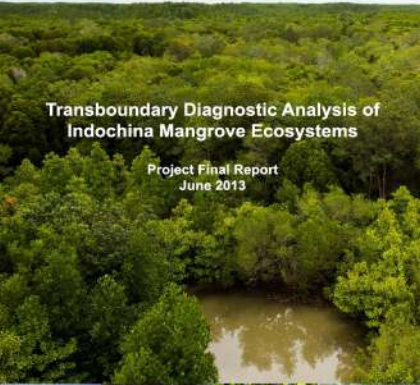
SIEPF

SIRINDHORN INTERNATIONAL
ENVIRONMENTAL PARK FOUNDATION

Sida

SWEDISH INTERNATIONAL
DEVELOPMENT COOPERATION AGENCY



Transboundary Diagnostic Analysis of Indochina Mangrove Ecosystems

Project Final Report
June 2013

Transboundary Diagnostic Analysis
of
Indochina Mangrove Ecosystems

PROJECT FINAL REPORT

June, 2013

This is the Final Report: Executive Summary and Main Text. The Cover Page, Bibliography and Annexes 1-4 are provided as separate PDF-files.

Executive Summary

Background

The Transboundary Diagnostic Analysis of Indochina Mangrove Ecosystems (TDA-IME) Project was implemented by the Sirindhorn International Environmental Park Foundation (SIEPF) from 01 July 2011 to 31 March, 2013. A macro-level, systematic scientific analysis of mangrove ecosystem integrity was undertaken to gain a better understanding of (a) how to maintain the health of Indochina's remaining mangrove ecosystems; and (b) how to reduce the rate of mangrove forest loss, which until recently has exceeded 1% per annum in Asia.

This project also aimed to enhance regional knowledge about mangrove ecosystems; strengthen national and regional assessments of mangrove forest area and ecological integrity parameters; promote knowledge-based regional cooperation; and serve as a platform for environmental dialogue on matters of regional and global importance relating to coastal ecosystem services and poverty reduction. The impacts of climate change on mangroves, and the potential roles mangrove ecosystems could play in climate change adaptation and mitigation, were given particular attention.

The project was implemented by a manager and secretariat based at SIEPF, with the support of a high-level Scientific and Technical Advisory Committee. The secretariat convened three regional-level workshops in Thailand, involving all six participating countries: Cambodia, Malaysia, Philippines, Singapore, Thailand and Viet Nam, plus Myanmar, to exchange knowledge about mangrove ecosystems in Indochina and discuss the need to adopt a regional approach to halt further loss and degradation of mangroves. A causal chain analysis of the proximate to fundamental causes of mangrove forest conversion and mangrove habitat degradation was developed, based on country status papers and advice from national experts who attended the workshops. Scientific research gaps and knowledge management needs were also analyzed. The experts considered, not only to gaps in scientific knowledge about mangrove ecosystems (especially those relating to mangrove economic values, and the role of mangroves in climate change adaptation and mitigation), but also to the failure of science to influence policy-making on mangroves (science-to-policy gaps). The fourth issue analyzed was the need for stronger regional cooperation and a more integrated management approach to conserve and restore the mangrove ecosystems of Indochina. A consultant team of mangrove experts was brought in during the final three months of the project to help SIEPF to prepare the final report and recommend possible post-project follow up activities.

Main Findings

The Indochina mangrove forests are among the most biologically diverse and extensive in the world. Two-thirds of the approximately 70 species of true mangrove plants occur here, with 11 species classified by IUCN as near threatened to critically endangered. Mangroves in the region have been exploited traditionally for charcoal and other wood products, and in recent decades, also converted on a massive scale for agriculture, aquaculture, as well as for urban and industrial development. Mangrove conversion and degradation not only reduce the direct provisioning services of mangrove ecosystems (timber, fuelwood, non-timber forest products and aquatic resources), but also their important regulating services, including coastal erosion and flood control, and reducing storm (and even tsunami) impacts. In the face of climate change, the region's mangrove ecosystems can play an even more valuable role, in both climate change adaptation and mitigation, but only if the remaining mangrove forests are properly protected and degraded areas rehabilitated.

Although mangrove forests are, due to their intertidal location, highly vulnerable to climate change, especially sea level rise, mangroves are also considered to be resilient at the ecosystem level. They have great interconnectivity because mangrove propagules and many mangrove-associated animal species can disperse widely. Commercially important fish and shrimp, and the mud crab *Scylla* spp. (a key mangrove-fisheries indicator group), utilize mangroves as nursery grounds, but then migrate offshore. Thus, there is not only connectivity between adjacent and transboundary mangrove areas, but also between mangroves and other coastal ecosystems (including coral reefs) and marine fisheries stocks. Trade in these fishery products, and therefore the economic benefits from them, also operate on a transboundary scale.

The threats posed by climate change - which compound major threats to mangroves not attributable to climate change - require a proactive, integrated and coordinated approach across a range of spatial scales. Issues of mangrove ecosystem connectivity, plant and animal dispersal capability, effective population size and genetic diversity need to be considered at scales greater than that of individual mangrove forest habitats; that is on transboundary and regional levels.

The causal chain analysis confirmed the already widely-held view that human population growth, poverty and profit-driven development priorities are the main root causes of mangrove forest conversion, driven by global market demand (e.g. for farmed shrimp). Mangrove habitat degradation similarly has population- and poverty-based root causes, coupled with the failure of conservation measures (even when enacted) to stop degradation activities. The impact of these root causes is compounded by poor public awareness of the indirect services provided by mangroves, and therefore of their true value to society.

In relation to scientific knowledge about mangroves much is already known, but scientists are not communicating effectively with policy-makers on the need to conserve mangroves and manage them sustainably following ecosystem-based principles. A science-to-policy communications infrastructure or "bridge" is needed for this situation to change.

The main areas where new scientific research is still required were identified as:

- Research to better predict the likely responses of mangroves to climate change.
- Studies to document and quantify the impacts of climate change on mangroves, and the potential roles of mangroves in relation to climate change adaptation and mitigation, as part of an ecosystem-based approach to coastal management.
- Valuation of all the goods and services provided by mangrove ecosystems.

Based on the causal chain analysis, an objective and four themes with ecological quality objectives (EQO) and targets for a future Strategic Action Plan were identified, as summarized below:

Proposed Objective:

Mangrove ecosystems in Indochina are returned to full ecological health and further net loss and degradation of mangrove forests in the region are halted, and where possible reversed by restoration programs.

Theme 1: Mangrove Forest Conversion

EcoQO: *All existing healthy mangrove forest ecosystems are protected and conservation legislation is fully enforced*

Targets:

- Legal, policy instruments and governance mechanisms are strengthened to achieve no further net loss of healthy mangroves.
- The area of mangroves within designated protected areas is increased significantly, with a priority to include transboundary sites.
- National targets for mangrove rehabilitation by area and species composition are proposed.
- Indicators of forest quality/ecological integrity are included in ecosystem monitoring programs.
- The potential of mangrove ecosystems for climate change adaptation and mitigation are fully realized.

Theme 2: Mangrove Habitat Degradation

EcoQO: *Degraded mangroves are restored and mangrove-associated aquatic resources are managed sustainably*

Targets:

- National targets for mangrove restoration by area and species composition are proposed, with priority given to transboundary sites selected by the countries.
- Countries develop and share examples of sustainable mangrove management mechanisms.
- Countries collaborate on joint management systems for mangrove-associated transboundary aquatic and fisheries/aquaculture species.

Theme 3: Research and Knowledge Management Needs

EcoQO: *Scientific knowledge on mangroves is strengthened and applied more effectively to improve the success of mangrove restoration/rehabilitation, protect endangered species, and better understand the impacts of climate change on mangrove ecosystems.*

Targets:

- Agree on and share best practices in mangrove restoration/rehabilitation at regional level, including demonstration sites.
- Fill key gaps in scientific knowledge on mangrove ecosystems through new research (see list of research topics in causal chain analysis).
- Establish a monitoring system regionally to study climate change impacts on mangrove ecosystems.

Theme 4: Regional Cooperation and Integrated Management Mechanisms for Sustainable Use of Mangrove Ecosystems

EcoQO: *Regional actions and governance mechanisms for mangrove ecosystems are implemented effectively*

Targets:

- Harmonize national legislation and strengthen national to regional policies to halt further mangrove losses, with the area of mangroves under formal protection to be increased regionally by 30% over five years.
- Establish an interdisciplinary regional Training and Capacity Development program capable of training 50 people per year.
- Convene regional meetings to: a) develop a regional Strategic Action Plan based on this report; b) formulate a regional Code of Conduct for Mangrove Ecosystems; c) develop a National to Regional Coordination mechanism for mangroves (such as an integrated committee of policy-makers and scientists).

For the foreseeable future, the coastal zones bordering the Indochina region will come under ever increasing pressure to both absorb the impact of more people as the human population grows, and to support the expansion and diversification of national economies. Transboundary cooperation on mangrove management, including the sharing of good practices, is fundamental to achieving sustainable mangrove ecosystem management, and as a means of coping with the additional challenges posed by climate change. At the implementation level, the countries of Indochina would benefit most by adopting sound mangrove ecosystem management practices into the national policy level, then cooperating together to apply them in practice on a transboundary scale.

This report outlines good practices in relation to mangrove co-management principles, including case studies from Cambodia and Viet Nam. Good practices for achieving poverty reduction through livelihood enhancement, and for effective communication among different stakeholder groups, are also reviewed. The reasons for past management failures, including poor results from mangrove rehabilitation programs, are also described.

The project's main conclusion is that an integrated approach to mangrove ecosystem management is vital, following the ecosystem-based approach. This approach is popular in principle with most governments, but is difficult to achieve in practice. National legal frameworks still relate to the environment and forests in general, rather than to mangrove specifically. Considerable capacity development and information-sharing will be required to make coastal area planning and management more integrated and ecosystem-based. This will also require significant improvements in regional and institutional coordination and cooperation.

This report contains a comprehensive set of general conclusions and recommendations on how such improvements could be achieved.

List of Abbreviations and Acronyms

APFIC/FAO	Asia-Pacific Fishery Commission/FAO
BOBLME	Bay of Bengal Large Marine Ecosystem Project
CBO	Community-Based Organization
cenTER Aarhus	Center for Tropical Ecosystems Research, Aarhus University
CPUE	Catch Per Unit Effort
DFID	Department for International Development
DMCR	Department of Marine and Coastal Resources, Thailand
EcoQO	Ecosystem Quality Objectives
FAO	Food and Agricultural Organization of the United Nations
FAO ROAP	FAO Regional Office for Asia and the Pacific
GEF	Global Environment Facility
GIS	Geographical Information System
ICM	Integrated Coastal Management
INGO	International Non-governmental Organization
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for the Conservation of Nature
LIDAR	Light Detection and Ranging
LME	Large Marine Ecosystem
MFF	Mangroves for the Future initiative
NATMANCOM	National Mangrove Committee
NGO	Non-Governmental Organization
NTFP	Non-Timber Forest Product
PA	Protected Area
ppt	Parts per thousand
ppm	Parts per million
PEMSEA	Partnerships for Environmental Management in the Seas of East Asia
RSLR	Relative Sea Level Rise
SAP	Strategic Action Program
SDS-SEA	Sustainable Development Strategy for the Seas of East Asia
SEAFDEC	Southeast Asian Fisheries Development Center
SCS	South China Sea
SIDA	Swedish International Development Cooperation Agency
SIEPF	Sirindhorn International Environmental Park Foundation
SLR	Sea Level Rise
STAC	Scientific and Technical Advisory Committee (of TDA-IME Project)
TDA-IME Project	Transboundary Diagnostic Analysis of the Indochina Mangrove Ecosystems Project
TEV	Total Economic Value
UNDP	United Nations Development Program
UNDP APRC	UNDP Asia-Pacific Regional Center
UNEP ROAP	United Nations Environment Program Regional Office for Asia-Pacific
UNESCO	United Nations Educational, Scientific and Cultural Organization
USD/US$	United States Dollar

Report authored by:

TDA-IME Consultant Team

Dr Donald J. Macintosh, cenTER Aarhus University, Denmark (Team Leader): Mangroves and sustainable development; and Senior Advisor, Mangroves for the Future (MFF) initiative – Don.macintosh@biology.au.dk Donald.MACINTOSH@iucn.org

Dr Elizabeth C. Ashton, Queen's University, Belfast, Northern Ireland: Mangrove community ecology; Code of Conduct for Sustainable Management of Mangrove Ecosystems - e.ashton@qub.ac.uk

Dr Barry Clough, Can Tho University, Viet Nam: Mangrove forest structure and productivity; mangrove ecosystems management - bazzym@gmail.com

Dr Peter Hogarth, University of York, United Kingdom: Mangrove biology and biodiversity; mangroves and climate change - peter.hogarth@york.ac.uk

Dr Bjorn Kjerfve World Maritime University: Physical and hydrological features of mangrove ecosystems - kjerfve@wmu.se

Mr Thomas Nielsen, cenTER Aarhus University, Denmark: Coordination, Information Management and TDA-IME Draft Report production and editing - Thomas.nielsen@biology.au.dk

Dr Klaus Schmitt, GIZ Vietnam, CTA Coastal Zone Management (CZM), Management of Natural Resources in Soc Trang Province: Coastal governance, mangrove rehabilitation and co-management - klaus.schmitt@giz.de

With additional contributions from:

Dr Ke Vongwattana, Ministry of Environment, Cambodia

Dr Swee Yeok Foong, Universiti Sains Malaysia, Malaysia

Dr Ong Jin-Eong, Universiti Sains Malaysia, Malaysia

Dr Gong Wooi Koon, Universiti Sains Malaysia, Malaysia

Dr Miguel D. Fortes, University of the Philippines, Philippines

Dr Jean (John) Yong, Singapore University of Technology and Design, Singapore

Dr Noparat Bamroongrugsa, Prince of Songkhla University, Thailand

Dr Pitiwong Tantichodok, Walailak University, Thailand

Dr Mai Sy Tuan, Hanoi National University of Education, Viet Nam

Dr Sonjai Havanond, Sirindhorn International Environmental Park, Thailand

Dr Apiwan Kamlang-ek, Kasetsart University, Thailand

Prof Gordon S. Maxwell, Caritas Institute of Higher Education, Hong Kong

TDA-IME Scientific and Technical Advisory Committee:

Prof Dr Sanit Aksornkoae (Advisor)	Dr Pornchai Nuchsuwan (Advisor)
Dr Monthip S. Tabucanon (Advisor)	Dr Sonjai Havanond (Chairperson)
Dr Noparat Bamroongrugsa (Member)	Dr Apiwan Kamlang-ek (Member)
Ms Sukanjanawadee Maneeratana (Member)	Dr Ampai Harakunarak (Member)
Dr Anuwat Nateewathana (Project Manager)	Mr Wanunwus Burtsit (Project Manager Assistant)

Ms Areeporn Sittiyanpaiboon, Mr Thanavit Chaiyapa, Mr Chenop Jaengjai (SIEPF Staff)

Cover Photograph: Rehabilitated mangrove forest in Trat, Thailand. (Photo credit: S. Sitaram.)

SECTION 1

Introduction to the Transboundary Diagnostic Analysis Project

An agreement was signed on 01 July, 2011 between the Swedish International Development Cooperation Agency (SIDA) and the Sirindhorn International Environmental Park Foundation (SIEPF) to implement a regional project on Transboundary Diagnostic Analysis of the Indochina Mangrove Ecosystems (TDA-IME Project). The project was designed to enhance regional knowledge, and strengthen national and regional assessments, by applying an analytical tool for identifying and prioritizing key issues impeding the sustainable management of transboundary mangrove ecosystems. The project covered six countries (Cambodia, Malaysia, Philippines, Singapore, Thailand and Viet Nam – Table 1); these countries border two large marine ecosystems (LMEs): the Gulf of Thailand and South China Sea; they also form part of the Indomalaya Ecozone.

The project's focus was to undertake a systematic scientific analysis of mangrove ecosystem integrity, taking a descriptive macro-level approach, with the following objective:

- To gain a better understanding of how to maintain the health of the region's remaining mangrove ecosystems effectively, as well as reducing the rate of loss, which is significantly higher than for other forest types.

In addition, the project aims were to:

- Enhance regional knowledge and strengthen consistent and coherent national and regional assessments;
- Serve as a basis for the future development of a comprehensive and regionally-agreed strategic plan of actions for addressing the priority transboundary mangrove ecosystems problems;
- Promote knowledge-based regional cooperation for environmentally sustainable development in Southeast Asia; and,
- Serve as a platform for environmental dialogue on matters of regional and global importance, relating to ecosystem services and poverty under climate variability.

It was further anticipated that outputs and experiences from the TDA-IME Project will be replicated and scaled-up in the design and implementation of other projects in different bioregions within Asia.

Project Rationale

The total area of mangrove forests worldwide is believed to have declined from 18.8 million hectares in 1980, to only 15.2 million hectares by 2005 (FAO, 2007). The highest rate of loss has occurred in Asia, at 1.01% annually between 2000 and 2005, which is well above the global average for mangrove loss of 0.66% per year (Table 2). On a regional basis, mangroves are most extensive in Asia (42%, or around 6 million hectares), followed by Africa (20%), North and Central America (15%), Oceania (12%) and South America (11%). Moreover, six of the ten countries with the largest extent of mangroves worldwide are found in the Asia-Pacific Region (Giri *et al.*, 2010; see Table 3); India (11th) and Philippines (15th) also rank in the 15 most mangrove-rich countries reported by the same study.

TABLE 1: Key features relating to mangroves, by country.

Country	Land Area (sq. kms)[1]	Coastline (kms)[2]	Population (millions)[1]	GDP Per Capita (USD)[2]	Estimated mangrove area (ha)	Source of the data on mangrove area	Other recent mangrove area estimates (ha)[3]	Main concentrations of mangrove forests and most important Protected Areas with mangroves[4]
Cambodia	181,040	443	15	2,400	78,502	UNEP 2002 (in TDA country report)	72,835	Koh Kong Province (6): Peam Krasop Wildlife Sanctuary, Botum Sakor National Park
Malaysia	328,550 (Peninsular Malaysia only)	2,068 (Peninsular Malaysia only) 4,675 (entire country)	30	16,900	100,808 (Peninsular Malaysia only) 505,386 (entire country)	Malaysia Forest Department (2010) Giri et al. (2010)	708,733	Sarawak and Sabah in East Malaysia; Perak, Johor and Selangor in Peninsular Malaysia (98): Matang Mangrove Forest Reserve, Kuala Selangor Nature Park, Bako National Park
Philippines	298,170	36,289	106	4,300	240,813 256,185	UNEP (2008) Giri et al. (2010)	256,462	Palawan, Quezon, Sulu, Zamboanga Sibugay (92): Palawan Biosphere Reserve
Singapore	714	193	5	60,900	735	TDA country report	463	Western Catchment, Pulau Ubin, Pulau Tekong (2): Sungei Buloh Wetland Reserve
Thailand	513,115	3,219	67	10,000	240,200	DMCR (2012)	248,362	Andaman Sea coast and Nakorn Si Thammarat, Chantaburi, Trat in Gulf of Thailand (22): Ranong Biosphere Reserve
Viet Nam	310,070	3,260	90	3,500	209,741	MARD (2008)	105,000	Mekong Delta and Red River Delta (17): Can Gio Biosphere Reserve, Xuan Thuy National Park and Ramsar Site, Mui Ca Mau National Park

[1] TDA country reports, except Viet Nam (World Bank data). [2] CIA World Fact Book (accessed 22.03.2013).

[3] World Atlas of Mangroves (Spalding et al., 2010), funded by ITTO and implemented by ISME.

[4] Data on the number of Protected Areas with mangroves from Spalding et al. (2010); most important PAs identified from TDA country reports.

It is important to note, however, that even basic information on the mangrove forest area per country is not known precisely. Thus, our understanding of the distribution and extent of mangrove forests in the world remains inadequate. The two most comprehensive and recent estimates for mangroves, by FAO (2007) and Giri et al., (2010), differ by 12% in their calculation of the global total area of mangroves. Estimates of mangrove area and rate of loss in the TDA-IME Project countries from other sources are shown in Table 4. The great variation in the reported mangrove area data for a number of countries represents a fundamental weakness in knowledge that is undermining the potential for sustainable mangrove management.

Notwithstanding the obvious limitations in the accuracy of the various mangrove forest area estimates, the trend in annual loss terms is of great concern, as the data in Table 2 show. (Note: the data have been taken from a single source (FAO, 2007) to reduce the variation evident between studies due to methodological and other differences.)

Mangrove forests play a vital role in the health of tropical coastal ecosystems and human well-being. Mangroves stabilize shorelines; provide nutrients for the marine environment; and support diverse aquatic life linked to the mangroves through their mangrove habitat associations, life histories and coastal food webs. Mangrove forests also consolidate soft sediments deposited along coasts, reduce soil erosion, and mitigate coastal storm and flood impacts. However, human pressure on coastal ecosystems is often extremely high due to economic development, especially for aquaculture, agriculture, urban and industrial infrastructure, and even tourism. As a result, the rate of conversion and fragmentation of mangrove forest habitat to other land uses over recent decades has been alarming.

It is not only the direct provisioning services of mangroves that are being lost, but also their important regulating services. These include coastal erosion and flood control, and mitigation of storm (and even tsunami) impacts. In addition, the vulnerability of mangroves to climate change is a growing concern, while their further loss may have wider negative consequences on marine ecosystems and climate in general (Giri et al., 2010).

It is a paradox that the reasons for mangrove loss are so well known (e.g. Alongi, 2002, Van Lavieren al., 2012), as too are the main drivers, namely population growth and human desire to exploit mangroves for short-term economic gain (e.g. Yoschak, 2009), but yet society seems incapable of conserving mangroves as a common good resource that can provide multiple benefits in the longer term. Over and above their widely reported contribution to human well-being and resilience, mangroves may also be particularly valuable for climate change mitigation and adaptation, at least over the next few decades (Macintosh et al., 2011).

TABLE 2: Status and trends in mangrove area, by country, in Indochina and for all Asia (1980–2005).

COUNTRY	1980	1990	Annual change 1980–1990		2000	Annual change 1990–2000		2005	Annual change 2000–2005	
Area	Area (ha)	Area (ha)	Area (ha)	%	Area (ha)	Area (ha)	%	Area (ha)	Area (ha)	%
Cambodia	**91,200**	**82,400**	**-880**	**-1.0**	**73,600**	**-880**	**-1.1**	**69,200**	**-880**	**-1.2**
China	34,157	28,344	-581	-1.8	22,966	-538	-2.1	22,480	-98	-0.4
Indonesia	4,200,000	3,500,000	-70,000	-1.8	3,150,000	-35,000	-1.0	2,900,000	-50,000	-1.6
Malaysia	**674,000**	**642,000**	**-3,200**	**-0.5**	**589,500**	**-5,250**	**-0.8**	**565,000**	**-4,900**	**-0.8**
Myanmar	555,500	536,100	-1,940	-0.3	516,700	-1,940	-0.4	507,000	-1,940	-0.4
Philippines	**295,000**	**273,000**	**-2,200**	**-0.8**	**250,000**	**-2,300**	**-0.9**	**240,000**	**-2,000**	**-0.8**
Singapore	**1,790**	**500**	**-129**	**-12.0**	**500**		**0.0**	**500**		**0.0**
Thailand	**280,000**	**250,200**	**-2,980**	**-1.1**	**244,100**	**-610**	**-0.2**	**240,000**	**-820**	**-0.3**
Viet Nam	**269,150**	**213,500**	**-5,565**	**-2.3**	**157,500**	**-5,600**	**-3.0**	**157,000**	**-100**	**-0.1**
Total	6,370,097	5,538,044	-14,904		5,084,055	-14,940		4,701,180	-8,700	-0.2
All Asia	**7,769,197**	**6,741,394**	**-102,780**	**-1.41**	**6,162,045**	**-57,935**	**-0.89**	**5,857,375**	**-61,014**	**-1.01**

Modified from: FAO (2007). The world's mangroves 1980 – 2005: A thematic study prepared in the framework of the Global Forest Resources Assessment 2005. The six countries directly involved in the TDA-IME Project are shown in bold.

TABLE 3: The 10 most mangrove-rich countries by area, and their cumulative percentage contribution to the global total area of mangrove forest (from Giri, *et al.*, 2010)

Rank	Country	Mangrove area (ha)	% of global total area	Cumulative contribution %	Region
1	Indonesia	3,112,989	22.6	22.6	Asia
2	Australia	977,975	7.1	29.7	Oceania
3	Brazil	962,683	7.0	36.7	South America
4	Mexico	741,917	5.4	42.1	North and Central America
5	Nigeria	653,669	4.7	46.8	Africa
6	Malaysia	505,386	3.7	50.5	Asia
7	Myanmar	494,584	3.6	54.1	Asia
8	Papua New Guinea	480,121	3.5	57.6	Oceania
9	Bangladesh	436,570	3.2	60.8	Asia
10	Cuba	421,538	3.1	63.9	North and Central America

TABLE 4: Change in the estimated total area of mangrove by country, over recent time periods.

Country	Change in mangrove area	Period of change	Observations	Source
Cambodia	-23%	1975-1997	94,600 ha to 72,365 ha	Mekong Secretariat/ UNDP/FAO (1994) Dept. Forest & Wildlife (1998)
Malaysia	-27%	1975-2000	All mangrove forest land in Malaysia, including Sabah and Sarawak	TDA country report
	-26%	1980-2008	State Mangrove Forest Reserve in Peninsular Malaysia only	TDA country report
Philippines	-15%	1980-2005	Data for Philippines are inconsistent, with wide variation*	FAO (2007)
	+ 7%	1984-2003	232,065 ha to 248,813 ha	TDA country report
Singapore	-91%	1953-1987	Increase may reflect restoration results, but also changes in methods of assessment.	Corlett 1987; Hilton and Manning, 1995;
	+52%	1993-2012		TDA country report
Thailand	-33%	1961-2000	367,900 ha to 245,200 ha	TDA country report
	-3.5%	2000-2009	252,751ha to 244,010 ha	DMCR (2012)
Viet Nam	-62%	1945-1999	Mangrove cover has increased since 1999 due to national rehabilitation programs	Maurand (1943); FIPI (2001);
	+34%	1999-2008		TDA country report

* According to Primavera (2000a) 279,000 ha of mangrove in Philippines were destroyed from 1951 to 1988.

Findings during the Inception Phase

The following initial macro-level analysis was provided in the TDA-IME Project Inception Report (January, 2012):

Over and above loss of mangrove area, mangrove habitats have declined in terms of biological diversity, forest structure and economic value, due to excessive harvesting of the most valuable trees. This has caused a shift in the forest composition towards smaller trees and secondary growth when larger trees were removed. The main factor leading to the loss of mangrove biodiversity is habitat loss caused by conversion or progressive degradation of the forest, water pollution and withdrawal. Even off-site activities can lead to mangrove degradation through siltation and changes in water flow and water quality, especially salinity change and changes due to pollution. Contaminants may be directly toxic to some marine organisms and their effects may be instantaneous or cumulative. Introduction of exotic species can also cause loss of habitat and biodiversity through competition with native species. It is also recognized that climate change now poses additional threats to mangrove ecosystems as mangroves occupy marginal land areas that would shrink significantly under the influence of projected sea level rise.

Many of the problems and causes of mangrove loss stem from failures in policy, management and enforcement of ecosystem protection measures. These need to be dealt with urgently. Recognition of the environmental, social and economic impacts associated with the decline and degradation of mangroves are now being addressed through legislative, management, conservation and rehabilitation efforts aimed at mitigating the negative impacts of development on mangrove ecosystems. However, many of the current management policies adopted are still sectoral in nature, which frequently leads to conflict of interests, and to continuing unsustainable exploitation of mangrove resources. An integrated approach to coastal area and ecosystem management through coherent science-policy development and concerted action is increasingly being regarded as the best way to achieve conservation and sustainable use of transboundary mangrove and other coastal resources. Drawing on insights from other initiatives in transboundary ecosystem governance, the focus of sustainable mangrove ecosystem management should be on international process (i.e., consensus-building and development of new policy instruments for combating the causes of mangrove deforestation/ecosystem degradation) and regime interaction (i.e., adaptation to climate change, multi-purpose program, reversing mangrove degradation trends while reducing poverty, and priority-setting and coordination).

Geographical Scope of the Project

The "Indochina" region, which today is generally referred to as mainland Southeast Asia, is an important bio-geographical region of the Indomalaya Ecozone, one of the eight major ecozones of the world. The TDA-IME Project directly involved Cambodia, Malaysia, Philippines, Singapore, Thailand, and Viet Nam.

Myanmar, which is also an important coastal country in western mainland Southeast Asia, is included in some of the project analyses and reporting in order to complete the geographical coverage of this region (see map, figure 1).

The inclusion of the Philippines extended the project's geographical focus to the southeastern boundary of the Indomalaya Ecozone. The islands of Indonesia as far east as Bali, plus Kalimantan and southern China, are also part of this ecozone. Thus, like Myanmar, information from Indonesia and southern China is also included in the project analyses and reporting, where it can contribute to a better understanding of the regional perspectives on transboundary mangrove ecosystem management.

This broader geographical coverage also has practical value, because China, Indonesia and Myanmar each share transboundary mangrove areas with the Indochina countries (Myanmar with Thailand, China with Viet Nam, Indonesia with Malaysia).

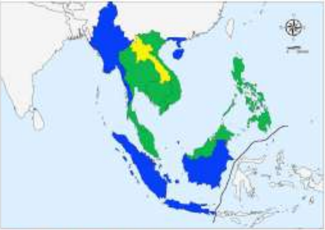


FIGURE 1: Map of the Indochina region and the Philippines, showing the project participating countries (in green), plus Myanmar, southern China and Indonesia as far eastwards as Bali (in blue); the coloured areas form a recognized biogeographical region: the Indomalaya Ecozone.

Definition of Mangroves Applied in the Project

In his pioneering review of the flora and fauna of mangrove swamps, William MacNae (1968) described use of the name "mangroves" to mean either "...*a community of trees or shrubs which grow in the sea*" or "*any one of the individual species which constitute that association*".

In recent decades the concept of mangroves as a coastal ecosystem - rather than just a community of plants (which MacNae termed the mangal) - has evolved. Appropriately, the term mangrove ecosystem takes into account the important physical structure of the mangroves, including mud banks (levees) and mud flats, plus the many creeks and other small waterways that permeate mangrove forests. It also includes the physio-chemical and biological processes that function at ecosystem level, plus vast populations of mangrove-associated animals, especially the marine aquatic fauna, that contribute substantially to the livelihood and nutritional needs of millions of traditional coastal fisherfolk in Indochina.

Defining the mangroves as an ecosystem is also fundamental to their effective conservation, restoration/rehabilitation and sustainable management, which is most likely to be achieved through an ecosystem-based approach (MEA, 2005; Macintosh *et al.*, 2011). One important reason for advocating this approach is that the physio-chemical and biological processes that determine mangrove structure also function at the ecosystem level (Hutchins and Saenger, 1987; Robertson and Alongi 1992).

TABLE 5: Benefits people derive from mangrove ecosystems.

Group	Benefits (Goods and Services)
Regulating services:	Protection of beaches and coastlines from storm surges, waves, and floods; reduction of beach and soil erosion; stabilization of land by trapping sediments; water quality maintenance; sequestration of carbon dioxide; and climate regulation
Provisioning services:	Subsistence and commercial fisheries (food, habitat, and nursery grounds for aquatic life); aquaculture, honey, fuel wood, timber and other building materials, and traditional food and medicines
Cultural services:	Tourism and recreation, and spiritual appreciation
Supporting services:	Cycling of nutrients, and habitats for species

Adapted from the Millenium Environment Assessment (2005).

While few would doubt the need to adopt an ecosystem-based approach to mangrove conservation and sustainable management, there is still today some confusion over what "true mangroves" are and what constitute "mangrove associates"? This distinction refers mainly to the mangrove plant community, because nearly all the mangrove animals are, *de facto*, associates (e.g. Soegiarto, 1999). Many species of birds, insects, mammals, fish and crustaceans use the mangrove forest opportunistically as their preferred, but not sole habitat. The mud lobster (*Thalassina anomala*) (Havanond, 2000) and the crab-eating frog (*Rana cancrivora*) (Hutchins and Saenger,1987) may be regarded as two of the few exclusive mangrove animals in Asia.

In describing the mangrove flora, Tomlinson (1986) noted that true mangroves "form forests with no understory except their own seedlings". The most useful, short definition of true mangroves is considered here to be the one given by Saenger (2002):

"A mangrove is a higher plant (tree, shrub, palm, herb or fern) which (1) predominantly grows in the intertidal areas of tropical and subtropical shorelines, which (2) exhibits a marked degree of tolerance to high salt concentrations and soil anoxia, and which (3) has propagules able to survive dispersal by seawater."

Tomlinson (1986) commented that *Nypa* is the only genus of palm with a viviparous fruit, indicating a mangrove-like specialization, a characteristic which also fits with Saenger's definition of true mangroves. The mangrove-associated fern *Acrostichum* is also included, as it can be the dominant vegetation in disturbed back mangroves, or in mangroves with high elevation caused by the mound-building activities of mud lobsters (Havanond, 1987, 2000; Havanond and Aksornkoae, 1989). Similarly, three species of *Acanthus* (or "mangrove thistle") are included, because this voracious climber is also typical of back-mangroves and disturbed sites with a high elevation.

Excluded from Tomlinson's definition of mangrove-associates are herbaceous or semi-woody plants that form the fringing coastal vegetation near true mangroves, and along sandy beaches; these include genera such as *Ipomea*, *Pluchea* and *Sesuvium*, plus grasses, rushes and sedges. However, these plants have great invasive capacity when mangrove forests become degraded and may therefore be useful indicators of mangrove habitat disturbance.

There are little more than 70 species of true mangrove plants worldwide (Spalding *et al.*, 2010 list 73 species), plus a handful of apparent hybrids (see Duke, 2006). Some 50 species, or around 70% of all mangrove species occur in Southeast Asia. Globally, 17 genera of flowering plants from 12 families have contributed mangrove species. But even within each of the genera that form the main constituents of mangrove forests in Southeast Asia, namely *Avicennia, Bruguiera, Ceriops, Lumnitzera, Rhizophora, Sonneratia* and *Xylocarpus*, there are not more than six species. This low level of diversity indicates just how challenging it has proved for terrestrial flowering plants to evolve in the harsh conditions represented by intertidal habitats.

In adopting the ecosystem-based approach as the most suitable way to address the issues and challenges for transboundary mangrove management, this report takes an inclusive view of "mangroves" meaning both true mangrove plants and mangrove associates, because both groups of species are important at the ecosystem level, through the goods and services they provide to coastal dwellers. And when considering mangrove management at a transboundary scale, it is almost certain that various habitat types will be represented, including mixed plant communities of true mangroves, mangrove and mangrove-associate species, other coastal or estuarine habitats dominated by associates like *Barringtonia* and *Nypa*, as well as non-mangrove plant communities.

The six countries covered by the TDA-IME Project: Cambodia, Malaysia, Philippines, Singapore, Thailand, Viet Nam share 42 true mangrove species, including the fern *Achrostichum speciosum* and the palm *Nypa fruticans*; the other species are trees or shrubs. According to FAO (2007) the species total per country ranges from 31 (Viet Nam) to 42 (Malaysia). These countries have the greatest mangrove species diversity in the world, with the exception of Indonesia with 48 species. A recent revision of the mangrove flora in Singapore updates the mangrove species there to 38 species (Yang *et al.*, in press). Uncertainty over what constitutes a mangrove-associated species explains the much wider variation in species numbers per country reported for this group (Table 6).

TABLE 6: Reported "true" mangrove plant species and "mangrove-associated" species, by country.

Country	No of "true" mangrove species	Mangrove-associated species	New threatened, vulnerable or endangered species	Source
Cambodia	30*	12-15	Not reported	MOE/Danida (1999); TDA Cambodia country report
Malaysia	40*	66	*Bruguiera hainesii* *Sonneratia griffithii*	FAO (2007); Japar Sidek (1994)
Philippines	28 (other reports list from 26 to 51 species)	34	*Avicennia rumphiana* *Camptostemon philippinense* *Aegiceras floridum* *Ceriops decandra* *Kandelia obovata*	TDA Philippines country report
Singapore	36* (one species is locally extinct)	Not reported	*Bruguiera hainesii* *B. sexangula* *Ceriops zippeliana*	Davison et al. (2008); TDA Singapore country report
Thailand	38*	43	*Bruguiera hainesii* *Brownlowia tersa*	Santisuk et al. (1988); TDA Thailand country report; FAO (2007)
Viet Nam	38*	72	Not reported	TDA Viet Nam country report

* The data include the mangrove-associates *Acanthus* (2-3 species) and *Achrostichum* (2 species). See definition and discussion of "true" mangrove species in the text (pp. 16-17).

TABLE 7: "True" mangrove species recorded from the countries bordering the South China Sea.

	Cam	Chn	Indo	Mal	Mya	Phil	Sing	Thai	Viet
Acanthus ebracteatus	✦	• ✦	• ✦	• ✦		✦	• ✦	• ✦	• ✦
Acanthus ilicifolius	✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦
Acanthus xiamenensis		•							
Acrostichum aureum	✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦
Acrostichum speciosum	+	• ✦	• ✦	• ✦	✦	• ✦	• ✦	• ✦	
Aegialitis annulata			• ✦			✦			
Aegialitis rotundifolia	•			?	• ✦			• ✦	
Aegiceras corniculatum	✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦
Aegiceras floridum			• ✦	✦		• ✦			• ✦
Avicennia alba	• ✦		• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦
Avicennia marina	✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦
Avicennia officinalis	✦		✦	✦	✦	✦	✦	✦	✦
Avicennia rumphiana (=lanata)			• ✦	• ✦		• ✦	• ✦	+	+
Bruguiera cylindrica	+	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦
Bruguiera exaristata			• ✦			✦			
Bruguiera gymnorrhiza	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦
Bruguiera hainesii			• ✦	• ✦		✦		✦	
Bruguiera parviflora		•	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦
Bruguiera sexangula	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	•	• ✦	• ✦
Bruguiera sexangula var rhyncopetala		•							
Camptostemon *philippinensis*			• ✦			• ✦			
Camptostemon schultzii			• ✦			✦			
Ceriops decandra	• ✦		• ✦	• ✦	• ✦	• ✦		• ✦	• ✦
Ceriops tagal	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦
Cynometra iripa				•	•			• ✦	
Cynometra ramiflora				•			•	•	
Excoecaria agallocha	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦
Excoecaria indica			• •	• ✦	✦		•	•⊠	
Heritiera fomes				✦	• ✦			• ✦	
Heritiera globosa			• ✦	•					
Heritiera littoralis	✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦
Kandelia candel	+	•	• ✦	• ✦	• ✦	✦	• ✦	• ✦	• ✦
Lumnitzera littorea	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦
Lumnitzera racemosa	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦
Nypa fruticans	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦
Osbornia octodonta			• ✦	• ✦		• ✦			
Pemphis acidula	✦	• ✦	• ✦	•	✦	• ✦	• ✦	✦	
Rhizophora apiculata	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦
Rhizophora x lamarckii			✦	• ✦		✦			
Rhizophora mucronata	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	✦
Rhizophora stylosa		• ✦	• ✦	• ✦		• ✦	• ✦		• ✦
Scyphiphora *hydrophyllacea*	✦	• ✦	• ✦	• ✦	✦	• ✦	• ✦	• ✦	• ✦
Sonneratia alba	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦
Sonneratia apetala	✦⊠				• ✦			•⊠	
Sonneratia caseolaris	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦	• ✦
Sonneratia griffithii				• ✦	• ✦			• ✦	
Sonneratia x gulngai			• ✦						
Sonneratia hainanensis		•							
Sonneratia ovata	✦	• ✦	• ✦	• ✦		• ✦	• ✦	• ✦	• ✦
Sonneratia x urama			• ✦	✦	✦				

Xylocarpus granatum	• •	• •	• •	• •	•	• •	• •	• •	• •
Xylocarpus rheksigensis			•	•	•	•	•	•	
Xylocarpus rumphii			•	•		•		+	

(Cam: Cambodia; Chi: China; Indo: Indonesia; Mal: Malaysia; Mya: Myanmar; Phil: Philippines; Sing: Singapore; Thai: Thailand and Viet: Viet Nam).

• From FAO (2007); ♦ From Spalding *et al.* (2010); □ From UNEP (2004);

+ Addition record listed in TDA-IME country reports; ▩ Not recorded in TDA-IME country reports

Additional species listed in Spalding et al. (2010).

	Cam	Chi	Indo	Mal	Mya	Phil	Sing	Thai	Viet
Aglaia cucullata				♦				+	
Dolichandrone spathacea			♦	♦	♦	♦	♦	♦	♦
Kandelia obovata	♦	+				♦			♦
Lumnitzera x rosea						?			
Sonneratia lanceolata			♦			♦	♦	♦	
Sonneratia x gulngai						♦			
Xylocarpus moluccensis	□			♦		♦	♦	+	

Additional species listed in UNEP (2004).

	Cam	Chi	Indo	Mal	Mya	Phil	Sing	Thai	Viet
Avicennia eucalyptifolia						□			
Brownlowia tersa	□			□				□	
Peltophorum pterocarpum				?				□	
Phoenix paludosa	□			□				□	□
Sueda maritime				?	□			□	

Additional species listed in TDA-IME country reports (2012)

	Cam	Chi	Indo	Mal	Mya	Phil	Sing	Thai	Viet
Ceriops zippeliana				+			+	+	+

Sources: FAO (2007): The World's Mangroves 1980-2005; UNEP (2004): Mangroves in the South China Sea, Spalding *et al.* (2010): World Mangrove Atlas; TDA-IME country reports and S. Havanond (pers. comm.).

Methodology and Process of the Analysis

The project adopted the transboundary diagnostic analysis (TDA) approach advocated by the Global Environment Facility (GEF) for its international waters focal area. TDA is a tool to identify the proximal, intermediate and fundamental (or "root") causes of water-related issues that are priority concerns for the countries involved. The analysis also attempts to determine those issues that are transboundary in nature, in terms of their causes and impacts. These are best mitigated by measures agreed on a bilateral or regional basis (Talaue-McManus, 2000). The TDA's other function is to provide the scientific rationale for the implementation of a Strategic Action Plan (SAP). A SAP is an agreed plan that subsequently guides the development and coordination of specific actions nationally and regionally.

The TDA process is explained in detail by Pernetta and Bewers (2012), who describe the expected outputs/outcomes of a TDA as follows:

- *A comprehensive listing of environmental issues and threats;*
- *A quantification of the scope and scale of each issue and threat;*

- *Prioritization of the issues and threats [to natural resources] in an international waters area, based on their relative significance;*
- *Identification of the causes and the jurisdictional origins of those causes for each issue and threat (i.e., identification of which issues and threats are purely national and which are transboundary);*
- *Identification and evaluation of options for intervention, primarily to address the causes of environmental degradation and threats.*

This TDA-IME Project Final Report does cover each of these outputs/outcomes to some extent, but it has a stronger focus on scientific evaluation of the environmental issues and threats facing mangrove ecosystems, plus the causes of mangrove loss/degradation, than on evaluation of the options for intervention. This emphasis reflects the project's stated aims to promote knowledge-based information exchange and regional cooperation, and to provide the scientific basis for developing a future SAP that would address the priority issues facing transboundary mangrove ecosystems management. This latter step will require a much wider consultation with national stakeholders than was possible within the project's scope. Although Pernetta and Brewers (2012) consider that the evaluation of potential interventions should be included within the TDA, rather than being left to the SAP formulation stage, they also note that such evaluations, especially the calculation of the relative costs and benefits of different options, can be rather resource intensive.

The TDA-IME Project analysis is also not typical of other TDAs conducted in the region because it deals with a single, intertidal ecosystem "the mangroves", which are limited to the narrow coastal fringe of the focal sub-region, rather than being an international waters entity *in senso stricto*. Thus, this report should be regarded more as a supplement to the TDAs already available for the Bay of Bengal and South China Sea LMEs, both of which include mangrove loss/degradation as one of the major issues they address.

While the TDA-IME Project has tried to make this report supportive of the TDAs for these GEF grant-supported LMEs, it has also sought to make the TDA findings for mangroves highly relevant for potential uptake by other initiatives and programs in the Southeast Asia region, such as Mangroves for the Future, PEMSEA and SEAFDEC. The potential for wider application of the TDA process outside the GEF framework is also regarded as a desirable development by Pernetta and Bewers (2012).

The TDA-IME Project's scientific analysis focused on climate change and mangroves, because this is an emerging issue that is not covered by the Bay of Bengal and South China Sea TDAs. It is consistent with the macro-level approach taken by the project, because climate change is a concern for all the countries of Indochina. Other gaps in scientific knowledge are also identified, together with an analysis of how to apply the considerable existing knowledge about mangrove ecosystems more effectively to improve coastal area management; that is, how to bridge the "science to policy" gap?

Relevance of the Approach

The TDA process, *in senso lato*, actually suits mangroves very well because they exist as transboundary ecosystems on several geographical and political scales. At a local scale, mangrove-fringed estuaries, lagoons or bays are shared commonly by two or more provinces or districts within a country (e.g. the Welu River Estuary, a large mangrove-fringed coastal lagoon bordered by Chantaburi and Trat provinces in eastern Thailand). Mangroves also form single ecosystems bordering the coastlines between neighbouring countries, e.g. along the Melaka Straits between Malaysia and Indonesia (Sumatra); the Kuraburi Estuary between Thailand and Myanmar, and the Straits of Johor between Malaysia and Singapore. Mangrove forests are also the major coastal habitat formation within the two Large Marine Ecosystems of Indochina, the Bay of Bengal and South China Sea, each of which is bordered by eight countries that together constitute about 42% of the world's mangrove forests by area and 70% by mangrove plant species.

Methodology

The initial macro-level analysis of the main issues affecting mangroves in Indochina identified a number of key findings from recent studies; these provided the framework for the TDA process that was then followed:

1) *Mangrove ecosystem conditions will change in response to the direct and indirect effects of climate change.*
2) *The policy challenge is to ensure the continued provision of mangrove forest goods and services, including carbon sinks.*
3) *Sustainable mangrove ecosystem management is integral to reducing the vulnerability of mangrove forests to climate change. The current failure to understand and address the integrity of the ecosystems limits the adaptive capacity of the forests.*
4) *Uncertainties about the magnitude, rate and even direction of climate change impacts on the ground.*
5) *Conflicts over the goals of adaptation – the need to balance social, economic and ecological goals.*
6) *Conflicts about means, even if countries could agree on goals.*

Three workshops were convened by the TDA-IME Project, in June and September, 2012, and February, 2013. Each workshop was attended by national mangrove experts from Cambodia, Malaysia, Philippines, Singapore, Thailand and Viet Nam, plus a number of other participants from Thailand. A Hong Kong-based project adviser also attended the workshops, while a mangrove expert from Myanmar was invited to the 2nd and 3rd workshops. The 3rd workshop also included invited participants from other regional programs and organizations: BOBLME/FAO, MFF/IUCN, PEMSEA and SEAFDEC, in order to achieve the project's additional aims of providing a platform for environmental dialogue and of promoting knowledge-based regional cooperation.

During the 3rd workshop a near-final causal chain analysis was prepared for the three main issues identified at the 2nd workshop: mangrove conversion; mangrove habitat degradation; and science and knowledge management gaps about mangroves. These issues were integrated into the TDA-IME Project draft Final Report, which was circulated for comment among all the workshop participants and STAC members. The consultant team leader also visited Cambodia, Thailand and Viet Nam to gather first-hand information and opinions from other mangrove projects and experts concerning the current and potential approaches to safeguard the ecological integrity of mangrove ecosystems, and thereby realize their adaptive capacity to climate change.

A 4th and final workshop was convened in Bangkok 25-26 March, 2013 to enable the STAC members, plus other experts and regional organizations, to peer-review the draft Final Report and make further recommendations to improve it. Draft conclusions and recommendations from the project were also discussed and peer-reviewed at the 4th workshop. The revised draft report was reviewed further by the STAC in April, 2013 and again at the STAC's final project meeting on 27th May, 2013.

Participants at the TDA-IME Project 1st Workshop at The Sirindhorn International Environmental Park, June, 2012. (Photo credit: J. Yong.)

National experts and other project participants visiting Kung Krabaen Bay Royal Project after the TDA-IME Project 2nd Workshop, September 2012. (Photo credit: J. Yong.)

National mangrove experts, plus representatives from other regional organizations and programs at the TDA-IME Project 3rd Workshop in Phuket, February 2013. (Photo credit: J. Yong.)

SECTION 2

Description of the Indochina Mangrove Ecosystems

Physical and Hydrological Features

Introduction

Mangrove wetland forests are the dominant natural ecosystem separating land and sea in a narrow fringe along sedimentary coasts in most of the world's tropical and subtropical regions. Mangroves are most prevalent and biologically diverse along open coastlines and within estuaries and deltas in Southeast Asia; this is considered by Ellison *et al.* (1999) to be due to a higher *in situ* evolution of mangrove taxa here compared to other regions. Globally, mangroves occur in 124 countries (FAO, 2007).

Mangrove ecosystems are a vegetated landform complex that changes continually as a result of dynamic biological and physical processes occurring over a spectrum of time scales (Thom, 1982). Hydrological processes are fundamental to the extent, distribution, structure and productivity of mangrove ecosystems (Kjerfve, 1990). Mangrove forests are inundated by ocean tides on at least an intermittent basis; they are also flooded regularly by rivers and runoff from the land (Kjerfve, 1990). The extent, physiography, structure, and productivity of mangrove wetland forests are a function of the degree and regularity of tidal inundation and terrestrial drainage, which are two processes serving to deliver sedimentation from land and marine sources. In fact, hydrological differences from site to site may be the dominant factor controlling the structure and productivity of coastal mangrove systems (e.g. Tomlinson, 1986; Saenger, 2002). Certainly, the regular tidal flooding by saline coastal waters limits the competition from non-mangrove species, except in the areas dominated by mangrove associates near the inland boundary, or "back-mangrove" zone.

Mangrove Setting

The most extensive mangroves are found on large sedimentary plains within river deltas and adjacent to river mouths with high freshwater discharge and regular inundation by meso- to macro -tides (tidal range greater than 1 m and 4 m, respectively), in wet humid tropical or subtropical settings. These are also the areas which, on a global scale, are most affected by relative sea level variability as a result of changes in land elevation due to human interventions (physical infrastructure and extraction of water, oil, and gas) and coupled with regional tectonic processes.

Some of the most extensive mangrove systems in the world are located in deltaic regions that exhibit a moderate tidal range of 2-4 m. In this situation, freshwater may actually be a more critical factor in controlling mangrove productivity than tidal range. Although mangrove species vary in their salinity tolerance, salinity is not necessarily a major influence over mangrove zonation. Most mangrove species are facultative halophytes and thus they do not require saline conditions for survival. Rather, they prefer brackish to saline waters during at least part of the year, possibly because salinity eliminates competition from non-salt tolerant plant species, or glycophytes (Thom, 1967). Mangroves become stunted when the salinity exceeds 40 ppt, or if drought conditions are prevalent.

The geomorphological structure of mangrove ecosystems includes natural mud banks (levees), extensive mud flats, plus numerous creeks and smaller waterways which intersect the forested wetland. Mud sediments rich in organic materials dominate, but silt- and sand-dominated sediments become more common further inland.

Freshwater runoff provides favourable conditions for mangrove colonization because it supplies nutrients and leaches the soil, thus keeping soil salinity within a tolerable range. The frequency and range of tidal inundation are critical factors in arid regions with low annual (or only seasonal) freshwater flow and high rates of evapotranspiration. Under these climatic conditions, bare hypersaline flats are found frequently just landward of the high tide level. These flats rarely support vegetation and are only inundated by an occasional extreme spring tide; this decreases evaporation and temporarily alleviates the hypersaline soil conditions. Progradation can, however, be episodic as seasonal storms can add a dynamic, even cyclic dimension to the process (Maxwell, 2000). Deltas are typically prograding because of the continuous supply of alluvial deposits from river runoff, which favours the colonization of mangroves. Mangroves contribute to land-building because they colonize a suitable substratum first and then add to progradation later, once they have become established.

The substratum also acts as a major geomorphological influence on mangrove development and zonation (Thom, 1967). Fine-grained alluvial mud, silt, and sand deposited into deltas are ideal substrata for mangrove colonization. Although some mangrove species do colonize on gravel or rocky substrata, their growth is stunted to varying degrees because of the sheer lack of soil, as well as the abrasiveness of the substratum to their roots (Maxwell, 2000). Exposed beaches are also ill-suited for mangrove growth because wave- and wind-deposited marine sands, and constant sediment movement, can cover and suffocate mangrove pneumatophores. Mangrove establishment is optimal on sheltered coasts with muddy alluvial sediments containing high content of silt. Important examples in Indochina where these ideal natural conditions for mangroves occur include the Gulf of Thailand, the Melaka Straits and the Mekong Delta.

Climate and mangroves

Climate plays a fundamental role in the growth and zonation of mangroves (Kjerfve, 1990; Mangrove Task Team, 1994), with climatic conditions regulating mangrove growth from macro- to micro-spatial scales.

Temperature is believed to have the greatest overall influence on the latitudinal distribution of mangroves (Tomlinson, 1986). Although mangroves are generally associated with tropical and subtropical regions, species vary considerably in their thermal tolerance, and several species survive into the temperate zone, including southern China and Okinawa Island, Japan. Mangrove distribution extends to higher latitudes along coasts with warm western boundary currents, but frost is a limiting factor for mangrove growth. Cold temperatures result in decreased tree height, a reduced leaf area index, and reduced species richness and forest complexity. Mangroves which employ C3 photosynthesis have the ability to adapt to cold temperatures, and transpiration demands on mangroves decrease in colder climates (Clough *et al.*, 1982). Temperature stress has a major influence on mangrove physiology, while cold temperatures and frost are clearly limiting factors for mangrove development. Overall, mangroves species are hardiest and most diversified in regions where the coldest monthly mean temperature is greater than 20°C and the annual temperature range is less than 10°C (Chapman, 1977). Low temperature is a powerful limiting factor on mangrove plant diversity, as witnessed by the presence of just one species at the southern biogeographic limit of mangroves in New Zealand, where only cold-tolerant ecotypes of *Avicennia marina* survive (Maxwell, 2001).

Species zonation differs between mangrove ecosystems in humid climates as opposed to arid climates (Blasco, 1984). In humid climates, rainfall leaches the soil more effectively in the landward zone, whereas at the seaward fringe, salinities are elevated by frequent periods of tidal inundation. The less salt-resistant species thus exist in the landward zone. But in arid climates subject to dry seasons, or long periods of drought and little river flow, high evaporation rates increase salinities at the landward margin, while salinity concentrations along the seaward edge are moderated by tidal inundation. The most salt-resistant species are thus found in the landward zone, often alongside extensive areas of bare sand with hypersaline soil conditions (Blasco, 1984).

Mangroves are found in both humid and arid climates. However, mangrove growth and species diversity are greatest in humid tropical areas where rainfall is plentiful and quite evenly distributed throughout the year, as in most of Southeast Asia. The critical factor for mangrove productivity is that the ratio of rainfall to evapotranspiration should be balanced, or positive. Rainfall does not appear to limit the global distribution of mangroves, but it does have a significant influence on the distribution and zonation of species. Rainfall serves as a primary controlling factor on salinity in mangrove environments; rainwater also leaches excess salts from mangrove soils, and thereby helps to keep soil salinity within tolerable limits, although this also leads to nutrient loss from mangroves (Boto, 1982).

Rainfall periodicity is yet another critical factor affecting mangrove species distribution. In climates that are humid throughout the year, salts are leached continuously from soils by heavy, but evenly distributed rainfall. Salinity levels are generally constant and stable throughout the year. The greatest diversity of species exists in such regions, including Indochina. In arid climates, or monsoonal areas with strongly seasonal rainfall distribution, the low rainfall or drought periods lead to high evaporation rates and, consequently, increased soil salinities. During the rainy season, this situation reverses, and soil salinity drops considerably. Mangrove diversity in arid and monsoonal regions is low because only a few species are able to tolerate the prevailing large salinity fluctuations and high extremes of salinity. This situation is well illustrated in Hong Kong, where cool, dry winters and hot, wet summers combine with marked seasonal salinity fluctuations. Consequently, despite being technically in the tropics, Hong Kong has only nine mangrove species (Hodgkiss, 1986; Maxwell, 1993).

Sea Level Variability

Coastal mangrove-covered landscapes and landforms exist at their present locations as a result of eustatic changes in sea level and global and local land adjustments (Kjerfve, 1990). During glaciation periods, a considerable fraction of the world's oceans was frozen into continental glaciers. At such times, global sea level reached a glacial low stand, with coastlines located near the outer edges of the continental shelves. Most recently, a glacial maximum occurred at the beginning of the Holocene period 16,000 years ago, when eustatic sea level stood 130 m below the present mean sea level. Then, following the onset of the most recent interglacial stage, the rising sea level invaded and flooded outer continental shelves, river valleys and low-lying coastal plains, and the present-day coastal plain estuaries and coastal lagoons were formed. Eustatic sea level reached within a few meters of its present elevation approximately 5,000 years ago (Fairbridge, 1980). Presently, eustatic sea level along tectonically stable coasts has been rising at a mean rate of 0.15 cm/century; at the same time, the global temperature has increased as a consequence of a warming climate, the greenhouse effect, and the melting of glaciers, sea ice, and the fringes of major ice caps. The present rate of eustatic sea level rise of 0.15 m/century is actually quite small compared to the 1.4 m/century rise in the early Holocene after the most recent glaciation maximum.

However, eustatic sea level rise is only half of the story. The most important factor controlling sea level is relative sea level change: the sum of eustatic sea level rise and net changes in land elevation. Most mangrove coasts are experiencing relative sea level rise at a rate 2-10 times that of eustatic sea level rise. This represents the combined effect of eustatic sea level rise plus changes in land elevation resulting from sediment compaction, withdrawal of fluids (potable water, oil and gas), and regional tectonics.

Land elevation is important because the physical development of mangrove systems depends on the accumulation and deposition of organic muds around mangrove roots; transport of terrestrial materials from eroding continents by rivers; and the net up-estuary transport of sand-sized materials from nearshore waters. As in-filling and progradation continue and coastal landforms progress through different stages of geological development, mangrove succession occurs, with one plant and animal community preparing the habitat for another, until a climax community is reached. Thus, mangroves can be considered both a pioneer and a climax biological community (Tomlinson, 1986).

Mean sea level also varies during the year, which causes more extensive inundation of mangroves after the peak hot season and after the season of most heavy rainfall. The annual cycle in mean sea level along coasts is explained by changes in specific volume (steric changes) as a result of summer heating of shallow waters with depths less than 100 m (Pattullo et al., 1955), and periods of local high rainfall/runoff. The effects are significant, even along tropical coasts, with a seasonal variation in mean sea level of 10-30 cm. In the tropics, the temperature variability is less pronounced; thus seasonal mean sea level variability is more a function of changes in synoptic wind and atmospheric pressure patterns; changes in the coastal ocean circulation, and seasonal pulses in freshwater runoff, including monsoon effects. For example, extreme seasonal mean sea level changes of 1.65 m occur in the upper Gulf of Bengal due to monsoon runoffs (Pattullo et al., 1955).

Mangrove ecosystem processes, and hydrological forcing functions, are influenced by the adjacent oceanic conditions, including coastal currents, tide and wave characteristics, sediment dispersal, salinity, meteorologically induced sea level variability (setup and set down), and cyclones/typhoons, and tsunamis, which all affect and control the extent, structure, and productivity of mangrove ecosystems. The most extensive mangrove forests occur on coasts with low wave energy, but these locations may still experience an occasional typhoon or cyclone, or a tsunami-generated wave, that can impact on, or even destroy mangrove forests.

Threats and Transboundary Issues

Mangrove wetlands in Indochina increasingly are being affected on the seaward side by relative sea level rise along most sedimentary coasts; and by human impacts from the landward side. Overall, hydrological processes in mangroves dominate the resultant environmental setting more than any other process besides conversion of mangroves for alternative economic use. With respect to mangroves, hydrology is the science of the degree and regularity of marine and fresh surface runoff and flooding; of subsurface/groundwater flow, drainage, and storage; and of the cycles and variability in precipitation and evaporation/transpiration. These variables are linked to local weather and climate regimes, and affect the geomorphologic landform characteristics, sedimentation and erosion, soil geochemistry and salinity, and all biotic processes, including mangrove species succession.

Perhaps the greatest indirect threat to mangrove wetlands is the modification of coastal hydrological flow and drainage characteristics by construction work: drainage ditches and canals; artificial levees, dikes and roads; and by diversion of water flow for agriculture or aquaculture use.

Mangrove ecosystems are not only national in scope; they also extend along coasts independent of political boundaries. The hydrological processes that mangroves depend on may also be transboundary in nature. Mangroves occupy a small area (relative to the size of the entire watershed) in the lower reaches of hydrological basins, which in the case of large river systems can be located in more than one country. Structures such as dams, diversions schemes, other major construction projects, and non-point source agricultural and sewage runoff throughout the watershed can affect the mangrove ecosystem. In this sense, large-scale construction works and land-based runoff constitute a transboundary challenge to mangrove ecosystem integrity, which needs to be addressed by adopting an ecosystem-based management approach, including evaluation of the goods and services provided by mangroves for the benefit of small-scale fishers and other traditional coastal dwellers, and how these can be safeguarded?

From an ocean perspective, mangrove ecosystems likewise constitute an international waters transboundary management challenge. Many large mangrove ecosystems extend along coasts between countries. Most importantly, mangrove propagules, fish and crustacean larvae, and other biological materials, are dispersed by coastal currents from one mangrove habitat to another, and to marine habitats, including sea grasses and corals reefs. Thus, it is pertinent to note that transboundary issues involving mangroves are not only regional in scope, because they also relate to current and tidal transportation of genetic material from one mangrove ecosystem to the next ecosystem and further afield, but they also encompass mangrove connectivity to other, non-mangrove ecosystems.

Biological and Ecological Characteristics

The biology and ecology of mangrove ecosystems has been studied extensively over the past thirty years, and there are now a number of books on this subject (e.g. Tomlinson 1986; Robertson and Alongi, 1992; Saenger 2002; Hogarth, 2007; Giesen et al., 2007; Clough, 2013; Ong and Gong, 2013), including country-specific reviews and guidebooks (e.g. Thailand: Aksornkoae, 1993; Viet Nam: Hong and San, 1993; Philippines: Primavera et al. 2004).

The Millennium Ecosystem Assessment determined that drivers of global change, such as land use changes and climate change, are threatening the capacity of natural ecosystems to provide key services (MEA, 2005). Biodiversity is widely regarded to be important in maintaining genetic richness, ecological functioning and the resilience of the ecosystem (Schultze and Mooney, 1993 and Heywood, 1995). The Indo-West Pacific region has the highest diversity of mangrove plant species (Duke, 1992; Duke et al., 1998; Ashton and Macintosh, 2002), as well as a rich mangrove fauna (Reid, 1986; Lee, 1998; Ashton et al., 2003a). Ricklefs and Latham (1993) offer a number of explanations for the high diversity in this region: it was the center of origin of mangrove speciation; or the presence of an adjacent diverse terrestrial flora, and a constant wet humid climate, together with the continuous presence of these factors since the end of the Cretaceous, may have enabled a continued increase in diversity, or prevented species extinction, when conditions were not ideal elsewhere. However, a converse explanation of mangrove evolution has been put forward by Ellison et al. (1999). Whatever the correct explanation, the mangroves of Indochina plus Indonesia (collectively the Indomalay Ecozone) represent important refugia of mangrove biodiversity. Consequently, mangrove conservation and sustainable use management are particularly important in this region (Macintosh and Ashton, 2002).

Mangrove Flora

A great deal is now known about the general floristic characteristics, ecology, growth and productivity of mangrove forests, although there are still many specific gaps in our understanding of the factors that control species distributions, zonation, forest structure and growth.

Some 73 species and hybrids of trees, shrubs and ferns are recognized as true mangroves (Spalding et al., 2010), although a wide range of other plants are also found in association and contribute to the floristic diversity of mangrove systems in Southeast Asia, particularly along more landward mangrove zones (Giesen et al., 2007). In this sense, they are transboundary species that form an important part of the vegetation transition from a fully intertidal to a terrestrial formation.

Some mangrove plant species are uncommon within their range, and populations are often fragmented by landforms and human use of the coastal zone. Habitat fragmentation reduces the resilience of mangroves to both natural and anthropogenic drivers, increasing the vulnerability of less common species to extinction (Duke *et al*., 1998a; Ellison, 2002). The loss of just a single species represents a significant loss of biodiversity in such a small group of only 70-80 highly specialized mangrove plant species and hybrids that are uniquely adapted to tropical and subtropical intertidal habitats.

Table 8 lists the critically endangered mangrove plant species in Indochina and other parts of Asia, based on the IUCN Red List of Threatened Species (2012), plus some additional sources, including the TDA-IME Project country reports. There are no doubt other species that should be added. A more detailed examination and status reporting on all the near threatened and endangered mangrove species and mangrove associates in Indochina is clearly warranted as one of the key transboundary studies needed to fill the remaining research gaps.

TABLE 8: Mangrove flora species at risk in Indochina and South Asia.

Family	Species	Status	Comments
Rhizophoraceae	*Bruguiera hainesii*	Critically Endangered	Very limited patchy distribution. It has been known to be previously present in South Asia, in Indonesia, Malaysia, Philippines, Papua New Guinea and Singapore. However, current estimates of known individuals are only known from Singapore and Malaysia.
Rhizophoraceae	*Ceriops decandra*	Near Threatened	Restricted to the east coast of India and Bangladesh, southwestern Thailand and western part of the Malay Peninsula.
Lythraceae	*Sonneratia griffithii*	Critically Endangered	Very rare and patchily distributed, in India, Malaysia, Myanmar, Thailand, the Andaman Islands, northwest Sumatra, and southeast Bangladesh.
Lythraceae	*Sonneratia ovata*	Near Threatened	Increasingly rare at the extremities of its range from Brunei Darussalam, Cambodia, China, Indonesia, Malaysia, Philippines, Singapore, Thailand and Vietnam.
Malvaceae	*Heritiera fomes*	Endangered	Bangladesh, India, Malaysia, Myanmar and Thailand.
Malvaceae	*Heritiera globosa*	Endangered	Endemic to Borneo (West Kalimantan, Indonesia). It has a very limited and patchy distribution within its restricted range as it is only found in freshwater-dominated riverine areas.
Malvaceae	*Brownlowia tersa*	Near Threatened	Considered very rare in India.
Bombacaceae	*Camptostemon philippinense*	Endangered	Very rare and has a limited and patchy distribution in Indonesia and the Philippines.
Myrsinaceae	*Aegiceras floridum*	Near Threatened	Limited to high-salinity areas in the Philippines, Indonesia Sabah (east Malaysia) and south Viet Nam.
Plumbaginaceae	*Aegialitis rotundifolia*	Near Threatened	Very restricted and patchy range in Bangladesh, India, Myanmar, Thailand and in a single location in northern Sumatra, Indonesia.
Arecaceae	*Phoenix paludosa*	Near Threatened	Occurs in India, including the Andaman and Nicobar islands, Bangladesh, Cambodia, Malaysia, Indonesia (Sumatra), Thailand and Viet Nam. It possibly occurs in Myanmar. However, it is very patchily distributed and uncommon throughout its range.
Others:			
Rhizophoraceae	*Kandelia candel*	Data deficient	Patchy distribution in pioneer position at seaward or riverine edges in Brunei, Thailand and East Asia (southern China, Hong Kong and Japan) where subtropical temperatures favour cold-tolerant species.
Rutaceae	*Merope angulata*[1]	Near Threatened	See footnote

SOURCE: http://www.redlist.org - IUCN (2012): IUCN Red List of Threatened Species. Version 2012 (accessed 28.03.2013) and Polidoro *et al.* (2010); species status follows the IUCN criteria; the above species are at an elevated threat of extinction.

[1] Example of a mangrove associate restricted to back-mangroves and river banks, in Thailand, Peninsular Malaysia and Singapore where it is currently very rare. The salt-tolerant nature of this species implies that it may be potentially useful as root stock for citrus cultivation.

Results from the relatively recent application of modern molecular genetic techniques in mangrove taxonomy (e.g. Ballment *et al.*, 1988; Duke *et al.*, 1998b; Scheue *et al.*, 2003, 2009a, 2009b) suggest that there is still much to be learned about the taxonomy and genetic diversity of mangroves. This is important for several reasons: (1) as indicated in the paragraph above, the loss of even one species of mangrove would represent a significant loss in terms of biodiversity, and possibly also of ecosystem functioning; (2) recent studies of the biochemistry and pharmacology of mangroves have reported species-specific differences in some metabolites and biologically-active compounds that could be involved in salt tolerance and adaptation to climate change (see Parida and Jha, 2010). Some other mangrove species appear to have potential in treating a range of human ailments, including some serious diseases (Bandaranayake, 1998).

Although not widely studied, there is evidence of phenotypic plasticity and perhaps of genetic diversity within some species from different localities. For example, in *Avicennia germinans*, *A. marina*, *Laguncularia racemosa* and *Rhizophora mangle* (McMillan, 1975; Markley *et al.*, 1982); and in *Kandelia candel* (Maxwell, 1995, 2007). It is highly likely that there are also phenotypic and genetic differences within populations of other mangrove species growing in different localities. This represents a major gap in present knowledge because: (1) it limits our ability to ensure that the full range of mangrove species diversity is preserved; and (2) it means that conservation of genetic diversity is best done *in situ* where further evolution of genetic and phenotypic traits may be possible, rather than in fixed gene banks.

Phenology

One of the requirements for mangroves to migrate landwards in response to sea level rise is that the trees can produce sufficient propagules to fuel migration. Many, perhaps most species, begin to flower by 10 years of age, and often as early as two to three years. One study has reported an earlier onset of flowering in response to elevated ambient CO_2 concentrations (Farnsworth et al., 1996). However, flowering does not necessarily translate into the production of viable propagules.

Phenological studies at Ranong on the Andaman Sea coast of Thailand, and on the west coast of Malaysia, have shown that there is a very high rate of abortion during bud formation and anthesis. For *R. apiculata* at Ranong, it takes about 32 months from the initiation of inflorescences to the release of mature propagules (UNDP/UNESCO, 1991). The first stage, the initiation of inflorescences to the formation of young buds, accounts for about half this time (ca 18 months). For *R. mucronata*, it takes only about 17 months from the initiation of inflorescences to mature propagule fall, chiefly because of rapid progress of the stage involving the formation of young buds, which takes only about a month compared with the 18 months required for this stage in *R. apiculata* (UNDP/UNESCO, 1991; Pandey and Pandey, 2008). In southern Viet Nam, at a similar latitude but with a longer and more pronounced dry season, Clough *et al.* (2000) found significant propagule production only in stands of *R. apiculata* over 12 years of age, propagule production being 397,000 ha^{-1} in 21 year-old stands and 680,000 ha^{-1} in 36 year-old stands. There is little comparable information for other mangrove species of the Family Rhizophoraceae.

Climate change is a multi-faceted process involving changes in a whole suite of factors that could potentially influence phenology. These include temperature (especially temperature extremes) and changes in seasons and rainfall patterns, as well as other potential stressors, any of which alone or in combination might alter the phenology of flowering and propagule production. These effects will not be the same on all coastlines where mangroves are now found, and different species might respond in different ways. In addition climate change could also affect the distribution and behavior of mangrove pollinators, which include bats, birds and insects (Saenger, 2002).

Clearly, at the generic level, mangroves as a group have survived significant changes in climate over their long history, but it is by no means certain that all present-day species will be able to do so in response to future climate change. There is simply not enough understanding of phenology and reproductive capacity to identify vulnerable species and confidently predict future outcomes in response to climate change. This deficiency is of some concern, because knowledge of the reproductive phenology of all mangrove species in a range of environments is critical to understanding the impact of climate change on species diversity and the likely distribution of mangroves in the future. If, for example, mangroves are forced to retreat landwards by a rise in sea level, what will be the earliest age at which each species can reproduce and what factors will influence the number of propagules produced (from flower formation through to the production of mature viable propagules)?

Coastal Protection

The devastating consequences of the 2004 Asian tsunami have re-ignited interest in the value of mangroves for coastal protection. Across the tsunami-affected region, it was reported that mangrove forests absorbed some of the wave energy and there is at least anecdotal evidence that people were better protected from the tsunami as a result (reviewed by Paphavisit *et al.*, 2008). A number of modeling studies also suggest that mangroves and some other types of forest greenbelt, of sufficient width and with an appropriate forest structure (tree size and density), could reduce the hazards associated with long period tsunami waves (Hiraishi and Harada, 2003; Harada and Imamura, 2005; Tanaka *et al.*, 2007; Hiraishi, 2008; Nandasena *et al.*, 2008a, 2008b; Tanaka, 2009 and Tanaka and Yagisawa, 2009).

While both modeling and common sense would suggest that coastal forest greenbelts can reduce the amplitude and energy of a tsunami wave, evidence that mangroves directly mitigated the impact of the 2004 Asian tsunami appears to be site specific and somewhat contentious. There are reports that mangroves reduced the impact of the Asian tsunami along some sections of the Tamil Nadu coast in southern India (Danielsen *et al.*, 2005; Kathiresan and Rajendran, 2005; but see also Kerr *et al.*, 2006 and Vermaat and Thampanya, 2006); and similarly, in Sri Lanka (Dahdouh-Guebas *et al.*, 2005 and Sakamoto *et al.*, 2009) and on the Andaman coast of southern Thailand (Harakunarak and Aksornkoae, 2005). Cochard *et al.* (2008) concluded that mangroves and other coastal vegetation probably provided some protection at several locations far from the epicenter of the earthquake, but provided no protection at all in many other locations, although this is contradicted by reports from Indonesia stating that some villages quite close to the epicenter of the earthquake were saved by the presence of extensive mangroves (Parish, 2005; UNEP, 2006). One of the difficulties with *post hoc* analyses like these is that it is often difficult to include all the factors that might have reduced the impact of the tsunami.

There is good evidence that mangroves can reduce the height and energy of smaller wind-driven waves (Maxwell, 2000; Mazda *et al.*, 1997, 2002; McIvor *et al.*, 2012). However, coastal wind-driven waves vary greatly in nature depending on offshore bathymetry, and there is a need for further field studies with mangrove bands of different species composition and width in a range of environmental settings.

Notwithstanding the mixed conclusions from the 2004 Asian tsunami, it seems reasonable to suggest that an unbroken band of dense, well-developed forest (mangrove or otherwise), one kilometre or so in width, would help to reduce the height and energy of a tsunami-generated wave, and will probably reduce the loss of life and property significantly in adjacent low lying coastal areas. Much narrower belts of solid mangrove forest cover can be effective against typhoons and tropical storms. In the case of northern Viet Nam, a typhoon-prone region, mangrove storm protection belts also significantly reduce the cost of maintaining the coastal dyke system (Tri *et al.*, 1998). Conversely, relatively open, degraded mangrove stands may provide little or no storm or wave protection (Paphavisit, *et al.*, 2008).

The Role of Mangrove Roots

It is generally agreed that the dense root systems of mangroves help to promote sedimentation; bind settled coastal sediments; and reduce the rate of soil erosion (Hutchins and Saenger, 1987; Augustinus, 1995; Wolanski 1995; Young and Harvey 1996; Furukawa *et al.*, 1997; Maxwell, 2000). Since different species of mangroves produce roots systems with different architectures, it is reasonable to suggest that a mangrove forest with a diversity of root structures would be more effective in minimizing erosion than one with a single type of root architecture. However, the relative efficiency of different root architectures in reducing erosion has still not been investigated in the field. This seems to be an important oversight given the likelihood that rates of erosion will increase in many locations due to climate change.

Another gap in our knowledge of mangrove root systems concerns their resilience to sea level rise, since the effect of rising sea level is likely to depend on the ability of aerial roots to supply oxygen to the trees' below-ground roots. Species with root systems that can adapt quickly to changes in sea level, or sediment level, are likely to fare better than those with less such adaptive capacity.

A superficial analysis of the structure and development of the four main kinds of mangrove root systems described by Tomlinson (1986) suggests that species with knee roots (e.g. *Bruguiera*) and plank roots (e.g. *Heritiera littoralis* and *Xylocarpus granatum*) are not well adapted to dealing with fast rates of sea level rise or high rates of sedimentation. The basis for this conclusion is that they need a significant investment in woody aerial roots, which take both time to construct and a large proportion of the tree's photosynthetic production. In the case of those species with stilt roots (e.g. *Rhizophora*) gas exchange is restricted largely to the lower, less woody sections of the stilt root. Adaptation to rising sea level, or rapid sedimentation, requires the production of new lateral extensions to existing stilt roots or the production of new stilt roots from higher up on the trunk, as well as the development of new underground root systems. In larger *Rhizophora* trees, the development of new root systems above and below ground not only takes time, but also involves the allocation of a considerable part of photosynthetic production to the formation of new roots. Thus in a climate change scenario that involves a wide range of potential stresses that could affect plant metabolism and growth, the capacity of *Rhizophora* to adapt to rising sea levels might be limited. This apparent, but still unconfirmed, vulnerability of species with plank, knee and stilt roots to rapid sea level rise might help to explain why neither *Bruguiera* (knee roots), nor *Rhizophora* (stilt roots), could apparently keep pace with rates of sea level rise above 12 cm per 100 years during the Holocene 10,000 year BP (Ellison and Stoddard, 1991), a rate well below current projections for sea level rise to 2100.

In contrast, mangrove genera with upwardly growing pneumatophores as aerial roots, such as *Avicennia* and *Sonneratia*, seem to be better equipped to handle moderate rates of sea level rise and sedimentation than *Bruguiera* and *Rhizophora* species. Pneumatophores have a much lower dry weight per unit volume or surface area than woody roots, since they contain mostly aerenchyma (spongy root tissue with large air spaces). Pneumatophores, apparently, can be produced rapidly in response to changes in sedimentation patterns (Young and Harvey, 1996). Moreover, since the growth meristem is at the top of the pneumatophore it could, in theory, continue to grow upwards in response to sea level rise, or sedimentation, without the need for the construction of more carbon-expensive woody roots. The capacity for vertical extension appears to be more limited in *Avicennia* than in *Sonneratia* species. The pneumatophores of old *Sonneratia* trees can extend to over 2 m above their point of attachment to the main cable roots, presumably reflecting a long history of adaptation to sedimentation. This assumption is rather speculative, but it does identify a serious gap in our understanding of how different species might be able to adapt to sea level rise. It is also highly relevant to mangrove rehabilitation – it would make sense to plant with species that are better able to adapt to rising sea level, provided of course, that they are also sufficiently suited to present hydrological conditions.

Forest Biomass, Growth and Carbon Storage

There is a large body of literature on the measurement of mangrove forest biomass and productivity, much of which is summarised by Komiyama *et al.* (2008). Other significant recent publications on mangrove biomass and carbon storage include Cole *et al.* (1999), Bouillon *et al.* (2008), Kauffman and Cole (2010), Donato *et al.* (2011) and Kauffman *et al.* (2011).

In well-developed, closed-canopy mangrove forests, total above-ground biomass normally ranges up to around 650 t ha^{-1}, depending on species composition, age and stand density (Komiyama *et al.*, 2008). One stand dominated by *Sonneratia* and *Bruguiera* on the West-Pacific island of Yap has been reported to have an above-ground biomass of over 800 t ha^{-1} (Donato *et al.*, 2011). Below-ground root biomass estimates are much less certain because of the difficulty of representative sampling; and also of distinguishing between living and dead roots, and other sediment detritus. Nonetheless, with the sole exception of *Rhizophora apiculata* monoculture plantations (Ong *et al.*, 2004), below-ground root biomass is usually somewhat higher than above-ground biomass, indicating that mangroves as a group (with the possible exception of *Rhizophora* spp.) invest a great deal of carbon in building underground root systems. This feature of mangrove forests explains their acknowledged importance for carbon sequestration as a climate change mitigation response (Donato, et al., 2011).

Mangrove Fauna

Crustaceans and Molluscs

Mangroves support a rich macro- and meio-fauna, consisting of terrestrial and aquatic (marine and freshwater groups) that include both resident and temporary resident species (Macintosh and Ashton, 2002). Faunal diversity is correlated with the high plant and habitat diversity found in the Indo-West Pacific mangroves (Jones, 1984; Reid, 1986; Ricklefs and Latham, 1993; Lee, 1998). Thus, the Indochina mangrove ecosystems are an important refugium for mangrove animals, as well as plants. A number of animals that depend on mangrove ecosystems are at risk and have been recognized in the IUCN Red List (Table 9). However, a large number of animal species related to mangroves are data deficient and thus cannot be assigned a risk status. Table 9 could be expanded considerably, but only large, well known species are included. Further research is required to fill gaps in our knowledge of these species. Mangrove habitat loss through conversion and human encroachment is a primary cause of their decline. These impacts on wildlife are likely to continue and increase as human population pressure intensifies.

A crucial aspect of faunal biodiversity for transboundary mangrove management is that many species, among them crustaceans, fish, mammals and birds, use the mangrove forest ecosystem during only part of their life-cycle. The level of mangrove dependency varies depending on the species and its life cycle characteristics (Manson *et al.*, 2005). Thus, the mangrove habitat supports many more species as visitors, or indirectly (e.g. via coastal food chains). These important support functions must be taken into account when planning conservation measures (Macintosh and Ashton, 2002). Clearly, transboundary mangrove areas can assist greatly in supporting migratory species in particular (Semmens *et al.*, 2011).

The dominant macrofauna components in terms of numbers and species in the mangrove ecosystem are crustaceans and molluscs (e.g. Sasekumar, 1974; Jones, 1984). These two invertebrate groups form an important link between mangrove detritus at the base of the mangrove food web and consumers at higher trophic levels, which include mammals, birds and commercial fish species (Macintosh, 1984). Macrofauna also modify the mangrove's physical, chemical and vegetation characteristics through their burrowing activities (Havanond and Aksornkoae, 1989; Smith et al., 1991) and by grazing on propagules, leaves and wood (Berry, 1972; Smith, 1987). Thus they play an important role in the ecological functioning of the mangrove ecosystem (Lee, 1998, 1999).

TABLE 9: Mangrove fauna species at risk in Indochina and the Indo-Pacific Region

Species	Common name	Status
Crocodylus porosus	Saltwater crocodile	Vulnerable; protected within reserves-India and Malaysia; collecting prohibited-Australia, India, Sri Lanka
Ardea cinerea	Grey heron	Endangered-Malaysia
Egretta alba	Great egret	Endangered-Malaysia and Puerto Rico
Leptoptilos javanicus	Lesser adjutant stork	Vulnerable-S and SE Asia
Mycteria cinerea	Milky stork	Vulnerable-SE Asia, protected within a reserve on Pulau Dua off western Java; collecting prohibited in Malaysia except by aborigines
Pitta megarhyncha	Mangrove pitta	Near threatened-Bangladesh, Indonesia, Malaysia, Myanmar, Singapore, Thailand
Platalea minor	Black-faced spoonbill	Endangered-Russia, China, Hong Kong, Japan, Korea, Thailand, Viet Nam and Taiwan
Macaca fascicularis	Long-tailed macaque	Near threatened-S and SE Asia, Protected within reserves-Malaysia
Nasalis larvatus	Proboscis monkey	Endangered-Found only in Borneo; protected within reserves
Panthera tigris sumatrae	Sumatran tiger	Critically endangered-found only in Sumatra; collecting prohibited
Panthera tigris tigris	Bengal tiger	Endangered-protected within reserves in India, Bangladesh, Bhutan, Burma and Nepal
Presbytis femoralis	Banded langur	Near threatened-SE Asia
Pteropus vampyrus	Malaysian flying fox	Protected within reserves in Malaysia
Dugong dugon	Dugong	Vulnerable: Dugong is declining or extinct in at least a third of its range; of unknown status in about half its range; possibly stable in the remainder – Australia. Native: Indian Ocean–eastern; Indian Ocean–western; Pacific–northwest; Pacific– western central
Carcinoscorpius rotundicauda	Mangrove horseshoe crab	Data Deficient. Native: India; Indonesia; Malaysia; Philippines; Singapore; Thailand
Tachypleus gigas	Giant horseshoe crab	Data Deficient. Native: India; Indonesia; Malaysia; Philippines; Singapore; Thailand
Tachypleus tridentatus	Tri-spined Horseshoe Crab	Data Deficient. Native: China; Indonesia; Japan; Malaysia; Philippines; Taiwan; Viet Nam

SOURCE: http://www.redlist.org - IUCN (2012). IUCN Red List of Threatened Species. Version 2012 (accessed 01.04.2013).

The most abundant and diverse mangrove crustaceans are the brachyuran crabs, which are dominated by the families Grapsidae and Ocypodidae. Grapsid crabs feed at low tide predominantly on fallen mangrove leaves and fruits; they also scrape the epiphytic algae from the surface of mangrove roots, trunks or branches and some clamber onto tree branches to eat live leaves. At high tide they avoid predators like fish by retreating into burrows. The subfamily Sesarminae, particularly the genus Sesarma is the most important in species number and abundance. The Sesarma species closely resemble each other in morphology and therefore the taxonomy is complex and confusing, particularly in Southeast

Asia and Australia. Many species are inadequately described (Davie, 1982). In the Indo-Pacific sesarmid crabs play an important role in the ecology of the mangroves through their selective destruction of propagules, as well as consuming and breaking down leaf litter (Robertson, 1986; Smith, 1987). Chansang and Poovachiran (1990) confirmed the important role played by the feeding activities of crabs and other crustaceans in breaking down mangrove litter to detritus in a Thai mangrove forest. They also showed that mangrove litter and detritus export occurred mainly during outgoing spring tides, where it is presumed to enrich coastal waters and serve as food for marine species.

Mangrove sesarmid crabs are also important economically in Cambodia and Thailand, where they are collected in huge numbers for processing as "boo samae", a delicacy used to flavour traditional dishes, like papaya salad.

Mangrove-dwelling Ocypodidae include the familiar fiddler crabs (*Uca* spp.). They are predominantly deposit feeders that ingest organic matter from the mud at low tide and assimilate the bacteria, diatoms and meiofauna that grow on the detritus fraction. Fiddler crabs must process large amounts of soil from the mangrove floor surface to obtain this food material. Because fiddler crabs are often very abundant in mangroves, occurring in densities up to 80/m^2 (Macintosh, 1984), they are capable of turning over large amounts of surface soil. Their feeding activity plays a major role in modifying the soil environment (retexturing the soil and altering its chemical composition). Fiddler crabs also have another important role in the mangrove ecosystem as a food source for numerous predators, including monkeys, birds, snakes, fish and other crabs (Macintosh, 1977).

Other mangrove crustaceans include a variety of burrowing species, such as mud lobsters (*Thalassina*), amphipods and isopods. The mud lobster is a subterranean deposit-feeder that forms large mounds up to 2 m high. Together with crabs in the mangrove forest, mud lobsters play an important role as "ecosystem engineers" (Jones *et al.*, 1994). Large *Thalassina* mounds create "small islands" of drier habitats above the highest tidal level that are suitable for a variety of other, more terrestrial, species. Their burrows also increase the surface area of the mud. This has benefits to the mangrove plants by increasing diffusion of gases. It also allows the forest to be flushed more easily at high tide promoting nutrient exchange (Lee, 1998). Experiments have shown that crabs can significantly affect the growth and productivity of mangrove trees (Smith *et al.*, 1991). Other crustaceans may cause significant damage to mangroves. Burrowing isopods can affect mangrove root growth and development (Ellison and Farnsworth, 1990). Barnacle settlement on mangrove seedlings can be a major cause of mortality in mangrove rehabilitation projects, because the sheer weight of many barnacles can bend and kill the seedlings (Maxwell and Li, 2006).

Some mangrove crustaceans have considerable commercial value, particularly swimming crabs of the family Portunidae; they include the mud crab *Scylla* spp. and blue swimming crab *Neptunus* (*Portunus*) *pelagicus*. Crabs of the genus *Scylla* are the largest invertebrate predators in mangroves and they are commercially important in many countries because they are exported to meet the high demand for live seafood in Asia's major cities.

Penaeid shrimps (*Penaeus merguiensis* and *P. indicus*), depend heavily on mangroves for feeding and breeding habitats (Ronnback *et al.*, 2002). They are also very important commercially with catches having strong positive correlations with mangrove area (Chong *et al.*, 1990 and Loneragan *et al.*, 2005). Mantis shrimps, or stomatopods, live in burrows in the mud on mangrove foreshores; they are collected for food mainly on a subsistence level.

Molluscs live on and in mangrove mud, or attach to roots, or forage in the forest canopy. They are mainly gastropod and bivalve species. In turn, these molluscs contribute to supporting higher trophic levels in the mangrove food web. Gastropod snails are the most conspicuous group; most species are deposit feeders that scrape organic particles from the surface of the mangrove soil or vegetation. In some places gastropods are collected as a local food source, for example *Cerithidea* in Southeast Asia and *Telescopium* in India. In the

Ranong Biosphere Reserve in Thailand, Macintosh et al. (2002) reported that more than 20 species of mangrove-associated molluscs were collected for food by local people. Some bivalves are also important on a commercial scale, for example cockles and clams that are abundant in the mudflats adjacent to mangroves. Oysters and mussels, found attached to mangrove roots, are also collected as food, while green mussels (*Perna viridis*) and the larger species of mangrove oysters are farmed commercially in suitable locations, including mangrove waterways.

The consequences of mangrove clearing on the associated faunal community have been reported on for only a few species and locations (Ashton *et al.*, 2003; Manson et al., 2005). Ashton et al. (2003) showed that management history and age of the mangrove forest stand played an important role in moderating crab community structure. They also showed that former tin-mining areas, former concession forests (for charcoal production), or abandoned shrimp ponds, rehabilitated by planting mangroves can recover in terms of crustacean and molluscan biodiversity. Rapid recolonization is possible because crustaceans and molluscs produce larval life stages with strong recruitment potential into the intertidal zone (Macintosh, 1984). In addition, adults can move into restored habitat from nearby mangrove sites (Ashton *et al.*, 2003). Thus mangrove areas across borders may act as important sources of recruitment, with larger transboundary areas being more robust than smaller ones. To help overcome mangrove degradation and protect biodiversity, a network of protected areas would provide refuges for fish and invertebrate species that could then recolonize adjacent impoverished areas.

Brachyuran crab and molluscan communities are ubiquitous throughout the mangroves of Indochina and an important component of coastal food webs. A high diversity of grapsoid crabs, especially sesarmids, may indicate good mangrove ecosystem health (Macintosh et al., 2002). One species may not be able to serve as an indicator alone, but changes in brachyuran crab community structure could be a useful tool for managers to monitor mangrove habitat status (Ashton *et al.*, 2003). Mangrove crabs are good indicators of ecological integrity because of their high visibility and physical impact on mangrove soil structure. Their high recruitment potential into rehabilitated mangrove habitats also makes them potential indicators of ecosystem recovery. Crab abundance can be estimated directly when they are active at low tide, or indirectly by counting the density of their burrows.

Other Benthic Fauna

Mangrove sediments also support high densities of epibenthic, infaunal and meiofaunal invertebrates. The rich epifaunal communities on mangrove tree roots, trunks and branches include sponges, hydroids, anemones, polychaetes, bivalves, barnacles, bryozoans and ascidians. These organisms represent important food sources for other invertebrates and fish (Farnsworth and Ellison, 1996). The macrobenthos include annelids, polychaetes, oligochaetes and hydrozoans. The meiofauna (defined as organisms ranging from 53 to 1,000 µm) consist mainly of nematodes, copepods and protozoans. Meiofauna are widely distributed and abundant, but poorly studied. Thus, their biodiversity is likely to be much higher than has been recorded to date. The abundance of meiofauna can number in the millions per square metre of soil. They are heavily concentrated in the upper centimeter, with their numbers falling off rapidly below this soil depth (Somerfield *et al.*, 1998). Meiofauna populations have high numbers of species and a high level of taxonomic diversity. Meiofauna are thought to be important in converting mangrove primary production to detritus and as a food source for many deposit-feeding or surface-grazing macrofauna. Crabs, mudskippers, penaeid shrimps and a number of fish species are reported to consume large quantities of meiofauna (e.g. Sasekumar, 1981). In conclusion, mangrove meiofauna are a little studied group of various animal taxa, but they can be regarded as an important component of the mangrove-coastal waters food web.

Insects and Spiders

Insects are diverse and abundant in mangrove forests, where they play important ecological roles, not least as part of mangrove food chains that make mangrove plant primary production available to aquatic consumers as detritus. Herbivores such as caterpillars and beetles feed on leaves causing significant damage that also accelerates the process of converting mangrove leaves to detritus. Detritivores such as termites eat dead wood or decaying leaves. Pollinators such as bees play crucial roles and can also produce significant quantities of honey, which is an important local food source in some countries (e.g. Viet Nam). Weaver ants, *Oecophylla smaragdina*, construct nests by folding mangrove leaves together using sticky secretions. *Oecophylla* feeds on the sugary secretions of the coccid bugs, which suck plant sap and other insects and will defend their nests and thus the mangrove tree they inhabit by attacking with a sharp bite.

Synchronously flashing "fireflies" (actually *Pteroptyx* beetles of the family Lampyridae) are associated with *Sonneratia caseolaris* mangrove trees in some areas in Asia and the western Pacific. In Selangor, Peninsular Malaysia and a few other locations in Indochina, including Cambodia and Thailand, the fireflies are a valuable ecotourism attraction. Conversely, mosquitos and sandflies, which can occur in abundance in mangroves, are a nuisance that may also affect human health. Conversion or degradation of mangroves may increase the risk of mosquito-borne malaria, one reason being that these practices create more standing water as potential breeding sites for mosquitos (Hong and San, 1993).

Various spiders inhabit mangroves, including web-building species (Family Gasteracanthidae) and wolf and jumping spiders, which descend from the trees at low tide to forage over the mud for insects. The spider *Pardosa* (Family Lycosidae) is adapted to a semi-aquatic life, made possible by a body covering of hydrofuge (water-repellent) hairs. It shelters and breeds in air-filled burrows in the intertidal mud and feeds on juvenile fiddler crabs (Stafford-Deitsch, 1996).

Amphibians, Reptiles, Birds and Mammals

Amphibians are rarely found in brackish or salt water, but the crab-eating frog *Rana cancrivora* is an exception and both the adults and larvae are quite common in the mangroves of Indochina.

Mangrove-associated reptiles include numerous species of snakes and lizards, crocodiles and turtles. Some snake species only enter mangroves intermittently from adjacent terrestrial habitats to forage; for example, pythons (*Python molorus*) and king cobras (*Ophiophagus hannah*). Other snakes are more specialist mangrove-dwellers, such as the cat snake *Boiga dendrophila* and the mangrove pit viper (*Trimeresurus purpureomaculatus*). Sea snakes (Hydrophidae) also utilize mangrove habitats. The primitive *Laticauda colubrina* breeds on land, but other sea snakes are fully aquatic. In Southeast Asia the mangrove monitor lizard (*Varanus indicus*) may reach up to 1 m in length. It is often caught and used as bait to trap mud crabs (Ashton, *pers. obs.*). The estuarine crocodile (*Crocodylus. porosus*) is found from India through Southeast Asia and Australia and can reach up to 8 m in length, but is now relatively rare in Indochina.

Many bird species have been recorded in mangrove forests, but most are not mangrove residents. They may migrate seasonally, commute daily, or at different states of the tide, or may use mangroves selectively as feeding, nesting or refuge sites (Macintosh and Ashton, 2002). For example, 200 bird species were recorded from mangroves in Australia, but only 14 passerine species were confined to mangroves, with 11 other species being found predominantly in mangroves, but frequently also occurring elsewhere (Noske, 1996). Waders probe for buried invertebrates on the mudflats, or amongst the mangrove trees. Herons, egrets and kingfishers catch fish in the shallow waters or prey on mudskippers and crabs on the mud surface. Storks, pelicans, ospreys and cormorants feed on large fish and may roost or breed in mangroves. Passerines like warblers, woodpeckers and flycatchers depend on the invertebrate fauna associated with mangrove trees for food. Mangroves are also the nesting sites for a number of threatened bird species, for example spoonbills (*Ajaia ajaja*) and the milky stork (*Mycteria cinerea*).

Few mammals are characteristic of mangrove habitats, but they include flagship species like the mangrove-adapted proboscis monkey in Borneo and the Bengal tiger, a top predator now restricted entirely to the Sundarbans mangrove forest. Most other mammal species occur in adjacent habitats, as well as mangroves; for example antelopes, deer, wild pigs and rodents. Monkeys are common in mangroves, where they feed as omnivores or herbivores. Macaques (*Macaca* spp.) forage on the mud for crabs and bivalve molluscs. They can also be a major pest in mangrove plantations because they have a tendency to uproot *Rhizophora* propagules (Gan, 1995), or feed on young *Rhizophora* prop roots. In contrast, langurs (*Presbytis* spp.) feed mainly on mangrove leaves and fruits.

Bats are attracted to the abundance of insects, fruit and nectar in mangrove forests. Many species of insectivorous bats (Microchiroptera) consume considerable quantities of insects. In Peninsular Malaysia the long-tongued fruit bat (*Macroglossus minimus*) and the cave fruit bat (*Eonycteris spelaea*) feed on *Sonneratia* nectar and pollen and are major pollinators of *Sonneratia* flowers. *Macroglossus* has a strong association with *Sonneratia* trees and has never been recorded away from mangrove areas. Two species of otters are also common in the mangroves of Indochina; they are well adapted to the intertidal zone, being able to feed on fish, crabs and molluscs (Sivasothi and Nor, 1994).

The above examples of mangrove-associated mammals demonstrate the interconnectivity between mangroves and other terrestrial habitats utilized by these same species. Domestic animals also graze in some mangrove areas, e.g. cattle, camels and goats in India, and cows in Viet Nam. Livestock can consume large quantities of mangrove foliage and thereby have a significant impact as degraders of mangrove forests.

A number of animals that depend on mangrove ecosystems are at risk and have been recognized in the IUCN Red List of Threatened Species (Table 9). Habitat loss through conversion and human encroachment is a primary cause of their decline. These impacts on wildlife are likely to continue and increase as human populations expand.

Protection of mangrove-dependent animals requires effective management of the entire mangrove habitat, especially critical areas like nesting or roosting sites for birds. Migratory species in particular, and those that require large territories, do not stay within borders, which is why transboundary protected areas may be essential for conserving some species. The most notable example is the Sundarbans mangroves shared by India and Bangladesh, which is vital for the future survival of the Bengal tiger. The particular challenges associated with aquatic migratory species, especially dolphins, are described in below.

Migratory Species

Mammals

It is obvious that transboundary mangrove management is particularly relevant to migratory animal species, which include various taxa, from birds to mammals, fish and crustaceans. Dugongs and cetaceans are entirely aquatic mammals found in mangrove creeks and rivers. Dolphins, porpoises and whales visit mangroves periodically, including the Irrawaddy dolphin (*Orcaella brevirostris*). Although more remains unknown than known about this species (Maxwell and Lai, 2012), several reports indicate that it has an ecological tolerance for fresh water, as well as estuarine/mangrove and marine environments (e.g. Kreb *et al.* 2010). The presence of the Ganges River dolphin (*Platanista gangetica*) in the Sundarbans mangroves, and assessments of cetaceans in the coastal waters of southeast Myanmar (Tun *et al.* 2006), lend additional support to the hypothesis that these dolphins do in fact have eco-physiological adaptations related to their known eco-diversity.

While scientific knowledge of the Irrawaddy dolphin is lacking, it would be wise to assume that river dolphins may be good indicators of coastal ecosystem health. Local fisher folk in Myanmar regard dolphins as life guards, or celestial fish ("Net nga") and would save an entangled dolphin if one is found alive (Tun *et al.*, 2006). Such traditional conservation ethics often have a scientific basis and a recent paper by Gamez-Salazar *et al* (2012) (cited by Ryan, 2012) does point out how river dolphins can be indicators of ecological health in large tropical rivers.

A review of the work by cetacean conservation agencies and organizations from 2006 to 2011 showed that small protected areas (PAs) may be ineffective in dolphin conservation (Maxwell and Lai, 2012). Mobile and essentially migratory populations of cetaceans do not confine themselves to PAs. A more holistic, ecosystem-wide regional (bio-geographical) transboundary management approach offers far more chance of success. Eco-parks and PAs will still have a place within such a transboundary approach, but are best thought of as core areas within a much larger conservation plan. Ecosystems and watersheds need to be woven into a bio-geographic plan which demonstrates advantages for all *jurisdictions* within the defined area. Such a plan would feature models of co-management, linking transboundary political jurisdictions and local communities together as joint stakeholders. (See Section 4 - Priority Areas for Future Interventions: Co-management.)

In conclusion, by demonstrating the role of river dolphins and related cetaceans as keystone species, they have the potential to serve not only as indicators of ecosystem health, but also to generate substantial economic returns on a transboundary basis through ecotourism.

Fish and Zooplankton

There is a rich and abundant fish fauna associated with the creeks, channels and other water inlets permeating mangrove forests. Some fish species have commercial value, while others are important links in the mangrove-coastal waters food web. Fish are important predators consuming amphipods, isopods, shrimp, nematodes, insects, gastropods, crabs, bivalves, other fish and planktonic larvae (Sasekumar *et al.*, 1992; Clayton, 1993). Mullets (*Liza* spp.) consume significant quantities of detritus. Estimates of fish diversity depend heavily on catching methods and intensity, so the figures reported may not be directly comparable. However, the scale of diversity among mangrove-associated fish communities is indicated by research in Selangor, Malaysia that reported 119 species and in the Philippines 128 species (Chong *et al.*, 1990).

Many of the fish are juveniles, which has led to the widely reported paradigm that mangroves are critical in sustaining production in coastal fisheries through their role as important nursery areas (Robertson and Duke, 1990; Manson *et al.*, 2005). There is solid evidence showing that fish, shrimp and mud crabs use mangrove habitat when they are juveniles, and it is suggested that the mangrove root system serves to reduce their vulnerability to predators (Vance *et al.*, 1990 and Primavera, 1997). Ronnback *et al.* (1999) reported that the distribution of fish and shrimp in the Pagbilao mangroves (Philippines) was related to the structural complexity of the mangrove root system.

Most significantly, Ronnback *et al.* recorded the highest density of shrimp in a replanted *Rhizophora* mangrove area, which they attributed to the greater root complexity in the plantation site, compared to natural *Avicennia* and *Rhizophora* habitats. This observation, and similar findings (e.g. Macintosh *et al.*, 2002) showing recovery of fish and crustacean populations in rehabilitated mangroves, are important because they demonstrate that a key component of mangrove ecosystem integrity - nursery habitat provision for commercially important aquatic species - can also be restored by replanting mangroves in degraded areas.

Diverse communities of zooplankton, high abundance (reaching 10^5 individuals/m^3) and biomass (up to 623 mg/m^3) have been recorded in mangrove ecosystems (Robertson and Blaber, 1992), where they are believed to make an important contribution to coastal food webs. Zooplankton can be divided into three size classes: micro-zooplankton (organisms from 20 to 199 μm), meso-zooplankton (200 μm to 2 mm) and macro-zooplankton (larger than 2 mm). The micro-zooplankton includes foraminiferans, ciliates, rotifers, copepod nauplii, barnacle nauplii and mollusc veligers. Copepods are the most abundant group in the meso-zooplankton and jellyfish the most important macro-zooplankton. Mero-zooplankton (planktonic larval stages of benthic invertebrates) span the full range of zooplankton sizes and can constitute up to 70% of the zooplankton community (Kathiresan and Bingham, 2001).

Chong and Sasekumar (1981) reported that post-larvae of the white prawn, *Penaeus merguiensis*, in mangrove nursery sites feed mainly on copepods, while juveniles consume mainly detritus, but also ingest foraminiferans, copepods, and crab and molluscan larvae. Other studies have also suggested that mangrove crab larvae may be an important food source in coastal aquatic food webs (Macintosh *et al*., 1991). They are easily identifiable from the unique shape of the zoea larvae stages, and therefore they could serve as a potential indicator of mangrove ecosystem health (= an aquatic productivity indicator).

Mangrove - Fisheries Linkages

A key transboundary research priority is to better understand the relationship between mangroves and coastal to offshore fisheries, from both an ecological and economic perspective. There is overwhelming evidence for the role mangroves play in supporting on-site and near-shore fisheries, as evidenced by the traditional knowledge of artisanal fishers in Asia who understand the role mangroves play as nursery grounds for many commercial aquatic species. Their local knowledge is well supported by findings from scientific studies on the life cycles of mangrove-associated species, ranging from fin-fish like mullets, snappers and mudskippers, to white shrimps and mud crabs (Macintosh, 1983; Ong and Sasekumar, 1984; Robertson, 1986; Vance *et al*., 1990; Moser *et al*., 2002; Bucholts *et al*., 2009). Fish larval studies along the Andaman Sea coast of Thailand have shown that larvae of the families Carangidae, Gobiidae, Clupeidae, Sciaenidae, Engraulidae Callionymidae Monocanthidae are abundant in mangrove ecosystems (reviewed by Macintosh *et al*., 1991). Conversely, in the Gulf of Thailand, destruction of mangrove forests was identified as a major cause of a decline in the number of fish species reported by Monkolprasit (1983). Boonruang and Janekarn (1985) recorded post-larvae of five species of commercially important penaeid shrimp in mangrove channels and along the seaward mangrove fringe in Phuket.

At a transboundary scale, there appears to be a positive relationship between the area of mangroves and offshore fisheries yields (MacNae, 1974; Turner, 1977 and Martosubroto and Naamin, 1977), but it is very difficult to demonstrate a causal link to explain these earlier reported correlations (Gilbert and Janssen, 1998).

The mangroves fringing enclosed shallow-water coastal areas, which include estuaries, bays, lagoons and larger formations like the inner Gulf of Thailand, provide habitat and food support to numerous commercially important fishery species including pelagic fish species (Clupeidae, Latidae, Mugilidae, Lutjanidae), marine catfishes (Ariidae, Plotosidae), shrimp (Penaeidae, Sergestidae), crabs (Portunidae) and bivalve molluscs, chiefly oysters and cockles (UNEP, 2004). Scientific evidence suggests that the relationship is highly site specific, with factors such as tidal range and salinity being highly influential, in addition to the type of mangrove habitat *per se* (Vance *et al*., 1990; Ronnback *et al*., 1999). For this reason, it is very difficult to compare fishery yields from sites with and without mangroves that are also similar in these other respects.

While it is clear that many commercial species of fish and crustaceans enter mangroves, and they are linked to other fish species through the coastal food web (e.g. Salini *et al.*, 1990), the key question is to what degree are mangroves "critical" to the productivity of coastal fisheries? This question is fundamental to decision-making about transboundary mangrove management, because aquatic species move across boundaries and are commonly landed and sold at considerable distances from where they are caught. Moreover, mangrove-associated fisheries have immense, but not yet quantified, socio-economic value throughout Indochina.

In a recent analysis of this issue, Manson *et al.* (2005) showed that mangrove characteristics (especially area and perimeter) were the dominant parameters accounting for differences in the catch per unit effort (CPUE) for three mangrove-associated commercial species (mud crab, banana prawn and sea bass) along the Queensland coast of Australia. In contrast, CPUE for a fish species that does not use mangrove as nursery habitat (the coral trout) was not related to the mangrove parameters, while estuary-associated species (tiger shrimp, blue swimming crab and blue threadfin) showed a weaker correlation to the mangroves than the mangrove-associates. Manson *et al.* concluded that the results represent evidence of a causal link between mangroves and fishery production for some species; and that mangrove nursery habitat is critical to sustaining the fisheries of these species.

The best indicator species to select in order to monitor the relationship between mangrove ecosystem health and fisheries productivity are probably the mud crabs (Genus *Scylla*). These large, edible swimming crabs are intimately associated with mangroves throughout Indochina, and support the economy of many coastal fishing communities. In the Pagbilao mangroves of Luzon in the Philippines, for example, mud crabs make up about 95% of the value of the artisanal fisheries (Gilbert and Janssen, 1998). Four species of *Scylla* are recognized (Keenan et al., 1998), with the mud crab populations studied in the South China Sea region usually comprising of two or even three of the species (Overton, 2000). They are identified locally by their colour differences: *S. olivacea* (black crab); *S. paramamosain* (white crab); and *S. tranquebarica* (green crab).

Mud crabs are an important transboundary group ecologically because the adult crabs migrate offshore, up to 50 kilometres (Hill, 1994). The berried females release planktonic zoea larvae that are transported back inshore by tidal currents (Ong, 1964), where they moult to become megalopa larvae, which is a settlement stage. It is not entirely clear where the megalopa larvae settle, but they then recruit into mangrove habitats as juvenile crabs (Moser, 2001), where they stay for three to five months until they reach the sub-adult stage (Figure 2).

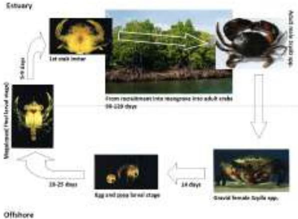


FIGURE 2: Life cycle of the mud crab Scylla olivacea in Ranong, Thailand (from Moser, 2001).

The life histories of the four Scylla species are believed to be similar (Overton and Macintosh, 2002), indicating that there is considerable natural movement of mud crabs across boundaries due to their adult spawning and larval recruitment migrations. They are also traded extensively across boundaries as they are easy to transport alive. Adult crabs are sold as high value seafood, while there is also significant movement of juveniles for stocking in aquaculture ponds. Mud crabs from Myanmar and Cambodia are imported into Thailand, for example, while "jumbo" crabs from Sri Lanka are advertised in restaurants in Malaysia and Singapore.

The abundance of mud crabs can be used as an indicator of mangrove ecosystem health, while their size (carapace width) can provide a very reliable indicator of fishing pressure. It is easy to measure the size of crabs caught by fisher folk at the point of sale to crab dealers ("middlemen") and the crabs' sex and maturity (immature, mature, gravid) can also be readily determined and recorded (Overton and Macintosh, 2002). Overfishing quickly translates into a decrease in the average size of mud crabs in the fishery, plus an increase in the relative number of immature crabs caught. These same indicators can be used to monitor the effectiveness of introducing fishery regulations, such as a minimum size rule, or a ban on removing female crabs during the breeding season.

Socio-economic and Development Aspects

The countries of Indochina are very diverse in area and coastal geography, population size, and GDP (see Table 1). Poverty is still prevalent in Cambodia, Philippines and Viet Nam, where per capita GDP is still only USD 2,400 to USD 4,300. This largely explains why coastal communities in these countries still have a high dependency on mangrove and other coastal resources. Malaysia and Thailand are middle income countries, while Singapore's per capita GDP is three times that of Malaysia and five times that of Thailand.

All six countries have extensive coastlines compared to their land area, especially Philippines. Cambodia's coastline is the shortest relative to the land area, but is very important to the country economically and as part of the transboundary coastline shared with Thailand and Viet Nam. Singapore actually has a very long coastline relative to its size, but stands out as being different to the other countries, having little policy interest in mangroves, although the two most significant mangroves areas still remaining in Singapore are well protected. As a result of the 2004 tsunami and concerns about climate change, mangroves are becoming more appreciated in the other countries for shore and storm protection, especially in the Philippines and Viet Nam; and to provide coastal communities with their basic livelihood and food security needs.

The historical and present uses of mangrove forests are summarized for each country in Table 10, based on information provided in the TDA-IME Project country reports. Mangroves in Cambodia, Malaysia, Philippines, Thailand and Viet Nam were exploited heavily for charcoal, a practice that, fortunately, has now almost ceased in the region. There is a ban on all mangrove tree-cutting in the Philippines, for example, and charcoal production in Thailand is now confined to small privately-owned forest areas. However, illegal tree-cutting continues in most countries due to inadequate enforcement of the regulations protecting mangroves.

The policy shift away from timber exploitation to utilizing mangroves only for non-timber forest products (NTFPs) means that as mangroves are rehabilitated and the resource increases, then the value of the mangroves' provisioning and supporting services to the fisheries and aquaculture sectors should also rise.

The importance of coastal fisheries and aquaculture in the economy of the region is very high, at more than 10 million tonnes per annum for capture fisheries, and about 7.65 million tonnes from marine and brackishwater aquaculture (Tables 11 and 12). As discussed in Section 2, it is almost impossible to relate the presence of mangroves to fishery yields on any scientifically-founded basis, but it is notable that the capture fisheries data include a number of mangrove-associated fish and shellfish species (e.g. milkfish, cockles). These and other mangrove-associates, like penaeid shrimp and oysters (*Crassostrea* spp.), are also strongly represented in the aquaculture data, at least for some countries. Thus, justification for conserving the remaining mangrove forests, and rehabilitating degraded areas back to an ecologically healthy state, is probably best made by researching the linkages between mangroves and fisheries/aquaculture on a transboundary scale, and where possible quantifying the relationships in economic terms.

For the foreseeable future, the coastal zones bordering the Indochina region will come under ever increasing pressure to both absorb more people as the human population grows, and to support the expansion and diversification of national economies. It is a paradox that higher fisheries production is required to help feed the rising population in coastal cities and towns, yet these urban settlements are themselves a major cause of mangrove loss and degradation, a trend which is actually reducing aquatic productivity and therefore the mangroves' food provisioning capacity.

Given the accepted failure of government-only mangrove management, Cambodia, Philippines Thailand and Viet Nam have introduced more progressive and socially acceptable conservation policies for mangrove forests, involving community participation in mangrove management. Variously known as community-based management, co-management, or stewardship, these alternative management systems involve the principle of shifting governance responsibilities from government exclusively, to a shared governance (co-management) or local governance basis.

An important section on co-management and mangroves is provided later in this report (Section 4), because co-management is regarded as the best management option to conserve and sustainably use mangroves. It should also be noted, that transboundary mangrove management should follow the same co-management principle of shared governance, which in a transboundary setting would involve cooperation between two or more national, provincial, or district governments, plus the other key stakeholders at these levels.

TABLE 10: The historical and present uses of mangrove forests by country, institutional arrangements and issues, and key national laws and policies that may pertain to mangroves. (The information is taken from the TDA-SAP Project country reports.)

Country	Main historical uses of mangrove forests and present threats	Present status and socioeconomic uses of mangrove forests	Institutional Arrangements and Issues	Policies and Legal Framework
Cambodia	Traditional timber and non-timber products. Severe exploitation for charcoal production by coastal migrants after the Khmer Rouge period.	Timber (firewood and construction materials) and traditional non-timber products. Community-based Ecotourism in PAs.	Environmental and NR management laws covering PAs are not enforced adequately—lack of human and financial resources. Unplanned and uncoordinated coastal development: infrastructure development prioritized by Provincial Authorities without development standards. Planning conflicts between Provincial and National decision-makers. Fishing violations are rarely prosecuted. Community participation and public awareness are still low.	Most of Cambodia's mangroves are within an extensive PA network designated by a Royal Decree on Creation and Designation of Protected Areas (1993) under MoE and managed by Department of Conservation and Protection. PA system is based on three zones: - Core Zone: high conservation value, with fragile ecosystems/endangered species. - Conservation zone: Adjacent to core zones allowing small scale community use on NTFPs with prior consent of local administration. - Sustainable development zone: gives priority to resource use by indigenous people and communities in PAs, based on agreements/permits issued by the Administration or MoE. Outside PAs mangroves come under Min. Agriculture, Forestry and Fisheries. Fisheries Law prohibits destructive fishing practices and mangrove cutting. Multi-sectoral coastal resource issues are the responsibility of a Natl. Coastal Steering Committee which coordinates between ministries; there is also a Natl. Clean Coastal Steering Committee dealing with pollution control and safe food issues.
Malaysia	Historically State forestry management for charcoal, timber, pole wood and wood chip; later, conversion to agriculture, aquaculture, urban and port development. A high density of ships route through the Straits of Melaka (a large mangrove fringed	Mangrove protection, conservation and sustainable use, but land use changes, urban development and pollution continue.	Policies and laws are predominantly sector-based, overlapping and complex administrative jurisdiction of different departments, plus segmented laws defeat sustainable management efforts. In Peninsular Malaysia three main agencies have responsibilities for mangroves: - Forest Department of Peninsular Malaysia (FDPM) - Forest Research Institute of	State governments determine laws for mangrove management, except when international agreements are involved, which are enacted by the Federal Parliament. Some federal laws are relevant to mangroves: a) National Forestry Policy 1978 (Revised 1993) b) National Policy on Biological Diversity 1998 c) National Policy on the Environment d) 3rd National Agricultural Policy e) National Wetlands Policy 2004 Laws relevant to mangrove management in Malaysia include:

	estuary), with oil pollution from operational discharge and accidental spills a serious threat		- Malaysia (FRIM) - Malaysian Timber Industry Board (MTIB) From 2005 to 2011 FDPM planted almost 5.7 million mangrove trees.	1. Forestry Act 1982 2. Environmental Quality Act 1985 3. Land Conservation Act 1960 4. Protection of Wild Life Act 1972
Philippines	Conversion to aquaculture ponds (289,000 ha); Salt production; human settlements	Aquaculture remains the main use of mangrove habitat, followed by urban and industrial development and tourism; coastal pollution is a concern. Wood harvesting from mangroves is banned.	Department of Environment and Natural Resources (DENR) has jurisdiction over mangroves. Local Government Units have jurisdiction over some aspects of mangrove management, including conversion and community-based forestry projects.	The revised Forestry Code of the Philippines (PD 705) has various enactments as Department Administrative Orders, covering e.g. mangrove conservation and conversion, establishing buffer zones in mangrove areas, and awarding mangrove stewardship contracts. A Community-based Forest Management Agreement (CBFMA, 1995) makes provisions of tenure available for communities that want to manage their mangroves. Mangrove management, protection and development come under DENR, except within communal forests.
Singapore	Fisheries and Aquaculture; Infrastructure development; Loss of functional back-mangroves (biodiversity threat); Currently: development pressure due to very limited land availability; pollution and waste disposal; freshwater reservoirs.	Only medium to remnant patches of mangrove forest remain; largest area is in (Sungai Buloh Wetland Reserve); important for Ecotourism and research use. No dependency on traditional mangrove products.	Mangrove conservation involves mainly the National Parks Board. EIAs for development projects that may impact natural areas and biodiversity are not mandatory, but there are examples of voluntary EIAs being arranged. As a highly developed country with a well-educated population, Singapore takes its responsibilities to protect the remaining high mangrove diversity seriously.	Singapore aspired to Green City status by 2030, but only Sungai Buloh Wetland Reserve and Mandai Creek mangroves are legally designated mangrove areas in Singapore (Parks and Trees Act). Laws that may apply to mangroves are: • Protection of flora and fauna in National Parks and Nature Reserves • Protection of flora and fauna within a Public Park • Protection of flora and fauna in other Parks
Thailand	1961-1979: Forestry (charcoal), mining, harbour and dam construction; 1979-1996: Shrimp farming (70,000 ha converted in G. of Thailand); Since 1996: aquaculture, urbanization and	Now timber production and environmental protection. Ecotourism in specific locations.	<u>Before 2002</u> Royal Forest Department (Ministry of Agriculture and Cooperatives) <u>Since 2002</u> Department of Marine & Coastal Resources (Ministry of Natural Resources & Environment <u>Weaknesses</u> (from DMCR, 2009): Past authority for mangrove management solely with	NEQA Act (1992), Forestry Act (1960) National Forest Reserves Act (1964), National Parks Act (1961), various Cabinet Resolutions, especially 1991: 5-year action plan to rehabilitate mangroves begins 1996: mangrove concessions ended, existing ones phased out Prospective Policy for Enhancement and Conservation of National Environmental Quality, 1997-2016

	industries.		Government; limited public and local participation; lack of regulations supporting action on enforcement; limited cooperation between mangrove management agencies; lack of systematic and coordinated environmental monitoring; limited and poorly targeted information and publicity materials. Forestry violations are rarely prosecuted.	National Policy sets three objectives: • Rehabilitation • Conservation • Sustainable management Rehabilitation programs since 1991, but only 3,200-4,800 ha/year was achieved 1991-1999.
Viet Nam	Charcoal production during the French period, then by State Forest Enterprises; fuelwood, tannin, thatching, honey, fodder and medicines; fisheries and aquatic products.	Before 1943 the mangrove area was 408,500 ha, but decreased to less than 50% by 2001; replanting has increased the resource to 209,741 ha (2006). Present use is fisheries, aquaculture and aquatic-collecting; plus some ecotourism sites.	Ministry of Agriculture and Rural Development is responsible for forests, fisheries, aquaculture as well as agriculture. Ministry of Natural Resources and Environment is responsible for wetlands, climate change and land use registration. Provincial and District Peoples Committees evaluate and approve land and forest conversion by organizations and households, respectively. Forest Inventory and Planning Institute updates the national forest inventory every 5-10 years; mangrove status and distribution maps are available for 12 coastal provinces, but data on illegal clearing and NGO planted areas are lacking.	Viet Nam has an extensive legal and policy framework for the environment and forests; e.g. Environment Protection Law 2005. National reforestation, or 661 program 1998-2010 and all forest land must be contracted or allocated to user groups. Mangrove restoration and development plan 2008-15 has a goal to increase mangrove area to 307,295 ha. National Forestry Strategy 2006-2020 aims to increase overall forest cover to 47%, and includes 29 coastal provinces. Mangroves come under MARD jurisdiction over forests, but there is no specific department for mangrove management. The roles of MARD and MONRE regarding mangrove forests overlap considerably, as MARD is responsible for the trees, MONRE for the land. The Land Law and Forest Protection Law require MARD and MONRE to coordinate, but in practice coordination is often weak at all levels.

TABLE 11: Production and value of marine capture fisheries in Southeast Asia, by country and species group, in 2009

Major species groups	Quantity (MT)									Value (US$ '000s)
	Cambodia	Indonesia	Malaysia	Myanmar	Philippines	Singapore	Thailand	Viet Nam	Total	
Shads, milkfish, barramudi, etc.		87,320	16,773		3,553	25	54		107,825	42,575
Flounders, halibuts, soles, etc.		28,930	6,801		920		6,537		43,278	38,906
Red fishes, basses, congers, etc.		127,980	47,876		13,610	86	31,885		221,258	108,811
Jack, mullets, sauries, etc.		781,190	176,738		346,167	501	124,756		1,438,350	824,768
Herrings, sardines, anchovies, etc.		589,570	26,324		580,759	43	101,808		1,257,904	557,971
Tunas		825,660	56,512		512,058	2	47,490		1,841,172	1,218,840
Mackerels		1,258,480	408,517		599,488	243	401,994		2,768,313	1,890,401
Sharks and rays		98,750	28,276		14,264	279	16,103		157,762	174,101
Misc. fishes	55,468	461,807	412,876	1,567,519	16,920	480	543,577	1,573,100	4,870,808	3,546,808
Crabs		89,320			31,241	32	25,270		125,863	156,171
Lobsters		11,580	805		280	11	1,308		13,815	20,367
Shrimps, prawns, etc.		139,750	28,294		41,511		92,594		282,809	908,308
Misc. crustaceans	5,313	96,160	73,137		5,982	332	5,170	127,300	313,894	5,879
Oysters		333							333	712
Mussels		520			29				549	1,578
Cockles, clams, etc.		71,780	23,746		361		18,295		112,192	141,301
Cuttlefish, squids, etc.		180,680	81,136		70,361	87	112,815		305,555	825,806
Molluscs	14,527	3,080					4,881		22,288	3,902
Invertebrates		8,600	4,013		1,282		3,965	398,900	414,760	14,148
Total	**75,008**	**4,789,410**	**1,350,220***	**1,567,519**	**2,418,838**	**2,121**	**1,498,102**	**2,098,309**	**14,146,387**	**10,416,861**

SOURCE: Fishery Statistical Bulletin of Southeast Asia (SEAFDEC, 2011).

* Updated figures provided by Fisheries Management Information Division, DoF Malaysia

TABLE 12: Production from Brackishwater aquaculture and mariculture in Southeast Asia, by country and by major species, in 2009 (MT)

Brackishwater aquaculture	Cambodia	Indonesia	Malaysia	Myanmar	Philippines	Singapore	Thailand	Viet Nam	Total
Penaeus vannamei							535,090	36,000	571,090
Penaeus monodon			16,351		47,850		3,580	316,000	383,681
Chanos chanos					280,610				280,610
Aquatic Plants nei		171,958							171,958
Penaeus spp	75	402,343	57,507*	2,204			493	68,700	526,903
Anadara granosa			64,938						64,938
Perna viridis			10,596						10,596
Lates calcarifer			14,225				15,660		29,885
Crassostrea spp			2,128						2,128
Marine fishes nei		508,758	19,667*	722			3,835	142,697	672,346
Total	**75**	**1,082,700**	**180,815***	**2,926**	**328,460**		**558,444**	**564,397**	**2,694,261**
Mariculture									
Aquatic plants nei		2,537,108			165,570				2,702,678
Eucheuma cottonii					1,462,203				1,462,203
Eucheuma denticulatum					112,222				112,222
Marine molluscs nei					1,447			166,003	167,450
Perna viridis					19,936		230,678		250,614
Anadara granosa							87,854		87,854
Crassostrea spp					19,931		18,395		38,326
Marine shrimps				50,464					50,464
Others	4,825				79,153	3,286		6,000	93,264
Total	**4,825**	**2,537,108**		**50,464**	**1,860,462**	**3,286**	**316,927**	**172,003**	**4,945,167**

SOURCE: Fishery Statistical Bulletin of Southeast Asia (SEAFDEC, 2011).

* Updated figures provided by Fisheries Management Information Division, DoF Malaysia.

Policy and Institutional Settings

Former governmental policies in a number of Asian countries have actually contributed significantly to mangrove losses. Mangrove conversion for agriculture and salt farming, and some forms of integrated mangrove aquaculture actually have a long history (e.g. Tiensongrusmee, 1972; Macintosh, 1982; Aksornkoae, 1993), whereas shrimp farming has made a more recent additional and often massive impact on mangrove loss. This situation has resulted from government policies and international development assistance advocating coastal aquaculture development from the 1950s to 1970s; followed by a rush into intensive shrimp farming that began in the 1980s, fuelled by "shrimp fever" among private investors.

In Viet Nam, following the end of the war with America in 1976, demobilized Vietnamese soldiers were encouraged to convert the mangroves in the Mekong Delta to shrimp ponds within State-owned Forestry and Fishery Enterprises. Also in the 1970s, Presidential Decree 704 (Fisheries Reform Code) in the Philippines called for a rapid expansion and development of the fisheries and aquaculture sectors. Primavera (1994) cites the situation that resulted in the Philippines, where fishponds accounted for 58% of the mangrove conversion by the 1970s, as a result of the government program to build ponds with the help of international funding. Development banks were also prominent in financing shrimp hatcheries and pond infrastructure at the start of the intensive shrimp farming boom in the 1980s. Until 1996, mangrove forest areas in Thailand not already converted to shrimp farms were assigned as concessions for charcoal production, but with little enforcement of the conditions of the concession contracts.

While most Asian countries have halted further mangrove conversion to aquaculture, the mangroves that remain today are also subject to other more recent threats, including pollution and climate change, especially sea level rise.

Table 10 summarizes the current institutional arrangements for mangrove forests in each country and lists some of the key national laws and policies that pertain to mangroves. Because mangroves are forests growing in the marginal intertidal zone, jurisdiction over them is less clear than for terrestrial forests. Different ministries may have overlapping jurisdictions for mangroves. For example, in Cambodia, Ministry of Environment (MoE) has responsibility for mangroves within protected areas, while mangroves are managed by Ministry of Agriculture, Forestry and Fisheries (MAFF) in other areas. In Viet Nam, the Ministry of Agriculture and Rural Development (MARD) and Ministry of National Resources and Environment (MONRE) share various responsibilities relevant to mangroves (see Table 10).

It can be concluded that inter-ministerial coordination on mangroves frequently is inadequate. There are also issues between the national ministries and provincial (or state, or municipal) authorities over decision-making, especially regarding coastal land use. Provincial authorities tend to prioritize development over conservation, irrespective of national laws on environmental protection. In Philippines, for example, individuals can gain ownership of mangrove land by paying a real estate tax to the municipal government. Large areas of mangrove have also been taken over illegally in most countries, particularly for aquaculture. Poor delineation of Mangrove Permanent Forest Estate (Philippines), or what is generally termed Protection Forest in other countries, makes it difficult to prevent encroachment and local authorities commonly lack the capacity, or will to challenge illegal occupancy of mangrove forest land.

The seriousness of policy failures and ineffective institutional management is well summed up by a statement about coastal resources in the Philippines, which are believed to be on the verge of irreversible damage: "*The public attributes this condition to excessive pressures exerted by ever increasing population, unscrupulous exploitation, industrialization and lack of ecosystem appreciation.*" (TDA-IME Project: Philippines country report, 2012).

Despite government replanting programs, plus numerous donor-supported and private sector-sponsored projects, mangrove rehabilitation efforts have not been sufficient to offset earlier mangrove losses. Mangrove forests have not yet recovered back to more than two-thirds of their original estimated extent. The major reason is that government mangrove planting schemes have usually fallen short of their targets. In Thailand, for example, the area of planted mangroves increased by only 20,000 rai (3,200 ha) annually between 1992 and 1996, but the target area was about three times greater (40,000 ha, compared to 13,568 ha actually planted (DMCR, 2009; TDA-IME Project Thailand country report, 2012).

Another major shortcoming of mangrove rehabilitation programs has been that replanting sites have been poorly documented. Even where the data on current mangrove forest area is considered to be accurate, there is usually almost no qualitative information provided about the forest status in terms of its ecological integrity. The information on mangrove area usually does not identify healthy mangrove forest from degraded areas, or whether the forest cover is original (primary), secondary growth, or plantation mangrove.

Mangrove replanting programs have often under achieved, not only in terms of the areas rehabilitated, but also in relation to forest quality, which has an important bearing on ecological integrity. Lack of quality control over propagule or seedlings supplies for planting, and inadequate monitoring of the survival and growth of planted mangroves, are common weaknesses. Planting is often performed in straight lines with a single mangrove species for cost and propagule-availability reasons, rather than trying to mimic nature in terms of species zonation and vegetation distribution characteristics. These practices have been much criticized (Quarto, 2012). Even if healthy propagules or seedlings are planted, there is often high mortality due to insect, barnacle or algae infestations, or physical damage by tidal and current action. The results are failure, or very "patchy" mangroves that may not constitute a functional forest in ecological terms.

If mangrove ecosystems are to fulfill their full potential as providers of multiple goods and services there must be a sea-change in government policies towards effectively conserving large areas of mangrove forest, plus the marine and freshwater hydrological systems that ensure the integrity of the coastal ecosystem. Present day economic valuation estimates of each hectare of mangrove forest do not present the true (full) value of mangrove ecosystem services, especially those related to climate change adaptation and mitigation, which include food provisioning, carbon sequestration, shoreline protection, and storm and flood mitigation.

National legal frameworks commonly relate to the environment and forests in general, rather than to mangrove specifically, and enforcement of environmental, forestry and fishery regulations remains weak in most countries. There is growing interest in integrated coastal management, but this will require government agencies to move away from sectoral management. Moreover, considerable capacity development will be needed to improve coastal area planning; and significant improvements in institutional coordination and cooperation will also be required.

Most countries are interested in integrated management of the coastal zone, but appropriate governmental restructuring, together with the development of a sound understanding of integrated approaches that also incorporate ecosystem-based management, will take years to achieve. Positive changes in the way that mangroves and other coastal resources are managed will certainly require a considerable investment in institutional capacity development and training, not least by international donors and regional projects.

Recommendations

Based on this policy and institutional assessment, a number of possible actions and other recommendations are provided in Sections 5 and 6 of this report. In summary, they include the following key actions:

It is recommended that a Regional Code of Conduct on the Sustainable Management of Mangrove Ecosystems be developed, as a tool to inform government policy makers, planners, and the private sector about mangrove ecosystems.

A regional study should be undertaken to assist countries to identify national policies that may actually be contributing to mangrove loss, or which are failing to protect mangroves because of, for example, an inadequate regulatory framework, sectoral/institutional weaknesses, or a lack of enforcement capacity (or will to enforce the regulations).

Propagules of *Bruguiera gymnorrhiza*; the floating, salt-tolerant fruits and propagules of many plant species give mangroves great dispersal capabilities. (Photo credit: D.J. Macintosh.)

The familiar stilt roots of *Rhizophora* trees; root architecture may determine how well different mangrove species cope with sea-level rise. (Photo credit: D. J. Macintosh.)

The extremely rare mangrove, *Bruguiera hainesii*; this species is listed as critically endangered in the IUCN Red List of Threatened Species (2012). (Photo credit: D. J. Macintosh.)

The "white" mud crab, *Scylla paramamosain*; this species and its close relative the "black" mud crab (*Scylla olivacea*) are important commercial species that are also good indicators of mangrove-coastal fishery linkages. (Photo credit: D. J. Macintosh.)

Local people hand-catching juvenile mud crab in the mangroves, Mekong Delta, Viet Nam. (Photo credit: K. Schmitt.)

Cast net fishing in Trat, Thailand. The numerous types of traditional fishing methods in mangrove ecosystems demonstrate the importance of mangrove-fisheries linkages to coastal communities throughout Indochina. (Photo credit: S. Sriarsm.)

SECTION 3

Major Transboundary Issues and Problems

Overview

On a global scale, and especially within Indochina, the main threats to mangrove forests have been degradation and conversion, which still continue at an alarming rate, although mangrove rehabilitation efforts are partially compensating for earlier mangrove losses in a number of Asian countries. These two closely related destructive processes result from over exploitation of coastal resources (degradation) and land-use changes for development reasons (conversion), especially to agriculture, aquaculture or urban/industrial use. Alongi (2002) noted that mangrove destruction usually has a positive correlation to human population density, implying that this is the main underlying, or "root cause" of mangrove loss.

Mangrove degradation results from a wide array of human exploitation activities: extraction of wood for timber, pole wood and fuelwood, including charcoal production; collection of non-timber products; livestock grazing and fodder collection; fishing activities; and partial cutting for boat access, for constructing jetties and house pilings, and for other structures, such as fishing stakes and aquaculture cages (often made from mangrove wood). While these and other uses of mangrove products are traditional and have occurred for centuries at a subsistence level in many Asian countries (e.g. Chan, 1986; Bandaranayake, 1998), spiraling human population pressures have greatly accelerated the degree of mangrove degradation in recent decades, to the point that other valuable services such as shoreline protection, biodiversity support and long-term carbon storage, have been lost or severely compromised.

Mangrove conversion, in contrast, in the form of industrial, commercial and urban infrastructure has removed vast areas of mangrove forest permanently. Coastal roads and sea dykes both destroy mangroves and isolate other areas from their natural hydrological regimes, resulting in gradual death of the trees through desiccation or water-logging. Mangrove conversion to agricultural land, salt pans or aquaculture ponds is still potentially reversible (slow, natural regrowth of mangroves, or assisted restoration or rehabilitation may be possible), but this is often hampered by land ownership issues, even when the land seems to have been 'abandoned'.

Estimates of the global mangrove area suggest a loss of 20 to 30% since 1980 (Spalding *et al.*, 1997; Millennium Assessment, 2006; Van Lieveren, *et al.*, 2012). However, the original global mangrove cover is not known, although Spalding *et al.* (2010) suggest that it could not have been less than 200,000 km^2 Even the most recent areal estimates differ widely, from about 110,000 to above 190,000 km^2 (reviewed by Giri *et al.*, 2010). The figures of 150,300 km^2 (FAO, 2007), 152,361 (Spalding *et al.*, 2010) and 137,760 km^2 (Giri *et al.*, 2010) are close to the average based on all the reported estimates.

In conclusion, it is probably safe to assume that about one-third of the world's mangrove forests have been destroyed since the 1960s (Alongi, 2002; Donato *et al.*, 2011) and that the present total is little more than 150,000 km^2.

While the historical loss of mangroves is imprecisely known, but clearly has been tens of thousands of square kilometres, the recent annual rates of loss have been easier to quantify. Spalding *et al.* (2010) suggest that the annual average loss of mangroves decreased from just over 1% in the 1980s, to 0.66% per annum during the five years 2000-2005. While this represents a slowing of the annual rate of loss of mangroves, it is still higher than the overall average rate of forest loss globally (0.6% per annum) over the same period (Hansen *et al.*, 2010).

The importance of the Indochina mangroves is obvious from their plant diversity (two-thirds of all true mangrove species occur in the Southeast Asian region) and the fact that five Asian countries alone: India, Indonesia, Malaysia, Myanmar and Philippines share more than one-third (34.5%) of the global total area according to Giri *et al.* (2010). The same authors also mention that only 6.9% of the world's mangrove forests come within formally protected areas.

Root Cause Analysis of Key Issues

Mangrove Conversion

The six countries participating in the TDA-IME Project contributed information on the proximate causes of mangrove conversion that are summarized in the Causal Chain Analysis (see Section 5). Except for Singapore, which specified land use changes along riverbanks for reservoir construction caused by the demand for freshwater, the other countries all listed urban and/or industrial development and aquaculture as the leading causes of mangrove conversion; while a further cause of mangrove loss has been conversion for agricultural use (mainly oil palm) in Malaysia and Thailand.

The intermediate causes of mangrove conversion are shared broadly by most of the countries; namely:

1. Coastal land use changes by governments that give priority to investments in urban/industrial developments and their associated infrastructure.
2. Commercial investments on coastal land based on short-term financial considerations without regard for the economic benefits of mangroves as a common access resource.
3. Failure of governments to regulate expansion and intensification of shrimp farming.
4. Inadequate EIA procedures to ensure sound alternative land use decisions.
5. Inadequate availability or consideration of mangrove economic data, including the diversity and full value of all mangrove services.
6. Lack of community participation in land use planning and approval processes.
7. Inadequate legal instruments, or their lack of enforcement, to prevent mangrove encroachment and eventual conversion (by stealth).

The fundamental, or root causes of mangrove conversion in Indochina have been population growth and demand for natural resources; profit-driven development priorities; and in the case of Singapore alone, an inadequate supply of freshwater.

An additional future underlying cause of mangrove loss is climate change (mainly from sea level rise and climate-related hazards), which is aggravating the already high anthropogenic impacts on mangrove ecosystems.

Mangrove Degradation

A similar matrix identifying the immediate and root causes of mangrove degradation was prepared from information contributed by the TDA-IME Project countries, but because the causes of mangrove degradation were similar country to country, the Causal Chain Analysis is shown as a region level one (see Section 5).

A number of the common causes of mangrove degradation overlap with the causes of mangrove conversion. This is not surprising, because degradation and conversion are often merely different stages in the process leading to complete mangrove loss. Ong (1993), for example, suggested that "burgeoning populations are possibly the biggest cause of mangrove destruction and degradation".

It is clear that there had already been significant losses of mangrove forests before coastal shrimp farming became widespread in Asia. This is borne out by the history of mangrove conversion in Thailand, where aquaculture only became the main cause of mangrove loss after 1980; prior to this date, salt farming, agriculture and coastal infrastructure accounted for about two-thirds of the mangrove area lost (Aksornkoae, 1983). In other countries, however, most notably in Indonesia, Philippines and Viet Nam, extensive integrated mangrove-aquaculture systems have operated for much longer and they have enjoyed something of a revival more recently as pollution and disease have caused repeated economic losses for intensive shrimp farmers. The integrated mangrove-aquaculture systems do not fully convert the mangroves, but actually depend on conserving the mangrove ecosystem services that shrimp and other aquatic species depend on in nature (albeit in a highly modified and somewhat degraded form).

Unlike conversion, mangrove degradation *per se* is often a slow process - taking place over several years, or longer, from a combination of various direct and indirect causes. The result is that there are many examples in Asia of apparently intact mangrove forests included in national inventories that are actually moderately to severely degraded.

The common causes of mangrove degradation country to country are:

1. Inadequate legal instruments, or their lack of enforcement, to prevent *in situ* mangrove degradation.
2. Disregard for the environmental health of mangroves by *ex situ* aquaculture, industrial and urban developments situated adjacent to mangroves.
3. Lack of regulations, or their enforcement, to prevent land-based pollutants entering mangrove ecosystems.
4. Diversion of freshwater for agricultural use before it reaches the coast.
5. Local to transboundary transportation of garbage by tides and currents into mangrove forests.
6. Poverty-related dependency on exploiting mangrove resources for food, fuel wood and timber by local communities, leading to overexploitation.
7. Demand from coastal aquaculture farmers for juvenile shrimps, crabs and fish of mangrove-associated species; and demand for other mangrove species as aquaculture feed.
8. Market-driven demand for mangrove-associated aquatic species regarded by suppliers and consumers as high value "seafood" (e.g. mud crabs, mangrove oysters, some penaeid shrimp and grouper species).
9. Low awareness among government, private sector and the general public about the importance of mangrove ecosystem services and of maintaining ecosystem integrity.
10. Coastal erosion aggravated by climate change impacts (causing both degradation and habitat loss).

And, paradoxically:

11. Mangrove rehabilitation practices selected on the basis of low cost and short term efficiency may create crowded monospecific mangrove plantations that are more vulnerable to pest infestations.

The fundamental causes of mangrove degradation are population growth and poverty; lack of capacity or will to enforce mangrove conservation and environmental protection measures; and poor public awareness of the indirect economic values of mangrove ecosystems.

Scientific Research and Knowledge Management

It would be misleading to claim that the body of knowledge on mangrove ecosystems is weak; in fact it is quite substantial - at least in relation to the main plant and animal constituents (e.g. Tomlinson, 1986; Saenger, 2002; Hogarth, 2007). But obviously there are still gaps in knowledge on several major aspects of mangrove biology and ecology that are important to transboundary mangrove management, especially: plant genetics, species distribution, phenology and seed dispersal; life cycles of mangrove-associated aquatic species; mangrove-associated marine migratory species; and mangrove-coastal fishery linkages.

Specific research and information needs are listed in the Causal Chain Analysis (see Section 5). The broader issues relating to information, and how it is being used/not used to support policy development and public awareness about mangroves, include the following:

1. The implications of climate change for mangroves are the over-riding research and information issues of today.
2. The application of knowledge to improve the results of mangrove restoration/rehabilitation efforts is also much needed. It is also apparent that even the most basic information on the status and distribution of mangroves is inadequate (Giri et al., 2010). In particular, the data on mangrove area rarely include any qualitative information on the state of health, or degradation, of the mangrove forest. This information is vital for planning mangrove restoration/rehabilitation on a transboundary scale, yet is almost completely lacking, or not readily available.
3. While more research is obviously desirable, the need to improve knowledge management is just as important, and even more so when seen from the policy perspective. The priority is for better information-sharing and communication on mangrove-related issues at all levels, from policy-makers, to local government and the general public. (This is revealed strongly from the analysis of scientific research and knowledge management needs: see Table 23).

Relating to knowledge management, the Causal Chain Analysis (Section 5) identifies insufficient or ineffective knowledge dissemination as a common immediate cause of poor mangrove planting success. Exactly the same conclusions have been reached by MFF from five years of implementing coastal resources management projects involving multiple stakeholders (MFF, 2012). Consequently, there is a need to educate and build capacity, not only for research, but also for communicating and using the existing knowledge on mangrove ecosystems more effectively in management. In particular, this includes the need to better integrate scientific and traditional knowledge, which is a fundamental requirement for the involvement of local communities in mangrove ecosystem management.

The following sub-sections expand on these important issues and conclusions. They are based on the Causal Chain Analysis and other outputs from the TDA-IME Project workshops; the review of mangrove ecosystems in Indochina (Section 2 of this report); plus experiences from MFF and other regional programs involved in coastal management.

Gaps in Scientific knowledge

This is an almost limitless topic where mangrove ecosystems are concerned, so the focus of the TDA-IME Project was confined to consideration of the scientific research gaps relating to mangroves at the transboundary scale, especially:

- Distribution and status of all near threatened to endangered mangrove species in Indochina.
- Research to better predict the likely responses of mangroves to climate change.
- Research to document and quantify, both ecologically and economically, the potential roles of mangroves in relation to climate change adaptation and mitigation, as part of an ecosystem-based approach to coastal management.

Research gaps under research area (a) include the many practical issues associated with mangrove restoration/rehabilitation and the need to improve on seedling survival and other indicators of ecological quality achievement.

1. Factors that control species distributions, zonation, forest structure and growth.
2. Phenotypic and genetic differences within species populations growing in different localities (hence the importance of *in situ* genetic conservation).
3. Studies on reproductive phenology and fecundity to identify vulnerable species in relation to climate change. (Knowledge of the reproductive phenology of all mangrove species in a range of environments will be critical to understanding the impact of climate change on species diversity and the likely future distribution of mangroves.)
4. Also related to climate change, research is needed to understand (a) the relationship between mangrove root architecture and soil erosion control; (b) the resilience of different mangrove root systems to climate change, specifically the ability of mangrove aerial roots to supply oxygen to the below ground roots under different sea level rise scenarios.
5. Site-specific methodologies and monitoring systems to achieve long-term, cost-effective mangrove restoration/rehabilitation.

In relation to research area (b), the key transboundary research priorities were identified as follows:

1. Comprehensive valuations of all mangrove-related goods and services, including indirect and non-use (existence and bequest) values, applied on a transboundary scale using standardized methodologies.
2. Transboundary scale analyses of the relationship between mangroves and coastal to offshore fisheries, from both an ecological and economic perspective.
3. Studies on the migration and coastal-habitat dependency of endangered aquatic species (dophins; dugongs, sea turtles).

Mangroves and Climate Change

Introduction

The Intergovernmental Panel on Climate Change (IPCC) has assembled and evaluated considerable evidence of global climate change, and has predicted the probable course of climate change throughout the present century. The evidence, conclusions, and predictions are presented in detail in the IPCC Fourth Assessment Report (AR4) (Solomon *et al.*, 2007). The predictions are based on our current understanding of the mechanisms that determine the world's climate, as well as on a range of possible future courses of human action that will impact on climate change. The Fifth Assessment report (AR5) Climate *Change 2013. Impacts, Adaptation, and Vulnerability* will be released in March 2014. Without anticipating the conclusions of AR5, it is already apparent that the predictions of AR4 are being fulfilled: for example, average sea level rise is tracking the highest projections of AR4 (Hoegh-Guldberg and Bruno 2010; Nichols and Cazenave 2010).

Whatever the detailed scenario, the general predictions are:

- A rise in the concentration of atmospheric carbon dioxide;
- acidification of the oceans (lower seawater pH);
- a rise in global average temperature;
- an increase in extreme high water events and storms;
- changes in the patterns of precipitation;
- a rise in sea level.

Overall, it has been estimated that global climate change is likely to result in the loss of 10-20% of mangrove forests 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 (Gilman, *et al.*, 2006; Alongi, 2008).

Vulnerability and Resilience of Mangrove Ecosystems

Because of their unique position at the interface between land and sea, mangrove ecosystems are vulnerable to changes in atmospheric, hydrological and meteorological conditions, and in particular, to rising sea level. In many cases, there are strong linkages between mangroves and other potentially vulnerable ecosystems such as coral reefs. The latter are more vulnerable than mangroves to rising sea temperature; hence mangroves might be affected indirectly by sea temperature change because of its effect on coral reef ecosystems (e.g. coral bleaching).

Conversely, mangrove ecosystems have attributes that can promote resilience to climate change and hence they are regarded as an integral component of ecosystem-based adaptation to climate change for many coastal communities in Asia (Macintosh *et al.*, 2009). Ecosystem resilience can be defined as "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to retain essentially the same function, structure, identity, and feedbacks" (Folke *et al.*, 2004). Essentially, mangroves are a dynamic, rather than a 'steady-state' ecosystem, and therefore they are capable of adapting to a variable environment.

An ecosystem impacted beyond its capacity for resilience will be replaced by an alternative one: this transition may be gradual or abrupt. Many examples of sudden ecosystem transitions have been described (Folke *et al.*, 2004, Seddon *et al.*, 2011). However among the factors promoting resilience in mangroves are below-ground nutrient reservoirs; high rates of nutrient flux and decomposition, resulting in rapid biotic turnover; complex biotic controls enabling internal reuse of resources; and simple tree architecture allowing rapid reconstruction after damage (Alongi 2008). The root systems of mangrove trees also show a remarkable capacity to grow adaptively to suit local conditions, like tidal level and soil texture.

Three broad categories of ecological properties support resilience in various ways: **diversity**, **connectivity**, and the **capacity to adapt** (Bernhardt and Leslie 2013).

Diversity

Species-rich communities are often more productive, use resources more efficiently, recover more rapidly from disturbance, and deter invasive species (Folke *et al.*, 2004 and Bernhardt and Leslie, 2013). In mangrove communities, for example, when mature trees die through storm damage, or for other reasons, the gap is more or less filled rapidly by a succession of species with differing dispersal and shade-tolerating capacities (Putz and Chan, 1986). The mangrove fauna typically includes a variety of species of ecologically similar sesarmid crabs, for example, that play a key role in energy and nutrient cycling. Functional redundancy implies the capacity of one species to compensate for another following disturbance (Bernhardt and Leslie, 2013), hence the number of similar sesarmid species promotes resilience within a mangrove community.

Species diversity is, in general, directly related to habitat area. The logarithmic species-area relationship in mangroves has been shown for mangrove tree species and mangrove fauna (Simberloff and Wilson, 1970; Saenger and Bellan, 1995). The causal nature of the relationship between mangrove area and faunal diversity has also been demonstrated (Simberloff, 1976).

Conclusion: a reduction in mangrove area could be expected to reduce biodiversity, and hence resilience to the impacts of climate change.

Connectivity

High species diversity implies a broad range of connections and interactions between species, thereby promoting ecosystem stability. Ecosystems with few links have been shown to be vulnerable to the removal of any given species. Although it has yet to be demonstrated empirically, it seems likely that species connectivity within mangrove habitats promotes resilience. It can be concluded further that connectivity between mangrove habitats is important in maintaining diversity within habitats. Moreover, connectivity between mangroves and other ecosystems, such as the open sea, coral reefs or rivers, may also promote resilience across ecosystems.

Conclusion: transboundary mangrove management would help to maintain connectivity between mangrove habitats; and between mangroves and other coastal ecosystems, which must benefit ecosystem resilience to climate change overall.

Adaptation

Mangrove trees and the mangrove fauna may experience considerable daily fluctuations in temperature, salinity and inundation: in general, they show remarkable physiological tolerance or resistance to environmental conditions. The trees have well-described mechanisms to exclude, tolerate, or excrete salt, for example (Tomlinson, 1986). Mangrove crabs combine great salinity tolerance with an ability to retreat into burrows to avoid temperature extremes (Edney 1961, Jones, 1984; Eshky *et al.*, 1995,). However, the limits to this tolerance are reflected in the latitudinal constraints on the distribution of mangrove forests (Hogarth, 2007), which are determined primarily by temperature.

Conclusion: in general, the ecological characteristics of mangrove communities endow them with considerable resilience against changing environmental conditions, as demonstrated by their exposure to wide daily fluctuations in temperature, inundation and salinity.

Mangrove Ecosystem Responses to Climate Change

While mangroves are considered to be resilient, when the impact of environmental stressors increases beyond a certain threshold an ecosystem may change irreversibly to a different state. The following analysis documents how mangroves might respond to the predicted changes in climate.

Rise in atmospheric CO_2

Carbon dioxide concentration in the atmosphere has already risen from 275-285 ppm (parts per million) to 379 ppm. The rate of rise is increasing, and atmospheric CO_2 is predicted to double by 2100, to 730-1020 ppm (Solomon et al., 2007; Hoegh-Guldberg and Bruno, 2010).

A direct effect of an increase in atmospheric CO_2 may be increased productivity and growth, but varying between species and depending on other environmental circumstances (Gilman *et al.*, 2008). In experimental situations, usually involving seedlings or young plants, experimentally raising CO_2 generally increases water-use efficiency, enhances growth, and results in earlier reproductive maturity, although species respond differently, and in some cases growth may actually be reduced (Ball and Munns, 1997; Ball *et al.*, 1997; Farnsworth *et al.*, 1996; Snedaker and Araújo 1998). In an area subject to changes in the pattern of precipitation (see below), altered freshwater availability would interact with changes in water use efficiency.

At an ecosystem level, the effect is difficult to predict, but might involve the expansion of mangroves into areas where their distribution is at present restricted by high salinity, together with some shift in species composition. In salt marsh communities, raised CO_2 levels have been shown to stimulate below-ground productivity, resulting in increased elevation of the soil surface: if this applied also to mangroves, it would enhance their ability to counter sea level rise (Langley *et al*., 2009).

Ocean acidification

An estimated 25 – 30% of total anthropogenic CO_2 emission has been absorbed into the surface layers of the world's oceans. The ocean's uptake of CO_2 lowers pH (raises acidity) and reduces the concentration of carbonate ions. Ocean pH has decreased steadily by 0.02 pH units per decade over the last 30 years, with an overall decrease of 0.1 pH units since the pre-industrial period: bearing in mind the logarithmic nature of the pH scale, this equates to a 30% increase in H^+ ion concentration. It is estimated that ocean pH will fall by a further 0.3 – 0.5 pH units by 2100. This represents "larger pH changes over the next several centuries than any inferred from the geological record of the past 300 million years" (Caldeira and Wickett 2003). Lower pH will be accompanied by a decline in carbonate ion concentration (Caldeira and Wickett, 2003; Orr *et al*., 2005; Doney, 2010).

The impact of acidification and reduced carbonate ion concentration is hard to predict because of the complexity of ocean processes. Calcifying organisms such as corals, molluscs, crustaceans and some planktonic species are likely to be the most affected. Molluscs and crustaceans are also important in mangrove ecosystem function (although mangrove crabs tend to be relatively lightly calcified species). Probably more significantly, there are vital ecological linkages between mangroves and coral reefs involving the movement of species and nutrients between these two habitats. Thus, if coral reefs struggle to survive in a lower pH environment, then mangroves will also be affected.

Temperature rise

Over the last century, global average surface temperature has risen by ~0.74°C: the rise by 2100 may be as much as 1.1 – 6.4°C (Solomon *et al*., 2007).

Photosynthesis, and other variable processes such as leaf production, generally increase with rising temperature. Most mangrove species have temperature optima, which differ between species. In Australia, most species peak between 21 and 28°C: the higher-latitude *Avicennia marina* has an optimum of 20°C, while the more tropically-distributed *Xylocarpus* peaks at 28°C (Hutchings and Saenger, 1987). Rising temperature might result in some alteration of species composition. However, as most mangrove trees experience daily temperature fluctuations of an order of magnitude greater that the predicted rise in average temperature, it is unlikely that the effect of increased temperature will be significant.

The global distribution of mangroves is defined by temperature, their latitudinal extremes being almost exactly delimited by the position of the 20°C winter isotherm. Thus, a rise in global average temperature might permit a modest geographical expansion of mangroves north and south of the equator. This would probably be limited by intermittent cold events, and also by topography: in the Indian Ocean, for example, the Asian land mass prevents northward expansion. Northward shifts in the distribution and abundance of marine species are already well documented (Walther *et al*., 2002; Hawkins *et al*., 2008). Species would respond differentially, hence some alteration in species interaction and ecosystem structure might result. However such effects on mangrove ecosystems are likely to be slight, except possibly at the northern and southern limits of mangrove distribution.

Storms

An increase in the frequency and severity of tropical storms is predicted (Solomon *et al*., 2007). Severe storms cause defoliation, tree death, and soil erosion (McCoy *et al*., 1996; Gilman *et al*., 2008). Storms remove older and taller trees selectively such that full forest recovery may take considerable time: mangrove ecosystems recover from intermittent events over a period of years. An increase in the severity and frequency of storms would limit the prospects for and rate of recovery, with potential long-term consequences for ecosystem integrity.

Increased precipitation

A global increase in average precipitation of up to 25% is predicted, with considerable regional variation (Solomon *et al*., 2007).

Since mangrove trees require fresh water, increased precipitation will generally benefit mangroves, allowing, for example, increased growth and reproduction, and improved propagule survival and settlement. The outcome might therefore be a local expansion of mangrove forest area and increased productivity.

Sea level rise

Global average (eustatic) sea level is predicted to rise by 0.18 – 0.59 metres by 2100: some predictions suggest a rise of up to 1 metre (Solomon *et al*., 2007; Nicholls and Cazenave 2010). About 75% of this rise is attributed to thermal expansion of the sea, the remainder being due to the melting of ice.

Eustatic sea level rise (SLR) is a global average: the actual sea level rise depends on regional and local factors. These include tectonic movement (the northern Bay of Bengal, for instance, is rising to the west and subsiding to the east); soil subsidence; local sedimentation and erosion; soil expansion through underground root production; soil compaction; and soil shrinking and swelling resulting from variation in sub-surface groundwater flow (Blasco *et al*., 1996; Cahoon and Hensel, 2006).

Although some studies show sedimentation keeping pace with current rates of local SLR, others conclude that the majority of mangrove sites have not been keeping pace (Alongi, 2008; Gilman and Ellison, 2010).

Where local shore levels do not keep pace with local SLR, lower-shore mangroves will be inundated more frequently, with adverse effects on plant growth and survival (Ellison and Farnsworth, 1997). Conditions further up the shore may improve with increased tidal inundation. The overall result, therefore, could be contraction of mangrove distribution on the seaward side, and expansion up-shore and inland (López-Medellín *et al*., 2011). Similarly, mangroves in river estuaries might become distributed more up-river than at present.

Upshore migration of mangroves would be possible only where this is permitted by topography, and if expansion is not blocked by human activities such as agriculture, roads, or other infrastructure. It has been estimated that 20 – 70% of intertidal habitat might be lost in ecologically important North American bays, where landward habitat expansion is curtailed by topography and by sea walls, over the next 100 years (Harley *et al*., 2006). No equivalent estimates are available for Indochina, but coastal roads in most countries, and dykes in Viet Nam and Malaysia especially, represent a significant barrier to the landward migration of mangroves.

Uncertainties in prediction: the known unknowns

There are many uncertainties in predicting the probable impact of global climate change on mangrove ecosystems:

1) The ecological response to shifting environmental variables may be non-linear
Most predictive models assume approximately linear, proportional, response to a shift in environmental variables, such as temperature, over the range in question. This may not be the case: as temperature rises, the ecological response may be greater than linear.

2) Environmental variables may be interactive
In general, predictions focus on a single aspect, such as increased temperature or atmospheric CO_2 levels. Ecological responses to simultaneous change in several

environmental variables "are unlikely to be additive, and their combinational dynamics are not likely to be linear" (Walther, 2010; Montoya and Raffaelli, 2012;) these factors make detailed prediction difficult.

3) The relationship between biodiversity and ecosystem function in mangroves is unclear

Climate change affects species differentially. This means that the relative abundance of species, or the actual species present within a particular mangrove habitat, is likely to change. In one recent assessment, eleven of 70 mangrove species were reported to be facing an elevated threat of extinction (Polidoro et al., 2010). Change in species composition is likely to affect ecosystem function, and the goods and services provided. It has been established, for instance, that the density and species mix of mangroves affects seedling survival and recruitment, and the ability of mangroves to trap sediment, and consequent elevation of the soil surface (Huxham et al., 2010). In temperate mesocosm experiments, invertebrate species richness was found to affect the release of nitrogen (as NH_4^+) into the water column (Bulling et al., 2010).

Lack of clear understanding of how mangrove ecosystems function makes it impossible to make clear predictions, but it seems likely that biodiversity loss would reduce mangrove ecosystem resilience; and, bearing in mind the species-area relationship (see above), it is likely that smaller areas of mangrove would show lower biodiversity, hence lower resilience.

4) The connectivity between separate mangrove habitats is not clearly understood

The degree to which physically separate mangrove stands are mutually interdependent is not understood. It has been demonstrated that the number of species of mangrove in one isolated population is directly related to the distance from other mangrove populations (Saenger and Bellan, 1995). A species at the extreme of its range may depend for recruitment on propagules dispersing from more 'core' areas with higher reproductive rates. Depending on the species, mangrove propagules can float for up to 100 days before rooting, so their dispersal potential is considerable. Thus, a mangrove area under stress may have a low *in situ* reproductive rate, but survive because of propagule immigration from more flourishing areas.

5) Mangroves are connected with other ecosystems

Mangroves are connected with other ecosystems: coral reefs, the open sea, rivers. Interaction may be by nutrient or energy flow through soluble or particulate matter, or through the movement of fish, invertebrates, birds or mammals. Climate change impact on one ecosystem impacts other ecosystems. A clearer understanding of the connectivity between different ecosystems is essential to making detailed prediction of the effects of climate change on mangrove forest ecosystems.

6) Will the impact of climate change be incremental, or catastrophic?

Predicting a linear response by an ecosystem to incremental change in a single environmental parameter is relatively straightforward. However, a linear response cannot be assumed; and, where several parameters change in parallel, where their effects are not additive, or where complex interactions occur, accurate prediction becomes virtually impossible. What is clear, however, is that the various components of climate change will, separately or in conjunction, place mangrove ecosystems under increasing stress. At some point resilience of the ecosystem will be insufficient to resist this stress, a threshold is passed, and progressive deterioration of the ecosystem will lead to its collapse, or an abrupt shift to an alternative more stable state, such as mudflats, saltmarsh or saline blanks.

Although some possible ecological indicators of such impending shifts have been proposed, most thresholds in ecosystems have been detected only after they have already been crossed (Bernhardt and Leslie, 2013). There is clear palaeo-environmental evidence of just such a shift in mangroves in the Galápagos approximately 2000 years ago, when the accumulating effect of slow environmental changes culminated in abrupt replacement of mangroves by a microbial mat (Seddon *et al.*, 2011).

Uncertainty in detailed predictions of the effects of global climate change should not detract from the conclusion that global climate change is an established fact and will continue for the foreseeable future; and that ecosystems - particularly mangroves - have been and will be affected significantly. The uncertainties in prediction affect only the timescale and extent of the impacts from climate change.

Conclusions

There is a compelling need to develop transboundary cooperation to assess the vulnerability of mangroves to climate change at regional level across Indochina, since climate change is a growing concern to all countries.

Transboundary mangrove conservation management is particularly necessary to protect biodiversity, and therefore the resilience of mangrove ecosystems to climate change.

Conservation efforts on a transboundary scale will help to ensure that fragmented areas of mangrove that are too small to be self-sustaining, and degraded or stressed areas of mangrove habitat that have lost their reproductive integrity, can still survive. This will be possible because of the high dispersion capacity of mangrove plant propagules, mangrove macrofauna and mangrove-associated fish species from ecologically healthy mangrove habitats.

Cooperation on a transboundary scale will require:

a) Monitoring of a number of specific sites in relation to climate change and other stressors on mangroves, e.g. sediment starvation (Pernetta, 1993).

b) Spatial mapping to plot the vulnerability of mangroves to climate change based on an agreed standard vulnerability index (an example proposed by Ellison, 2012 is provided in Section 4).

c) Regionally coordinated efforts to help countries improve the management effectiveness of existing Marine Protected Areas, especially those containing significant areas of mangrove and other coastal habitats.

d) Identification of mangrove sites that could be designated as new transboundary Protected Areas.

An area of abandoned shrimp ponds being rehabilitated by planting mangroves, Pranburi, Thailand. (Photo credit: D. J. Macintosh.)

An integrated mangrove-shrimp pond in the Mekong Delta, Viet Nam, although this form of aquaculture can be sustainable, it commonly leads to at least partial degradation of the mangrove ecosystem. (Photo credit: D. J. Macintosh.)

SECTION 4

Priority Areas for Future Interventions

Based on the preceding literature review, plus findings of the Causal Chain Analysis and country field visits, several priorities can be identified for transboundary management to maintain, or restore the integrity of the region's mangrove ecosystems and reduce further mangrove forest loss:

1. Halting any further loss of the region's remaining natural/semi-natural mangrove forests.
2. Improving the areal estimates of mangrove forests and including qualitative assessment of ecosystem health based on common, regionally agreed criteria (e.g. vulnerability index).
3. Expanding and improving the restoration/rehabilitation of degraded mangrove ecosystems.
4. Communicating the values of mangrove ecosystems to policy-makers and general society more effectively.
5. Sharing and replicating/up-scaling successful models of mangrove management and sustainable use involving local communities (e.g. co-management, stewardship).
6. Sharing and replicating/up-scaling successful livelihood enhancement opportunities, to reduce poverty among traditional coastal communities and make them less dependent on mangrove resources (e.g. mangrove eco-tourism projects).
7. Assessing the vulnerability of mangrove ecosystems to climate change on a local to regional scale as part of a region-wide mangrove ecosystem monitoring program.
8. Researching mangrove-related issues of transboundary importance:
   a. Valuation of mangrove goods and services;
   b. Mangrove-fisheries ecological linkages and their economic value;
   c. Migration and coastal habitat dependency of endangered aquatic species (dolphins, dugongs and sea turtles);
   d. Phenotypic and genetic differences between mangrove species populations and how species interconnectivity can support ecosystem resilience;
   e. Techniques to achieve long-term, cost-effective mangrove rehabilitation;
   f. Implications of sea-level rise and global warming/climate change on mangrove structure and function (e.g. on mangrove root growth and reproductive phenology).

Restoring/Rehabilitating Mangroves

Introduction

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, scientists, international and national organizations, local NGOs, 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, restoration, creation of mangrove bio-shields, and mangrove education and recreation. Similarly, the project implementing agencies (particularly INGOs, NGOs and CBOs) have also displayed diverse interests, priorities and management approaches.

Mangroves are rather easy species to plant, either as fruits or propagules collected directly from mature trees just before they fall, or as seedlings reared in dedicated nurseries. There are numerous reviews and technical manuals covering mangrove planting techniques in Asia by country and by species (e.g. Field, 1988; Lewis, 1998; Thinh *et al.*, 2009; Quarto, 2012). However, merely planting mangrove propagules or seedlings does not guarantee that ecosystem integrity, or even a viable forest, will result.

There have been many failed mangrove restoration attempts, particularly those initiated soon after the Asian tsunami of 2004. Failures have been due to various factors, with poor site selection, inappropriate species selection for planting, and failure to reconnect the planted area to its near original hydrological regime, being among the most common ones (MFF, 2012).

The terms restoration and rehabilitation are commonly used as synonyms, whereas they have related (but quite distinct) meanings *in senso stricto*. Lewis (1990) defines restoration to be "specifically any process that aims to return a system to a pre-existing condition whether or not this was pristine." Rehabilitation is a more general term used to "denote any activity that aims to convert a degraded system to a more stable condition" which may not be the same as its historical one.

Critics of assisted restoration involving mangrove planting have advocated for natural or "ecological" restoration using a simple five step process explained by Lewis and Marshall (1997). This takes a strong ecosystem-based approach in recognizing that mangrove forests are part of a larger coastal ecosystem complex that includes other habitats and plant communities, including mud flats, sea grass beds and salt flats that might otherwise be considered of "low value" (Lewis, 1998).

While the principles of natural restoration are sound, the time scale required is often much longer than local communities, or the projects and programs financing mangrove restoration, can afford. In an attempt to bridge the gap between waiting for nature, compared to the other extreme of planting mangrove seedlings in monoculture formation, some experts now recommend mimicking nature by e.g. planting seedlings in clusters around the remaining mature trees (e.g. Thinh, 2009).

Among the numerous mangrove restoration/rehabilitation 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 issues, such as management responsibilities and user rights.

Overall, because of the highly project-oriented nature of most mangrove planting activities, there has been very little critical evaluation of the results, or compiling of the lessons learned. However, recently, an extensive review of experiences with mangrove restoration/rehabilitation, especially since the 2004 Asian tsunami, was conducted (MFF, 2012). This study identified the following actions to help ensure the successful restoration (or rehabilitation) of mangroves and their long-term management and sustainable use:

Actions to Ensure Success

- Consultation with, followed by participation of local communities in all mangrove restoration, protection and management activities, with the aim of imparting knowledge, and providing technology transfer for mangrove restoration and sustainable management.

- 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.
- Providing mangrove restoration and environmental awareness and educational programs 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 programs 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 arrangements 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 management.

The MFF (2012) review also identified some precautions that should be taken with ecologically sensitive sites.

- 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.
- 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.
- In the particular case of abandoned aquaculture farms, and other recoverable former mangrove areas, techniques that can restore the hydrological and soil conditions back to their near-to original state are a prerequisite for successful restoration/rehabilitation.

Protecting Biodiversity

The available evidence points to the importance of transboundary scale mangrove conservation and restoration as the most viable way to conserve biodiversity and protect endangered migratory species like the Irrawaddy dolphin. Connectivity between mangrove habitats across political boundaries is important for biodiversity conservation, while larger areas of mangrove forest seem to have a positive correlation with fishery yields, even if the causal relationship is less apparent (see Section 2).

Manson *et al.* (2005), for example, showed that the catch per unit effort for key mangrove-associated fish and crustacean species is correlated with mangrove area and perimeter (i.e. the total length of mangrove-fringed coastline). Thus, it would be highly desirable for countries, provinces and districts to prioritize mangrove conservation and restoration sites in a manner that maximizes the transboundary extent of mangrove forests. The logical conclusion is that this would contribute to both biodiversity conservation and fisheries production, while also giving a greater measure of protection (or at least habitat availability) to endangered migratory species.

Involving Local Communities in Mangrove Management

The many services that mangrove forests in Indochina provide include their crucial role as 'bio-shields' for the protection of people and their assets from physical and climatic impacts, including erosion, storms and flooding. The often narrow belt of mangroves which protects the coast from these forces must also be safeguarded against human threats (figure 3). But this cannot be achieved by looking at the mangrove belt in isolation, i.e. a sectoral approach under the jurisdiction of a single authority. Protection must be part of an integrated coastal management (ICM) approach which involves all stakeholders in a participatory process; and which includes adaptation measures to climate change. Furthermore, all the measures must be site specific and appropriate.

FIGURE 3: The coastal zone of Soc Trang, southern Viet Nam. The photograph shows (left) mudflats; and (center) a narrow mangrove belt (around 200 m wide), with severely eroded areas in the foreground and beyond; (right) a sea dyke with sluice gates and aquaculture ponds. (Photo credit: K. Schmitt.)

However, development and the unsustainable use of natural resources are threatening the protection function of the mangrove forest belt. This situation is exacerbated by the impacts of climate change, particularly the increased intensity and frequency of storms, floods and by rising sea levels. In order for mangrove forests to fulfil their protection function they must be protected from human impacts such as destructive fishing methods, logging and encroachment.

Mangrove protection is often the role of the national Forest Department and its local agencies. However, these authorities may lack the man-power or the financial resources to do this in an effective way. In Viet Nam, mangrove protection through individual ownership of small plots of mangrove forest, or forest protection contracts, has been tried as an alternative. The effectiveness of these approaches was analyzed by Joffre and Luu (2007) and Pham (2011). They concluded that individual household-based forest protection contracts did not result in more effective protection and management of mangrove forests. In fact, the opposite was the case, because the amount paid per year and hectare was not enough to actively engage people in forest protection activities. Instead, it encouraged them to generate their own income by cutting the forest for fuel wood rather than protecting it. The experience in Viet Nam with forest protection contracts clearly shows that mangrove protection and management, which relies on individual ownership of small plots of forest, does not work in a situation where a highly dynamic coast is protected by only a narrow belt of mangroves (as in figure 3). In such a situation, forest protection obligations are more important than rights to forest management (Sikor and Nguyen, 2011). Approaches which focus on mangrove protection do not address the needs of those who depend on natural resource collection from mangrove forests for their livelihood.

One way to avoid the problems associated with a mangrove forest protection by the conventional forest authorities, or through individual ownership/responsibility for small forest plots as in Viet Nam, is to directly involve those people whose livelihoods depend on the use of natural resources from the protective mangrove forest belt. If these people can develop ownership and ensure sustainable use of resources, then effective protection can follow. This goal can be achieved through co-management, an approach that has already proved successful for the management of natural resources worldwide (for a comprehensive overview of co-management see Borrini-Feyerabend et al., 2004, 2007).

Co-management

The main principles of co-management are summarized below. Two case studies describing examples of mangrove co-management in Soc Trang Province in the Mekong Delta, Viet Nam and in Koh Kong Province in Cambodia are provided in Annexes 2 and 3, respectively.

Co-management, or shared governance (see text box below and Table 13 below on the use of these terms), is a type of management/governance in which decision-making power, responsibility and accountability are shared between governmental agencies and other stakeholders, in particular the indigenous peoples and local communities who depend on the natural resources culturally and/or for their livelihoods (Borrini-Feyerabend, 2011).

> International conservation polices and agreements developed over the last 15 years not only talk about participation, culture and equity, they also deal with governance. In contrast to Management, which is about *what to do*, Governance is about *who decides what to do*. Therefore, the term shared governance should be used when talking about co-management to avoid a one-sided focus on *what to do* and to include the important element of *who decides what to do*. In this report, the term co-management is used with the clear understanding that it includes shared governance (Borrini-Feyerabend, 2011).

Four main governance types can be identified in relation to who holds management authority and responsibility and is held accountable for the crucial decisions regarding the designated area and natural resources at stake: (1) the government (and its agencies at various levels); (2) various actors together; (3) the owners of the concerned land and natural resources; and (4) the concerned indigenous peoples and local communities (Table 13) (Dudley, 2008; Borrini-Feyerabend, 2010).

TABLE 13: Governance types from the IUCN protected area matrix (Dudley, 2008; Borrini-Feyerabend, 2010).

Governance by government			Shared governance[1]			Private governance[3]			Governance by indigenous peoples and local communities	
Federal or national ministry or agency in charge of management	Sub-national ministry or agency in charge of management	Government-delegated management (e.g. to an NGO)	Transboundary management[2]	Collaborative management (various forms of pluralist influence)	Joint management (pluralist management board)	Declared and run by individual land-owner	...by non-profit organizations (e.g. NGOs, universities, co-operatives)	...by for profit organizations (e.g. individual or corporate land-owners)	Indigenous territories and conserved areas – declared and run by indigenous peoples	Community conserved areas, declared and run by local communities

[1] Shared governance also referred to as co-management.

[2] A particular form of shared governance concerns transboundary areas and natural resources (e.g. water bodies, migrating fauna, fisheries), which involve at least two or more governments and possibly several other local actors.

[3] Land and natural resources that are under individual, NGO or corporate control or ownership.

Co-management, in the context of protection and sustainable natural resource management of mangrove forests, can be described as a partnership agreement in which a resource user group obtains the right to sustainably use natural resources on a defined area of state-owned land with Protected Forest status, while being responsible for the sustainable 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. To make this work in practice, resource users and local authorities jointly negotiate a formal agreement on their respective management roles, responsibilities and rights.

Co-management can be achieved through a process of negotiation where representatives of governments, communities and other actors meet, exchange their views, find an accord about aims and solutions and develop a formal co-management agreement about sharing authority, responsibility and accountability regarding the area and natural resources at stake. A shared governance arrangement will ensure that stakeholders not only deal with technical and practical matters when implementing the agreement (what to do about the natural resources at stake), but also about decision-making processes and institutional issues.

The co-management process and guiding principles

The co-management process can be described in three main phases: 1) organizing for the partnership; 2) negotiating co-management plans and agreements; implementing and 3) revising the plans and agreements: "learning-by-doing" (Borrini-Feyerabend et al., 2004), or adaptive management.

The following key conditions are a prerequisite for carrying out the co-management process:

1. All stakeholders (from provincial to village level) must support joint governance and adaptive management.
2. All stakeholders understand that, through the participatory process and an agreement, the co-management group must get the right to manage mangroves jointly with relevant local authorities without the need for landownership.

3. Members of the co-management group must depend on resources from the mangroves for their livelihood.
4. Local authorities must be willing to play their role in joint governance and therefore cannot delegate their role entirely to the co-management group.
5. The site must be suitable for mangrove co-management. This means that the existing purpose of the mangrove forest must be coastal protection and sustainable use of resources to meet the livelihood needs of the local population. And it must be ensured that there are no plans for development of the coastal zone for other purposes such as oil exploitation, wind farms, or industrial use.
6. A legal option must exist to formally establish a co-management group which is empowered to negotiate with local authorities/state agencies and technical departments.

The key elements, or characteristics, of co-management, compared with other forms of forest governance and management (see text box below) can be summarized as:

> Co-management and Community Forestry: Community forestry is forest management, usually with a focus on silviculture, including timber and non-forest timber product utilization, enrichment of natural forests, afforestation of bare land and benefits from environmental services. It has a clear emphasis on management and on forest land allocation. In community forestry the government's role is often that of a technical advisor, not a joint decision-maker. However, in recent years, issues related to governance have become more and more important in community forestry. Therefore, community forestry can also be described as a form of community governance, which is different from co-management, as the latter involves shared management, or shared governance.

(1) a participatory negotiation process; (2) a co-management agreement; and (3) a pluralistic governance institution, or integrated management board (Borrini-Feyerabend, 2011).

Co-management is a local, small-scale (village level) solution to natural resource management which must be <u>appropriate</u> and <u>site-specific,</u> and must be implemented as part of an <u>integrated-</u> or <u>ecosystem-based</u> approach. In a situation where forest protection obligations are more important than rights to forest management (this is the case for mangrove protection forests in Viet Nam, for example), transfer of tenure to communities possesses little value. Also community forestry (or community governance) would not be the most effective way of maintaining and enhancing the protection function of mangrove protection forests, while at the same time providing livelihoods for local communities. In such a setting shared governance (or co-management) should be applied.

Co-management is a site-specific solution, recognizing that each site is different in terms of its socio-economic conditions and natural resource use patterns, and this must be considered when applying the co-management process. Whether or not co-management is appropriate for a given site also depends on its bio-physical and socio-economic conditions and resource-use patterns. The site must be suitable for mangrove co-management (see key condition 5 above). Co-management as an approach is suitable for many protection forests in Viet Nam, as they are often located in front of the sea dykes and will remain protection forest for the foreseeable future. Whereas, in localities where mangroves cover large areas in sheltered sites, or inland from the sea dyke system, other management regimes can be applied to effectively manage the mangroves as have been documented for Malaysia by Kamaruzaman and Dahlan (2008) and Viet Nam by Minh *et al.* (2001).

The three main phases of the co-management process explained by Borrini-Feyerabend *et al.* (2004) can be also be described in a four-step process, as follows (and illustrated in figure 4).

The four steps are:

1) consultation and organization - this step will end with the formal establishment of a resource user group;
2) a series of negotiation meetings - these will end with a formal agreement between the local authorities and the resource users;
3) implementation of the agreement; and
4) monitoring and evaluation (adaptive management or "learning by doing"). Note: this is both a step in the process and at the same time, a principle of co-management.

In addition to the four steps four key principles must be applied during the co-management process. These are the guiding principles which apply to co-management in general, but care must be taken to account for site-specific differences both in terms of soci-economy and ecology.

Everything has to happen within the framework of an integrated coastal management (ICM) approach, and whatever is done must be done in a participatory way (Participation) following four steps. Zonation of the forest into areas in which different management regimes are applied increases the effectiveness of management and protection.

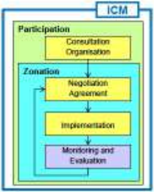


FIGURE 4: Overview of the four steps of the co-management process and the four key principles.

Potential for transboundary implementation

It is important to note that the mangrove co-management principles and process described above, and the co-management case studies from Viet Nam and Cambodia provided in annexes 2 and 3, are essentially village level approaches to natural resource management which must be appropriate and site-specific in a situation where mangrove forest protection obligations are (or become) more important than rights to forest management.

As also explained in the previous sections, appropriate and site-specific considerations are not restricted to the ecological setting alone; they must also include socio-economic conditions, e.g. differences in culture, language or religion within the community, as well as the overall political frame work. Therefore, while co-management is essentially a local solution to protecting mangroves, it could be implemented along entire coastlines and across boundaries following the guidelines and principles described here providing the six key conditions are in place. This will ensure not only effective, site-specific and appropriate protection and sustainable use of the mangroves as part of an integrated approach to coastal management, but also because co-management must be applied on a site-specific basis, it will also respect the differences in socio-economic and political conditions of different countries, or provinces/districts, rather than aiming for a simple "one solution fits all" approach.

Poverty Reduction

A recent report prepared for the Bay of Bengal Large Marine Ecosystem (BOBLME) Project (Townsley, 2010) highlights the prevalence of poverty among communities dependent on coastal and marine resources. Particular social or ethnic groups are commonly associated with this dependence. Many of the Khmer ethnic minority group in Viet Nam's Mekong Delta, for example, are heavily dependent on hand-collecting of minor aquatic products from the mangroves, and activity which they undertake on a subsistence and opportunistic basis. This form of subsistence exploitation of mangrove resources is also still widespread in many other coastal areas and communities of Indochina (e.g. Macintosh *et al.*, 2002).

Coastal areas still offer a relatively diverse range of what Townsley (2010) refers to as "resource niches". These niches create many opportunities for exploitation, but also for conflict. They are, or were until quite recently, open-access or common property resources, which mean that they are particularly important for the poor, who typically have very limited alternatives to subsistence fishing and gleaning. However, the traditional rights of poor or ethnic groups over coastal resources are increasingly threatened by other user groups, while their low social status also limits their access to political power and representation. In addition to their lack of empowerment, Townsley (2010) also noted that those who depend on coastal and marine ecosystems for their livelihoods are influenced by a wide range of sectoral policies and policy processes; he concluded that: "The impacts of conflicts between policies in different sectors are often felt most strongly in coastal areas because of the high and multiple development pressures exerted on them."

It is irrefutable that the combination of over-fishing and loss of mangroves and other coastal habitats important in the life cycles of fishery species has severely affected the livelihoods of coastal communities across the Asian region. Thus, the poor are forced to continue to exploit mangrove resources in a manner that is further degrading the resource base. The result is that the other ecosystem services that mangroves can provide are also being diminished.

Despite the severity of these problems, good insight and experience has been gained by regional programs, like BOBLME/FAO and MFF/IUCN, on how to overcome them. The following assessment made by an APFIC/FAO consultative group on improving the livelihoods of small-scale fishers and aquaculture households aptly sums up the nature and scope of the approach needed (APFIC, 2009):

- Investment in effective resources management and governance and maintenance of ecosystem health are the major foundations or prerequisites for supporting and improving the livelihoods of small-scale fishers and aquaculture households.

- Policy development following the principles of the Code of Conduct for Responsible Fisheries and using the ecosystem approach to fisheries and aquaculture aims at achieving a balance between ecological well-being, human well-being and good governance. There is a close linkage between the policy objectives of economic development, providing for food, income and sustaining livelihoods and fisheries management, conserving biodiversity, habitats and resources.
- There is a need for specific policy development that addresses the small-scale sector and the promotion of diversification within it. This should reflect and respect the rights of the small-scale fishers, particularly in key areas such land tenure and access.
- Improved incomes and livelihood security is a clear need for many resource-dependent fishing communities and small-scale aquaculture communities. Incomes are declining and the natural resource base is becoming increasingly degraded.
- Diversification is constrained by lack of coherence between national and local development planning and serious capacity and skills gaps. Local budgetary allocation/resourcing is rarely directed at natural resources and weak governance undermines many initiatives.
- Small-scale fishers and aquaculture communities are marginalized in development as they are often considered too poor and too difficult to work with. They frequently lack collateral or assets and there may appear to be limited options to diversify.

These needs and constraints also apply to mangrove-dependent households, the majority of whom are similarly reliant on small-scale fishing and/or aquaculture. Mangroves for the Future (MFF) has found that small projects led by local NGOs or community groups can achieve positive results, when they address some of these issues in combination. Mangrove restoration activities alone may receive little community support, but when combined with alternative livelihood opportunities and measures to empower the communities, and/or enhance governance over coastal resources, many MFF projects were successful. These projects have generally combined coastal habitat conservation, and/or mangrove restoration/rehabilitation, with improved fishery-based livelihoods, aquaculture, or alternative (non-fishery based) livelihoods (MFF, 2011).

MFF has also gained many other valuable lessons from the implementation of small grant projects, as summarized below:

- Recognizing the importance of empowering mangrove-dependent households, many of the projects involved collective action by forming, or supporting existing community groups, such as fisher cooperatives, womens' groups and wildlife clubs for youths.
- Projects that helped introduce non-fishery-based livelihood activities to fisher households revealed the need to support marketing, as well as the production side of the activity.
- Taking time to understand local conditions and attitudes can be vital to project success, especially when dealing with very traditional communities suspicious of external influences.
- Educating people requires much thought and perseverance, and educational materials must be well designed to best suit their intended audiences.
- Project activities sensitive to climatic or weather factors, such as mangrove planting, horticulture and agriculture, must be timed very carefully and risk factors (for example, flooding) taken into account. Project managers should also be aware that local people may be unavailable to participate in project activities during peak seasons for agricultural or fisheries-related work.
- It is important to engage with local government; "engagement" ranged from simply informing local authorities about project activities, to setting up joint committees to facilitate multi-stakeholder involvement in local resource use planning. The level of engagement depended on whether the aim was just to seek official endorsement of the project, or to actually involve local authorities in its management. In many cases,

the most desirable outcome was for the project to help build trust between local government agencies and the local communities (project beneficiaries). In some projects, most notably in Thailand, creating solidarity among several involved communities helped attract greater government support.

All of the above experiences and lessons learned agree well with the general guidance on the best approaches to achieve poverty reduction provided by various donor organizations and NGOs. The DFID guidelines (see text box below) are still among the most appropriate as an approach to improving the livelihoods of poor coastal dwellers.

People-centered Approach to Poverty Reduction (DFID, 1999)

The livelihoods approach puts people at the centre of development. This focus on people is equally important at higher levels (when thinking about the achievement of objectives such as poverty reduction, economic reform or sustainable development) as it is at the micro or community level (where in many cases it is already well entrenched).

At a practical level, this means that the approach:

• starts with an analysis of people's livelihoods and how these have been changing over time;

• fully involves people and respects their views;

• focuses on the impact of different policy and institutional arrangements upon people/households and upon the dimensions of poverty they define (rather than on resources or overall output *per se*);

• stresses the importance of influencing these policies and institutional arrangements so they promote the agenda of the poor (a key step is political participation by poor people themselves);

• works to support people to achieve their own livelihood goals (though taking into account considerations regarding sustainability).

Sustainable poverty reduction will be achieved only if external support (i.e. support from outside the household) works with people in a way that is congruent with their current livelihood strategies, social environments and ability to adapt.

People – rather than the resources they use or the governments that serve them – are the priority concern. Adhering to this principle may well translate into providing support to resource management or good governance (for example). But it is the underlying motivation of supporting people's livelihoods that should determine the shape of the support and provide the basis for evaluating its success.

Awareness, Education and Communication

This section deals with the transfer of data, information, ideas, opinions and experiences between individuals and institutions within society; between organizations; and between countries. Because the terminology is often used imprecisely, the following definitions (see text box below) are provided (based on MFF, 2011).

In addition, *local knowledge (or traditional wisdom) is defined* 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 (Tanawat and Boonplod, 2012).

Some of the key underlying causes of mangrove loss and degradation relate to low awareness of the environmental and economic services that mangroves provide, compounded by poor communication between the holders of scientific knowledge, policy-makers, the private sector and traditional coastal resource users. These diverse stakeholders require different forms of data and information, and they obtain their information and communicate in quite different ways. Scientists communicate their research findings, including highly technical data, in academic journals that are not usually accessed by non-scientists, or at scientific conferences. Policy-makers and the private sector use other formal, but distinct, communication channels.

Best practice	A method or activity which has been demonstrated to be effective.
Capacity development	A process in which an individual or organizations skills or abilities are improved.
Communication	The act of conveying information, ideas or feelings through a medium such as speaking or writing.
Data	Discrete and objective facts, measurements, or observations that can be analyzed to generate information.
Dissemination	A method of communicating knowledge where messages are sent to a receiver.
Explicit Knowledge	Knowledge that can be codified in formal, systematic language and shared in discussion or writing. Examples include a document, publication, training course manual, a website article, or a report of research findings.
Information	Data that has been categorized, analyzed, summarized, and placed in context in a form that has structure and meaning.
Knowledge	A combination of data and information—to which is added expert opinion, skills, and experience—and results to a valuable asset that aids decision making. Also referred to as 'know-how'; organized information; information with judgment; or the capacity for effective action. Knowledge may be tacit, explicit, individual, and/or collective. It is intrinsically linked to people.
Knowledge Management	The systematic management of processes enabling vital individual and collective knowledge resources to be identified, created, stored, shared, and used for benefit. Effectively integrates people, process, and technology. Its practical expression is the fusion of information management and organizational learning.
Learning	The process of acquiring knowledge or modifying behaviour based on experience.
Lessons learned	Concise descriptions of knowledge derived from experience that can be communicated through methods and techniques, such as story-telling and debriefings, or summarized in databases. These lessons often reflect on what was done well or poorly, what one might do differently, and how one might improve processes to be more effective in the future.

In contrast, coastal communities have traditional (often verbal) forms of communication, supplemented by external knowledge, usually from NGOs and other local sources, including community to community learning. In a study of local knowledge management on mangroves among coastal communities on the Andaman Sea coast of Thailand, Tanawat and Boonplod (2012) found that most villagers learn themselves from occupations related to mangroves, such as fishing, or they learn from others in their community. Some villagers also gain knowledge from experts and documents at meetings or workshops they attend, or from visits outside their communities sponsored by external agencies. These include exchange programs in which one community with substantial local expertise about mangroves acts as a learning center, or "best practice" community, for others.

Most coastal communities also share similar patterns of disseminating and sharing knowledge through monthly village meetings, mangrove planting activities, youth camps, and group discussions. In Muslim communities, Islamic concepts and rituals, for example Friday prayers, strongly influence ideas and their transfer.

In the same study, Tanawat and Boonplod (2012) also documented the knowledge gaps, or additional knowledge, required by the communities based on a questionnaire survey. (The term "aquatic life banks" refers to community-managed mangrove nursery or spawning areas, where e.g. juvenile mud crabs are released, or egg-bearing females are held until they release their larvae.)

- Mangrove cultivation technique for windbreaks (85% of respondents);
- 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%).

Consistent with the above analysis, community leaders and local experts advised that they most desired more knowledge on sustainable mangrove utilization to provide economic incentives for community members, and on strengthening community groups and organizations.

This example from southern Thailand is valuable, because it illustrates the specific sources of knowledge, communication methods and learning needs among typical mangrove-dependent village communities. It also reveals that the community members and leaders are quite aware of the importance of mangroves, and what knowledge they would like to gain most in order to improve the quality and sustainable use of mangrove resources. These points are frequently overlooked by development projects and programs, which tend to focus on "awareness-raising" and "capacity building", rather than on identified learning needs and the practical application of new knowledge.

Many of the MFF small grant projects, for example, placed emphasis on awareness-raising, but some project implementers seemed unclear as what "awareness" actually is, or what "awareness- raising" means? Moreover, the often produced awareness-raising materials (e.g. leaflets, posters) are not an end in themselves, and will be more effective if they are linked to longer term goals via a communications plan (MFF, 2011).

The MFF (2011) study also reported on other important conclusions from its many projects regarding existing knowledge, communication and learning needs:

Climate change and gender equality: in almost 80 projects covering six countries the understanding of the role of coastal ecosystems (such as mangroves) in climate change adaptation or mitigation seemed to be very limited. Similarly understanding of gender equality issues was inadequate; when reporting on gender aspects, many project managers tended to do so in the form of generalities or stereotypes about the roles of men and women.

Existing knowledge: project managers could have taken more advantage of the existing knowledge available on good practices; e.g. for mangrove restoration. For example, in Thailand mangrove research centers are a good source of knowledge and expertise. Conversely, local expertise on achieving livelihood improvement, and tackling gender equality issues, was inadequate. When reporting on gender aspects, many project managers who mentioned women and women's groups tended to do so only in the form of generalities or stereotypes.

Providing 'open access' to information: access to information is essential to empower decision -making. To achieve this, projects should make information materials 'open access' (i.e. free to copy for non-commercial purposes) and to make them available to all interested parties. The project managers reported that information materials were frequently used by groups such as school environmental clubs, environmental NGOs, and youth groups during their various events. If made available, environmental messages in the form of songs, videos, radio spots and other media will continue to reach audiences for a considerable time after the project ends.

Communicating effectively: the Small Grant projects achieved impressive results regarding communications, generating coverage in the media (print, radio, TV and online); they also developed a large range of promotional material, including DVDs, t-shirts, pamphlets, posters and wall calendars, as well as training manuals and other educational materials. However, not enough consideration was given to understanding the profile and information needs of the target audiences for these various communication products. It is especially important to provide information in a relevant form.

Project back-stopping: carefully targeted back-stopping, linked to capacity building, could significantly improve the performance of future SGF projects, particularly in management-related areas, such as project reporting. Thus, MFF should give further consideration to the types and levels of backstopping that would most benefit local project managers and other stakeholders. This recommendation applies particularly to the MFF cross-cutting themes of gender equality, climate change considerations and effective communications, which often were not well understood by project managers.

Sharing information: it is clear that project managers can learn a great deal from one another if effective information-sharing mechanisms are in place. In addition to exchange visits, where practical, MFF should give consideration to the use of online and social media tools, as a means of facilitating the sharing and exchange of information between projects.

Valuing Mangrove Ecosystems and Financing their Sustainable Use

Although they represent less than 0.5% of the world's forest area, and only 0.8% of tropical forests by area, mangroves have considerable ecological importance as the primary productivity base of an often rich and complex ecosystem, and also as 'ecosystem engineers', creating and modifying the physical and geochemical environment in which many other species live (Gutiérrez *et al.*, 2013).

It is hard to assign quantitative economic values to mangroves, but one frequently cited estimate is USD 10,000 per hectare per year, or USD1.6 x 10^{12} globally for mangroves (Costanza *et al.*, 1997). Wells (2006) and Spalding et al. (2010) suggest an average of USD 2,000 to 9,000 per hectare per year (at 2007 equivalent values) for large areas of mangrove that are already being utilized by adjacent human populations. Much higher values have been reported for some particular locations in Southeast Asia, with the value of shrimp fisheries alone reaching USD 14,000 to 17,000 per hectare of mangroves (UNEP, 2007). Converting all the estimates to 2013 equivalent values would of course increase the figures further. In addition, Carbon sequestration by mangroves has global significance: one estimate is that mangroves account for a total worldwide carbon storage of 4-20 Pg, that is up to 20 billion tonnes, or roughly equivalent to 2.5 times annual global CO_2 emissions (Donato *et al.*, 2011; Siikamäki *et al.*, 2012).

In terms of their economic significance in Indochina, there are few estimates of the total value of mangroves, regionally or nationally, but it is recognized that mangroves are of major importance to tropical and subtropical coastal communities. On a local scale, their socio-economic value can be very high to mangrove-dependent households, even when the monetary value appears to be only modest. Among the major goods and services provided by mangroves are:

- direct exploitation for timber, fuelwood, charcoal, forage for domestic animals, food, medicines and other minor products;
- primary sources of aquatic food species and species important for aquaculture;
- provision of shelter and nursery habitat for other species, including those that are the basis of coastal finfish and crustacean fisheries;
- coastal protection against soil erosion and flooding;

- protection, as 'bio-shields', against typhoons and tsunamis, absorbing wave and wind energy (and hence effective for mitigation against some of the expected effects of climate change);
- education and ecotourism (important on a more location-specific basis).

The provision of these mangrove goods and services is predominantly local, and varies considerably between localities. Thus, mangrove loss or degradation is felt primarily locally and severely in the case of mangrove-dependent communities. However, because of the interconnectedness between mangrove areas, and between mangroves and other ecosystems - seagrasses, coral reefs, the open sea, rivers - mangrove, economic valuations should be attempted at transboundary and regional scales.

Recent reviews by Salem and Mercer (2012) and Vo *et al.* (2012) provide comprehensive analyses of the estimated economic values for mangrove ecosystem services based on previously published studies dating from the 1990s (e.g. Lal, 1990; Ruitenbeek, 1992; Sathirathai, 1998). They also identify limitations in the methodologies used for ecosystem valuation and compare the diverse economic data that have been generated using the different methods applied. A recent manual on the economic valuation of mangroves, including methodology for the economic assessment of alternative mangrove management options, is also available (Bann, 2010), as well as an earlier review of mangrove economic valuation methods and results by Spaninks and van Beukering (1997), plus guidelines on similar valuation methods for wetlands and coastal resources by AWB (1991) and Barnton (1994).

Ecosystem services are defined by the Millennium Assessment (2005) as *"the benefits provided by ecosystems to humans, which contribute to making human life both possible and worth living"*. Another definition of the term that is more applicable to mangrove ecosystems is given by Vo *et al.* (2012): *"ecosystem service comprises of all the goods and services provided by natural and modified ecosystems that benefit, sustain and support human well-being"*. Unfortunately, human society emphasizes the "market-delivered" elements of well-being and judges value almost exclusively from market prices (TEEB, 2010). This explains why the non-marketed services provided by ecosystems have consistently been over-looked.

The above issue is the most crucial one for policy choices affecting mangroves. Sathirathai (2004), for example, pointed out that in Thailand, because many mangrove ecosystem services are not market-based, they have not been considered in development decision-making; decisions have been based on commercial considerations only. Indirect values important to traditional mangrove users, especially the mangroves' coastal fisheries support function, have largely been ignored by national land-use policy-makers. In her study in Surat Thani, southern Thailand, she showed that conversion of mangroves into a shrimp farm is financially viable as a commercial decision by the owner, but is not economically viable from the view point of society (Sathirathai, 1998).

Another crucial consideration in the present analysis, with major implications for a future Strategic Action Plan for transboundary mangroves in Indochina, is the argument put forward by Ronnback *et al.* (2003) that rehabilitation of coastal ecosystems inevitably will be more expensive than preserving existing mangrove habitat. Ronnback (2007) also found that traditional mangrove users in Kenya derived significantly more environmental services from natural mangroves compared to replanted ones.

In other cases, including Asia, however, where extensive mangrove habitat loss or degradation has already occurred, affordable rehabilitation methods are needed to restore the diminished ecosystem services (Vo *et al.*, 2012). Evidence from studies in Cambodia, Malaysia and Thailand also shows that aquatic biodiversity and productivity can be almost as high in rehabilitated sites as in mature mangroves (e.g. Ashton *et al.*, 2003). Moreover, in these and other Asian countries, there are only vestiges left of what can be considered natural mangrove forest. Nonetheless, one important conclusion is that priority should be given to conserving the remaining natural/semi-natural mangrove forests, rather than focusing on restoration/rehabilitation.

The conclusions reached by Vo *et al.* (2012) are also particularly relevant to transboundary mangrove management because different countries, with different social, economic and institutional make-ups, are involved, such that local conditions will determine the values of mangrove ecosystem services. They point out the need to: (a) undertake site specific valuations of ecosystem services; (b) standardize the definition of each ecosystem service and its valuation methods; and (c) strengthen the link between ecosystem valuation and policy-makers. The first two points relate to methodology and are relevant to consideration of further research needed to improve transboundary mangrove management. The third is the most important as it addresses the fundamental question of how to ensure that decision-makers actually make use of economic valuation data?

Development decisions are still usually based on cost-benefit analyses, not ecosystem values; thus Vo *et al.* (2010) suggest that a tool for accessing the economic values of a particular ecosystem is needed. They also advocate for economic valuation of all the ecosystem's goods and services (i.e. TEV) because society gives more attention to financial figures and quantities.

The challenge of communicating more effectively with decision-makers about the value of mangroves was raised earlier by Gilbert and Janssen (1998). They cautioned that part of the problem may be that ecologists have not communicated their knowledge adequately to decision-makers. Thus, on the one hand there is a need to conduct more comprehensive valuation studies that clearly show the linkages between mangrove ecosystems and economic indicators of human well-being; but on the other, a need to more effectively communicate and apply the findings to improve coastal area policies and management in practice (Emerton, 2006).

The analysis by Salem and Mercer (2012) covers 44 previous studies with a total of 149 mangrove ecosystem service observations, with the great majority (74%) coming from Asia. They categorized the observations under 10 ecosystem service headings, with the mean, median and ranges derived from these studies expressed in USD per hectare of mangrove per year (see Table 14).

The mean values for forestry and recreational uses are high and similar (each is around USD 38,000 ha/year), while fisheries is slightly below USD 24,000/ha/year. However the median values for the 44 estimates used in the analysis present a very different picture, with the non-use value (including existence and bequest values) being by far the highest at over USD 15,000 ha/year, followed by indirect use values for water/air purification and waste assimilation (USD 5,801 ha/year) and for coastal protection (USD 3,604 ha/year). While this is the most complete analysis of mangrove economic valuation data available, it also reveals the extreme variation among the data, as shown by the lowest and highest estimates for each product or service category (Tables 15 and 16). This highlights not only the effect of applying different valuation methods, but also that mangrove ecosystem service values are highly country and site-specific. For example, countries with higher per capita GDP value coastal protection and carbon sequestration more highly than lower GDP countries. Moreover, there is also great variation in the reported farm gate prices for even basic products, like mangrove timber and blood cockles, on a country to country and location to location basis (UNEP, 2007).

TABLE 14: Ecological mangrove functions, economic goods and services, types of value, and commonly applied valuation methods

Ecological function	Economic goods and services	Value type	Commonly used valuation method(s) *
Flood and flow control	Flood protection	Indirect use	RCM and MP
Storm buffering / sediment retention	Storm protection	Indirect use	RCM and PF
Water quality maintenance /	Improved water quality	Indirect use	CVM
Nutrient retention	Waste disposal	Direct use	RCM
	Commercial fishing and hunting (food)	Direct use	MP and NFI
Habitat and nursery for plant and animal species	Recreational fishing and hunting	Direct use	TCM and CVM
	Harvesting of natural materials (wood, fodder, food, medicines, etc.)	Direct use	MP and NFI
	Energy resources	Direct use	MP and NFI
Biodiversity	Appreciation of species existence	Non-use	CVM
Carbon sequestration	Reduced global warming	Indirect use	RCM
Natural environment	Recreation, tourism	Direct use	CVM and TCM
	Existence, bequest, option values	Non-use	CVM

SOURCE: Salem and Mercer (2012). The Economic Value of Mangroves: A Meta-Analysis. Abbreviations represent: market prices (MP), production function method (PFM), travel cost method (TCM), contingent valuation method (CVM), replacement cost method (RCM), and net factor income (NFI).

TABLE 15: Quantities of products provided by mangrove forests (per ha per year).

Product and units	N	Mean	Std. Dev.	Min	Max	Median
Fish, shellfish, molluscs (Kg) *	29	539	748	10	2,500	126
Shrimp (Kg)	22	146	119	6	340	109
Timber (Kg)	3	5,976	6,658	289	13,300	4,340
Timber (m^3)	15	6	4	1	13	5
Fuel wood, charcoal (Kg)	6	5,140	11,393	6	28,370	511
Fuel wood, charcoal (m^3)	7	102	102	2	230	92
Carbon (Mg)**	34	5.27	15.41	0.02	90.5	1.69

Modified from Salem and Mercer (2012). The data show the number of estimates (N) used to calculate the Mean (± standard deviation) and Median value for each product; the lowest (Min) and highest (Max) estimates are also shown;

* Two observations also include shrimp. ** Mg = metric ton (10^6 g).

Country and regional estimates for the annual economic value of goods and services per hectare of mangrove forest were estimated for the South China Sea region by UNEP (2007). The summary results from the UNEP study are shown in Table 17. The data were weighted to eliminate the effect of price variation for a particular product within each country. The results illustrate the great disparity between countries in terms of which mangrove goods and services were most valued, and the per hectare values assigned to them. The estimated total value for mangrove goods and services in the South China Sea region was around USD 5.2 billion per year, with about 50% of this total accounted for by Indonesia.

TABLE 16: Summary statistics for mangrove valuations by type of service (USD/ha/ year)

Service	N	Mean	Min	Max	Median
Fisheries	51	23,613	10.05	555,168	627
Forestry	35	38,115	18.00	1,287,701	576
Coastal protection	29	3,116	10.45	8,044	3,604
Recreation & tourism	14	37,927	1.74	507,368	1,079
Nutrient retention	1	44	-	-	-
Carbon sequestration	7	967	39.89	4,265	211
Nonuse	6	17,373	3.77	50,737	15,212
Biodiversity	1	52	-	-	-
Water and air purification/ waste assimilation	4	4,748	12.43	7,379	5,801
Traditional uses	1	114	-	-	-
Total	149				

Modified from Salem and Mercer (2012), abbreviations as in Table 15.

TABLE 17: Weighted mean national and regional values for annual production of goods and services by mangroves bordering the South China Sea.

Mangrove Goods	Cambodia	Malaysia	Philippines	Thailand	Viet Nam	Regional
Timber	779.05	9.59	202.61	0.00	10.91	**73.46**
Firewood	17.35	0.00	66.21	108.90	292.93	**2.89**
Poles	0.00	0.00	2.34	0.00	0.00	**0.00**
Charcoal	71.79	0.00	0.82	2.42	0.00	**0.45**
Leaves/grass foods (Thatch, fodder)	13.06	0.00	1.90	0.00	0.00	**0.27**
Fruit/propagules	0.00	0.00	0.00	0.00	0.00	**0.00**
Bark (tanning & dyes)	0.00	0.00	0.00	0.00	0.00	**0.00**
Medicine	0.00	0.00	0.00	0.00	0.00	**172.52**
Sap (sugar, alcohol, acetic acid)	0.00	0.00	0.00	0.00	0.00	**0.00**
Wood for	0.00	0.00	0.00	0.00	0.00	**0.00**
Fish capture	0.00	0.00	180.80	208.86	280.41	**253.64**
Fish fry	0.00	0.00	0.00	51.11	0.00	**37.43**
Eels	0.00	0.00	0.00	0.00	0.00	**33.31**
Crab capture	0.00	0.00	12.52	22.38	0.00	**165.46**
Prawn capture	0.00	0.00	11.81	108.37	0.00	**213.19**
Shellfish collection	0.00	0.00	2.08	388.47	0.00	**89.26**
All Fisheries resources	0.00	3,632.95	0.00	0.00	0.00	**813.64**
Insect and larvae collection	0.00	0.00	0.00	0.00	0.00	**0.00**
Worms	0.00	0.00	0.00	0.00	0.00	**43.86**
Wildlife	0.00	0.00	0.00	0.00	0.00	**16.19**
Zooplankton	0.00	0.00	0.00	0.00	0.00	**0.00**
Jellyfish	0.00	0.00	0.00	0.00	0.00	**0.00**
Honey & wax	0.00	0.00	0.00	0.00	0.00	**0.00**
Algae	0.00	0.00	0.00	0.00	0.00	**0.00**
Total value of goods USD per Ha	**882.18**	**3,642.54**	**479.62**	**926.42**	**483.96**	**1,664.97**
Mangrove Services						
Ecotourism	0.00	0.00	0.00	0.00	0.00	**43.26**
Nursery Function	0.00	0.00	0.00	0.00	0.00	**673.25**
Sediment retention	0.00	0.00	0.00	0.00	0.00	**66.42**
Coastal Protection	0.00	0.00	0.00	2,198.48	0.00	**443.88**
Windbreak	0.00	0.00	0.00	0.00	0.00	**7.65**
Carbon Sequestration	0.00	0.00	0.00	69.40	0.00	**69.29**
Oxygen Production	0.00	0.00	0.00	0.00	0.00	**2.88**
Option Value	0.00	0.00	0.00	0.00	0.00	**60.73**
Aesthetic Value	0.00	0.00	0.00	0.00	0.00	**10.95**
Total value of services USD per Ha	**0.00**	**0.00**	**0.00**	**2,268.08**	**0.00**	**1,207.23**
Grand Total Goods and Services	**882.18**	**3,642.54**	**479.62**	**3,194.51**	**483.96**	**2,872.20**
Total Area of Mangrove Ha	**72,350**	**503,100**	**28,016**	**62,616**	**156,600**	**1,089,136.00**
Value of Total Annual Production USD	**63,826,022**	**1,836,107,388**	**13,436,103**	**199,407,796**	**71,091,633**	**3,128,286,711**

SOURCE: UNEP (2007). Note: zero values mean that no farm gate price could be found to value the product, or it is not used in the country concerned.

For the four countries represented in both the South China Sea region and Indochina (Cambodia, Malaysia, Philippines and Viet Nam) the per hectare values range from USD 882 to 3,643, with a total resource value of USD 2.15 billion per annum (from Table 17). However, with the exception of a value for coastal protection in Thailand, these estimates are of the direct value of mangrove goods only; and, moreover, they are believed to be conservative (J. Pernetta pers. comm.). They are, however, quite consistent with Dixon's (1989) pioneering estimate that the average forestry and fishery benefits alone from mangroves are USD 500 to 2,500 per hectare per year.

The UNEP (2007) study is also valuable because it provides a framework (as in Table 17) for assessing mangrove goods and services specifically in the Indochina region. Table 17 also reveals that there is a lack of economic data for many even quite common mangrove products in some countries; and data is even more deficient in relation to the value of mangrove services.

Following the 2004 tsunami, and with the apparently increasing frequency and severity of severe weather events, plus other impacts caused by climate change, the need to reconsider and improve on the indirect and non-use value estimates for mangroves has become a widely recognized priority in coastal development, but actual progress has been slow.

Studies before the Asia tsunami considered that the storm protection function of mangroves had a value of around USD 50 per hectare in Viet Nam (Tri *et al.*, 1998) and USD 80 in Sri Lanka (Batagoda, 2003). Whereas, Sathirathai (1998) put the value of mangrove coastline protection and stabilization in Thailand at USD 3,000/ha/year, and the carbon sequestration value at USD 100/ha/year. A much higher carbon sequestration value of USD 1,810 ha/year was assumed for the mangroves on the west coast of Peninsular Malaysia (MPP-EAS, 1999). It is clearly difficult to apply such widely varying economic estimates to give a meaningful overall estimate of mangrove ecosystem value in Indochina.

Non-use values of mangroves are even harder to quantify and the reliability of methods based on the concept of "willingness to pay" have a number of short-comings (e.g. Turner *et al.*, 1994). The MPP-EAS (1999) study in Malaysia applied a non-use value for mangroves of USD 11,040 per ha per year, while Bann (1999) derived an estimate of almost USD 7,500 per hectare per year for the non-use values specifically for the mangroves in Johor.

Of particular relevance to the TDA and priorities for a future Strategic Action Plan, Salem and Mercer (2012) advise that future valuation studies should also report on the health of the mangroves, since this will strongly influence their true economic value. Similarly, Salem and Mercer note the importance of describing the management system, e.g. for forestry or fisheries production, as obviously this has a major bearing on the yields (and therefore values) of mangrove-derived goods like wood, fish and shellfish. Their recommendations fit well with those given earlier in this report that qualitative assessments of mangrove forests should be made, rather than only areal estimates. For both ecological integrity and economic valuation reasons, mangrove habitat quality must be investigated and reported on a transboundary scale.

Assessing Mangrove Vulnerability to Climate Change

In the longer term, reducing the impact of global climate change requires global action to address its causes, particularly in relation to CO_2 emissions. Mitigating the ecological effects of climate change, in contrast, depends on local to regional action based on an understanding of the type of threats to the natural environment, plus assessment of the relative vulnerability of different areas and ecosystems to those threats. Appropriate management action can then follow.

The impact of climate change on mangroves in different locations will depend on the environmental setting, plus other factors such as tidal range, sedimentology, salinity regime, community composition, and shore profile (Ellison 2012). In most areas, sea level rise is likely to have the greatest impact. Key factors to take into account in any assessment of climate change in coastal areas are relative sea level rise (RSLR), sedimentation rate, and shore topography.

Relative Sea Level Rise is a function of overall sea level rise, modulated by rising or falling of the land level, and by net sedimentation levels within the mangroves. Overall sea level rise is predicted by the IPCC survey (Solomon et al., 2007). Uplifting or subsidence of the site as a whole may be caused by tectonic action or sediment compaction (as, for example, in the Ganges Delta: Blasco et al.,1996). Assessment of relative sea level rise can involve tidal gauge data or three-dimensional mapping using techniques such as LIDAR (Light Detection and Ranging), with comparison of historical data, or repeated assessments to establish rates of change.

Sedimentation rate If this is not sufficient to keep pace with sea level rise, a site is at greater risk of destruction. Sedimentation rate can be measured directly by installing permanent vertical stakes against which net accretion can be measured periodically.

Shore topography A shallow slope indicates a given RSLR will affect a greater horizontal area than a steeper one. Shore gradient may be assessed by standard surveying, or more technical methods such as LIDAR.

RSLR may result in the upshore/inland migration of mangroves. An indication of whether this process is occurring may be gained by assessment of whether mangrove losses are occurring at the seaward fringe, and expansion at inland fringe, possibly at the expense of other vegetation such as saltmarsh communities. Historical records, such as aerial photographs or satellite imagery, may already be available to assess mangrove landward migration. Local knowledge can also provide valuable information.

The establishment and periodic assessment of permanent upshore/downshore transects can be used to monitor any landward shift by mangroves. However, mangrove upshore migration may be limited by either shore topography or the presence of anthropogenic barriers: agriculture, roads, and buildings. These must be taken into account in vulnerability assessments.

Other aspects of climate change affect mangrove ecosystem function and health more generally (as do non-climate-related impacts). There are numerous established methods of assessing forest coverage, biodiversity, photosynthesis, productivity and other important ecosystem functions. To discern patterns and changes in these, an appropriate selection of sites, fixed sampling areas, transects or quadrats needs to be established, with periodic repeated assessments at standardized times of year.

Much of the value of ecosystem assessment methods lies in between-site comparison, plus time sequence analysis, and these approaches are particularly important in assessing ecosystem vulnerability to climate change. Consequently, standardized methods and procedures, applied similarly across space and time, are crucial for monitoring purposes, and they should be applied at country, transboundary and regional scales.

Ellison (2012) presents a comprehensive framework for the vulnerability assessment of mangroves, in which standard assessment methods are discussed in detail, key variables of mangrove habitats measured by those methods are systematically categorized, with semi-quantitative figures assigned to different levels of impact (an example is shown in Table 18). These figures can then be combined to give an overall assessment of each site's vulnerability.

The appropriateness and applicability of the Ellison scheme has been demonstrated in disparate mangrove sites, in Cameroon, Tanzania and Fiji (Ellison 2012). It also proved to be a valuable approach in assessing the vulnerability of mangrove habitats in the Indochina. Such methods are suggested as a good starting point from which to develop a regionally-agreed framework for assessing the current status and vulnerability of the Indochina mangrove forest ecosystems.

TABLE 18: Codes used to record mangrove ecosystem condition

Code	Condition	% Canopy Cover	Example Features of the Mangrove Habitat
1	No or slight impact	76-100	Fairly continuous canopy of trees but possibly some gaps and regrowth. Only isolated damage to trees or saplings.
2	Moderate impact	51-75	Broken canopy of trees with lower regrowth and recruitment areas. Some trees cut and stripped.
3	Rather high impact	31-50	Tree canopy uneven; majority of the area are not showing regrowth; bare mud.
4	High impact	11-30	Only a few trees remaining at canopy height. Extensive clearance and some recruitment, large areas of bare mud.
5	Severe impact	0-10	Extensive clearance to bare mud, little recruitment, few trees remain alive.

Modified from: Ellison (2012).

Actions to Mitigate Climate Change Impacts on Mangrove Ecosystems

Maintenance of healthy mangrove ecosystems, and the goods and services derived from them, depends primarily on safeguarding mangrove forests in the face of the multiple impacts of climate change. In terms of an effective management strategy, this translates into supporting those features of mangrove ecosystems that promote resilience, as discussed earlier in this report. Some important ecosystem management strategies to support mangrove resilience in the face of climate change have been summarized by Bernhardt and Leslie (2013) (see Table 19).

A related list of management strategies to promote mangrove resilience, but with more emphasis on socio-economic considerations, was suggested by McLeod and Salam (2006) (see Table 20).

TABLE 19: Management strategies to enhance mangrove resilience.

Resilience component	Ecological mechanism	Management strategies
Diversity	Functional redundancy	Limit overharvest; manager at multiple spatial scales; reserves in areas of high species diversity
	Response diversity	Limit overharvest; protect heterogeneous habitats
Connectivity	High connectivity within habitat	Extract across trophic levels to maintain intact interactions, or limit extraction
	Population connectivity	Prevent habitat fragmentation; create reserve networks, restore degraded habitats
	Ecosystem connectivity	Protect ecologically connected habitats (e.g. coral reefs, seagrass beds); limit nutrient pollution; manipulate hydrology (e.g. river flow)
Adaptive capacity	Plasticity	Maintain genetic diversity and habitat heterogeneity
	Dispersal ability	Protect (or create) dispersal 'corridors' or 'stepping stones', particularly along climate gradients
	Habitat movement	Facilitate landward shift of mangroves by habitat preparation; creation of new mangrove habitat
	Population size	Maintain large and/or connected networks of habitats, managed for large effective population size
	Genetic variation	Manage for evolutionarily significant units; maintain large reserve areas; restore with individuals from climatically diverse populations

Modified from: Bernhardt and Leslie (2013).

TABLE 20: Ten Strategies Managers Can Apply to Promote Resilience.

No.	ACTION
1	Apply risk-spreading strategies to address the uncertainties of climate change.
2	Identify and protect critical areas that are naturally positioned to survive climate change.
3	Manage human stresses on mangroves.
4	Establish greenbelts and buffer zones to allow for mangrove migration in response to sea-level rise, and to reduce impacts from adjacent land-use practices.
5	Restore degraded areas that have demonstrated resistance or resilience to climate change.
6	Understand and preserve connectivity between mangroves and sources of freshwater and sediment, and between mangroves and their associated habitats like coral reefs and sea grasses.
7	Establish baseline data and monitor the response of mangroves to climate change.
8	Implement adaptive strategies to compensate for changes in species ranges and environmental conditions.
9	Develop alternative livelihoods for mangrove-dependent communities as a means to reduce mangrove destruction.
10	Build partnerships with a variety of stakeholders to generate the necessary finances and support to respond to the impacts of climate

From: McLeod and Salam (2006).

Conclusions

The threats posed by climate change, which compound the other major threats to mangroves not attributable to climate change, require a proactive integrated and coordinated approach across a range of spatial scales.

In particular, issues of mangrove ecosystem connectivity, plant and animal dispersal abilities, effective population size and genetic diversity need to be considered at a scale greater than that of particular mangrove habitats (see details in Section 2).

The resilience-promoting strategies listed in Tables 19 and 20, covering mangrove diversity, connectivity and adaptive capacity, plus some socio-economic considerations, are not only relevant to the impact of climate change on mangroves. Essentially, they are also good practices in sustainable natural resources management in general; and most are, to varying degrees, already implemented in some mangrove management systems around the world.

Transboundary cooperation on mangrove management, including the sharing of good practices, is fundamental to addressing both sustainable management and climate change-related issues.

The need in Indochina is to have these good practices endorsed at national policy level and then applied in practice on a transboundary scale.

A womens' group assisted after the tsunami to earn supplementary income from mangrove-based handicrafts, Ranong, Thailand. (Photo credit: D. J. Macintosh.)

The livelihoods of a great many coastal dwellers, like this fisher of *Acetes* shrimp, still remain heavily dependent on mangrove ecosystem health. (Photo credit: D. J. Macintosh).

Collecting dead wood from the mangrove coastal protection zone, Soc Trang, Viet Nam (Photo credit: D. J. Macintosh.)

Mangrove forest in Ranong, the wettest province in Thailand, is essential to maintaining the integrity of the coastline against flooding and erosion. (Photo credit: D. J. Macintosh.)

SECTION 5

Towards a Strategic Action Plan to Address Transboundary Mangrove Problems

Causal Chain Analysis

The following Causal Chain Analysis tables were prepared during the TDA-IME Project 2nd and 3rd workshops, based on discussion among the participating country and regional representatives. Mangrove conversion (Table 21) is shown at country level, because the main causes of conversion differ to some extent country to country.

Mangrove habitat degradation is presented as a regional level analysis (Table 22), because degradation has common immediate and root causes country to country. The analysis of science and knowledge gaps is also presented at regional level for the same reason (Table 23), although the countries fall into two main groups based on their level of policy interest towards mangroves.

TABLE 21: Causal Chain Analysis 1: Mangrove Loss and Conversion (Country Level)

Conversion	Immediate causes	Root causes	Externalities
Cambodia			
Conversion of mangrove areas	• urbanization • encroachment of mangrove forests • Vague boundary demarcation people move at will into coastal mangroves	• *Absence of zone plans, especially a national master plan* • *Attractiveness of coastal zone for people (migration)*	Climate Change and sea-level rise World economic drivers
Malaysia			
Conversion of mangroves to other uses	• oil palms (Sabah and Sarawak) • shrimp and aquaculture ponds • urban development	• *Central Government prioritizes development over mangrove conservation*	Climate Change and sea-level rise World economic drivers
Philippines			
Conversion of mangroves to other uses	• Inadequate law enforcement – no clear classification of land use or tax mapping, which is the responsibility of local governments • Land use conversion due to aquaculture and industrial development	• *Poverty and population growth* • *Few law enforcers* • *Inadequate zoning (coastal planning and land use)*	Climate Change and sea-level rise World economic drivers
Singapore			
Conversion of land along rivers	• Demand for freshwater reservoirs	• *Inadequate fresh water supply*	Climate Change and sea-level rise World economic drivers
Thailand			
Conversion of mangrove areas	• Inadequate legislation for conservation and preventing encroachment – institutional arrangements, uncoordinated framework, lack of enforcement (zoning) • urban and industrial development • prices of agricultural products (competing demands for land use, such as oil palm, shrimp farming	• *Lack of political interest to legislate for and enforce mangrove conservation* • *Government prioritizes development over mangrove conversion* • *Market forces create high demand for land conversion to agriculture/aquaculture*	Climate Change and sea-level rise World economic drivers
Viet Nam			
Conversion of mangrove areas	• land reclamation for aquaculture • high population density • urbanization and industrial development • mining (in some specific locations, for tin, coal, iron) • land use changes	• *Population pressure (outstanding importance)* • *High international demand for seafood* • *Demand for open pasts coal, tin and iron*	Climate Change and sea-level rise World economic drivers

TABLE 22: Cause Chain Analysis 2: Degradation of Mangrove Habitat (Regional)

Effects/Impacts	Key Issues	Proximate (direct) Causes	Intermediate Causes	Root (fundamental) Causes	Externalities
Reduction in mangrove forest cover (biomass) Reduction in nursery, spawning, feeding grounds (refugia) for mangrove-associated aquatic species Reduced provisioning services (e.g. wood, fishes/shellfish, seedlings) Changes in the hydrological regime and salinity – alteration in species composition/abundance Bio-chemical changes in mangrove substrates Increased coastal erosion and potential impacts on biodiversity/genetic loss and reduced resilience Siltation – beyond the capacity of certain mangrove species to cope Potential widespread disease and insect infestation	**Degradation of mangrove habitat**	Over-harvesting of mangrove forests – tree cutting Encroachment from human settlements Destructive fishing methods and over-fishing Coastal aquaculture (land and water-based) Neighboring industrial activities (harbor / port infrastructure / shipping / etc.) Wastewater and land-based sources of pollution	Food/livelihood needs of mangrove-dependent communities *In situ* profit-driven investment *Ex situ* profit driven investment National mangrove conservation policies are inadequate, or not enforced Regulations for pollution control inadequate, or not enforced lack of public pressure on development decision-making	Population Growth (increasing human pressure on space and natural resources) Lack of alternative livelihood sources Short term economic interests/income drive decision making Mangrove value perceived as low in economic policy decisions Eco-business potential of mangrove ecosystems not being realized by society Capacity or will to enforce standards is lacking Poor public awareness of mangrove ecosystem economic values	Climate change and sea-level rise World economic drivers

TABLE 33: Causal Chain Analysis 3: Scientific Research/Knowledge Management (Regional)

Effects / Impacts	Key Issues	Proximate (direct) causes	Intermediate Causes	Root (fundamental) causes
Mangrove forests continue to be converted and degraded Existing scientific knowledge about mangroves is not benefiting society Gaps in mangrove science of importance society (e.g. valuation of mangroves; ecological processes; climate change impacts)	**Inadequate scientific research on mangrove-related issues of trans boundary importance** Specific research needs include: • distribution and status of all threatened to endangered mangrove species in Indochina; • phenotypic and genetic differences between mangrove species populations; • valuation of mangrove goods and services; • best practices to achieve long-term, cost effective mangrove rehabilitation; • implications of climate change, especially sea level rise, on mangrove structure and function; • mangrove-fisheries ecological linkages; • migration and coastal habitat dependency of endangered species (dolphin, sea turtle and dugong).	Shortage of mangrove marine scientists;	Scientific information not reaching policy makers Inadequate funding for mangrove research and research capacity-building Lack of science to policy communications "infrastructure" (e.g. integrated mangrove committees/NATMANCOM) Climate change concerns have not stimulated research on mangroves and ecosystem-based adaptation Inadequate public awareness information services about mangrove ecosystem values to society	Science to policy gaps (Cambodia, Philippines, Thailand, Viet Nam) Little or no policy interest (Malaysia, Singapore)
Little or no public pressure on governments to enforce mangrove conservation measures, or enact stronger policies Inadequate replication of good mangrove restoration and sustainable use practices	**Lack of awareness and knowledge on potential opportunities generated by mangroves**	Insufficient education and knowledge-sharing about mangroves; Sustainable use mechanisms/co-management are not widely practiced		

TABLE 24: Towards a Regional Strategic Action Plan (SAP) for the Indochina Mangrove Ecosystems

Proposed Objective:

Mangrove ecosystems in Indochina are returned to full ecological health and further net loss and degradation of mangrove forests in the region is halted, and where possible reversed

Themes and Ecosystem Quality Objectives (EcoQO):

Theme 1: Mangrove forest conversion

EcoQO: *All existing healthy mangrove forests are protected and conservation legislation is fully enforced*

Targets:

- Legal, policy instruments and governance mechanisms are strengthened to achieve no further net loss of healthy mangroves.
- The area of mangroves within designated protected areas is increased significantly, with priority to include transboundary sites.
- National targets for mangrove rehabilitation by area and species composition are proposed.*
- Indicators of forest quality/ecological integrity are included in ecosystem monitoring programs.
- The potential of mangrove ecosystems for climate change adaptation and mitigation are fully realized.

Theme 2: Mangrove degradation

EcoQO: *Degraded mangroves are restored and mangrove-associated aquatic resources are managed sustainably*

Targets:

- National targets for mangrove restoration by area and species composition are proposed, with priority given to transboundary sites selected by the countries.*
- Countries develop and share examples of sustainable management mechanisms.
- Countries collaborate on joint management systems for mangrove-associated trans boundary aquatic and fisheries/aquaculture species.

Theme 3: Research and knowledge Management Needs

EcoQO: *Scientific knowledge on mangroves is strengthened and applied more effectively to improve the success of mangrove restoration/rehabilitation, protect endangered species, and better understand the impacts of climate change on mangrove ecosystems*

Targets:

- Agree on and share best practices in mangrove restoration/rehabilitation at regional level, including demonstration sites.
- Fill key gaps in scientific knowledge on mangrove ecosystems through new research (see list of research topics in causal chain analysis).
- Establish a monitoring system regionally to study climate change impacts on mangrove ecosystems.

Theme 4: Regional Cooperation and Integrated Management Mechanisms for Mangrove Ecosystems

EcoQO: *Regional actions and governance mechanisms for mangrove ecosystems are implemented effectively to achieve sustainable use*

Targets:

- Harmonize national legislation and strengthen national to regional policies to halt further mangrove losses, with the area of mangroves under formal protection to be increased regionally by 30% over five years.
- Establish an interdisciplinary regional Training and Capacity building program capable of training 50 people per year.
- Convene regional meetings to: a) develop a regional Strategic Action Plan based on this report; b) formulate a regional Code of Conduct for Mangrove Ecosystems; c) develop a National to Regional Coordination mechanism for mangroves (such as an integrated committee of policy-makers and scientists).

* The targets will differ significantly country to country, but will contribute to a measurable regional gain in mangrove area and ecological integrity.

Objectives and Targets for a Future Strategic Action Plan

The root cause analysis presented in Tables 21 to 23 documents the immediate and root causes of (1) mangrove conversion; (2) mangrove habitat degradation; and (3) weaknesses in scientific research and knowledge management on mangroves ("science-to-policy" gaps).

The analysis was developed further to include a Regional Objective, together with four Themes and corresponding Ecological Quality Objectives and Targets for a future Strategic Action Plan (SAP) for the Indochina mangrove ecosystems, as shown in Table 24, plus potential interventions to be considered in the SAP development process (Table 25), based on the views of national and regional experts who attended the TDA-IME Project 3rd and 4th workshops.

TABLE 25: Potential Actions (from TDA-IME Project 3rd and 4th workshops).

Potential Actions 1: Mangrove Forest Conversion **EcoQO: All existing healthy mangrove forests are protected and conservation legislation is fully enforced**	
Action Category	Potential Intervention
Institutional arrangements and Governance	• Incorporate mangrove conservation into national and local development policies (this is the most important intervention) • Increase the amount of mangrove forests coming within Protected Areas, especially at transboundary locations
Legal and policy reforms	• Strengthen legislation frameworks to action mangrove forest conservation enforcement based on incentives
Management measures	• Develop and fully apply Coastal Zone classifications • Promote diverse mangrove eco-tourist ventures (reduce pressure on coastal resources exploitation) • Reduce negative enhancing links and understanding between relevant groups (e.g. mining industry and coastal resource managers)
Enforcement and compliance	• Enact legislation frameworks to archive mangrove forest conservation enforcement based on incentives
Awareness and communication	• Catalyze Media support, mobilize societal influences .(peer pressure at multi-levels, especially political ones)
Human capacity development	• Create understanding of the rights-based approach (respecting and encouraging the views of citizens) • Strengthen awareness and empowerment at community level

Potential Actions 2: Degradation of Mangrove Habitat **EcoQO: Degraded mangroves are restored and mangrove-associated aquatic resources are managed sustainably**	
Action Category	**Potential Interventions**
Institutional Arrangements and Governance	• National level - Strengthen or Create **Inter-Agencies** multi-sectoral coordinating mechanism that addresses mangrove ecosystem conservation as part of the larger ecosystem based approach to watershed, coastal and ocean governance • Local / Community level - Strengthen or Create local Governmental multi-sectoral coordinating mechanism that addresses mangrove ecosystem conservation as part of the larger ecosystem based approach to watershed, coastal and ocean governance •
Legal and Policy Reforms	• Adapt ICM as framework for mangrove/coastal habitat conservation • Assure that policies reflect the true (tangible and intangible) values of mangrove ecosystems Make community participation in mangrove ecosystem conservation mandatory • Create / Provide legal basis for mangrove stewardship/co-management arrangements • Create economics incentive in mangrove protection rehabilitation and management
Management measures	• Land and Sea use zoning (Coastal Marine Special Planning) • Enrichment mangrove planting on selected areas • Coastal Master Plans are inclusive of mangrove management • Effective waste management • Implement mangrove management licensing systems • Certification scheme for mangrove forest products
Enforcement and compliance	• Adequately resourced enforcement • Improve compliance through community engagement

Potential Actions 3: Research and Knowledge Gaps. **EcoQO: Scientific knowledge on mangroves increased and applied to improve the success of mangrove restoration/rehabilitation, protect endangered species, and better understand the impacts of climate change impacts on mangrove ecosystems**	
Action Category	**Potential Interventions**
Institutional Arrangements and Governance	• Make additional budgetary allocations for targeted research on mangrove science, especially the impacts of climate change • Leverage private sector funding for mangrove research • Establish regional network of mangrove researchers [network for exchange - mangrove portal] • Establish/re-establish National Mangrove Committees
Legal and Policy Reforms	• Documenting and analysing local knowledge on mangrove management • Integration of scientific knowledge with local knowledge to support community management of mangroves (e.g. co-management of mangroves)
Awareness and communication	• Package scientifically accurate information to facilitate mangrove management • Collate university/academic research for dissemination [including gray literature] • Develop an effective dissemination mechanisms for proactive communication • Translate mangrove scientific information into local languages
Human Capacity Development	• Scientific training in mangrove sciences (e.g. regional programs) • Regional exchange and networking of mangrove researchers • Include relevant mangrove and coastal area management subjects into public administration training • Participatory action research in mangrove monitoring to enhance the capacity of local communities and improve their understanding of ecological integrity

Potential Actions 4: Integrated and Regional Management Mechanisms for Mangrove Ecosystems **EcoQO: Regional actions and governance mechanisms for mangrove ecosystems are implemented effectively to achieve conservation and sustainable use targets**	
Action Category	**Potential Interventions**
Institutional Arrangements and Governance	• Strengthen or Create a Regional Inter-Governmental coordinating mechanism that addresses mangrove ecosystem conservation as part of the larger ecosystem based approach to watershed and coastal area governance (this mechanism could be developed from the formal mechanisms for regional cooperation established by the UNEP/GEF/SCS Project, and/or those currently operated by BOBLME and MFF) • Convene, together with governmental agencies and regional organizations like BOBLME/FAO, MFF, PEMSEA, SEAFDEC, UNDP/RCAP and UNEP/ROAP a Regional Conference every two or three years to review coastal governance issues, including conference sessions devoted to transboundary cooperation and mangrove ecosystems • Together with other regional projects and programs, organize regular symposia, seminars, workshops, etc., for policy-makers and practitioners on topics and emerging issues important to achieving successful transboundary mangrove ecosystem management
Legal and Policy Reforms	• Initiate an expert-led regional review of the legal basis for all the Protected Areas in Indochina that include mangrove forests and make recommendations on strengthening management effectiveness to fulfil their legal status and policy objectives, including those under international conventions (Biosphere Reserves, RAMSAR sites, World Heritage sites) • Identify potential new Protected Areas, especially transboundary sites, that would help conserve mangrove forests of high biodiversity value, and/or sites with good prospects for recovery of ecological health through restoration efforts
Awareness and communication	• Create a Task Team of regional mangrove experts to bridge the science to policy gap, and help governments to better integrate environmental considerations into coastal development planning • Develop the MFF website as a regional mechanism for information exchange on transboundary mangrove management, with dedicated content for key stakeholder groups (government agencies, coastal managers, community leaders, researchers, schools and universities)
Human Capacity Development	• Formalize the current regional training courses on Integrated Coastal Management, Project Cycle Management, and Mangrove Restoration and Monitoring, offered by MFF/BOBLME, into a five-year capacity development program, linked to national training institutions and trainers.

SECTION 6

Conclusions and Recommendations

Introduction

The following are a broader set of conclusions and recommendations that emerged from the TDA-IME Project 4th workshop, at which transboundary mangrove management was discussed with a particular focus on the following themes:

- Strengthening **Policies and Governance** over mangroves
- Ensuring the **Ecological integrity** of mangrove ecosystems
- Assessing the future for mangroves in relation to **Climate Change**
- Improving **Regional Cooperation** for transboundary management of mangrove ecosystems

Priorities for Transboundary Mangrove Ecosystem Management

Several priorities can be identified for transboundary management to maintain the integrity of Indochina's mangrove ecosystems, reduce further mangrove forest loss, and manage mangrove ecosystems sustainably in the face of climate change.

1. *Halting further loss of the region's remaining mangrove forests.*

On a global scale, and especially within Indochina, the main threats to mangroves have been degradation and conversion. The fundamental or "root" causes are population pressure and poverty, government development priorities and private sector profit-driven investments. Despite government-supported mangrove rehabilitation programs, plus NGO and private sector projects in a number of countries of the region, loss of mangrove forest area and ecological integrity continue. Moreover, globally only around 7% of mangrove forests are safeguarded within protected areas, and an even smaller percentage involve local communities as custodians.

Recommendations

- Based on the success of the Code of Conduct for Responsible Fisheries in Southeast Asia (which includes aquaculture), it is recommended that a Regional Code of Conduct on the Sustainable Management of Mangrove Ecosystems be developed, as a tool to inform government policy makers, planners, and the private sector about mangrove ecosystems.
- It is further recommended that a regional study is undertaken to assist countries to identify national policies that may actually be contributing to mangrove loss, or are failing to protect mangroves due to e.g. an inadequate regulatory framework, or lack of enforcement capacity (or will).
- Countries should also be assisted to identify additional mangrove areas that could be given protected area status, at the same time safe-guarding the rights of local communities.
- Priority should be given to designating regionally significant and representative mangrove sites as protected areas that can contribute measurably to the genetic diversity and ecological integrity of the region's mangrove ecosystems.

2. *Improving the areal estimates of mangrove forests and including qualitative assessment of ecosystem integrity based on common regionally agreed criteria (e.g. vulnerability index).*

There remains considerable uncertainty about the areal extent, species composition and ecosystem integrity of mangroves in most countries. This can be attributed to the use of different methodologies for mapping mangroves, and the inclusion by some countries of severely degraded mangroves in the national inventory. Since vulnerability to further degradation, and the ecological integrity and function of mangrove ecosystems is highly dependent on species richness, functional diversity and forest quality, there is a need for more robust estimates of mangrove area and ecosystem integrity.

Recommendations:

- It is recommended that improved and up-to-date estimates of the area of mangroves and their species composition be made using standardized regionally consistent methodologies, and that these include at least a qualitative assessment of ecosystem integrity or health, based on regionally agreed criteria.
- These assessments should include, for example: canopy cover, species richness and functional diversity parameters. They will require a combination of remote sensing data – supported by ground-truthing, plus other field-level observations.
- It is also recommended that national and regional level capacity development activities on applying the agreed methodologies for mangrove assessment be provided, supported by an information management system to receive and compile country data for regional and transboundary use.

3. *Expanding and improving the restoration/rehabilitation of degraded mangrove ecosystems.*

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. However, there have been many failed mangrove restoration attempts due to various factors, with poor site selection, inappropriate species selection for planting, and failure to reconnect the planted area to its near original hydrological regime, being among the most common ones.

The application of knowledge and coastal land use planning is essential to improve the results of mangrove restoration/ rehabilitation efforts. Qualitative information on the state of health, or degradation, of the mangrove forest is vital for planning mangrove restoration/rehabilitation, particularly at transboundary scale. Mangrove restoration/rehabilitation projects have also had disappointing results because they simply planted mangrove seedlings without giving adequate attention to the wider ecosystem and socio-economic issues, such as resource-use access rights, and the mechanisms to safeguard these rights for local people through co-management, stewardship, or other community-centered management arrangements.

Overall, because of the highly project-oriented nature of mangrove restoration/rehabilitation activities, there has been inadequate critical evaluation of the results, or compiling of the lessons to be learned from the regional experiences.

Recommendations:

- It is recommended that a comprehensive manual on best practices in mangrove restoration/rehabilitation be prepared for regional adoption. It should be disseminated widely and translated into local languages.
- The manual should also be used to support in-country practical (on-site) training courses which cover the entire spectrum of site-specific restoration/rehabilitation solutions.

4. *Communicating the values of mangrove ecosystems to policy makers and general society more effectively.*

Some of the key underlying causes of mangrove loss and degradation relate to inadequate awareness of the environmental and economic services that mangroves provide, or lack of attention to them, by different stakeholder groups, compounded by poor communication between holders of scientific knowledge, policy makers, the private sector and traditional coastal communities. These issues highlight the need for better information-sharing and communication on mangrove-related issues at all levels, from policy makers, to local government and the general public. There is a need to educate and build capacity, not only for research, but also for communicating and using existing knowledge on mangrove ecosystems. This includes particularly the need to better integrate scientific and traditional knowledge, which is a fundamental requirement for the involvement of local communities in mangrove ecosystem management.

Recommendations

- It is recommended that countries are assisted to introduce, or strengthen national coordinating mechanisms, like the National Coordinating Bodies of the Mangroves for the Future (MFF) initiative, in order to bridge science to policy gaps regarding mangrove conservation and management.
- Similarly, opportunities for greater dialogue on mangroves and related coastal issues should be developed through the existing regional coordination mechanisms available, such as the ASEAN Secretariat, FAO/BOBLME, MFF, PEMSEA and SEAFDEC, supported by regional policy-briefs on key mangrove-related issues (e.g. on the true environmental cost of different coastal development options; avoidance cost values of mangroves for coastal and storm protection; the value of mangroves in absorbing and breaking down pollutants).

Awareness-raising about environmental issues, as well as clear and effective communication between stakeholders, are important prerequisites for the successful implementation of mangrove restoration/rehabilitation, protection and management activities. Educating people requires much thought and perseverance, and educational materials must be well designed to best suit their intended audiences and learning environment, whether formal, informal or non-formal.

Environmental education and awareness-raising must aim at promoting positive change. This can be achieved through communication approaches which recognize that presenting facts alone does not ensure a change of human behaviour. It is therefore essential to reach specified target groups (particularly the youth and through them their parents) via a range of communication channels and approaches to facilitate, change.

An environmental education strategy should ensure that key messages are repeated by using multiple channels, links with "role models" or "champions", indigenous, religious groups and schools, and link with policy and advocacy activities.

Recommendations

- In order to identify the key messages, carry out environmental awareness assessments for the various target groups.
- Produce teaching materials and teacher training manuals on mangroves, and advocate for their inclusion in national school curricula.
- Evaluate the use and effectiveness of the information about mangroves developed for different audiences.

5. *Sharing and replicating/up-scaling successful models of mangrove sustainable use involving local communities (e.g. co-management, stewardship).*

Mangrove forests are crucial as 'bio-shields' for the protection of people and their assets from physical and climatic impacts, including erosion, storms and flooding. This often narrow belt of mangroves must be safeguarded against human threats.

Co-management is the most effective way of maintaining and enhancing the protection function of the mangrove forest belt in a situation where mangrove forest protection obligations are (or become) more important than rights to forest management. Co-management also provides livelihood support for local communities; and contributes to improved governance.

Although co-management is a local (village level) solution to protecting mangroves, it could be implemented along entire coastlines and on a transboundary basis if the appropriate principles are applied.

Recommendations

- Share lessons learned about co-management from different countries in national and regional workshops.
- Develop a mangrove co-management training manual with focus on key conditions for successful co-management, guidelines and principles while emphasising the local, small-scale character of this site-specific solution to mangrove protection and management.
- Promote networking among co-management practitioners in the region (including co-management trainers, consultants, project managers).

6. *Sharing and replicating successful livelihood enhancement opportunities, to reduce poverty among traditional coastal communities and make them less dependent on mangrove resources).*

There is growing repository of information from MFF small grant projects implemented by IUCN and UNDP, plus many other NGO- or CBO-led projects that provide good examples of effective livelihood interventions, including analysis of the reasons for their success.

Recommendations:

- Provide case studies of successful project interventions on livelihood enhancement (although these will be country-specific and implemented at local level, it is expected that critical analysis of case studies would provide incentives for others to replicate the approaches).
- Conduct livelihood project evaluations to demonstrate impacts on the quality of life of local people, especially women.
- Document and share sustainable livelihood ventures arising specifically as a result of co-management initiatives; document other best practices related to community livelihood improvement and share lessons learned.
- Provide opportunities for community to community learning.

7. *Assessing the impact of climate change/climate variability on mangrove ecosystems at a local to regional scale as part of a region-wide mangrove ecosystem monitoring program.*

Because mangrove forests are confined to the intertidal fringe of mainly tropical coastlines, they are indisputably amongst the most vulnerable forest ecosystems to climate change, their response and resilience to the multi-factorial consequences of climate change have been far less widely studied than those of many other forest ecosystems. Similarly, the potential values of mangrove ecosystems for climate change adaptation and mitigation have been mentioned, but rarely quantified. The responses of mangroves to climate change, and therefore their capacity to provide climate adaptation and mitigation benefits are likely to be highly site specific, depending on local geomorphology and hydrology, on adjacent land use and human activity, and on the species richness and functional diversity of the ecosystem.

Recommendations

- It is recommended that an integrated region-wide mangrove ecosystem monitoring program be established to assess local and regional scale vulnerability/resilience of mangrove ecosystems to climate change.
- The program should be designed to monitor at both representative and regionally significant mangrove sites, as well as at selected sites with special characteristics, such as small populations of rare or endangered species; and in selected areas with a high livelihood dependency on mangrove resources among the local communities.
- The program should be developed with a common approach and standardized methodologies to enable the assessment of regional and vulnerability and responses.

Regional contribution:

- Site selection criteria; monitoring methodology; communicating results and providing regional data analysis and other feedback.

National contribution:

- Allocation of site(s) and commitment to support long-term monitoring and data analysis.

B. Researching mangrove-related issues of transboundary importance:

Although the knowledge base for mangroves is quite substantial, there are knowledge gaps in several main areas important to achieving sound ecosystem-based management: species and ecological connectivity, valuation of mangrove services, including fisheries-related supporting services, and the impacts of climate change/climate variability on mangroves.

The following research studies are recommended for implementation at regional and transboundary levels:

a) Valuation of mangrove goods and services at national to transboundary scales;
b) Mangrove-fisheries ecological linkages and their economic value;
c) Migration and coastal habitat dependency of endangered species (dolphin, dugong and sea turtle);
d) Phenotypic and genetic differences between mangrove species populations and how species interconnectivity can support ecosystem resilience;
e) Techniques to achieve long-term, cost-effective mangrove rehabilitation;
f) Implications of sea-level rise and global warming/climate change on mangrove structure and function; and on the corresponding capacity of mangrove ecosystems to provide climate change adaptation and mitigation benefits;
g) Assessment of the use of mangroves as part of integrated solutions for coastal erosion control.

TABLE 38: An Indicative future TDA Initiatives Regional Workplan, based on the TDA-MIE Final Report recommendations. NOTE: Priority TDA activities and outputs are underlined; the other activities and outputs shown would be undertaken collaboratively, or implemented by other regional programs.

THEMES	MAIN ACTIVITIES/OUTPUTS	2014	2015	2016	2017	2018
Legal and Policy Reforms, Institutional Strengthening and Governance	Prepare and disseminate a **Regional Code of Conduct** on the Sustainable Management of Mangrove Ecosystems, as a tool to inform government policy makers, planners, and the private sector about mangrove ecosystems.	—	—			
	Undertake a **Regional Study** to assist countries to identify national policies that may actually be contributing to mangrove loss, or are failing to protect mangroves (including factors contributing to coastal erosion).	—				
	Initiate an **Expert Legal Regional Review** of the legal basis for all the Protected Areas in Indochina that include mangrove forests and make recommendations on strengthening management effectiveness to fulfil their legal status and policy objectives, including those under international conventions (Biosphere Reserves, RAMSAR and World Heritage sites).	—	—			
	Identify potential additional **Protected Areas**, especially transboundary sites, that would help conserve mangrove forests of high biodiversity value, and/or sites with good prospects for recovery of ecological health through restoration efforts (target 30% increase in mangrove protected area).	—	—			
	Establish/strengthen the **National Mangrove Coordinating Body** in each country (e.g. MARD/NEC/DAM, MFF NCB).	—				
	Strengthen or Create a **Regional Inter-Governmental Coordinating Mechanism** that addresses mangrove ecosystem conservation as part of a broader ecosystem-based approach to watersheds and the coastal zones, and support annual meetings.	—	—	—	—	—
	Convene, together with governmental agencies and regional organizations like BOBLME/FAO, MFF/IUCN, PEMSEA, SEAFDEC, UNEP/RCSP and UNEP/COBSEA a **Regional Conference** every two to three years to review regional coastal governance issues.	—		—		—
Capacity Development, Awareness Raising and Communication	Organize regular **Symposia, Seminars, Workshops, Study Tours for Policy-Makers** and practitioners on topics and emerging issues important to achieving successful transboundary mangrove ecosystem management.	+ +	+ +	+ +	+ +	+
	Develop an **Environmental Education Strategy for Mangrove Ecosystems**: carry out environmental awareness assessments for different target groups, produce teaching materials and teacher training manuals on mangroves, and advocate for their inclusion in national school curricula.	—	—	—	—	—
	Conduct **Participatory Action Research in Mangrove Monitoring** at three selected demonstration sites to enhance the capacity of local communities and improve their understanding of ecological integrity.		—	—	—	—
	Prepare and disseminate a **Manual on Best Practices in Mangrove Restoration/Rehabilitation**, including local language versions. (This manual should also be used to support in-country practical (on-site) training courses which cover the entire spectrum of site-specific restoration/rehabilitation solutions.)	—	—			
	Provide **Case Studies** of successful interventions **to enhance the livelihoods** of coastal communities, plus **co-management and benefit-sharing models**, supported by **guidelines and training manuals**.		—		—	
	Develop a dedicated **Regional Mangrove Website** as a mechanism for information exchange on transboundary mangrove management, with dedicated content for key stakeholder groups (government agencies, coastal managers, community leaders, researchers, schools and universities).	—	—	—	—	—
	Formalize the current **Regional Training Courses** on Integrated Coastal Management, Project Cycle Management, and Mangrove Restoration and Management, offered by AIT/RSBLME, into a five-year capacity development program, linked to SIBP and other educational centres.	—	—	—	—	—

Research and Knowledge Management	Create a **Task Team of Regional Mangrove Experts** to bridge the science-to-policy gap, and help governments to better integrate environmental considerations into coastal development planning. Improve current estimates of the **Area of Mangroves, Species Composition** and **Vulnerability Assessment** using standardized, regionally consistent methodologies, including qualitative assessment of ecosystem integrity or health, based on regionally agreed criteria. Plan and implement an **Integrated Region-wide Mangrove Ecosystem Monitoring Program** to assess local and regional scale vulnerability/resilience of mangrove ecosystems to climate change. Support **Applied Research Studies** to fill knowledge gaps about mangrove ecosystems; such research should focus on: • Valuation of mangrove goods and services at national to transboundary scales • Mangrove-fisheries ecological linkages and their economic value • Migration and coastal habitat dependency of endangered species (dolphin, dugong, turtle) • Phenotypic and genetic differences between mangrove species populations and how species interconnectivity can support ecosystem resilience • Techniques to achieve long-term, cost-effective mangrove rehabilitation • Implications of sea-level rise and global warming/climate change on mangrove structure and function, and on the corresponding capacity of mangrove ecosystems to provide climate change adaptation and mitigation benefits • Assessment of using mangroves as part of integrated solutions for coastal erosion control					

Annexes

(As separate PDF Files)