCN Pakistan, 2011).

The progressively increasing rate of natural regeneration suggests that protecting degraded mangrove areas from grazing and other human disturbance may be a useful strategy for facilitating natural recovery of mangrove vegetation, as compared with replanting. The data indicate that the number of naturally regenerated saplings exceeded the number of saplings actually planted by the project.

It was also observed that consistent protection allowed recovery of the natural growth of mangroves stunted by animal grazing. An estimated 68, 325 and 250 stunted mangrove plants/ha were recorded at Keti Bunder, and an estimated 63, 0 and 129 plants/ha at Shah Bunder, in the areas planted in 2011, 2010 and 2009, respectively.

Based on these findings, it is recommended that during the early years of mangrove restoration, attention should be paid to protecting existing mangrove vegetation against prevailing threats rather than simply opting for large-scale replanting. Replanting can be considered at a later stage to fill any large gaps. Such an approach would be both cost-effective and sustainable.

4. Conclusions and recommendations

Large-scale mangrove restoration requires methodological approaches that yield a fair and reliable assessment of the progress and impact of restoration. Such assessments provide useful insights for resources managers looking to improve their performance and develop adaptive management systems. They also help in building confidence and trust between project implementing agencies and donors. For these reasons, M&E should form an integral part of mangrove restoration strategies.

To be successful, however, M&E of large-scale mangrove restoration requires suitable methods that minimise human bias and yield reliable assessments effectively and efficiently. Such methods should take into account the challenges of mangrove forest terrain, including its remoteness, difficult access, and lack of reference points. This paper has described a suitable methodology used in monitoring and evaluation of large-scale mangrove planting in the Indus Delta under the Sindh Coastal Community Development Project.

Based on the experience of using this methodology, it can be concluded that the application of a simple random sampling approach generated useful and reliable information within existing cost and time constraints. These results were welcomed by the project implementing and executing agencies, and the donor.

The overall lesson from using the described methodology is that it can improve project performance by producing information which allows planting survival rates to be increased. This improvement stems largely from the better management practices adopted by the project implementing agencies as a result of the positive feedback from annual M&E. It is recommended, therefore, that the methodology developed for the Indus Delta be considered for use by other large-scale mangrove replanting initiatives in similar conditions.

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Towards Coastal Health Archive and Monitoring National Programmes (CHAMPS) for assessing change, and identifying drivers of change, in tidal wetlands and coastal margins

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Abstract

There is ample evidence of diminishing mangrove and tidal wetland areas worldwide that provide fundamental and highly beneficial ecosystem services, such as blue carbon capture and storage, shoreline stabilization, habitat and nursery functions, and more. Despite such important benefits across regional landscapes and in specific locations, what is missing from coastal assessment tools is a means to broadly evaluate, quantify and monitor changes to such critical coastal resources. Presented here is a standard and encompassing strategy. This can be used also for assessing and monitoring rehabilitation sites, and restoring resource benefits when damaged or lost.

Current global assessments focus primarily on declining area and increasing loss, along with serious threats to biodiversity. Each of these is extremely important, fuelling considerable current concern. Yet the missing measures of habitat condition are arguably even more worrying. By all accounts, habitat condition and functionality continue to deteriorate despite important efforts to protect key areas – a situation exacerbated further by global climate change. An urgent need exists to identify and quantify key stressors, particularly anthropogenic ones. A broad methodology is required for monitoring coastal ecosystems threatened by ever-increasing demands and pressures on these important areas.

To achieve success with such a strategy, an agreed protocol and methodology must distinguish regional changes due to natural events from numerous human impacts, whether direct or indirect. Better targeting of particular stressors is needed to enhance the resilience of coastal ecosystems, allowing them to better counter increasingly more frequent and damaging additional pressures. Such a scheme is proposed, coupled with an evaluation system that can be used to classify all drivers of change, and identify observed ecosystem responses. Recent innovative adoption of current technologies further demonstrates how local communities can participate with researchers, using the Shoreline Video Assessment Method to usefully monitor estuarine and coastal margins. Armed with such insights and evidence, managers of valuable coastal natural resources will be in a better position to optimize specific management regimes that effectively mitigate key impacts, allowing coastal ecosystems to more effectively respond and adapt – promoting their survival in an uncertain future.

Keywords: mangroves, wetlands, rehabilitation, climate change, ecosystem monitoring

Session IV

Mangroves, Climate Change and DRR

Navigating mangrove resilience through the ecosystem-based adaptation approach: lessons from Bangladesh

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Abstract

Mangroves are important resources in coastal ecosystems that contribute multiple ecological and social services. Bangladesh has a history of planting mangroves to stabilize newly accreted land (*char*), transforming it into protective and productive ecosystems for the benefit of coastal communities. Yet livelihood pressures caused by unequal access to lands are pushing communities to deforest and encroach mangroves. Environmental stress related to climate change, including rapid and sudden cyclonic wind, and storms and inundation induced by sea level rise, is aggravating the existing threats to the critical social and ecological functions of the mangroves. The project "Community-Based Adaptation to Climate Change through Coastal Afforestation" has focused on community-based livelihood development through coastal land restoration and integrating social roles in mangrove plantation development and management. This paper highlights project findings related to the ecosystem-based adaptation approach and its potential application for integrated mangrove ecosystem management.

Community-based restoration of coastal lands is a productive resource regime for adaptation and sustaining mangrove functions in Bangladesh. Supported by the project, local communities in two coastal districts of Bangladesh have restored fallow, periodically inundated and saline mangrove lands into collectively managed natural resources to be used for multi-scale livelihood practices. An innovative land-use model, known locally as FFF (Forest, Fish, Fruit), is contributing to community ownership of livelihoods and socially inclusive resource governance. As part of the model, coastal communities participate in mangrove nursery establishment, plantation management and preventing illegal human interventions.

This paper highlights the importance of mangrove policies that avoid narrow protection and ecological goals, controlling social variables under the threat of climate change and managing opportunities within the most desirable social context. Lastly, it is argued that shifting from the conventional protection approach to an integrated social-ecological system provides renewal opportunities for mangroves and communities to adapt to climatic shocks and build resilience in the long run.

Keywords: mangroves, afforestation, climatic changes, livelihoods, Bangladesh

1. Introduction

Mangroves are highly productive ecosystems occupying brackish water zones along tropical and subtropical coasts (Datta *et al*., 2012). Mangrove ecosystems support a range of ecological functions for fish and crustacean species, including effective sediment trapping, nutrient recycling, and protecting shorelines from erosion. As mangroves thrive in a highly dynamic ecosystem, their growth and declining adaptive function often reflect the changing social and ecological conditions of the coastal environment (Field, 1998). With coastal geomorphological changes, mangroves are facing rapid social changes; population pressure for food production and urban development have changed the habitat into undesirable states along coastlines globally (Alongi, 2008). Inadequate understanding of how different constituents in the complex system respond to climate changes and develop adaptation measures is a significant constraint for mangrove management (Nicholls *et al*., 2007). Mangrove resilience is interrelated with complex ecological and social processes, as well as management responses to coastal morphological changes and the impacts of climate change.

There are significant natural and planted mangrove zones along Bangladesh's exposed, long coastline. Natural mangroves along the south-west to mid-west coast originally covered about 601,700 ha (4.07% of total land area and 40% of total forest area). Coastal mangrove afforestation has long been a component of the government's disaster risk reduction programme to protect coastal communities. Mangrove plantations gained momentum for stabilizing and improving newly accreted lands into forest vegetation and productive agricultural lands. Records from 1960–2000 show mangrove coverage as 142,835 ha (BFD, 2012) but due to cyclonic wind damage, succession or regeneration failure, and human demand for livelihoods and commercial shrimp farming, the present extent may be just 132,000 ha.

Coastal ecosystems are facing increasing threats of extreme disaster and climate change related stress in Bangladesh, and mangrove plantations will not substitute for ecological restoration and enhancing the adaptation capacity of local communities. Loss of mangroves is not only a threat to coastal ecosystem, but also affects the well-being of local communities. Coastal communities in Bangladesh depend on planted mangroves for limited forest products; most of them depend on livelihoods closely related to climate-sensitive agriculture and open fishing practices (Iftekhar and Takama, 2008). Until recently, mangrove plantation in Bangladesh was limited in its scope for integrating dynamic coastal ecosystem characters and diverse social needs within management interventions. With the growing incidence of disasters, ecological restoration of mangroves will not suffice; access to new land tenure and alternative livelihoods are increasingly important for adaptation of coastal communities. Appropriate land use for alternative livelihoods and conservation of mangrove are required as a part of the ecosystem-based integrated approach.

Mangroves provide opportunities for simultaneous change and development of new land management interventions for adaptation in Bangladesh. Plantation mangroves are a potential adaptation and mitigation interface in Bangladesh due to afforestation opportunities in newly accreted lands and successive user options for livelihood development. Bangladesh's National Adaptation Programme of Action and Climate Change Strategy and Action Plan have prioritized coastal afforestation in ecologically fragile areas. As yet no specific policy has been developed for incorporating climate change risks in coastal land management or developing collaborative resource management in planted mangrove ecosystems. Managing resilience in mangroves is related to an integrated socio-ecological approach for species diversity and human capacity to endure shocks without diminishing critical and regular functions. Sustainable management of coastal land resources is important not only for building protective coastal ecosystems by mangroves, but also for developing equitable ownership as a foundation of community well-being.

Participatory resource management can improve environmental integrity, economic efficiency of actions and equity for local community in sustainable benefit distribution (Nandy and Islam, 2010). Community-led local resource protection can draw participation and collective actions to deal with climate change impacts and build resilience of socially disadvantaged communities (Allen, 2006). Management of mangrove resources and sustainable livelihoods of vulnerable social groups are indeed great challenges to promote adaptation and build resilience. Christoplos *et al*. (2010) emphasized that an ecosystem protection approach can bring "win-win" options for adaptation by collaborative and local participation for natural resource management to conserve valuable ecosystem service flows for livelihoods, risk reduction and long-term poverty alleviation.

Ecosystem-based adaptation (EBA) is an emerging development approach which integrates ecosystem conservation with community-based practices to produce sustainable goods and services (Sterrett, 2011). EBA is important for integrating coastal communities through ecosystem-based interventions, flexible decision-making, and participatory local resource development. Developing adaptation programmes based on EBA draws management attention to the ecosystem level. The approach can combine restoration of critical mangrove ecosystem services with multidimensional social and ecological opportunities for coastal communities to enhance adaptation and resilience. The resource context and scale of particular interventions required to enhance resilience have to be determined.

This study aims to focus on adaptation practices in planted mangrove ecosystems in Bangladesh. The project "Community-Based Adaptation to Climate Change through Coastal Afforestation" (CBACC-CF) is used as an EBA case study from Bangladesh. Supported by GEF, UNDP and the Government of Bangladesh, and the first global Least Developed Countries Fund (LDCF) adaptation project, it is working to reduce vulnerability to the impacts of climate change induced risks in coastal regions of Bangladesh (CBACC-CF, 2012). The project focuses on community-based adaptation initiatives for building protective coastal ecosystems through raising mangrove plantations and innovative land use for sustainable livelihoods. The following sections discusses how these land uses are improving the adaptive capacity of coastal communities and constructed mangrove ecosystems as a whole.

2. Materials and methods

Since 2009, CBACC-CF has been working in the most vulnerable sites in four coastal districts of Bangladesh to reduce coastal communities' vulnerability to climate change. Its focus is on enhancing the resilience of coastal communities and protective ecosystems, through community-led interventions in afforestation and livelihood diversification. A key project strategy is combining different government departments and strengthening climatic risk reduction efforts through institutional capacity building. The project target sites are Anwara, Hatiya, Char Fasson and Barguna Sadar in, respectively, the Chittagong, Noakhali, Bhola and Barguna coastal districts.

The implementing partners of the project are: Bangladesh Forest Department (BFD), Bangladesh Forest Research Institute (BFRI), Ministry of Land, Department of Agriculture Extension, Department of Livestock Services (DLS) and Department of Fisheries (DoF). The project emphasizes the importance of forming local Co-management Committees (CMCs), one per coastal district, with representation from implementing local government agencies, civil society, and elected members. Each CMC must have at least three women members.

Empowering the landless and marginalized groups of coastal communities and increasing their adaptive capacity to cope with anticipated climate change impacts are the major thrusts.

To this end, the project is demonstrating diversified livelihood programmes, including adaptation interventions based on afforestation, agriculture, livestock and fisheries.

The afforestation programmes with mangrove and non-mangrove species are implemented with BFD on different types of accreted lands. The project is currently using *Sonneratia apetala* on newly accreted lands, underplanted with nine other mangrove species (*Heritiera fomes*, *Excoecaria agallocha*, *Xylocarpus mekongensis*, *Cynometra ramiflora*, *Aegiceras corniculatum*, *Bruguiera sexangula*, *Phoenix paludosa*, *Nypa fruticans* and *Ceriops decandra*) in moderate to highly accreted coastal habitats to minimize the adverse impact of *S. apetala* monocultures, to enrich biodiversity, and to provide continuous forest cover.

Since 2010, the project has promoted and demonstrated eight different types of adaptation measures including: mangrove plantations on newly accreted lands; model plantation of nine new mangrove varieties; non-mangrove mound plantation in moderately accreted lands; dyke plantation including the FFF model in moderate to highly accreted lands; and strip plantation on roadsides in project sites. To promote resilient livelihood practices, demonstrations and training programmes have been conducted on improved agricultural practices, modern aquaculture practices, and improved livestock practices, with livelihood support provided by the project.

The relevant baseline data (before project intervention), as well as data collected by the Project Management Unit after project intervention, are used in this paper.

2.1 Brief description of the coastal land-use model in Bangladesh

The CBACC-CF project has pioneered an innovative land-use model for providing climate resilient livelihoods for coastal communities living around mangrove plantation areas. The key part of the model, known locally as the Forest, Fish, Fruit model (Triple F, or FFF), uses largely encroached, periodically inundated and unproductive fallow lands behind mangrove forests to develop participatory ownership and adaptation practices (Nandy, 2011). Much of this fallow land was open access property captured by local elites through encroachment for further deforestation (Nandy and Islam, 2010; CBACC-CF, 2012).

The project realized that livelihoods of people living around mangrove plantations depend heavily on four climate-sensitive sectors: agriculture, forestry, fisheries and livestock. Climate change impacts on these sectors contribute to the low adaptive capacity of coastal communities. The FFF model was developed to explore new options for resource and income generation by integrating all four sectors in one system to sustain a continuous flow of resources. The model comprises short-term, medium-term, medium to long-term, and long-term resource generation measures that contribute to recurrent income generation, leading ultimately to livelihood sustainability and increased adaptive capacity of poor coastal communities.

Since project inception, land ownership has been transferred to coastal communities with tenure for diversified livelihood practices. A ditch and dyke system is being used to promote adaptation practices, and currently over 50 ha of fallow land has been developed for pilot adaptation interventions in two coastal districts; another 70 ha is underway in another district. In each hectare, eight ditches and nine dykes were developed and distributed to eight families, on a ten-year land ownership agreement with renewal opportunities depending upon the beneficiaries' performance. Importantly, local people contribute half of the labour costs by working in earth excavation for ditch and dyke development.

3. Results

3.1 Integrated approach to community adaptation through the FFF model

The FFF-based adaptation practices are providing alternative livelihood measures to coastal communities, especially to manage income risks during lean periods or erratic shocks from heavy rainfall or tidal inundation. Depending on crop duration and frequency of income generation, these interventions are described as short-term and medium-term measures. The project has introduced improved technologies and provided inputs to raise yields. High-yielding varieties require optimum levels of organic fertilizer and other nutrients. Although the implementing partners have provided skills development training, this has generally been ignored by the beneficiaries as a result of the relief culture in the coastal zone of Bangladesh.

3.1.1 Short to medium-term adaptation measures

Short-term crops planted as dyke vegetation provide household needs and quick income-generating options. Each family currently cultivates 6–7 types of leafy vegetables on a 60 m long and 3 m wide strip on top of the dyke. Scaffolding erected on the edges of the ditch provides space for creeping and hanging vegetables such as country bean, cucumber, bottle gourd, bitter gourd and sweet gourds. In the first six months, 64% of the families produced 80–100 kg of leafy vegetables. Sale of the surplus vegetables increased family income, on average, by nearly US$25 per month. Table 1 shows that each beneficiary has generated, on average, BDT 35,000 (US$434) per year from adaptation interventions. Family income ranges from BDT 21,000 to 67,000 depending on the level of management of their ditch and dyke. The best performers have been able to earn an additional income of more than BDT 67,000 (US$827) per family per year from their ditch and dyke allotment.

Table 1 Annual family income from different adaptation interventions (all figures are in thousands of Bangladesh taka, BDT)

Beneficiary group	Annual income before AI[a] (*A*)	Income from AI			Annual income after AI (*B*)	Difference (*B* – *A*)	Adaptive capacity rank[b]
		AI 1	AI 2	AI 3			
1	29.00	40.00	15.00	12.00	67.00	38.00	H
2	67.00	18.00	80.00	36.00	134.00	67.00	H
3	25.00		40.00	6.00	46.00	21.00	M
4	50.00	41.00	41.00	10.20	76.20	26.20	M
5	79.00	60.00	60.00	27.40	102.4	23.40	M
Average	50.00	24.50	47.20	18.32	85.12	35.12	–

[a] Adaptation intervention: 1 = Agriculture; 2 = Aquaculture; 3 = Livestock.
[b] H = High; M = Moderate.

Of the three types of adaptation intervention measures tested, aquaculture interventions are the most lucrative, followed by agriculture interventions. This is largely because the majority of beneficiaries are fishermen. The ditch is farmed with fast-growing fish varieties in demand locally. This meets household protein needs and brings additional income from fish sold at the local market. With the project's support, a single ditch produces about 100–120 kg of fish yearly, generating income of up to US$300 per family from fish sales. Coastal families that depend on fishing, or work as day labourers on sea and river boats, for seasonal livelihoods (July–September), expect the ditch arrangement to serve as an alternative adaptation practice. The ditch system is a highly appreciated multipurpose community asset for rainwater harvesting, fish farming, and irrigating dyke vegetation in the dry season.

3.1.2 Medium to long-term adaptation measures

The dyke system also offers medium to long-term adaptation options and medium-term income generation in 2–3 years with two high-yielding fruit varieties: BAU-Kul (*Ziziphus mauritiania*) and BAU-Guava (*Psidium guajava*). Developed by the Fruit Tree Improvement Unit of Bangladesh Agriculture University (BAU), they are a good source of vitamins and minerals, and fruit twice a year. Each beneficiary has planted 24 seedlings of the fruit varieties between forest tree species on their dyke. They bear fruit eight months after planting, but sizeable harvests take 2–3 years. During interviews, beneficiaries have said they expect high yields and income from the fruit trees. Each variety has the potential to produce 10–20 kg of fruit per tree and generate a family income of about US$500 per year.

Coastal communities have not only pursued regular, short-term and medium-term alternative income options, but also planted forest tree species on their dyke for long-term benefits. Planting trees and palms (*Cocos nucifera*) on dykes will provide communities with timber, fuelwood from branch pruning, and also food products. Forest trees, a component of the FFF model, will afford protection to the model plantations themselves and the surrounding land and community from climatic impacts.

The integrated adaptation measures provide additional income of US$25–30 per month per family in the off-season (November to April) from farming and river fishing. The project has until now been able to increase the adaptive capacity of at least 40% of the participating coastal communities to a moderate or high level, whereas 20% have yet to be mobilized. A noteworthy observation is that the successful FFF beneficiaries motivate other participants to increase their resource-generation options.

3.2 Integrated approach to mangrove habitat restoration for climate change adaptation and mitigation

The project is being implemented in coastal areas that are most vulnerable to the extreme weather events expected to increase in frequency and intensity as the climate changes. There is no alternative to mangroves for building coastal ecosystems to protect against severe cyclones and tidal surges. The Bangladesh government has already focused on establishing vegetative shelterbelts throughout the country's exposed coastal areas (see Ishtiaq Uddin Ahmad, this publication). A single pioneer mangrove species, *S. apetala*, has been used exclusively in newly accreted lands because it is highly tolerant to being submerged, even for 3–4 days. However, these monoculture mangrove plantations now encounter numerous problems, aggravated by the impacts of climate change, and the mature *S. apetala* plantations in Bangladesh's coastal zone have a large number of gaps owing to a lack of regeneration.

To enrich and sustain functional vegetation, the project has introduced nine commercially important mangrove species to fill gaps in almost 100 ha of *S. apetala* plantations (see list above). This effort will increase the density of trees and prevent damage from high winds and other weather events. The species were evaluated and selected by BFRI for differently inundated coastal habitats (Islam and Nandy, 2001). The model demonstration of the project introduced new coastal forest guidelines and large-scale practices that will increase forest productivity and sustain biodiversity throughout coastal areas.

In the past, mangroves were planted to address conventional disaster risk reduction and land stabilization, not deforestation or climate change mitigation. Now, however, it is increasingly recognized that well-managed coastal ecosystems provide a wide range of services that can help local communities adapt to current and future climate change hazards. This is one reason why the project has introduced commercially important mangrove species. Mangrove plantations provide physical protection, and the root system of some species traps sediment at such high rates they can even reverse the effect of sea level rise or river erosion through land reclamation, and also bolster the protective capacity of the coast against storm surges or cyclones.

The estimated loss of forest cover in Bangladesh from 1990–2010 averaged 2,600 ha per year. The project's efficiently implemented mangrove afforestation programme plants around 3,000 ha annually, matching the country's annual loss of forest cover, and contributing to global climate change mitigation efforts through the comparatively high carbon-retention capacity of mangrove forests.

The project's mangrove plantation activities are directed at ensuring ecological sustainability for social benefits in coastal areas. The coastal communities were always engaged in mangrove nursery and plantation management activities at project sites. The project's accomplishments to date in developing an integrated approach to mangrove habitat restoration for climate change adaptation and mitigation are listed below:

- Mangrove plantations have been established on 5,600 ha by engaging 128,000 man days in cash-for-work (CfW) programmes.
- Dyke plantations (including the ditch and dyke arrangement of the FFF model) have been established on 50 ha and another 70 ha is underway, engaging 71,400 man days in CfW programmes, and involving 960 beneficiaries (400 have taken over their allotments; 560 have yet to be approved by the CMCs).
- Mound plantations established on 322 ha, engaging 96,004 man days in CfW programmes, and involving 270 coastal beneficiaries.
- Strip plantations totalling 615 km have been completed with the involvement of 3,075 beneficiaries.
- A 100 ha model demonstration plantation of nine mangrove species is almost complete; it involves 60 beneficiaries organised into groups.
- A total of 12,200 people have been trained in mangrove nursery production and community-based nursery and plantation management. Some 1,406 coastal beneficiaries have been trained in improved technologies for agriculture, aquaculture and livestock.

Local communities believe that climate change is increasing the risks to their lives and livelihoods, and that there is no alternative to mangroves for reducing the impacts of tropical cyclones and storm surges. Fishermen understand that the mangrove forest protects their fishing boats and trawlers from direct hits by storm surges. Local communities living close to mangrove sites have formed small groups for raising and maintaining nurseries as well as for outplanting activities. With project support, participating beneficiaries receive cash on a daily basis for work in raising seedlings, nursery maintenance and plantation. Special agreements have been signed with selected beneficiaries who oversee and maintain the plantation sites, for long-term benefits including the sharing of profits. Local BFD and BFRI teams have built partnerships with the coastal communities, involving women's groups in site-specific project activities.

4. Discussion

The resilience of planted mangroves is closely associated with restoration practices that enhance regenerative functions and minimize canopy gaps to improve ecosystem capacity to cope with climate change impacts (Alongi, 2008). Managing gap dynamics in the large mangrove forests of Bangladesh is important as mature trees are felled or uprooted by extreme cyclonic wind and storm shocks. When man-made *S. apetala* monoculture mangrove forests in Bangladesh reach maturity, the surviving trees represent only 25–30% of the trees originally planted (Nandy, 2010). Filling the gaps in these *S. apetala* plantations should be considered an urgent priority. The quality of regeneration in terms of species diversity is crucial to improve ecosystem function of mangrove plantation regimes (Nandy *et al*., 2004), Hence, the enrichment plantation approach with selected mangrove species would be the way forward. Suitable candidates may be found among the nine commercially productive species being tested in the project's demonstration model.

The adaptation innovations address coastal land-use dynamics, and the management of mangrove resources through community-led regimes, in Bangladesh. Multiplying co-benefits by mangrove restoration and alternative livelihoods through the FFF model is a major step towards building the resiliency of coastal areas in Bangladesh. It is a "win-win" strategy that can counter the periodical inundation and salinity intrusion risks of traditional land practices, and also generate production benefits. In the past, mangrove afforestation programmes neglected community participation as a result of their protection-oriented management goals. They also lacked ownership and livelihood options for resource generation. The current practice enhances mangrove conservation by integrating the complex social and ecological systems of coastal areas. On one hand, there is enrichment planting and community-based nursery development and maintenance, and on the other, resource benefits through sustainable livelihoods, thus creating a potential ecosystem-based adaptation approach in coastal areas of Bangladesh.

To generate long-term adaptation benefits, institutions must follow an integrative ecosystem management approach (Folke *et al*., 2007). New adaptation interventions appropriate for a flexible social-institutional system should be tried out. The community-based approach of CBACC-CF has focused heavily on developing partnerships with diverse stakeholders to ensure its adaptation interventions are successful. Collaborative land-use innovations by coastal communities and local institutions trigger shared learning and joint problem-solving, thereby enabling better understanding, anticipation and response to climate change. Adaptation interventions in the model improve proactive planning and the exchange of information to manage the risks of climate variability in sensitive seasons, whether it be for coping with frequent inundation threats or using rainwater harvesting for aquaculture and watering dyke vegetation. Broadly, access to local institutional services has improved community capacity to integrate climatic information in their livelihood development efforts, and to deal with current and anticipated risks.

Application of the community-based approach was always difficult, as specialized institutions such as BFD, DLS or DoF were unable to provide long-term income generation options. Nandy *et al*. (2003) emphasized the importance of institutional relationships, mutual trust and land ownership in participatory resource management of mangrove ecosystems. Adger *et al*. (2005) refer to transformational changes in managing coastal ecosystems, which offer novelty in practices and adaptive decision-making to shift from a conventional approach to new networking and institutional arrangements. Developing trust and networking between local communities and institutions to help deploy innovative practices is a basic principle of the project. The integrated approach, by involving all service providers such as agriculture, fisheries and livestock, provides a continuous flow of resources and helps to develop mutual trust and ownership.

The voluntary role of coastal communities in guarding mangrove forests is the ultimate outcome of this integrated approach, and has been referred to as a positive transformation due to the project. Owing to manpower constraints in BFD, a single forest guard is currently responsible for guarding and protecting more than 1,500 ha of mangrove forest, whereas CBACC-CF has accommodated eight families per hectare in the adjacent mangrove forest. Under the agreements with these families, they will serve as a “watchdog” to control illegal activities in the mangrove forest, and will no doubt also keep an eye on their FFF resources. This type of positive transformation is a must for future EBA in Bangladesh; it will also serve to supplement the existing institutional capacity of BFD. CBACC-CF is the first project in Bangladesh in which landless and marginalized coastal communities are accessing government lands through a benefit-sharing scheme (Nandy, 2012). Income generation from this scheme will increase their food security and access to health services and education.

Responsibility for coastal land management in Bangladesh has always been fragmented between local Forest and Land Offices. The project has mediated conflicts related to land rights while sustaining a cost-effective adaptation programme. The FFF initiative creates an institutional interface to provide climate change information and related critical services, in an integrated manner, to enhance adaptation success. The defined and coordinated roles among implementing government departments has improved institutional networking for delivery of project services. The local CMC is currently the collaboration platform among implementing government departments, to share progress, feedback from communities for contingent risk management, and improve service transfer. Notably, after the project began, capacity-building of local institutions enhanced the synergies in delivery of adaptation services to coastal communities. Disaster and climate change related risks are currently well addressed as a shared responsibility of service institutions such as the Forest, Agriculture, Livestock and Fisheries Departments.

5. Conclusions

As of today, the project has introduced a number of innovative interventions. The key lessons for scaling up these interventions can be summarised as follows:

- Mangrove ecosystems can generate large-scale social and ecological benefits if periodically inundated coastal lands are used for multi-level resource generation. By empowering coastal communities with land rights through access to government lands, the project has opened a new window of opportunity for rational coastal land use in Bangladesh. Community-based innovative practices in newly accreted lands, and access to local institutional services, improved their capacity to integrate climatic information in climate-resilient livelihood development. The success of the project to date has been driven by rainwater harvesting in the ditches for multi-level resource generation. A major lesson is that many other opportunities are needed to expand the rainwater harvesting system to promote aquaculture and irrigate dyke vegetation throughout the year.

- Transformation from conventional and standardized monoculture plantation to a much more complex, managed forest can offer ecosystem benefits to current and future mangrove plantations. Planting with a mix of species in gaps is likely to improve the adaptive response of vulnerable mangrove patches to coastal geomorphological changes, as well as provide social and economic benefits to coastal communities.

- The FFF model of the project, accommodating eight families per hectare on government lands, appears to be a rational land-use model in a land-scarce country such as Bangladesh. It converts unused land into a productive resource management regime and protects the land from encroachment. However, specific policy interventions are needed to deal with threats such as false ancestral land claims leading to illegal leasing of mangrove lands.

- The voluntary guarding of mangrove forests by project beneficiaries is also an important achievement of CBACC-CF that not only strengthens the institutional capacity of BFD, but also secures the EBA approach from illegal interventions and ensures participatory adaptation initiatives.

- Based on the project's experience, it is recommended that policies are developed on the sustainability of the protective coastal "greenbelt", as well as climate-resilient livelihood strategies to support EBA in coastal Bangladesh.

- For the first time, CMCs for adaptation have been adopted by the CBACC-CF project for effective implementation of adaptation interventions in Bangladesh. The participatory structure of these CMCs means that local communities are well-represented in decision-making, including the selection of project beneficiaries in vulnerable coastal areas.

- Lastly, a key lesson is that disaster-prone coastal areas require a self-sufficient and sustainable land-use system, supported by farmers' organizations and societies, to remove the disaster relief culture that exists amongst many coastal communities.

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Disaster risk reduction through mangrove conservation and rehabilitation: a case study in the Ayeyarwady Delta, Myanmar

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Abstract

In May 2008 Cyclone Nargis devastated virtually all of the Ayeyarwady Delta of Myanmar, an area that had not experienced such a disaster in recorded history. According to the Post-Nargis Joint Assessment report, some 17,000 ha of natural forest and 21,000 ha of forest plantation were damaged at an estimated cost of MMK 14 billion (US$140 million). Thus, restoration of mangrove forests in the delta became a huge task for both the government and civil society organizations.

Most NGOs working in the field of disaster risk reduction (DRR) realized that collective action was crucial. In August 2009, with the support of DFID's Pyoe Pin programme and SIDA, the Mangrove and Environmental Rehabilitation Network (MERN), comprising 17 local NGOs, was formed to support joint work on DRR through mangrove restoration. MERN undertakes mangrove conservation and rehabilitation, and livelihood improvements, by providing small grants to members and by supporting joint projects that involve cooperation among several members. All project activities are implemented through community-based organizations (for example forest user groups).

In 2009–2011, a total of 41 villages and 6,460 households participated in projects to establish mangrove plantations, improve livelihoods, raise awareness, and build capacity for community-led DRR across the delta. In total, about 340,000 mangrove and non-mangrove trees were planted. To reduce the consumption of fuelwood, 600 energy-efficient stoves were distributed. For livelihood improvements, 4,000 ducks, 25,000 fishes and cash crops for home gardens were provided to poor families participating in mangrove rehabilitation. A total of 800 villagers were trained to improve their technical and managerial skills for mangrove conservation and rehabilitation. The mangrove species planted were mainly *Avicennia officinalis*, *Sonneratia apetala*, and *Bruguiera gymnorrhiza*. Their survival rate was more than 80%; attacks by crabs and rodents, plus uncontrolled grazing, being the main causes of damage and mortality.

As there was little experience of networking among local NGOs, management was not well synchronized in the early days of MERN. Understanding between members was enhanced by learning and information sharing throughout project implementation. MERN also conducts policy advocacy relating to revision of the forest law and community forestry instructions that will empower local communities in sustainable forest management. Other challenges remain, however, such as improper land-use planning, poverty, a lack of alternative energy sources, and inadequate funds for mangrove conservation and rehabilitation in the Ayeyarwady Delta.

Keywords: mangroves, rehabilitation, Cyclone Nargis, disaster risk reduction, Myanmar

1. Introduction

Myanmar, with a total land area of 676,577 km², is the largest country in mainland Southeast Asia. The population of the country was estimated at 58 million in 2009. Myanmar is still well-endowed with natural forests covering 47% of the country's total land area (31,773,000 ha). The Permanent Forest Estate (PFE), comprising Reserved Forests, Protected Public Forests and Protected Areas, covers 31% of the total land area. Myanmar has a total length of

2,832 km of coastline, and 467,330 ha of mangroves (Forestry in Myanmar, 2011). Mangrove forests are distributed in Rakhine State and Tanintharyi and Ayeyarwady Divisions.

The Ayeyarwady Delta, with a population of 4 million, was very badly hit by Cyclone Nargis in May 2008. The official death toll was 77,738, with 55,917 reported missing. The United Nations estimates 2.4 million people were directly affected, mostly in the delta. According to the Post-Nargis Joint Assessment, some 17,000 ha of natural forest and 21,000 ha of forest plantations were damaged at an estimated cost of MMK 14 billion (US$140 million). The loss of environmental services from the natural mangrove forests was estimated at MMK 46 billion (US$460 million) (UN/ASEAN/Government of Myanmar, 2008).

Myanmar is not a naturally disaster-prone country. Previous cyclones were not as strong as Nargis. As a result, when Nargis struck, the country was largely unprepared. Moreover, over the preceding 10–20 years, the delta's mangroves experienced large-scale clearing, removing a life-saving storm barrier.

It has been a herculean task to restore the delta's mangrove forests. Local NGOs and CBOs are key players in building the capacity of local communities for natural resource management. Rather than action by individuals, experience elsewhere in Myanmar shows that collective action is more effective.

The Mangrove and Environmental Rehabilitation Network (MERN) has emerged as a key actor in DRR through mangrove restoration in Myanmar. Comprising 17 local NGOs, MERN was formed in August 2009 with support from DFID's Pyoe Pin programme and SIDA. MERN's main objective is to promote natural resource management activities through community participation for sustainable utilization and DRR in the Ayeyarwady Delta and other coastal areas.

MERN's Central Executive Committee (CEC) deals with policies and guidelines and its Fund Board (FB) handles fund raising. Once established, MERN adopted a policy paper that set its spatial and thematic priorities, time frame, and funding needs, and issued standard operation procedures (SOPs).

2. Materials and methods

The main objective of this study is to evaluate the opportunities and challenges of mangrove restoration projects undertaken by MERN members in the Ayeyarwady Delta in order to extract lessons learned from small grant and joint projects, and to provide recommendations for future work.

MERN's articles of association, policy papers, SOPs, progress reports, and project monitoring reports were reviewed in order to understand its objective and activities. Field observations were made to evaluate projects by member organizations. Some members are working on several projects in the delta through both small grant and joint projects. By direct observation in the field, challenges and opportunities were assessed. Staff of the Myanmar Forest Department (MFD), project staff and community members were interviewed to identify the project's tangible and intangible benefits.

Lessons learned were identified at learning and sharing workshops with members. Conservation and reforestation sites were visited to determine the condition and survival rates of planted trees. Semi-structured interviews with line departments was made to understand the impact of existing policies, laws, and instructions, and the extent to which they support mangrove conservation and reforestation through public participation.

3. Results and discussion

3.1 MERN Policy

After its establishment, MERN developed a 5 year policy paper setting spatial and thematic priorities with an estimated budget of US$7.3 million. It addresses six environmental issues: deforestation, loss of biodiversity, land degradation, climate change and increase of vulnerability to natural disasters, competition for land use, and poverty reduction.

The policy paper has identified four objectives for the implementation of activities:

1. Enhance environmental sustainability and biodiversity.
2. Increase community adaptive capacity and resilience.
3. Reduce poverty and mangrove dependency.
4. Promote environmental governance.

In line with these objectives, targets to be completed within a 5 year time frame are:

1. Conserve 100% of critical mangrove ecosystem and hotspots, and ecologically enrich these areas.
2. Protect 100% of vulnerable communities while focusing on policy priority areas.
3. Increase income for half of the poorest of the poor households in priority areas and secure food and nutrition.
4. Encourage 100% participation of vulnerable communities in decision-making, natural resource management and environmental conservation.

Geographical priorities in the Ayeyarwady Delta are five townships severely affected by Cyclone Nargis: Bogalay, Laputta, Mawlamyine Kyun, Ngapudaw and Pyapon. As a result of mangrove clearing for charcoal and shrimp production, these areas are highly vulnerable to natural disasters, and will also be affected by sea level rise due to climate change.

MERN's goals are probably too ambitious to be achieved within five years. There are many limitations and barriers such as the lack of a legal framework, staff capacity constraints, and bureaucratic red tape. To date, MERN has secured US$4 million of its US$7.3 million fund-raising target.

In terms of overall geographic priorities, the Ayeyarwady Delta and Mon and Rakhine States are the main areas of project intervention. There is a pressing need to extend activities to Tanintharyi Division where mangrove forests are under threat from conversion to shrimp ponds, settlements, and industrial development. It would be difficult for MERN to cover important freshwater wetlands such as Inle Lake owing to a lack of funds.

It is not easy to undertake community-led natural resource management, as the law does not support such a bottom-up approach. For example, although it recognizes the importance of public participation, the Forest Law provides only very limited provisions for such participation. In response, MERN has conducted policy advocacy to persuade decision makers to review and revise legal instruments that could promote public participation in natural resource management.

3.2 Policy advocacy

MERN has made policy recommendations to the Ministry of Environmental Conservation and Forestry (MOECAF) on the 1995 Community Forestry Instructions and the proposed new Forest Law and Environmental Law. Some members also participated in the preparation of a Disaster Management Law organized by the Ministry of Social Welfare, Relief, and Resettlement.

MOECAF usually invites the MERN Chairman, some CEC members and MERN's Technical Advisor to meetings and workshops at which they give advice, ideas and policy recommendations. For example, MERN provided substantial input to a government strategy on mangrove conservation and rehabilitation in the delta.

Ecosystems Conservation and Community Development Initiative (ECCDI), a MERN member, has researched the status of community forestry in Myanmar and submitted recommendations to the MFD. In principle, the MFD has agreed to include these recommendations in the revision of the Forest Law, which was issued in 1992. The new Forest Law is expected to be approved in the fourth session of parliament in 2012.

MERN, together with the Myanmar Timber Merchant Association and forestry scholars, compiled a discussion paper emphasizing people's participation in sustainable forest management to assist the revision of forest law. MERN members Forest Resource Environment Development and Conservation Association (FREDA), ECCDI, and the Biodiversity and Nature Conservation Association, were invited by MOECAF to provide input to the Environmental Law that was recently passed by parliament.

MERN's policy advocacy has had some success. MOECAF has agreed to take into account MERN's recommendations for revision of legal instruments. However, many opportunities for policy advocacy relevant to the thematic areas of MERN still remain.

3.3 Capacity-building

MERN's policy requires that 10% of all funds received are allocated for building the capacity of its members. To do so, training on social mobilization, project cycle management, financial management, mangrove forest management, and livelihood improvements has been carried out with the assistance of a pool of resource persons. With assistance from DFID, members have also been trained in evidence-based research.

MERN has also organized training courses for journalists on environmental issues, so that they can better convey environmental messages to the public.

In 2010 and 2011, with SIDA's support, three MERN representatives attended a forest certification training event in Sweden. With the support of Wetlands International, two MERN representatives attended participatory monitoring and evaluation training workshops organized by the World Fish Centre in Cambodia in March and July 2012. With DFID funding, eight participants from MERN's members visited Viet Nam to study mangrove and coastal management and livelihoods development in 2011. In February 2012, three MERN representatives were invited by IUCN to attend a conference on building coastal resilience in Thailand.

Despite these events, progress on capacity building is considered unsatisfactory relative to the targets set in the policy paper. MERN has not effectively engaged the pool of resource persons established to assist with capacity-building and research. Cross-visits between projects are still inadequate.

3.4 Networking

MERN has established working relationships with several local and international organizations. MERN works closely with the Environmental Thematic Working Group of UNDP Myanmar. Several MERN members participate in the Food Security Working Group on livelihood development and land management.

MERN has worked with several international organizations, including Oxfam Novib, Action for Mangrove Reforestation, Kokusai Kogyo Co. Ltd from Japan, FAO, UNDP, IUCN, MFF, WWF, Wetlands International, World Fish Centre, Forest Trends, and SSC Forestry, a Swedish forest certification group. This has resulted in several capacity-building opportunities.

However, networking between MERN and other organizations is still at am early stage. It needs to move towards practical collaboration that supports mangrove conservation and rehabilitation activities in a timely and effective manner.

3.5 Joint projects

3.5.1 Achievements

MERN's FB has raised funds for small grants and joint projects implemented by its members (see Figure 1 below). The main fund (Basket A) is financed by donors, principally DFID. The FB allocates 10% of these funds for capacity-building of its members. The balance is used to fund members under a small grant scheme. For instance, any member can apply for a small grant to carry out a project in line with MERN's priorities. MERN reviews all proposals to ensure relevance, technical quality, and value for money.

For joint projects (Basket B), funds come from three sources: donors, co-funding from Basket A, and contributions from implementing partners. Joint projects involve member organizations working on different thematic areas in the same geographic area. For example, one organization works on livelihood improvements while another works on mangrove rehabilitation.

Joint projects in which three or more member organizations work together have been carried out in the Ayeyarwady Delta and Rakhine State. The project in the delta was funded by Oxfam Novib (EUR 200,000) and the Pyoe Pin programme (US$60,000) for two years in Bogalay

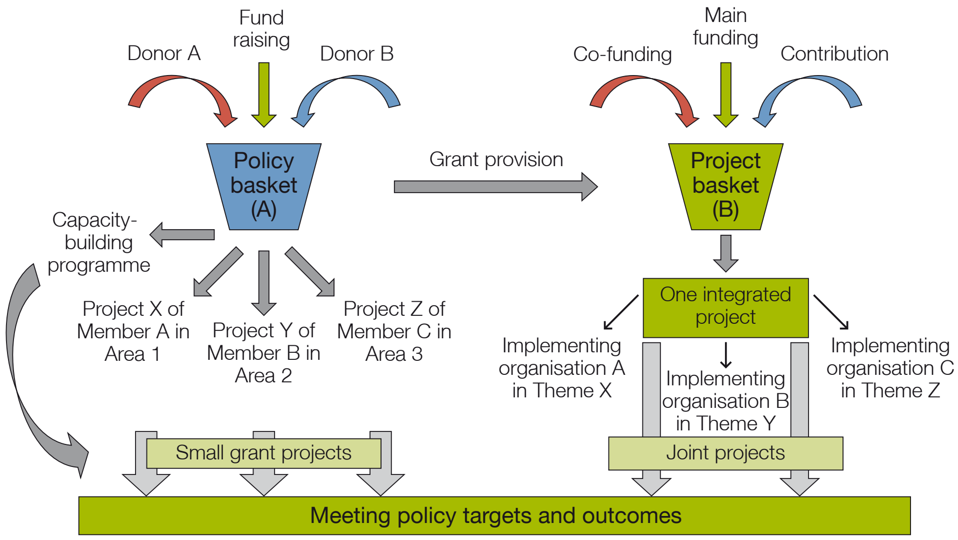

Figure 1 Illustration of funding mechanism for small grant and joint projects

Township. The project in Rakhine State was funded by the multi-donor Livelihood and Food Security Trust Fund (US$3 million) and Pyoe Pin (US$60,000) for three years.

The title of the joint project being implemented in the delta is Mangrove Empowerment and Livelihood Security (MEALS). Three member organizations are working together in 16 villages covering a total of 12,221 beneficiaries. The goal of the project is to sustain mangroves and conserve biodiversity by improving local mangrove governance. MEALS applies the following step-wise procedure to implement project activities:

1. Preliminary assessment
   - Village data
   - Selection of village
   - Set up
2. Baseline survey
   - Household awareness questionnaire
   - Resource map
   - Venn diagram
   - Histogram
   - Seasonal calendar
   - Wealth ranking
   - Climate analysis
3. Village awareness meeting
   - 20 minute talk
   - Display
   - Drama
   - Storytelling
   - Group discussion
   - Video show

4. CBO formation
   - Member nomination
   - Member approval
   - Executive Committee election
   - Development of rules and regulations
   - Record keeping
   - Training
   - Saving
5. Village conservation plan
   - Household conservation initiative
   - Group conservation initiative
   - Village participatory patrolling scheme
   - Livelihood support fund

So far, 17 CBOs have been formed, and 19 staff have been trained in project management. The project trained 34 CBO members in mangrove conservation and another 34 local people in financial management. In total, 2,316 people have attended awareness-raising campaigns on DRR and mangrove conservation and rehabilitation. Some 280 people have benefited from a micro-grant scheme. Another important achievement for MERN is that through these projects it further developed its SOPs.

An important project outcome was participatory patrolling of the 13,000 ha Meinmahla Wildlife Sanctuary in Bogalay, in cooperation with the MFD. The sanctuary forms the largest area of mangroves in the delta and served as a "bioshield" for nearby communities during Cyclone Nargis. If it is totally protected, exposure to natural disasters will be greatly reduced.

The micro-finance component also demonstrated success, with several CBOs starting up small businesses. The information campaigns initiated by the project are gaining ground as community members are becoming increasingly aware of the costs of mangrove cutting and the benefits of mangrove conservation.

3.5.2 Opportunities and challenges

There were opportunities and challenges in the course of project implementation. Opportunities included winning the cooperation of senior MFD officials, and the availability of skilled staff for social mobilization and capacity building.

However, the project also encountered challenges that slowed progress. These included resistance from low-level MFD officials to participatory patrolling of the wildlife sanctuary. They may have been concerned about the loss of authority or income from bribes from illegal cutting and fishing. Another challenge was that most of the villagers had a false expectation of the project, hoping that it would contribute money directly to individual families.

3.5.3 Lessons learned

The joint projects have yielded a number of valuable lessons. The following come from the MEALS project:

- Proper social mobilization and awareness-raising campaigns are vital for securing community buy-in.
- Close coordination, including monthly coordination meetings, between project implementation partners is crucial.
- Policy engagement (for example on joint forest management) is needed for successful project implementation.
- The structure of the project team and delegation of authority must be clear.

3.6 Small grant projects

3.6.1 Achievements

MERN wants to use the small grant projects to demonstrate and replicate best practices. In 2009–2011, eight MERN members implemented eight small grant projects in Bogalay, Pyapon, Mawlamyine Kyun and Laputta Townships in the Ayeyarwady Delta and in Than Phyu Zayat Township in Mon State. These grants covered mangrove rehabilitation and conservation, livelihoods and food security, capacity building and awareness raising, and coordination and environmental governance. Table 1 below lists the project titles and implementing organizations.

Table 1 MERN small grant projects

Title	Organisation
Rehabilitating Mangroves and Improving Food Security of the Nargis Victims Through Enhanced Technical Capacities and Community Agro-Forestry	ECCDI
Assistance for Community-Based Forest Management	National Ecumenical Church Fund, Myanmar
Rehabilitation and Restoration of Mangrove and Livelihood	Border Area Development Association
Awareness Raising and Capacity Building for Local Communities to Recover Mangrove Vegetation	Mon-region Society Development Network
Promotion of Community Initiative Environmental Conservation in Rural Community	Metta Mon General Service Cooperative
Mangrove Restoration and Community Forestry in Hpo Au San Village	FREDA
Feasibility Study for Desalination of Seawater and Environmental Conservation in Mangrove Forest Area	Envir-Kleen Technologists' Association
Mangrove Conservation Awareness Raising through Demonstration Nursery	Social Vision Services

The small grant projects have benefited 6,460 households in 41 villages, rehabilitated 120 ha of degraded land, mostly using mangroves and windbreak trees. Local people grew about 155,000 trees, including fuelwood species, multipurpose species, and fruit and cash crop species, in and around their compounds and farm lands. The total area rehabilitated is about 160 ha. Local communities also received 4,000 ducks, 25,000 fish and about 600 fuel-efficient stoves. Seventeen training events were held and over 800 persons were trained. Awareness-raising events were held between two and four times in each village. The projects distributed 5,500 pamphlets, 123 posters and 300 booklets.

3.6.2 Opportunities and challenges

Like the joint projects, the small grant projects faced opportunities and challenges. The projects generally succeeded in securing the cooperation of line departments and local authorities. Most MERN members were already familiar with the local communities they worked with through their participation in post-Nargis emergency humanitarian assistance.

The major challenges were the lack of proper land-use planning, and a lack of experience in establishing mangrove nurseries and replanting mangroves. Some projects could not persuade villagers to participate in project activities because their immediate needs were outside the scope of the project. Also there was often a lack of local ownership of the mangrove plantations.

3.6.3 Lessons learned

The following lessons come from working with local communities on the small grant projects:

- It is not easy to improve the quality of newly-formed CBOs (such as community conservation groups and forest user groups) in a relatively short time. It is much easier if the CBOs already exist.
- As the project periods were short, mangrove plantation and conservation were ineffective.
- Replication of best practices through establishment of demonstration plots was effective.
- Small grant projects are effective at raising awareness, short-term capacity building, and developing knowledge products.
- Only the project outputs were evaluated; it is necessary to explore how these resulted in outcomes and long-term impacts.

3.7 Performance of mangrove plantations

MERN has established 160 ha of mangrove plantations in small grant project areas. Besides plantations, regeneration improvement felling and enrichment planting were carried out to enhance the quality of degraded natural forests. The major species grown in the mangrove plantations are *Avicennia officinalis*, *Avicennia marina*, *Bruguiera* spp., *Sonneratia apetala*, *Heritiera fomes*, *Lumnitzera racemosa*, *Excoecaria agallocha* and *Xylocarpus moluccensis*. Planted mangroves achieved a survival rate of 80% and reached a height of 1–3 m.

Major disturbances observed in mangrove plantations were attacks by rodents and crabs, and uncontrolled grazing. The number of rodent attacks increased sharply in the Ayeyarwady Delta after Cyclone Nargis. Crabs mostly attacked young seedlings. Caterpillar attacks on *S. apetala* seedlings were noted in nurseries and during the early stages of plantations. Due to the lack of land for buffaloes, which are used for paddy cultivation in the delta, uncontrolled grazing is a major threat to plantations located near villages.

4. Conclusions and recommendations

Over the past two-and-a-half years, MERN has achieved several of its 5 year objectives, notably the implementation of small grants and joint projects. Capacity-building and policy advocacy were also partially successful. MERN represents the first attempt by local NGOs to work together formally. So, inevitably, MERN has faced challenges working with members with a range of interests and attitudes.

MERN has policies and SOPs to sustain the network and guide its project activities. But it is too early to say whether these have been put in place systematically. MERN has to respond to rapidly changing conditions in Myanmar and internationally as they affect the country. The following points are intended to improve the quality of MERN's future work:

1. Review policy targets against the achievements of the past two-and-a-half years.
2. Review and revise small grant and joint project guidelines, based on results so far.
3. Engage the media and develop knowledge products to raise public awareness on sustainable mangrove management and DRR.
4. Speed up capacity-building efforts for members and other relevant stakeholders.
5. Extend advocacy work to local governments, as they are responsible for environmental conservation.
6. Raise the funds needed to achieve all targets by 2014.
7. Formulate proper strategies for mangrove conservation and reforestation in consultation with relevant stakeholders.
8. Initiate public-private partnerships to support long-term sustainable mangrove use.
9. Lead the formation of CBOs, and facilitate networking among CBOs working on sustainable mangrove management.
10. Extend networking to cooperation and learning and information exchange between local and international organizations.

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Adapting to natural disasters and contributing to climate change mitigation: mangrove community forestry in Viet Nam

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Abstract

Da Loc Commune in Thanh Hoa Province in northern Viet Nam is vulnerable to increasing extreme weather events. The damage caused by Typhoon Damrey in 2005 was a pivotal moment for the commune, leading to mangrove reforestation initiatives for managing disaster risk. Involving local communities as direct partners led to this project's success compared to earlier, less-participatory initiatives. In the time required for the mangroves to reach maturity, a number of secondary benefits have emerged. Besides the income benefits from enhanced aquaculture, mangroves also serve as powerful carbon sinks. Thus, while originally designed as an adaptation measure, the project has strong mitigation benefits. It has also shed light on a number of important issues:

- Official recognition of community management rights over the mangroves has been critical in ensuring the sustainability and commitment of local communities. However, currently these rights are short-term (five years). The sustainable management of the mangroves is contingent on establishing longer-term community rights.

- Trade-offs have emerged that may threaten the project. The income potential of aquaculture practices that are destructive to the mangroves is a strong temptation. Careful analysis of the costs and benefits of both adaptation and mitigation actions is needed.

- Unless equitable benefit-sharing mechanisms are in place and participatory decision-making processes are incorporated for the well-being of vulnerable community members, there is a risk that the success of the project will be compromised.

- Pre-existing, locally adapted knowledge can be highly beneficial to projects. Understanding and incorporating local knowledge may lead to innovations that enhance effectiveness and improve uptake by local communities.

Keywords: mangroves, participatory approach, disaster risk management, climatic changes, carbon sinks, Viet Nam

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1. Introduction

Da Loc is a coastal commune in Thanh Hoa Province, north-central Viet Nam, and covers an area of 11,116 km^2. The East Sea and the Len River border the commune and support much of the agriculture and aquaculture in its ten villages.

The commune's geography exposes it to threats that are intensifying with climate change (IPCC, 2007; ADB, 2009; Buffle *et al.*, 2011). Da Loc experiences 5–6 typhoons a year, in addition to continuous sea encroachment and flooding (Trinh, 2009). In 1982, the government constructed a 5 km sea dyke around the commune to protect against typhoons. However, despite substantial investment, the dyke has suffered continuous damage from extreme weather events.

Mangrove afforestation is a promising option to protect both the community and the sea dyke. Starting in 1989, the Japanese Red Cross, Save the Children and government collaborated to plant 350 ha of mangrove seedlings in offshore areas bordering Da Loc. After testing several different mangrove species, they selected *Kandelia candel* and *Sonneratia* sp. Survival rates proved disappointing, however; in some instances only 15–20% survived within a year of planting.

In 2005, Typhoon Damrey inflicted serious damage on Da Loc. The sea dyke failed to protect the commune except where mangroves remained to buffer the storm. In these sheltered areas, agricultural land suffered less seawater intrusion, whereas elsewhere sea water swept several kilometres inland, destroying settlements and livestock, and taking human lives (Kempinski, 2009; Buffle *et al*., 2011). The long-term impacts on agriculture and freshwater supplies are still being felt.

This demonstration of the value of mangroves inspired CARE International to take an active role in the regeneration and further expansion of mangrove forests in Da Loc. CARE facilitated a Community-Based Mangrove Reforestation (CBMR) approach, which empowered local communities as stewards and beneficiaries of the mangroves.

2. Materials and methods

The methodology used in this study is qualitative and exploratory. Participatory Rural Appraisal (PRA) facilitated the collection, presentation, and analysis of the data with local community members. Research questions that directed the focus group discussions and interviews were:

- What have been the physical changes in the local environment over the recent past?
- What have been the impacts of any such changes on local communities and their livelihoods?
- What are the sustainable livelihood assets possessed by the community, particularly linked to forests, which might contribute to adaptive capacity?
- How are community forestry management strategies contributing to adaptation and mitigation needs?
- How are forest management strategies, including mitigation initiatives, potentially adversely impacting the adaptive capacity of local communities?

The authors attended an inception workshop in Bangkok on 1–3 August 2011 to review the proposed methodology. Investigative methodologies were drawn from common PRA tools, alongside more climate change-specific tools developed by AIT/UNEP (2011) and CARE (2009), including:

- Focus group discussions.
- Natural resource flow and spot maps.
- Extended livelihood profiles.
- Hazard, vulnerability, and action profiles.
- Ecosystem services' change matrix.
- Risk reduction development service profiles (AIT/UNEP, 2011).
- Supplemental seasonal calendars, hazard mapping and vulnerability matrix (CARE, 2009).

The principal researcher (Sen Le Thi Hoa) visited the case study sites on at least three occasions. Focus group discussions and semi-structured interviews were used, along with other tools adapted to the context. Community participants were divided into groups of no more than 20 people for the PRA exercises. In-depth interviews with individual households, village leaders, local authorities, and selected relevant professionals were conducted. In addition, secondary data from official documents were acquired. Lastly, a small workshop was conducted to summarize, share, and validate the information collected.

3. Results

3.1 Climate change and perceived impacts in Viet Nam and in Da Loc

The fourth assessment of the Intergovernmental Panel on Climate Change (IPCC) in 2007 noted that most climate change assessments in Viet Nam at that point had been qualitative, and that a pressing need existed for more empirical data. Despite this, it pointed to clear climate change impacts already occurring, with weather conditions becoming more extreme and unpredictable (IPCC, 2007). In its Second National Communication to the United Nations Framework Convention on Climate Change (UNFCCC), the Vietnamese government reported increasing average temperature rises over the past several decades, more cold fronts, and growing intensity of typhoons affecting coastal areas (GoV, 2010). Annual average temperatures increased by 0.1°C per decade from 1900 to 2000 with summers becoming hotter (Hoang and Tran, 2006).

3.2 Community perceptions of climate change

Most of the stakeholders surveyed have at least a basic understanding of the term "climate change", generally gained from local media and projects. Commune-level officials tend to have a better understanding, and many have had opportunities to attend specific training on climate change adaptation and mitigation. All community members claim to have been negatively impacted by what they perceive to be climate change, pointing to declining agricultural productivity attributed to erratic seasons and rainfall, seawater intrusion, and the effects of natural disasters.

In common with seasonal shifts experienced in other parts of the country (Oxfam, 2008), Da Loc villagers report that since the late 1990s, the dry season has lengthened considerably, beginning a month earlier and lasting a month longer (Oxfam, 2008). Cold spells have also changed in both duration and intensity, with villagers reporting unprecedented lows of 7°C. *Tieu Man*, a regular natural flooding event that normally occurs at the end of April, signalling the start of crop planting, has not happened for several years (Oxfam, 2008).

> "*The weather has been changing too much. It's not regular as it was before. People now experience very hot days, then a freezing cold winter.*"
>
> — Mr Dao Van Nhe, Dong Tanh village, Da Loc Commune.

> "*We used to have three or four definite seasons: spring, summer, autumn and winter… Now we have two: hot and cold. In previous years, rainfall came between spring and winter. Now it rains in autumn and winter. With these changes, we cannot forecast our agriculture production activities… It just rains whenever and however.*"
>
> — Mrs Nguyen Thi Dien, Dong Tanh village, Da Loc Commune

Fresh water is becoming scarcer. Groundwater tables are falling, partly because of human activities such as land-use management and agricultural practices, and salt water has intruded up to 10 km inland and is affecting the flow dynamics of the Len River.

3.3 Changes in natural assets and livelihood implications

Da Loc villagers estimate that since Typhoon Damrey struck, household incomes from agriculture and animal husbandry have dropped by an average of 20%, and by closer to 50% in villages near the coastline. This is attributed, at least in part, to the lasting impacts of typhoon storm surges as well as rising sea levels*.

During PRA, the villagers estimated that average rice yields have dropped from 6,940–7,500 kg/ha to 4,170–5,560 kg/ha since Typhoon Damrey, reducing food security. The land available for rice cultivation has also declined over time, mainly because of salinization and conversion to aquaculture. In 2009 and 2010, more than half of the households were forced to purchase rice for consumption, an increase of 15% from previous years.

Da Loc now faces serious freshwater shortages. Owing to a longer dry season and rising sea levels, the Len River is affected by sea water throughout the year. This is forcing communities to explore other water-access options, including purchasing water for household needs, filtering water, rainwater harvesting, and requesting water donations from other communities.

Irregular weather patterns are linked by villagers and district authorities to a number of new and intensifying human, crop, and animal diseases. Villagers report an increased onset of diseases such as rice seedling blight (*Pyricularia oryzae*, also known as rice blast fungus or rice rotten neck), rice leaf-folder (*Cnaphalocrocis medinalis*), and what may be foot-and-mouth disease among cattle and pigs, and avian influenza in poultry. These diseases have emerged rapidly and present serious management challenges for the community.

Marginalized households and women in particular face growing health risks from the lack of clean water:

> "*Women, who are more active and social in Da Loc, have been more affected by climate change and environmental pollution than men because we are responsible for more work like taking care of the family, the fields, and animals, as well as social activities.*"
>
> — Mrs Tran Thi Xuyen, Yen Dong village, Da Loc Commune

Although there is no direct evidence of a causal relationship between these diseases and climate change, expected climate change impacts include increased incidence of human, livestock, and crop disease (ADB, 2011).

Animal husbandry has been adversely impacted as drought, seawater intrusion and cold spells have reduced the available grazing area. Reductions in fodder availability have curtailed animal-raising activities, affecting poorer households in particular. Coupled with emerging animal diseases, the PRA exercises indicated that the cattle population has declined by 45%

* According to MONRE (2008), average sea level rise along the shoreline of Viet Nam from 1993 to 2008 was about 3 mm per year.

since 2005, and more than half of households have stopped raising pigs. Although there are moves to purchase commercially produced feed and medicine for animals, the costs have effectively eliminated this option for poorer households. Seawater intrusion on *coi* grass habitats and subsequent conversion into aquaculture are also leading to loss of income from traditional local handicrafts such as sedge mats and other similar products.

Expanding brackish water habitats around the commune have also led to new opportunities through aquaculture and capture fisheries. The reforestation of the mangroves has led to the expansion of sandy mudflats that now cover 1,300 ha. These coastal wetlands provide an ideal habitat for valuable brackish aquatic species such as molluscs, oysters, hard and soft crabs, *Còi* fish, and shrimp.

PRA revealed the growing economic importance of aquaculture and especially molluscs. Before the CBMR project, daily harvests of molluscs averaged 2 kg per person, selling at US$1.20/kg. Today, as a result of improved habitat and strict harvest regulations, the yield is 5–10 times greater. Besides aquatic species, the areas around the mangroves also support livelihood activities such as duck rearing and bee keeping.

However, questions are emerging about how equitably these new natural resources are distributed. In 2010, about 46% of the mudflat area was allocated to individual households for aquaculture at fixed rents set by the district and provincial government. Those able to pay the high rents have been the primary beneficiaries. Conflicts are already emerging within the community over mudflat access and the opportunity costs of strict mangrove conservation.

3.4 Adaptive capacities

As Da Loc faces more unpredictable seasons and increasing intensity and frequency of extreme weather events, the community is drawing on its various livelihood assets to respond (Buffle *et al*., 2011). Da Loc has demonstrated considerable resilience, understood as the ability to adapt or recover from potential hazards (*UN/ISD*R, 2004) via livelihood diversification. The livelihood assets that support both adaptive capacity and resilience in Da Loc are summarized in Table 1 below.

3.5 Climate change vulnerabilities

With a long coastline (3,200 km) and densely populated river deltas, Viet Nam has a long history of dealing with natural disasters. It is considered one of the five countries in the world most-vulnerable to climate change (ADB, 2009). Da Loc is particularly vulnerable given its high population concentration in low-lying areas. As many properties are only 2.3 m above sea level, without dykes these assets would be lost.

In 2010, the incidence of poverty* in Thanh Hoa Province was 19.8%, and relative poverty was 23.5%†. Agriculture-based livelihoods, land scarcity, and vulnerability to natural hazards are identified by commune officials as major barriers to poverty alleviation.

* The Ministry of Labour, Invalids and Social Affairs (2011) categorizes extremely poor households in rural areas as having an average monthly income of under US$20 per person; relatively poor households have an average monthly income of US$20–26 per month.

† Thanh Hoa Province General Statistical Office (2010).

Table 1 Community assets in Da Loc Commune

Type of asset	Livelihood assets	Effects on adaptive capacity
Natural	Land available: 1,350 ha including 450 ha of agricultural land Mangrove forests: 500 ha Coastal mudflats: 1,300 ha Len River and tributaries	Land to support subsistence agriculture (primarily rice) Benefits from mangroves including disaster risk reduction and income potential from aquaculture and carbon sequestration
Physical	Sea dykes: 5 km Road infrastructure Accessible public transport Accessible pre-school, primary and secondary schools Health care station	Protection from natural disasters and extreme weather events Access to services, markets, etc. Economic mobility through education Support for medical care
Financial	Formal credit systems through national banks Informal credit system: private and farmers' group saving initiatives	Investment opportunities in diversified income-generating activities
Social	Associations for women, farmers and youth, along with a Green Team that raises awareness about environmental issues Hard-working, collective work ethic	Channels for disseminating information and raising awareness Opportunity to respond to changes with collaborative activities and actions

Note: Fifty-two villagers participated in two focus group discussions. In-depth interviews were conducted with individual households, commune and district leaders, and CARE staff; and a workshop was held in Da Loc to supplement and validate data.
Source: Key informant interviews, 2011.

While community members are described as diligent and enthusiastic about collective work, Da Loc faces a severe drain of human capital. In 2010 and 2011, an estimated 1,700 young people from a total commune population of 7,694 (about 22% of the population) migrated in search of employment (Thanh Hoa Statistics Office, 2010).

3.6 Responses to environmental changes and development needs

Da Loc is responding to climate change, environmental, and broader socio-economic changes with coping, adaptive, and in some cases, inappropriate adaptive strategies. Some of the most common adaptive responses include:

- Maintaining mangroves for their protective function.
- Changing areas of land use, crops, and cropping patterns to respond to seasonal weather changes (Pereznieto *et al*., 2011).
- Increasing use of crop species that are resistant to drought and salt water.
- Employing agricultural techniques, such as use of fertilizer and pesticides, to respond to declining crop productivity and diminished land resources; this has increased needs for intensification.
- Investment in irrigation systems in response to growing water scarcity (Pereznieto *et al*., 2011).
- Transition from rice farming for subsistence to cash-based aquaculture.
- Reduction in livestock rearing owing to high costs and diminished natural resources.
- Digging of water ponds around fields for freshwater storage.
- Migration to cities for employment (Thanh *et al*., 2010).

Many of these strategies represent planned adaptation, but not all are based on long-term forecasting and full information. Coping measures such as the increased use of pesticides and fertilizers are expensive and have health impacts. Others, such as a shift in livelihoods from rice farming to aquaculture, have increased wealth, at least in the short term.

Da Loc has also developed its social capital. The community's flood committees have been instrumental in supporting disaster management, and the youth-based Green Team actively raises awareness about climate change and environmental management.

4. Discussion

In climate change initiatives, adaptation and mitigation approaches do not always complement each other, and can conflict (Laukkonen *et al*., 2009). Efforts to mitigate climate change may hinder the adaptive capacity of local communities and *vice versa*. However, the Da Loc mangrove-planting project illustrates the potential for adaptation activities and mitigation goals to be mutually reinforcing.

CARE's initial project goals focused on disaster risk management and responding to environmental and climate changes. However, mangroves are among the most effective carbon sequestration ecosystems, capturing as much as four times more carbon than tropical rainforests (Khan *et al*., 2009; Donato *et al*., 2011). The project has therefore made simultaneous contributions to both climate change adaptation and mitigation.

Although the synergies between adaptation and mitigation in Da Loc are strong, they are not without trade-offs. Unanticipated opportunity costs have emerged through the growth of a high-value mollusc industry, which is potentially destructive to the mangroves. Given Viet Nam's high level of interest in REDD+, Da Loc residents are aware of the potential for carbon financing. If the CBMR project develops into a mitigation project that brings in carbon finance, the added revenue may strengthen community support for mangrove conservation.

The CBMR project has made substantial contributions to adaptive capacity by diversifying livelihoods. If the whole community is to benefit, however, mechanisms are needed to ensure equitable sharing of benefits. These must include transparent, participatory processes for determining access to and sharing of benefits, and ensuring that marginalized groups are not further disadvantaged.

The project used a range of media sources and social events to build awareness about climate change and environmental management. These activities built community buy-in and have been important in the success of the initiative. Besides the values of the mangroves, the community recognizes the social benefits resulting from the project, including better education, awareness, and strengthening of social capital.

Additionally, disaster risk reduction and adaptation strategies have benefited from incorporating local experiences and indigenous knowledge. For example, community members avoided using pesticides to remove barnacles from mangroves. Instead, since they knew when the barnacles had the thinnest shells, they planned the best times to remove them manually.

Because mangroves in Viet Nam are classified as protection forest, they cannot be directly allocated to households or communities for management. However, the CARE project facilitated negotiation of agreements among local communities, the District People's Committee, and Forest Department offices, to establish the rights, roles, and responsibilities of the local community in managing the mangroves. The community considers this a key accomplishment and *de facto* recognition of its right to benefit from the mangroves. This agreement has provided a powerful incentive for the improved management of the mangroves.

5. Conclusions and recommendations

Community forestry offers the potential to contribute to both adaptation and mitigation. By placing communities at the centre of management strategies, community forestry provides a platform for initiatives which seek to maximize mitigation while ensuring social and environmental safeguards are upheld. Using the livelihood assets framework, community forestry helps to ensure that adaptive capacity is safeguarded and that the balance between livelihoods and conserving ecological assets is maintained. To undermine any natural, physical, human, financial, or social assets is to diminish adaptive capacity. Preventing this should therefore form the foundation of community forestry.

Despite the contributions that community forest management can make to strengthening adaptive capacity, there are still potential pitfalls and points of tension. It is important to identify where the fault lines may lie between different objectives and approaches (including forest management, local livelihoods, conservation, adaptation, and mitigation) and possible trade-offs. Mitigation initiatives, such as REDD+, while articulating safeguards and giving priority to protecting local rights, ultimately aim at maximizing carbon sequestration in forests. This goal may conflict with other interests and it is important that potential trade-offs are identified, assessed, and taken into consideration during project design and implementation.

5.1 Recommendations

For practitioners and project developers

- Incorporating local knowledge helps to increase the effectiveness of adaptation and mitigation practices, and promotes local adoption. Engaging communities through participatory action research to identify solutions ensures buy-in and may yield useful and innovative approaches.

- "Low-hanging fruit", where adaptation actions have additional mitigation benefits and *vice versa*, should be sought. Synergies can be deliberately planned for and incorporated into adaptation and mitigation project design.

- Rural communities are among the poorest. Poverty alleviation and livelihood development are critical to securing community support. An important part of livelihood development, given the remoteness of many forest-based communities, is facilitating market access and building capacity for added-value processing and marketing of natural products.

- Local communities need financial and non-financial incentives for forest protection through activities such as patrolling and forest inventory.

For policy makers

- Mangroves in Viet Nam are classified as protection forest and cannot be allocated directly to households or communities for management. For sustainable mangrove management, however, land tenure reform should be accelerated with an emphasis on community land titling as a means of securing long-term community commitment.

- Coordination among government agencies horizontally and vertically should be ensured. This is particularly needed between district and provincial governments, and should involve the agencies responsible for protected area management where this is not the responsibility of the forest department.

- Carbon rights and the benefits accruing from them are a complex issue that must be addressed at the national level to ensure community support and the fair recognition of community contributions.

- Policy makers should identify models of successful mitigation–adaptation initiatives and, where appropriate, scale them up, prioritizing the capture of lessons learned.

For further research

- It is important to assess the costs and benefits of adaptation and mitigation actions to communicate tangible and non-tangible benefits, and trade-offs.

- There is a lack of quantitative data on climate change. A high priority should be monitoring environmental changes that may be associated with climate change, to strengthen and clarify the impacts and value of mitigation and adaptation actions.

- Knowledge-sharing and networking within and between countries should be supported. An urgent need exists to build capacity and regional information sharing is an important part of this task.

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Ecological mangrove restoration: re-establishing a more biodiverse and resilient coastal ecosystem with community participation

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Abstract

Mangrove forests are vital for healthy coastal ecosystems in many regions of the world. They support an immense variety of sea life, and are prime nesting and feeding sites for hundreds of migratory bird species. Healthy mangrove forests purify water flowing through them to the sea, and form a natural coastal shield against floods, storms or other natural disasters such as hurricanes and tsunamis. And mangroves can sequester far more carbon per hectare than tropical rainforests. Beyond these irreplaceable ecosystem services, mangroves provide important socio-economic benefits to coastal communities. In regions where the forest has been destroyed, local coastal communities face serious problems of diminished wild fisheries and threatened traditional livelihoods.

Despite these important functions, more than half of mangrove forests globally have been destroyed over the past century, mainly by human development. Reforestation programmes in these areas would rebuild mangrove ecosystems and increase the potential for sustainable development. Relatively few examples of successful, long-term mangrove rehabilitation exist, however, partly because most attempts have not corrected the problems causing mangrove loss in the first place. Moreover, the great majority of mangrove restoration efforts are merely hand planting of a single species – *Rhizophora*, or red mangrove – forming monocultures rather than truly restoring biodiverse, multi-species mangrove forests. Many plantings are not restoration, but rather attempts at ecosystem conversion of natural mudflats to mangroves.

In search of a compromise between assigned economic worth and biodiversity, Mangrove Action Project (MAP) promotes the concept and practice of Community-based Ecological Mangrove Restoration (CBEMR). This holistic approach to mangrove restoration views the proposed plant and animal communities to be restored as part of a larger ecosystem, connected with other ecological communities that also have functions to be protected or restored. Mangrove forests can self-repair, or successfully undergo secondary succession, if the normal tidal hydrology is restored and if there is a ready source of mangrove seedlings or propagules from nearby stands that are accessible to reseed an area. CBEMR focuses on re-establishing the hydrology which will facilitate this natural regeneration process. CBEMR also engages local communities in the restoration process, empowering them to be stewards of their environment, and enabling them to regain the livelihoods destroyed when the mangroves were destroyed. Three-day intensive workshops train local people to do CBEMR, and community management plans ensure project sustainability.

Working with local communities and NGOs, MAP has been piloting small successful CBEMR projects in Thailand, Indonesia, and El Salvador. Many challenges remain, however, such as the need for more robust monitoring and evaluation with internationally recognized outcome indicators; issues of land tenure and site availability; restrictions imposed by donors; carbon offset plantings encouraging ecosystem conversion rather than true mangrove restoration; and securing government permits and approvals. MAP plans to continue its CBEMR work with new projects in Southeast Asia and Latin America, gradually brought to greater scale, and in the process learn to overcome current challenges and further refine the CBEMR model.

Keywords: mangroves, restoration, biodiversity, participatory approach, carbon sinks

1. Introduction

1.1 Importance of mangroves and need for restoration

Mangrove forests are vital for healthy coastal ecosystems in many regions of the world. They support an immense variety of marine life, are a refuge for juvenile fish, crabs, shrimp and molluscs, and serve as nurseries for coastal fisheries. Healthy mangrove forests play an important role in carbon sequestration – their ecosystems and associated wetlands account for nearly a third of the world's terrestrial carbon stores and sequester more carbon per hectare than tropical rainforests (Ramsar Secretariat, 2002). Mangroves also form a natural coastal shield against floods, storms and other natural disasters such as hurricanes and tsunamis. Beyond these irreplaceable ecosystem services, mangroves also provide important socio-economic benefits to coastal communities.

Despite these important functions, more than half of all mangrove forests have been destroyed in the past century, mainly by causes stemming from human development (FAO, 2008). FAO statistics indicate that mangroves are still being lost at a rate of about 1% a year. This means that nearly 150,000 ha of mangroves are lost each year (FAO, 2008). In addition, mangrove ecosystems and salt marshes are vulnerable to the negative effects of climate change such as rising sea levels, higher temperatures and natural disasters. In regions where the forest has been destroyed, local coastal communities are left with marginal or unproductive fisheries and the loss of their traditional livelihoods.

Reforestation programmes where the mangroves have been lost would therefore rebuild mangrove forest protection and restore the potential for sustainable development. The improvement of mangrove ecosystems through restoration will enhance their functions as a natural water treatment system and spawning grounds for fish, thereby improving health and livelihood possibilities to the benefit of marginalized local communities; and restoring the vital carbon sequestration powers of these forests.

1.2 Failure of usual mangrove restoration methods

Very few organizations have so far dealt effectively with mangrove restoration, and relatively few examples exist of successful, long-term mangrove rehabilitation, partly because most restoration attempts have not corrected the underlying problems responsible for mangrove loss. The great majority of mangrove restoration attempts are merely hand planting of a single species – usually *Rhizophora*, or red mangrove – forming monocultures rather than restoring a biodiverse mangrove wetland. These attempts have largely failed, either leaving dead seedlings and much disappointment in their wake, or establishing mangrove plantations or monocultures with limited potential for biodiversity.

This practice of hand planting propagules and seedlings is aptly described by ecological mangrove restoration pioneer Dr Robin Lewis as "the gardening method," whereby monoculture plantations of usually one or two varieties of mangrove are established (Lewis, 2009). These plantations are less resilient to natural disasters, diseases or insect infestations. In tropical areas where there may be two or more dozen mangrove species, it makes little sense to label this "gardening" approach as "restoration", because the natural biodiversity and productivity of the original healthy mangrove forest is not an outcome of this simplified technique. Most often, these "gardening" efforts fail to establish any significant lasting mangrove cover.

After the 2004 Indian Ocean tsunami, there was an urgent, yet ill-conceived, reaction to establish protective mangrove greenbelts. A wide call was issued and supported by many governments, intergovernmental agencies, and NGOs. The majority of these rather hastily planned mangrove "restoration" attempts failed because of badly chosen sites or wrongly selected species for planting. Many red mangrove seedlings or propagules were hand-planted in disturbed former mangrove sites, as well as mudflats and salt flats. Few of these survived because the necessary conditions for seedling survival were not clearly evaluated in advance (Dahdouh-Guebas *et al*., 2005; Dahdouh-Guebas, 2006; Samson and Rollon, 2008).

The failures were due to many factors: poor site selection, lack of understanding of mangrove ecology and hydrology, short project periods and a desire for quick results from donors, lack of community consultation and participation, relief agencies with no previous experience with mangroves, lack of follow-up and monitoring, and planting mainly *Rhizophora* spp. seedlings and propagules, regardless of whether this was appropriate for the selected site. In short, too often the wrong species were planted in the wrong place at the wrong time.

One reason for this monoculture approach is that the specific species planted can produce desirable wood products that can be sold on local markets and so improve the livelihood of people living in the surrounding communities. However, these plantations are often established on mudflats, salt flats and even seagrass beds, thus attempting to convert one viable and important ecosystem into another. This is not a wise solution when attempting to "restore" ecosystem functions, even if these projects do successfully establish some mangroves. Most often, these "gardening" efforts fail to establish any significant mangrove cover (Lewis, 2005, 2009; Dahdouh-Guebas *et al*., 2005; Samson and Rollon, 2008).

1.3 The CBEMR alternative

In search of a compromise between economic value and biodiversity, Mangrove Action Project (MAP) promotes the concept and practice of Community-based Ecological Mangrove Restoration (CBEMR). This is based on a set of basic ecological principles and is capable of restoring a much more naturally functional and biodiverse mangrove ecosystem than other, more capital and labour-intensive, methods such as monoculture hand-planting (Lewis, 2009).

MAP saw the opportunity and need to introduce the ecological mangrove restoration methodology to improve the success of mangrove restoration. The challenge was to adopt and introduce ecological mangrove restoration, only described previously in scientific journals, to the socio-economic and cultural situation of mangrove communities, NGOs and governments of developing countries in Asia. In the process, MAP has developed CBEMR, a sustainable model that engages and integrates local communities. This paper describes CBEMR, its preliminary outcomes, and the resulting challenges, opportunities and lessons learned.

2. Materials and methods

2.1 Ecological mangrove restoration (EMR) defined

Ecological restoration has been defined as "the process of repairing damage caused by humans to the diversity and dynamics of indigenous ecosystems" (Jackson *et al*., 2006).

Ecological mangrove restoration (EMR) is a holistic approach to mangrove restoration that also includes a view of the proposed plant and animal community to be restored as part of a larger ecosystem with other ecological communities that also have functions to be protected or restored. EMR was developed by MAP's chief technical advisor, Dr Robin Lewis, a consultant based in Florida with over 30 years of experience in mangrove restoration, mostly in Florida and Latin America. Lewis has used EMR very effectively to restore both the biodiversity and functionality of mangrove ecosystems (Lewis, 2009).

EMR aims at the restoration of certain ecosystem traits and the replication of natural functions. It has been shown that mangrove forests worldwide can self-repair or successfully undergo secondary succession over periods of 15–30 years if: i) the normal tidal hydrology is not disrupted; and ii) the availability of waterborne seeds or seedlings (propagules) of mangroves from adjacent stands is not disrupted or blocked (Lewis, 1982; Cintrón-Molero, 1992).

Because mangrove forests may recover without active restoration efforts, it has been recommended that restoration planning should first look at the potential existence of stresses such as blocked tidal inundation that might prevent secondary succession from occurring, and plan on removing those stresses before attempting restoration (Hamilton and Snedaker, 1984; Cintrón-Molero, 1992). The second step is to determine by observation over six months to one year if natural seedling recruitment is occurring once the stress has been removed. There should be evidence of volunteer seedlings appearing on site within one year of the hydrological adjustments. If not, a reassessment of the hydrology and identification of other potential problems should be undertaken. If seed limitation is a factor, then buckets of collected seeds can be broadcast on an incoming spring tide. Only if natural recovery is not occurring should the third step of assisting natural recovery through planting be considered.

Unfortunately, many mangrove restoration projects move immediately into planting of mangroves without determining why natural recovery has not occurred. There may even have been a large capital investment in growing mangrove seedlings in a nursery before the stress factors are assessed; this often results in major failures of planting efforts. Instead, MAP supports the restoration of a naturally functioning habitat through the six-step EMR approach to restoration and not "plantation forests" with disregard for natural species composition. (Lewis, 2005).

2.2 MAP introduces CBEMR

MAP is partnering with local communities and other NGOs to restore degraded and destroyed mangrove areas. MAP's CBEMR programme works to restore natural hydrology or water flows, thus greatly increasing the overall success rate for regenerating large areas of degraded mangrove forests. This method has proven extremely successful in past endeavours by Robin Lewis – for example in West Lake, Florida – and is being implemented by MAP in small-scale projects in El Salvador, Indonesia and Thailand. The method is also cost-effective and produces a more biodiverse restoration with excellent long-term results (Stevenson *et al.*, 1999). These small-scale projects are serving as working models, intended to inform and inspire larger-scale, more intensive applications of EMR where it is needed. If applied more broadly, the CBEMR method could restore ecologically biodiverse and healthy mangrove ecosystems in an effective, long-term and economical manner (Lewis, 2005). MAP is especially interested in restoring some of Asia's estimated 250,000 ha (R. Lewis, pers. comm.) of abandoned shrimp farms in former coastal wetland areas.

2.3 The six steps of EMR

Before beginning a mangrove restoration project, preliminary research is needed. In selecting a specific site for mangrove restoration, the things to refer to include tide tables and measured tidal levels. Also, one should look for available literature about the mangroves of the area describing their distribution and tidal requirements. Are there any recent or even historical relevant aerial photos? Have there been prior efforts to restore mangroves in the area, and if so, what were their results in terms of successes and failures? What were the lessons from these prior efforts? (Lewis *et al*., 2006; Brown, 2008).

2.3.1 Step 1: Understand the local mangrove ecology

It is important to understand both the individual species ecology and the community ecology of the naturally occurring mangrove species at the site, paying particular attention to patterns of reproduction, propagule distribution and successful seedling establishment. For example, mangroves often occur in zones – groupings of the same species of mangrove within a whole mangrove forest. Zoning occurs because different species of mangrove need particular conditions to grow. Some species require more water than others; some may be more tolerant of salinity.

2.3.2 Step 2: Understand the normal hydrology

One must understand the normal hydrology that controls the distribution and successful establishment and growth of targeted mangrove species. Each mangrove species thrives at a different substratum level, which partly dictates the amount of exposure the mangrove will have to tidal waters. Thus, it is important to study tide charts for the area and take measurements in healthy mangroves relating to substratum height and depth for the various species of mangroves occurring at each depth.

It is also vital to imitate the slope and topography (relative height) of the substratum from a nearby healthy mangrove forest. And, it is essential to note the critical periods of inundation and dryness that govern the health of the forest.

2.3.3 Step 3: Assess the modifications of the mangrove environment

One must then assess the modifications of the mangrove environment that have occurred and that may prevent natural secondary succession. Any plans for mangrove restoration must first consider the potential existence of stresses, for example blocked tidal inundation, that might impede secondary succession, and plan on removing those before attempting restoration. It is important to understand the past use of the area. First and foremost, was the area intended for restoration actually a mangrove area in the past? Often, mangroves are planted in areas such as mudflats, salt marshes or lagoons on the assumption that the area would be better off, or more productive, as a mangrove forest. This is ecosystem conversion, not restoration. Mudflats have their own ecological purposes, such as serving as feeding grounds for migratory shorebirds.

It is best to work with the local community to help determine how the mangrove area has changed over time, and why, and what factors might be affecting mangrove regeneration. Besides blockage of tidal exchange, these may include:

- Lack of fresh water.
- Hypersaline or acid sulphate soils (usually found after intensive shrimp farming).
- Overgrazing by livestock such as goats, cattle and camels.
- Shoreline abrasion and lowered substratum levels.
- Human or boat traffic at landing sites.
- Over-exploitation of trees for fuelwood.

2.3.4 Step 4: Selecting a restoration site

Select appropriate restoration areas that are both likely to succeed in rehabilitating a forest ecosystem and cost effective through steps 1–3, above. Consider the available labour to carry out the project, including adequate monitoring of progress towards meeting the quantitative goals established beforehand. This step includes resolving land ownership and use issues necessary for ensuring long-term access to and conservation of the site.

Survey techniques used to select a suitable site employ topographic survey instruments, such as an auto-level, that help determine relative substratum elevation. An elevation survey can also be undertaken using simple tools such as a water level, rubber tubing and metre sticks.

One basic theory behind hydrological rehabilitation is to recreate a natural slope and substratum height which will support normal tidal flow, and the natural re-establishment and growth of mangrove seedlings. Dyke walls of disused shrimp ponds need to be levelled, and ditches need to be filled. If one cannot level dyke walls entirely, opening strategic breaches may be enough to support the exchange of tidal waters and should lead to further degradation of the walls over time. If heavy equipment cannot be obtained, one may need to recruit community volunteers or employ community labour to get the job done.

2.3.5 Step 5: Design the restoration programme

A restoration programme is developed for the sites selected in step 4 to restore the appropriate hydrology, including the original tidal streams, and to use natural volunteer mangrove recruitment for natural plant establishment. Tidal streams run through mangrove areas from the terrestrial edge to the sea. They are narrower upstream, widening as they meander to the coast. They are fed from the landward edge by ground water, springs, surface runoff and streams. Because they are connected to the sea, tidal streams facilitate the exchange of tidal waters in and out of the mangrove area, and are the routes for natural seedlings to enter and colonize an area. When tidal streams are disturbed, seedling recruitment may be blocked and the affected site's existing mangroves may dry out, and die over time.

Determine by observation if natural seedling recruitment is occurring once the stress has been removed; this means monitoring. Are seedlings coming into the area and naturally taking root? If so, what is the density of the natural recruits and what is the health and vitality of the seedlings?

In the case of rehabilitating disused shrimp ponds, it may be enough to create “strategic breaches” in the dyke walls. In this case, less rather than more cuts are better. This is because the “tidal prism” (the amount of water that can enter an opened pond between high and low tide) needs to be channelled to the maximum extent possible through a few key openings that are wider downstream than upstream. This mimics the normal operation of tidal streams in mangroves (see above). Fewer openings produce greater velocities as the flow is restricted, which in turn produces scouring, which keeps the human-made openings open and reduces the chances of siltation and closure. Creating too many openings will distribute the tidal prism over many points, reducing the velocity and thereby inducing less scour and more siltation.

Even if mangroves survive for several years in a rehabilitated area, they may remain stunted, or even die out, unless hydrological conditions are truly supportive of mangrove growth. If seedlings have established in the rehabilitation area, but at lower densities than hoped for, planting may be considered. But planting costs can double the overall cost of a project and may limit the biodiversity of the site because of competition from planted mangroves. If no seedlings have established in the area, even though a natural seed source is nearby, it will be necessary to re-evaluate the effectiveness of the hydrological rehabilitation. Perhaps there are still blockages to normal tidal flow or there is a disturbance in the seed source.

2.3.6 Step 6: Planting

Plant propagules or seedlings *only* after determining through steps 1–5, above, that natural recruitment will not provide the quantity of successfully established seedlings, rate of stabilization, or rate of growth, required for project success. Several good guides to effective mangrove planting are available on the Internet. It is a good idea to do some small test plantings to ensure that conditions are suitable for the desired species rather than mass plantings. Mangrove species can be tested in small dense plots at the correct strata height. Any natural occurring mangrove trees on site or volunteers will be an excellent reference for planting. As mangrove do not grow naturally in straight rows, these should be avoided.

There are four sources of seeds/propagules for mangrove planting:

1. Raising seedlings in a nursery from local seed sources.
2. Direct planting of propagules.
3. Transplanting of wild seedlings.
4. Broadcasting fruits or propagules directly onto the water surface at incoming spring tides.

2.4 Community engagement

A critical element that MAP has added to Robin Lewis’s EMR model is community engagement and empowerment, recognizing that sustainable mangrove restoration requires the full participation of local affected people. For local populations, mangroves provide food, medicines, tannins, fuelwood, charcoal and construction materials. For millions of indigenous and local coastal residents, mangrove forests are vital for their everyday needs. Pisit Charnsnoh of Thailand’s Yadfon Foundation has called mangroves the “supermarkets of the coastal poor,” offering dependable, basic livelihood support that sustains their traditional cultures (Warne, 2007). MAP builds on these traditional community ties to the mangroves.

To involve the communities from the start of the project, it is important to learn about the past and present condition of the proposed mangrove site and the relationship and use of the mangroves by the local community. Also, any past efforts at mangrove restoration should be evaluated. In the first place, the community will need to develop a management plan to deal with the causes of mangrove destruction. This could be due to overexploitation for fuelwood, illegal cutting, development encroachment, grazing by livestock, or other conflicting uses. Often it will take time to develop and implement a workable solution. At other times a viable strategy may not be found, impeding any mangrove restoration plans.

The CBEMR approach is introduced to local community members interested in acting as future monitors and resource managers at the sites selected. This presentation is meant to encourage the local community to get involved, which is one of the main points of interest to help build the capacity of local communities to better manage and conserve their natural resource base (Lewis *et al*., 2006).

Once the community is engaged, the local conservation group will develop a community management plan, which is critical to the process as the primary force preventing the repeated degradation of the restoration site. Strong community stewardship ensures a central stakeholder role in future mangrove management decision-making. A programme for monitoring and evaluation of restored sites by local community members is built into the CBEMR process with a 3–5 year plan to ensure success of the endeavour.

Attaining community-based management or co-management status will greatly aid the long-term protection of the restoration site. Once the management plan is successfully implemented, mangrove restoration can move forward in parallel (Lewis *et al*., 2006).

MAP offers three-day intensive CBEMR training workshops that instill the basic principles of EMR in participants and also incorporate hands-on fieldwork at actual restoration sites. Each workshop is geared towards the local conditions of the host country and region, involving local mangrove ecologists, local officials, local communities and their associated CBOs and NGOs in the process. Once the community is trained, MAP offers guidance and technical support to ensure the success of restoration.

2.5 The overall project objectives of CBEMR

The CBEMR objectives are:

- Restoration and sustainable management of mangrove forests by the target communities following the EMR approach at selected pilot sites.
- Protection and conservation of mangroves as carbon sinks and biodiversity hotspots through community participation and development of long-term plans for their sustainable and profitable use.
- Protection of the shoreline from wave action and erosion (precaution for cyclone and tsunami-endangered areas) and improvement of water quality in the mangrove wetlands.
- Development of effective community networks and the initiation of strategic community-based projects for the sustainable use and conservation of mangrove forests.

- Identify and develop sustainable alternative livelihoods to improve community welfare and reduce the exploitation of mangroves and other natural resources.
- Provide an incentive for local community member participation in the EMR process via a fair wage paid to those employed on both the restoration itself and the ongoing monitoring and management follow-up activities.
- Dissemination of knowledge, both scientific and indigenous, on EMR methods.

3. Results

Working examples of successful EMR are found in Florida at West Lake (work done by Robin Lewis over a decade ago), as well as in Indonesia at Tiwoho in North Sulawesi, where MAP Indonesia and the local NGO, KELOLA, restored an area of abandoned shrimp ponds (Lewis, 2005; Earthrise, 2011).

4. Discussion

4.1 Advantages of CBEMR over other current methods

MAP's CBEMR programme involves a more methodological ecosystem approach than the usual monoculture restoration efforts, incorporating natural mangrove dispersal and ecological recovery. The key is in the restoration of the hydrology of the area being considered for restoration, and then working with nature itself to help facilitate regeneration of the area's naturally occurring mangrove species. This is followed by adequate monitoring and evaluation at each site to assess progress, take corrective action, and better ensure success and replicability (Lewis *et al*., 2006). The CBEMR concept is based on a set of basic ecological principles and is capable of restoring a much more naturally functional and biodiverse mangrove ecosystem than other more capital and labour-intensive methods such as hand-planting. It is also based on principles of community engagement and empowerment, recognizing that sustainable restoration requires the active participation of the affected local communities.

4.2 Challenges, obstacles and opportunities ahead

4.2.1 Comparative analysis of current methodologies is needed

We need to define more clearly what constitutes "restoration" and what should be labelled a "success." Too often, just planting a certain number of *Rhizophora* propagules represents success, when in reality these mass hand-plantings may be dismal failures with quite poor seedling survivability, resulting in the forced conversion of one important wetland ecosystem (the mudflat or salt flat) into another (the mangrove). This ecosystem conversion is often unsuccessful in establishing a viable mangrove system, while simultaneously ruining the original functionally important system. These mass single-species plantings most often result in monoculture plantations at best or large-scale failures at worst – a waste of time and effort.

Frenetic one-day competitions have even been introduced to the "restoration" scene, when mass plantings of over a million mangrove seedlings have set and reset superficial world records in countries such as Pakistan and Senegal. However, what do such records mean if these planted seedlings do not survive, or if once-viable coastal ecosystems are irreversibly altered by converting from one system to another? Who is doing the follow-up and noting the particulars of these "restoration" attempts? And there clearly needs to be a follow-up on the many attempts at restoration to ensure restoration is actually occurring, and these need be done over a period of at least five years or more to confirm the results. How can we learn the lessons that need to be learned, and avoid the mistakes that need to be corrected, without such follow-up verification and comparison with an agreed upon set of "best practices" for mangrove restoration? Otherwise, where is the science in the methodology? Without proof of authenticity, will our restoration attempts become mere hyperbole?

Further analysis is needed to determine more accurate values of selected benefits and services, and the intrinsic worth of such factors as biodiversity and resilience to restore an ecosystem that benefits both nature and livelihoods.

4.2.2 Need for more robust monitoring and evaluation of CBEMR

To ensure success, long-term monitoring and evaluation must be built into any restoration framework. Too often, little follow-up in monitoring and evaluation occurs, and thus little is gained in terms of lessons that could be learned from past mistakes or successes. Success is often judged by percentage of surviving seedlings at 3–6 months, and sometimes one or two years after the attempt at restoration, but we need at least five years to better understand the nuances that determine success or failure at each unique restoration site. And we need to define more clearly the outcome indicators used for determining that success. Are we looking for restored biodiversity, forest density and height, or other factors?

According to Robin Lewis, determination of success is likely time-specific. He suggests preparing a "time zero," or baseline, report by setting up test quadrants and comparing them statistically with similarly sized quadrants in the control areas (R. Lewis, pers. comm.). According to Dr Norman Duke of Mangrove Watch, for tidal wetlands, "…there has been no suitable assessment methodology that managers can readily use. So these valuable wetland ecosystems have largely been neglected by managing agencies and monitoring programs - a factor that arguably may have contributed to some declines" (Mangrove Watch, 2011; Baird and Quarto, 1994). Mangrove Watch is helping to implement effective monitoring and assessment programmes in Australia and is starting up in Thailand by providing training support.

4.2.3 Funding-driven restrictions

Donors have also made it hard for MAP to pursue effective CBEMR programmes by providing only one or two years of funding, whereas at least five years of funding is required to carry out CBEMR effectively because of the monitoring and evaluation needs. Donors seeking to support only short-term results are unwittingly engendering long-term failures. Funding for monitoring five years after the end of an EMR project is required.

4.2.4 Lack of landowner permission

One frequent obstacle centres on legal access or permission to sites needing to be restored. Time and again, MAP has gained permission from a landowner to restore a particular site, only to be told afterwards that the agreement to proceed is no longer valid because the landowner has had a change of mind, or some other legal or titling issue has surfaced. This forces MAP to look elsewhere for a suitable site, resulting in lost time and effort.

4.2.5 Siting challenges caused by climate change

A new siting challenge is caused by a phenomenon of climate change: rising sea levels.

Mangroves will need open lands behind them to colonize when rising sea levels force them inland, otherwise they will be permanently submerged and drowned. Therefore, forethought must go into planning to establish and preserve a buffer behind the mangroves where mangroves can "migrate" inland as the sea level rises to re-establish themselves above the rising low tide mark. This will prove a challenge because of the extensive development happening behind mangroves, including roads, shrimp farms, industrial complexes, hotels and urban centres. These will potentially hinder or block the necessary access areas which mangroves can colonize as sea levels rise. The infrastructure and dykes, berms and roads can also block important freshwater inputs into the mangroves, causing stress.

4.2.6 Ecosystem conversion encouraged by carbon offset plantings

As a result of the ratification of the Kyoto Protocol in 1997, carbon offset plantings are being implemented worldwide under the Clean Development Mechanism. This mechanism allows developed countries to meet a part of their greenhouse gas reduction obligations through carbon offset projects in developing countries (Jackson *et al*., 1995). To date, however, only afforestation and reforestation projects have been accepted under the Kyoto Protocol. This has led to criticism that the Protocol encourages plantation-style forests consisting of monocultures with little resemblance to naturally occurring forests, and so does not truly address the issue of continued deforestation and degradation. In addition, it may encourage the planting of mangroves in areas where they do not naturally occur to the detriment of other coastal habitats (such as mudflats).

4.2.7 Issues of employment

Traditional monoculture planting often involves long-term employment in nurseries and planting sites, whereas CBEMR, especially if it uses heavy equipment, creates little local employment. So finding ways to employ local people in the protection and maintenance of the restoration site is a challenge. Most projects are designed to be relatively short (1–3 years) so finding long-term financial support is also a challenge to enable long-term employment.

CBEMR can try to involve paid local labour in the physical hydrological work, depending on the availability of labour and the time available. Yet nearly all abandoned shrimp ponds have been constructed using heavy equipment, and sometimes it is unfeasible to correct the hydrology by slow and difficult hand-digging.

4.2.8 Issues of alternative livelihoods

Alternative livelihood introduction is costly but important for community buy-in and project sustainability. Creating livelihoods increases the inputs, resources and costs of the project compared with just the technical aspects of EMR (such as restoring hydrology). CBEMR is about community development, as well as mangrove restoration. Mangrove restoration needs to be integrated into the community rather than just seen as a separate activity. This can be expensive and time-consuming, but it ensures greater long-term success.

4.2.9 Land tenure and securing suitable restoration sites

Finding sites to restore is currently the greatest barrier and challenge to implementing CBEMR in Southeast Asia. In Thailand, nearly all abandoned shrimp ponds under the control of the Department of Marine and Coastal Resources have already been planted out by the department. Other abandoned ponds which were formerly mangroves are either in private hands with land deeds or illegally occupied where the land is under dispute. If land is privately owned, then purchasing the land would be required, which is expensive. In two previous projects in Thailand and another now underway, the greatest time and effort has been spent in trying to locate and secure suitable sites. The first project in Krabi, Thailand, had to change site three times and nearly one year passed before physical CBEMR work could begin. The Lang Da village site also came with the restriction that the shrimp pond wall could not be breached, so MAP had to rely only on the natural erosion of the sluice gate for tidal exchange. The wealthy landowner, whose main concern was operating fishing trawlers, allowed the use of the site for CBEMR research, but MAP could not reach a long-term agreement with him.

Another site in Thailand was on community mangrove land used illegally to construct shrimp ponds. At first the illegal occupier agreed to return three ponds to the community for EMR, but then changed his mind. It was only after a long effort involving many meetings, a community petition, and discussion with government offices, that one pond was made available to the community; this decision took six months of a one-year project.

The same problem of securing CBEMR sites is also occurring in India, Cambodia, Indonesia and the Philippines. In the Philippines, abandoned fish and shrimp pond lands are held under leases. And, in Cambodia, the Participatory Management of Coastal Resources of Cambodia project under the Ministry of the Environment could not locate any available sites in Koh Kong Province despite an eight-month search.

4.2.10 Government permission and permits

In Thailand it is illegal to bring heavy equipment into the mangrove zone without a permit. This can be a lengthy and expensive process, raising another barrier to CBEMR. MAP's first attempt to get such a permit required letters and approvals from various government departments requiring a great deal of time to secure. After about three months (six months into the one-year project), MAP gave-up and resorted to human labour. This example fortunately turned into a win-win situation as the project funds stayed in the community. Yet this could be a major barrier if heavy equipment is required to restore the hydrology. In other locations, it may prove a minor obstacle if good relations can be developed beforehand with the right people and responsible offices.

4.3 Going forward

MAP is currently engaged in a CBEMR project on the Andaman Sea coast of Thailand, and is actively seeking both project partners and donors for new CBEMR projects in such locations as the Gulf of Fonseca (El Salvador, Honduras, and Nicaragua); the Choco Coast of Colombia; the Sundarbans of India; Lake Maracaibo in Venezuela; and additional sites in Thailand. The sites will be strategically selected to:

1. Further improve the CBEMR methodology.
2. Systematize the resolution of the challenges presented above.
3. Demonstrate CBEMR feasibility on a larger scale.
4. Explore integration of CBEMR into national and international initiatives such as national coastal ecosystem plans, carbon offsets, payments for ecosystem services, and REDD+.

To disseminate knowledge on CBEMR and allow its wider application in different countries, MAP is organising a series of CBEMR workshops to train stakeholders from different backgrounds in CBEMR methods. The plan is to establish regional core groups of trained restoration practitioners. These core groups will share information and experiences on how best to implement EMR projects taking local conditions into consideration.

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Annex Links to Videos on EMR

Ban Tale Nok EMR Demonstration Project: http://www.youtube.com/watch?v=qKL3KJE3Xsw.
Krabi Mangrove Training: http://www.youtube.com/watch?v=NOA-AI0RLKk.
EMR Animation Indonesia: http://www.youtube.com/watch?v=R5fGyx9sjDg&feature=plcp.

Annexes

Annex 1 Colloquium programme

30 AUGUST 2012 (Day 1)		
08 00 – 08 30	**Registration**	
08 30 – 10 00	**OPENING CEREMONY**	
	Welcome address	Ms Meenakshi Datta Ghosh Country Representative, IUCN India
	Mangroves for the Future – Introduction, and a brief on the Regional Colloquium	Dr Steen Christensen Mangroves for the Future (MFF) Coordinator
	Inaugural Address	Dr J. R. Bhatt Director, Ministry of Environment and Forests Government of India
	Vote of Thanks	Dr N. M. Ishwar Mangroves for the Future (MFF) India Coordinator
10 00 – 10 30	Coffee/Tea break	
10 30 – 12 30	**SESSION I:** **Economic and Environmental Values of Mangroves and the Need for their Restoration/Rehabilitation: Status and Challenges** ► *Valuation, carbon sequestration and restoration of mangrove ecosystems in India (**J. R. Bhatt** and **K. Kathiresan**)* ► *Indonesian mangroves: critical challenges and strategies for their sustainable management after the 2004 Indian Ocean tsunami (**Sukristijono Sukardjo**)* ► *An overview of mangrove restoration efforts in Pakistan (**Shamsul Haq Memon**)* ► *A collaborative approach between tourism and coastal communities: a present-day need and opportunity for mangrove management and conservation in Sri Lanka (**P. Upali Ratnayake**)*	
12 30 – 14 00	Lunch break	
14 00 – 15 30	**SESSION I** (continued) ► *Mangrove restoration efforts in Sri Lanka (**T. S. Ranasinghe**)* ► *Status of mangrove plantations in the living delta: an overview of the coastal afforestation experience of Bangladesh (**Ishtiaq Uddin Ahmad**)* ► *Mangrove conservation and restoration in the Indian Sundarbans (**P. Vyas** and **K. Sengupta**)*	
15 30 – 16 00	Coffee/Tea break	
16 00 – 18 00	**SESSION II:** **Lessons Learned from Mangrove Rehabilitation Projects** ► *Lesson learned from the programme* Let's Plant Mangroves*: a case study from villages in Banten and Central Java provinces, Indonesia (**W. Mahardi**)* ► *Restoration of deteriorated wetlands in Kumana (Yala East) National Park, Sri Lanka: a pilot project on mangrove restoration (**P. Suranga Ratnayake**, **Y. Mapatuna** and **P. N. Dayawansa**)* ► *Afforestation of coastal mudflats in Gujarat, India (**C. N. Pandey** and **R. Pandey**)* ► *Genesis and present status of restoration practices in saline blanks in India (**V. Selvam**, **R. Ramasubramanian** and **K. K. Ravichandran**)* ► *Mangrove restoration and planting in micro-tidal barrier-built estuaries and lagoons in Asia – ideology versus sustainable ecosystem science? (**Jayampathi I. Samarakoon**)*	
19 30	Colloquium Dinner	

31 AUGUST 2012 (Day 2)

08 30 – 10 30 **SESSION III:**
Guidelines for Good Practices in Mangrove Restoration/Rehabilitation

- *Mangrove rehabilitation through community involvement: establishing mangrove conservation awareness and education (**Sylvanna Antat**, **Lyndy Bastienne** and **Terence Vel**)*
- *Local knowledge management for mangrove management (**Tanirat Tanawat** and **P. Boonplod**)*
- *Active versus passive restoration of mangroves: developing models for sustainable rejuvenation of mangrove ecosystems used for shrimp farming in North-Western Province of Sri Lanka (**Sevvandi Jayakody**, **J. M. P. K. Jayasinghe** and **Anushka H. Wijesundara**)*
- *Restoration and return of mangroves and fisheries in abandoned aquaculture farms (**V. Selvam**, **A. Sivakumar** and **R. Ramasubramanian**)*

10 30 – 11 00 Coffee/Tea break

11 00 – 12 30 **SESSION III** (continued):

- *Clam seed production and benefit-sharing in Xuan Thuy National Park, Viet Nam (**Nguyen Viet Cach**)*
- *Mangrove planting, community participation and integrated management in Soc Trang Province, Viet Nam (**Klaus Schmitt**)*
- *Monitoring framework for replanted mangrove areas – sharing the experience from Pakistan (**Ghulam Qadir Shah**)*
- *Towards Coastal Health Archive and Monitoring National Programmes (CHAMPS) for assessing change, and identifying drivers of change, in tidal wetlands and coastal margins (**Norman Duke**)*

12 30 – 14 00 Lunch break

14 00 – 16 00 **SESSION IV:**
Mangroves, Climate Change and DRR: The Way Forward and a Call for Action

- *Navigating mangrove resilience through the ecosystem-based adaptation approach: lessons from Bangladesh (**Paramesh Nandy** and **Ronju Ahammad**)*
- *Disaster risk reduction through mangrove conservation and rehabilitation: a case study in the Ayeyarwady Delta of Myanmar (**Maung Maung Than**)*
- *Adapting to natural disasters and contributing to climate change mitigation: mangrove community forestry in Viet Nam (**Sen Le Thi Hoa**, **R. Suzuki** and **M. F. Thomsen**)*
- *Ecological mangrove restoration: re-establishing a more biodiverse and resilient coastal ecosystem with community participation (**Alfredo Quarto**)*

16 00 – 16 30 Coffee/Tea break

16 30 – 17 30 **Presentation of the Draft Call for Action Statement and Closing**

Impressions on the Colloquium	Ms Meenakshi Datta Ghosh Country Representative, IUCN India
Key Messages from the Regional Colloquium – Call for Action	Professor Donald Macintosh Senior Advisor, MFF
CBD COP-11 – Expectations	Dr Balakrishna Pisupati, Chairman, National Biodiversity Authority, India
Regional Colloquium and the links to CBD COP-11	Mr Hem Pande, Additional Secretary Ministry of Environment and Forests, India
Vote of Thanks	Dr Steen Christensen, MFF Coordinator Mr Shamsul Haq Memon, Pakistan

Distribution of certificates – Scientific presentation course

1–2 SEPTEMBER 2012 (Field Visit)

1 September 2012

- Visit to Auroville and its Botanical Garden
- ICT-based Village Resource Centre of M. S. Swaminathan Research Foundation (MSSRF), Pondicherry
- Overnight in Chidambaram

2 September 2012

- Visit to mangroves in Pichavaram
- MSSRF-initiated restoration of abandoned shrimp farms
- Return to Chennai

Participants in the MFF Regional Colloquium. Photo © Ranjith Mahindapala.

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Mangroves for the Future
INVESTING IN COASTAL ECOSYSTEMS

Mangroves for the Future (MFF) is a partnership-based initiative promoting investments in coastal ecosystems that support sustainable development. MFF provides a collaborative platform for the many countries, sectors and agencies tackling the challenges to coastal ecosystem conservation and livelihood sustainability, and is helping them to work towards a common goal.

MFF builds on a history of coastal management efforts before and after the 2004 Indian Ocean tsunami, especially the call to sustain the momentum and partnerships generated by the immediate post-tsunami response. After focusing initially on the countries worst-affected by the tsunami – India, Indonesia, Maldives, Seychelles, Sri Lanka and Thailand – MFF has now expanded to include Pakistan and Viet Nam. MFF will also continue to reach out to other countries in the region facing similar challenges, with the overall aim of promoting an integrated, ocean-wide approach to coastal area management.

MFF seeks to achieve demonstrable results through regional cooperation, national programme support, private sector engagement and community action. This is being realized through concerted actions and projects to generate and share knowledge more effectively, empower institutions and communities, and enhance the governance of coastal ecosystems.

Although MFF has chosen mangroves as its flagship ecosystem, the initiative embraces all coastal ecosystems, including coral reefs, estuaries, lagoons, wetlands, beaches and seagrass beds. Its management strategy is based on specific national and regional needs for long-term sustainable management of coastal ecosystems. These priorities, as well as newly emerging issues, are reviewed regularly by the MFF Regional Steering Committee to ensure that MFF continues to be a highly relevant and responsive initiative.

Learn more at: www.mangrovesforthefuture.org