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Proceedings of the meeting and workshop on

Guidelines for the Rehabilitation of Mangroves and other Coastal Forests damaged by Tsunamis and other Natural Hazards in the Asia-Pacific Region

ITTO/ISME PPD 134/07 Rev. 1 (F)

Meeting: Okinawa, Japan, 15-16 June 2007
Workshop: Bangkok, Thailand, 23 August 2008

November 2008

International Society for Mangrove Ecosystems
International Tropical Timber Organization
and
University of the Ryukyus

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Edited by H.T. Chan & J.E. Ong

Photo by S. Baba

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International Society for Mangrove Ecosystems
and
International Tropical Timber Organization

International Society for Mangrove Ecosystems (ISME)

The International Society for Mangrove Ecosystems (ISME) is an international non-profit and non-governmental scientific society established in August 1990. Headquarters is located in Okinawa, Japan. ISME was certified as a Foundation in 1992 by the Japanese Law of Foundation. In 2003, under a new Japanese law of promoting specified non-profit activities, ISME was registered as a Non-profit Organization (NPO). Among other items, the Statutes of ISME indicates that "the Society shall collect, evaluate and disseminate information on mangrove ecosystems" and "promote international cooperation." ISME has been carrying out its activities at global level in the three pathways: in brief, a) application of knowledge to particular situations; b) training and education; and c) exchange of necessary information. ISME's activities have been supported with collaboration and links by a number of other organizations, universities, research iustitutes and local communities. As of November 2008, ISME's membership includes 38 institutions and over 1000 individuals from 89 conutries.

International Tropical Timber Organization (ITTO)

The International Tropical Timber Organization (ITTO) is an intergovernmental organization promoting the conservation and sustainable management, use and trade of tropical forest resources. Its 60 members represent about 80% of the world's tropical forests and 90% of the global tropical timber trade. ITTO develops internationally agreed policy documents to promote sustainable forest management and forest conservation and assists tropical member countries to adapt such policies to local circumstances and to implement them in the field through projects. In addition, ITTO collects, analyzes and disseminates data on the production and trade of tropical timber and funds projects and other actions aimed at developing indnstries at both commnnity and iudustrial scales. All projects are funded by voluntary contributions, mostly from consumer member countries. Since it became operational in 1987, ITTO has funded more than 750 projects, pre-projects and activities valued at more than US$300 million. The major donors are the governments of Japan, Switzerland and the USA.

Cover photo: Mangrove-associated fisheries, Ranong, Thailand by S. Baba

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1. BACKGROUND

1.1 Proceedings of the Meeting and Workshop

The Proceedings are a compendium of two meetings organised by ISME and ITTO in collaboration with a number of institutions in the host countries. This publication represents one of the outputs of the ISME/ITTO Pre-Project PPD 134/07 Rev. 1 (F) on *Guidelines for the Restoration of Mangroves and other Coastal Forests damaged by Tsunamis and other Natural Hazards in the Asia-Pacific Region.* Other expected outputs include a manual on guidelines for rehabilitation of mangroves and other coastal vegetation damaged by tsunamis and other natural hazards, and a full project proposal as follow-up to the present pre-project.

The two meetings were:

a. Meeting on *Guidelines for the Restoration of Mangroves and other Coastal Forests damaged by Tsunamis and other Natural Hazards in the Asia-Pacific Region*

Organised by ISME and ITTO in collaboration with University of the Ryukyus, the two-day meeting *was* held in Okinawa, Japan from 15-16 June 2007. The meeting coincided with the 21st Pacific Science Congress, which was held from 12-16 June 2007. Day One was held in University of the Ryukyus while Day Two was held in the Ginowan Convention Centre. Fourteen participants from seven countries attended the meeting (Appendix I). Participants of the JICA Training Course on Conservation and Sustainable Management of Mangrove Ecosystems were also present as observers.

b. Workshop on *Restoration of Mangroves and other Coastal Forests damaged by Tsunamis and other Natural Hazards in the Asia-Pacific Region* and *Impacts of Global Warming on Mangrove Ecosystems and their Mitigation Options*

The one-day workshop was organised by ISME and ITTO in collaboration with Thailand Environment Institute (TEI) and Department of Marine and Coastal Resources (DMCR) of Thailand. It was held in T.K. Palace, Bangkok, Thailand on 23 August 2008 (Fig. 1) in conjunction with the Seventh General Assembly of ISME which was convened the day before.

The Opening Session of the workshop started with Welcoming Remarks by Ambassador Noboru Nakahira, Vice-President of ISME. This was followed by Opening Remarks by Dr. Ma Hwan Ok, Projects Manager, Reforestation and Forest Management, ITTO. As Dr. Ma was not able to attend, his Opening Remarks were read by Prof. Baba.

The Technical Session of the workshop started with a discussion on the progress of the ISME/ITTO Pre-Project on *Guidelines for Restoration of Mangroves and other Coastal Forests damaged by Tsunamis and other Natural Hazards in the Asia-Pacific Region*. The discussion was moderated by Dr. H.T. Chan, Coordinator of the Pre-Project.

About 150 overseas and local participants attended the workshop (Appendix II). UN and Non-Governmental Organisations represented at the workshop included FAO, UNDP, IUCN, TEI, Wetlands International, World Food Program, WWF and Mangroves for the Future. Local government departments and universities represented included Department of Marine and Coastal Resources, National Research Council of Thailand, Pollution Control Department, National Economic and Social Development Board, Department of Environment Quality Promotion, Tourism Development Board, Chulalongkorn University, Kasetsart University, King Mongkut's University of Technology and Mahidol University.

Fig. 1. Participants and honourable delegates of the Workshop held in Bangkok, Thailand on 23 August 2008

Seated from left to right (second row):
Dr. Masakazu Kashio (Forest Resources Officer of FAO), U. Aung Myint (General Secretary of Renewable Energy Association Myanmar), Prof. François Blasco (Vice-President of ISME), Prof. Sanit Aksornkoae (President of TEI and Treasurer of ISME), H.E. Ambassador Noboru Nakahira (Vice-President of ISME), Prof. Salif E. Diop (President of ISME), Dr. Aye Myint Maung (Deputy Director-General of Forest Department Myanmar) and Dr. Chan Hung Tuck (Vice-President of ISME)

1.2 Seventh General Assembly of ISME

The Seventh General Assembly of ISME was held in T.K. Palace, Bangkok, Thailand on 22 August 2008. ISME was truly honoured that H.E. Banyin Tangpakorn, the Honourable Deputy Minister of Commerce and the Acting Minister of Natural Resources and Environment of Thailand, was able to find time to grace our occasion and to deliver his keynote address. ISME was equally honoured by the presence of H.E. Bannasopis Mekwichai, the Honourable Vice-Governor of Bangkok Metropolitan and of Dr. Nisakorn Kositrat, Director-General of Department of Marine and Coastal Resources.

Before the keynote address by H.E. Banyin Tangpakorn, Prof. Sanit Aksornkoae, President of TEI and Chairman of the Organising Committee welcomed all delegates and participants. The Opening Session of the Assembly ended with an Opening Address by Prof. Salif E. Diop, President of ISME. A group photograph of honourable delegates of the Opening Session of the Assembly is shown in Fig. 2.

During the Business Session of the Assembly, election results of the Executive Committee of ISME were announced. As endorsed by members of ISME, honorary members of the Executive Committee for the coming term (2008 to 2011) will remain the same as the previous term (2005 to 2008). They are:

President:
Prof. Salif E. Diop (Senegal)

Vice-Presidents:
H.E. Ambassador Noboru Nakahira (Japan)
Prof. François Blasco (France)
Dr. Chan Hung Tuck (Malaysia)

Treasurer:
Prof. Sanit Aksornkoae (Thailand)

Executive Secretary:
Prof. Shigeyuki Baba (Japan)

Ms. Nozomi Oshiro was appointed Assistant Executive Secretary by the Executive Committee of ISME. The next General Assembly will be held in Ho Chi Minh City, Vietnam in 2011.

Fig. 2 Honourable delegates of the Seventh General Assembly of ISME held in Bangkok, Thailand on 22 August 2008.

From left to right:
Prof. Shigeyuki Baba (Executive Secretary of ISME), H.E. Bannasopis Mekwichai, Honourable Vice-Governor of Bangkok Metropolitan, Prof. Sanit Aksornkoae (President of TEI and Treasurer of ISME), H.E. Banyin Tangpakorn, Honourable Deputy Minister of Commerce and Acting Minister of Natural Resources and Environment of Thailand, Prof. Salif E. Diop (President of ISME), H.E. Ambassador Noboru Nakahira (Vice-President of ISME) and Dr. Nisakorn Kositrat, Director-General of Department of Marine and Coastal Resources

2. OPENING SESSIONS

2.1 Okinawa Meeting

Welcoming Remarks by Ambassador Noboru Nakahira, Vice-President of ISME

Prof. Aprilani Soegiarto,
Ex-President of ISME,

Prof. François Blasco and Dr. Chan Hung Tuck,
Vice-Presidents of ISME

Prof. Sanit Aksornkoae,
Honorable Treasurer of ISME and
President of Thailand Environment Institute

Dr. Shigeyuki Baba,
Executive Secretary of ISME

Dear Participants,

Ladies and Gentlemen,

A warm welcome to Okinawa, Japan

Due to prior commitments, Prof. Salif Diop, our President, is not able to be with us. He extends his sincere apologies.

This two-day regional meeting on restoration of mangroves and other coastal forests in Asia-Pacific to safeguard against damage by tsunami and other natural hazards is organised by ISME. It is part of the 21st Pacific Science Congress, Sub-theme 1-16: *Challenges of Rehabilitation in the Post-tsunami and Capacity Building for Mangrove Ecosystem in the Pacific and Asia regions.*

Ladies and Gentlemen,

We have been informed that our ISME/ITTO pre-project on *Guidelines for the Restoration of Mangroves and other Coastal Forests damaged by Tsunamis and other Natural Hazards in the Asia-Pacific Region* has been approved by ITTO for immediate implementation. The decision was made during the 42nd Session of the International Tropical Timber Council (ITTC) held in Port Moresby, Papua New Guinea from 7-12 May 2007. It is good news for ISME as funds are now available to support some of the expenses incurred for this meeting.

For the rest of today, there will be presentations on coastal rehabilitation efforts, tsunami damage and protective functions of mangroves in the various geographical zones in Asia-Pacific. The presentations will take the form of country and regional reports along with technical reports. We are grateful to Dr. Ong and Dr. Maxwell who will be chairing the sessions and summarising some of the highlights of the day. We thank University of the Ryukyus for providing the venue of our meeting today.

Tomorrow, we will be having our group discussions in the Ginowan Convention Centre. Two concurrent sessions will be convened to draft the guidelines on coastal rehabilitation with emphasis on lessons learnt, and to assess the protective functions of mangroves and other coastal forests in mitigating the impacts of tsunami. Group One (to be led by Dr. Ong) will initiate the drafting of guidelines while Group Two (to be led by Prof. Blasco) will document the protective functions. The final session on follow-up activities will be important. All of us will have a role to play in the preparation of the manual, which is an expected output of this pre-project.

For the international participants, I hope that your stay at University of the Ryukyus International Guest House is comfortable. The ISME Secretariat has worked very hard to organise this two-day Regional Meeting. To Prof. Baba, Ms. Nozomi and other staff members, our sincere gratitude.

2.2 Bangkok Workshop

Welcoming Remarks by Ambassador Noboru Nakahira, Vice-President of ISME

Prof. Salif E. Diop,
President of ISME

Prof. François Blasco and Dr. Chan Hung Tuck,
Vice-Presidents of ISME

Prof. Sanit Aksornkoae,
Honorable Treasurer of ISME and
President of Thailand Environment Institute

Prof. Shigeyuki Baba,
Executive Secretary of ISME

Dear Participants,

Ladies and Gentlemen,

A warm welcome to Bangkok, Thailand

Many of you would agree with me that our Seventh General Assembly, held yesterday afternoon, was a great success. ISME is truly honored that H.E. Banyin Tangpakorn, the Honorable Deputy Minister of Commerce and the Acting Minister of Natural Resources and Environment of Thailand, was able to find time to grace our occasion and to deliver his Keynote Address. ISME is equally honored by the presence of H.E. Bannasopis Mekwichai, the Honorable Vice-Governor of Bangkok Metropolitan and of Dr. Nisakorn Kositrat, Director-General of Department of Marine and Coastal Resources. On behalf of ISME, I would like to thank Prof. Sanit and members of the Local Organizing Committee for having done such a good job.

ISME is also thankful to the International Tropical Timber Organization (ITTO), Thailand Environment Institute (TEI), and Department of Marine and Coastal Resources (DMCR) our co-sponsors. Without their support, our meetings would not be possible. Congratulations to our President, Prof. Salif Diop and current members of the Executive Committee who will be serving ISME for another term (2008 to 2011).

It is unfortunate that Dr. Ma Hwan Ok, Projects Manager, Reforestation and Forest Management of ITTO, is not able to attend. His Opening Remarks for this Workshop will be read by Prof. Baba immediately after my Welcoming Remarks.

Ladies and Gentlemen,

We have a long day ahead of us today.

Our morning session will be on *Rehabilitation of mangroves and other coastal ecosystems*. It will be moderated by Dr. Chan and Prof. Gong. There will be a discussion on the draft manual and proposal on rehabilitation of mangrove and other coastal ecosystems following damage by natural hazards. These are expected outputs of our on-going ITTO/ISME pre-project on *Guidelines for the Restoration of Mangroves and other Coastal Forests damaged by Tsunamis and other Natural Hazards in the Asia-Pacific Region*, financed by ITTO and implemented by ISME. The discussion will be followed by case-studies from Thailand and Malaysia on rehabilitation of mangrove and other coastal ecosystems following damage by natural hazards.

In the afternoon, the session will be on *Impacts of global warming on mangrove ecosystems and their mitigation options*. It will be moderated by Dr. Clough. There will be presentations on Impacts of recent natural hazards in the Bay of Bengal, Devastation of the recent cyclonic storms in Myanmar, the Mangrove for the Future Initiative, Impacts of the tsunami in Solomon Islands, and Mangroves and sea-level change. The afternoon session will end with a discussion on Conclusions and Recommendations.

To all participants, I hope that your stay at the TK Palace Hotel is most comfortable. The Local Organising Committee and the ISME Secretariat have worked very hard to organise our Seventh General Assembly yesterday, our Workshop today and our Field Excursion tomorrow. To all those involved in organising these events, we extend our sincere gratitude.

Opening Remarks by Dr. Ma Hwan Ok, Projects Manager, Reforestation and Forest Management, ITTO

H.E. Ambassador Noboru Nakahira,
Vice-President of ISME

Prof. Shigeyuki Baba,
Executive Secretary of ISME

Dr. Nisakorn Kositratna,
Director-General of DMCR, Thailand

Distinguished Guests and Participants,

Ladies and Gentlemen,

I have the honour of welcoming you all today to the opening of the Asia-Pacific Regional Workshop on Restoration of Mangroves and other Coastal Forests damaged by Tsunamis and other Natural Hazards which is jointly organized by the International Tropical Timber Organization (ITTO), International Society for Mangrove Ecosystems (ISME) and Thailand Environment Institute (TEI). First, on behalf of Mr. Emmanuel Ze Meka, Executive Director of ITTO, please allow me to put on record our deepest appreciation to ISME and TEI for their excellent arrangements in convening this important regional workshop in Bangkok.

The theme of this workshop is *Restoration of mangroves and other coastal forests damaged by tsunamis and other natural hazards*. This is an important issue to all of us, particularly for the work of ITTO since mangrove forests have enormous potential to contribute to climate change mitigation and adaptation. I am sure that all of us are aware of the importance of sustainable management of tropical forests, including mangroves, in providing multiple benefits such as biodiversity conservation, climate change mitigation and adaptation, and livelihoods for forest-dependant peoples. Rehabilitation of degraded mangrove forests could help mitigate climate change by increasing sequestering carbon stocks while simultaneously providing many ecological and socio-economic benefits.

Over the past two decades, ITTO has developed internationally agreed policy documents to promote sustainable forest management and has assisted tropical countries in the adoption of such policies to be implemented in the field. For instance, ITTO's *Guidelines for the Sustainable Management of Natural Tropical Forests* and *Criteria and Indicators for the Sustainable Management of Tropical Forests* are important contributions to forest management in the tropics. In the area of rehabilitation of secondary tropical forests, ITTO has published *Guidelines for the Restoration, Management and Rehabilitation of Degraded and Secondary Tropical Forests* which are being widely applied in many tropical countries.

I am pleased to refer to the *ITTO Mangrove Workplan* (2002-2006) which specifies five selected areas of activities, namely, Conservation and sustainable management; Mangrove information and awareness; Socioeconomic aspects; Mangrove ecosystem functions and health; and Cooperation and capacity building. In line with the *ITTO Mangrove Workplan*, I trust this workshop will contribute to the rehabilitation of mangrove forests affected by natural disasters such as tsunamis, recent cyclone Nargis and others. In addition, the workshop will provide guidance in supporting the conservation and sustainable management of mangrove forests. Considering the urgent need for assistance to the recent cyclone Nargis affected mangrove forests, it is worthwhile for this workshop to devote appropriate time to discuss what conld be done at the regional level and what would be priority areas in rehabilitation for key stakeholders including national governments, bilateral agencies, and regional and international organizations.

In view of the growing recognition of the important role of tropical forests in addressing global challenges such as stabilizing climate change, protecting biodiversity and tackling poverty reduction of forest-dependant peoples, I also sincerely hope that the outcome of this regional meeting will provide useful inputs on how to formulate and highlight carbon components in mangrove rehabilitation activities. In particular, it is hoped that the importance of developing practical guidelines on how to incorporate and integrate carbon sequestration can be recognized and relevant recommendations can be made at this regional meeting. I trust that such recommendations will be reviewed at relevant ITTO meetings in future and ITTO will have a sound program on mangrove in the context of sustainable forest management that can attract increased funding from a broader base of donors to enable the Organization to assume its increasing role in this field.

Natural disaster is a serious threat to the tropical forest ecosystem, but at the same time it offers a great challenge on how to rehabilitate the ecosystems affected by such natural disasters. I have every confidence that with the active participation of all of you, this regional meeting will be able to address the urgent need for the development and implementation of appropriate measures and actions to rehabilitate the mangrove ecosystems affected by tsunamis and Nargis and to enhance the role of mangrove in maintaining a healthy ecosystem.

Finally, I hope that the partnerships and networks established here in Bangkok under ISME will be enhanced for the development and implementation of mangrove rehabilitation actions in the region.

Rehabilitation of mangroves in Peninsular Malaysia after the 2004 Indian Ocean tsunami

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1. Introduction

Mangroves are unique forest ecosystems of tropical and subtropical coastlines. Their importance is not only limited to their socio-economic benefits but also to their role in protecting coastal areas from natural hazards. Mangroves constitute a unique tropical ecosystem, occurring most extensively along the protected coasts, either on muddy to sandy bottoms covered by tidal fluxes (ITTO, 2002). Mangroves differ from other forest ecosystems in that they receive large inputs of organic matter and energy from both land and sea. Mangroves also store large quantities of organic carbon.

At the end of 2003, the extent of mangroves in Malaysia was estimated at 566,856 ha (NRE, 2005). Of the total, 436,714 ha of mangroves were designated as Permanent Forest Reserves while the remaining 130,142 ha as Stateland Forests. Although mangroves represented about 1.7% of the total land area of Malaysia, the area was reported to be the third largest in the Asia Pacific, after Indonesia and Australia (FDP, 2004).

Today, mangroves in Malaysia are facing serious threats from development pressures and there is an urgent need to keep this unique ecosystem for conservation and protection purposes. It has been well reported and documented that mangroves act as an excellent buffer to reduce impacts of storm surges, heavy tropical rains and tsunami. The experience of tsunami tragedy on 26 December 2004 reported less serious destruction in Malaysia compared to Indonesia, Sri Lanka and Thailand. The northern part of the west coast of Peninsular Malaysia was not spared from destructive actions of gigantic waves especially in areas with little or no mangrove vegetation. Therefore the importance of this ecosystem in providing protection against strong waves and winds cannot be underestimated.

In the past, Malaysia has been conducting reforestation activities mainly for the production of charcoal, firewood and poles. There is hardly any experience in planting mangroves for conservation and coastal protection. It has been found that extensive mudflats along the west coast of Peninsular Malaysia are devoid of vegetation. Most of the flats are unstable for natural succession to take place due to active erosion and accretion occurring within the area. Once stabilized, natural regeneration mostly by *Avicennia* species will occur.

Since the December 2006 Indian Ocean tsunami, there has been a perception that mangroves will provide protection from such events. Responding to this, the Government of Malaysia has encouraged mangrove rehabilitation although it has recognized the value of mangroves and their conservation, before the tragic tsunami. The main objective of this paper is to discuss some of the techniques used in rehabilitating mangroves in the country before and after the tsunami.

2. Rehabilitation before the tsunami

Before the tsunami, mangrove ecosystems in Malaysia were rehabilitated mainly for charcoal, firewood and pole production. The Matang mangrove in the state of Perak represents an excellent example of such sustainable forest management practices.

2.1 Rationale for reforestation

The Matang mangrove has been sustainably managed for wood production based on working plans. Emphasis has been on intensive reforestation after clear felling. The rationale for reforestation is to ensure a sustained supply of quality wood for production of charcoal, firewood and poles. Other objective includes the maintenance of the ecosystem, which supports a flourishing fishing industry and a variety of wildlife species.

2.2 Site selection and preparation for planting

The planting of *Rhizophora* is done in logged areas, which experience daily tidal inundation. In this case, site preparation is unnecessary. However, drier site may require site specific treatments, as *Acrostichum* ferns often infest open and drier sites. They form tall dense thickets and problematic to treat silviculturally.

In Matang, site preparation in the form of fern eradication has become an important silvicultural activity of planting programs (Chan, 1989). During the 1970's, uprooting the clumps of ferns using a wedged iron bar was introduced. However, this manual method was found to be ineffective and laborious. Subsequently, in the early 1980's, eradication trials using a herbicide called Hexazinone (Velpar 90) was found to be effective in killing the ferns. Since the cost of eradicating feru using Velpar 90 is about US$280 per ha (this amounts to about eight times the cost of actual planting), the extent of the area treated had been reduced. From 1980 to 1986 and from 1987 to 1992, total areas of 2,276 ha and 1,308 have been treated, respectively.

In 1988, a cost-effective technique of eradicating *A. aureum* was developed (Chan, 1989). The fronds were cut down using a saw-edged disc, and after a month, Velpar 90 was sprayed onto newly sprouted fronds. In view of the succulent nature of the newly sprouted fronds, there is effective downward translocation of the herbicide into the rhizomes. Spraying young fronds with herbicide was proven to be more cost-effective, rather than spraying onto mature fronds. As the herbicide is toxic and can be washed into adjacent waterways through tidal flushing, its use is confined to inland areas where tidal inundation is infrequent.

2.3 Choice of species

Rhizophora apiculata and *R. mucronata* are the two most important commercial mangrove tree species planted in the Matang Mangroves. Trees often have straight boles and they produce timber of high caloric value. These characteristics make them suitable for the production of construction poles, charcoal and firewood.

Under plantation conditions, the growth habits of these two *Rhizophora* species differ considerably. *R. mucronata* fruits precociously at 3 to 4 years while *R. apiculata* fruits at 6 to 7 years. *R. apiculata,* when planted at wide spacing, tends to form multiple stems. However, *R. mucronata* is characteristically single-stemmed. Another interesting feature is the marked ability of *R. mucronata* to produce adventitious buds when the upper portion of the seedling is damaged. This coppicing ability is absent in *R. apiculata.*

2.4 Planting techniques

At the Matang Mangroves, direct planting of *Rhizophora* propagules is by far the most widely used technique of reforestation. Its timing largely depends on the availability of propagules and hence it is often carried out during the fruiting season. Fruiting of *Rhizophora* is annual, precocious and prolific. Production is synchronized within and between trees of a species. The season of mature propagule fall-offs of *R. apiculata* and *R. mucronata* occurs annually from September to November and from June to September, respectively (Chan *et al.*, 1991).

Planting using propagules

Only fresh-fallen mature and insect attack-free propagules are collected. Propagules damaged by the scolytid beetle, *Poecilips fallax* or by rough handling are rejected. Collection of predispersed propagules from the trees is also made although the process is more tedious. The distinct abscission collar between the fruit and the hypocotyls can distinguish between mature and non mature propagules on the tree. The abscission collar in *R. apiculata* and *R. mucronata* is red and yellow, respectively. It is preferable that planting be done promptly to reduce mortality due to storage.

The planting operation for *Rhizophora* is simple and can be done by untrained labourers. It involves inserting the propagule into the often soft and moist mud. The depth of planting is usually 5 to 7 cm. Planting is carried out along predetermined lines and at fixed spacing by the planting crew. The spacing for *R. apiculata* and *R. mucronata* are 1.2 m × 1.2 m (6,944 seedlings per ha) and 1.8 m × 1.8 m (3,086 seedlings per ha), respectively.

Propagules of *R. apiculata* and *R. mucronata* are procured on a contract basis at a cost of US$3.30 and US$4.80 per thousand, respectively. A labour force of 2.5 man-days is required to plant up a hectare in a day. At spacing of 1.2 m × 1.2 m for *R. apiculata* and 1.8 m ×1.8 m for *R. mucronata,* the estimated cost is US$40 and US$32/ha, respectively.

Planting using potted seedlings

Mature propagules are collected directly from the trees or gathered when fallen. Collected propagules are then sorted to ensure that only sound ones will be potted in the nursery. The choice of site for establishing the nursery is crucial so that the tides inundate the potted seedlings daily. Raised seedlings require a growth period of five to six months before they can be planted in the field. By then, they would have acquired two to three pairs of leaves.

Line planting at 2 m × 2 m spacing is adopted and this corresponds to about 2,500 seedlings per hectare. The cost of planting potted seedlings is about US$580 per hectare (Ismail Awang & Gan, 1989). The bulk of the cost incurred is due to raising and tending the seedlings in the nursery.

Planting using potted seedlings is an effective technique in overcoming the problems related to predation. Potted seedlings with woody stems are resistant to both crab and monkey attack. In view of the higher cost of planting, the use of potted seedlings is restricted to problematic sites only.

Planting using wildings

In Matang, natural regeneration of *Rhizophora* is often bountiful. Wildings of *Rhizophora,* which are readily available in the vicinity of seed trees, can therefore be used as planting stock for planting establishment. The technique of collection is simple and essentially involves extracting wildings of 0.5 m to 1 m in height from the substrate using a specially designed steel corer of 10 cm diameter (Chan, 1988). The corer is pushed into the ground in a spiral motion and then shaken to dislodge the plug of soil carrying the wilding. Penetration is aided by turning the two handles and by having a serrated edge at the bottom of the corer. Collected wildings are then placed onto wooden trays and transported for planting. Boats will be required for transporting wildings over greater distances.

The method and spacing for planting wildings are essentially the same as that for potted seedlings. Initial results from a trial carried out in Matang showed only 8% mortality three months after transplanting (Chan, 1988). A labour force of 50 man-days is required to plant a hectare at 2m × 2m spacing and at an estimated cost of US$170. To reduce the cost of transportation, it is desirable that wildings be collected from nearby forest areas adjacent to the planting site.

2.5 Cost implications

Reforestation programs have become a routine silvicultural activity and are carried out annually at the Matang mangrove. From 1987 to 1992, 4,300 hectare of mangroves have been reforested. This amounted to an average of 700 ha per year. At an estimated planting cost of US$34 per hectare, the annual budget ranged from US$6,430 in 1990 to US$39,370 in 1991.

2.6 Problems encountered

In Matang, sesarmid crabs have been reported to damage newly planted propagules of *Rhizophora* in small-scattered plantations (Noakes, 1951). Crabs operate by nibbling into the spongy inner tissues of propagules, often girdling or biting right through them. Attack occurs at the collar region or just above or below the mud surface. Propagules of *R. mucronata* are less susceptible to crab attack than those of *R. apiculata*. The conditions that favour crab attack are not known, though they may be fostered by a shortage of food supply in logged areas.

In some logged areas, damage by troops of long-tailed macaques (*Macaca fascicularis*) has caused failure of planting programs. Macaques damage newly planted propagules by uprooting them. A planting trial carried out showed that *R. apiculata*, which suffered a mortality of 99% after one and half months, is much more susceptible than *R. mucronata*, which suffered a corresponding mortality of 55% (Chan, 1988). In more inland areas that are less frequently inundated by tides, *Acrostichum* ferns grow in dense thickets. Their presence stifles the growth of existing natural regeneration and impedes the dispersal and establishment of water borne propagules. Hence, these infested areas are often devoid of natural regeneration of commercial mangrove tree species.

3. Rehabilitation after the tsunami

3.1 National task force committee

Realising the need to stabilize shoreline areas that could potentially be affected by tsunamis in the future, a National Task Force Committee (NTFC) was formed by the Ministry of Natural Resources and Environment to monitor the progress and implementation of coastal planting programs in the country. NTFC was supported by two technical committees, namely, the Planning and Implementation Committee (PIC) and the Research and Development Committee (RDC).

PIC was tasked to plan, administrate and monitor the implementation of planting mangroves and other suitable coastal species while RDC was tasked with carrying out R&D in developing improved planting techniques and in establishing demonstration areas of successful rehabilitation in eroding coastal areas.

3.2 Activities of PIC

Headed by the Forestry Department Peninsular Malaysia, PIC implements planting programs in various states of the country aimed at stabilising coastal areas. Currently, these activities are located in areas that have low risk of coastal erosion. To date, 4,000 ha of coastal areas have been identified to be suitable for planting of which 1,400 ha are under the permanent forest reserves and 2,600 ha are in stateland forests (NRE, 2005).

3.3 Activities of RDC

Chaired by FRIM, RDC aims to conduct research on developing techniques of coastal stabilisation prior to planting, especially in eroding areas. Stabilisation was done by constructing geotubes at a predetermined distance from the shore (Fig. 1). These hard engineering sand-filled structures would act as wave breakers. The accumulating mudflats at the leeward side of the geotubes will be planted with mangroves.

Fig. 1. A geotube being filled with sand during high tide

The sediments accumulated between the geotubes and the shore, are fine and liquid in consistency. As they provide poor anchorage for seedlings to grow, two planting methods, namely the Ridley Encasement Method and the Compressed Mattress Method were tested.

The Ridley Encasement Method was modified by using bamboo tubes of 1 to 1.5 m length depending on the depth of mud. The bamboo tubes were pushed into the mud with about 0.3 m extruding above the mud surface. The top portions were filled with mud prior to planting of *Rhizophora* propagules. The tubes were expected to provide additional protection to seedlings against wave action and allow better chance for seedlings to develop aerial roots that will anchor into the soft mud.

The Compressed Mattress Method involved the planting *Avicennia* species in a rectangular frame of hollow iron reinforced with plastic netting around the frame to form an open box. Potted *Avicennia* seedlings were placed inside the box and the remaining space inside the box was filled with dried fibres from empty fruit bunches of oil palm. Being light, the fibres facilitated transportation to the planting site and were expected to help in trapping sediments. Filled with EFB fibres and containing potted seedlings, the whole box was then placed into the soft sediment with both ends tied to an anchoring pole to prevent the box from being swept away by currents. The fibres and sediments were expected to form a growing media for the seedlings to grow.

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Rehabilitation of mangroves in Sri Lanka and Thailand after the 2004 Indian Ocean tsunami

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1. Introduction

The tsunami that struck coastal areas stretching over several thousand kilometres around the Indian Ocean on 26 December 2004 was one of the worst natural disasters recorded in recent times. The earthquake that resulted in the tsunami occurred in the extreme western end of the "Ring of Fire" an earthquake belt that accounts for over 80% of the world's largest earthquakes. The fault started just east of the city of Acheh (Indonesia) and extended hundreds of kilometres north. The affected region harbours many significant marine and coastal ecosystems including mangroves, coral reefs, sea grass beds, coastal dunes, mudflats, salt marshes, backwaters and lagoons, which all play a vital role in sustaining the living natural resources on which a significant proportion of human population depends. The damage to the ecosystems was exacerbated due to the fact that many of them were stressed by unsustainable resource use, such as over-fishing, and habitat destruction, including development or indiscriminate cutting down of mangroves for shrimp farming. Many coastal wetlands including protected areas were affected by the large inflow of seawater and wreckage during the tsunami, with longer-term effects including changes in hydrology and plant community composition.

Assessment reports of the affected areas suggested that coastal areas which had dense mangrove forests, mature shelterbelt plantations and other substantial vegetative cover, suffered fewer human losses and less damage to property and built infrastructure than those areas where the coastal forests ecosystems had been degraded or converted to other land use. There were instances of damage to mangroves trees in several dense patches but the damage to landward resources in previously degraded areas was more prominent. Other coastal forests and tree-dominated landscapes also performed important role of natural shelterbelt and preventing further damage to human life and property.

A massive international and national effort has been mobilised to respond to the tsunami, involving a wide range of sectors, agencies and levels of scale. As part of these efforts, IUCN has established a Tsunami Task Force to provide technical assistance and targeted field activities to ensure that environmental considerations are considered in post-tsunami reconstruction efforts. IUCN is also implementing a number of activities in direct support of the post-tsunami reconstruction process in affected countries.

This project on mangrove rehabilitation builds upon successful cooperation between IUCN and the Autonomous Organisation for National Parks (OAPN in Spanish), Ministry of Environment of Spain. Key results from this project will be actively promoted through IUCN communication mechanism as to enhance the visibility of the Government of Spain and OAPN in post-tsunami reconstruction efforts. Project documentation and publications will give a high profile to the support of the Government of Spain and OAPN, and community-based mangrove replanting activities will be publicised to the media and other press with full credit to the Government of Spain and OAPN.

2. Background

The earthquake that occurred on 26 December 2004, and the tsunamis that followed it, brought widespread devastation in the countries around the Indian Ocean. An estimated 250,000 people lost their lives or are missing, many more were made homeless, with a total of nearly five million people thought to have been affected directly by the disaster.

Review of the crippling damages caused by the tsunami showed that mangrove forests play a vital role in buffering the force of the waves and protecting human settlements. The countries that were hardest hit by the tsunami - Indonesia, Sri Lanka, India and Thailand - were all among those that experienced a net loss in mangrove cover over the last ten years. In addition to the protective effect of these ecosystems, mangroves are key to local livelihoods by providing breeding grounds for fish and other marine species, food, fodder, building material and natural medicines upon which local people depend. Mangroves also act as a natural water filtration system taking up excess nutrients, and have a carbon sequestration function that supports climate change mitigation.

While almost 40% of the world's mangroves are concentrated in Asia, the region also accounts for the highest loss in mangrove area over the last decade. More than half of the total area (some 208,220 ha) of Thailand's mangrove forests disappeared between 1961 and 1993, and Sri Lanka has also experienced significant reduction in mangrove areas. This loss can be attributed to the large-scale conversion of mangroves for conversion to shrimp ponds, agricultural encroachment, development of settlements and tourism infrastructure development. Building a sustainable economic and livelihood base which does not harm the natural environment is vital to supporting the long-term conservation of coastal ecosystems.

As has become all too clear in the aftermath of the tsunami, loss and degradation of these vital natural ecosystems impacts heavily on coastal populations - in economic, livelihood and social terms, as well as through the loss of vital life support and protection services.

As post-tsunami reconstruction takes place, there is an urgent need to restore and rehabilitate mangroves and other coastal ecosystems which provide valuable goods and services to coastal populations, and to ensure that these actions are implemented in a participatory and scientifically sound manner. This natural infrastructure will play a key role in maintaining the physical and socio-economic security of coastal settlements and livelihoods in the future, and reducing their vulnerability to natural and human disasters.

Protected Areas established to protect important biodiversity and ecosystems, provide a particularly important mechanism through which to achieve mangrove conservation. They comprise priority areas in which to commence mangrove rehabilitation in the coastal zone. In most cases, intervention will be needed to help restore or re-establish fully functional mangrove ecosystems in and around Protected Areas, including:

- Action is required to rehabilitate mangroves and other ecosystems which were destroyed by the tsunami itself.
- A massive international effort is being invested in post-tsunami reconstruction.
- There is an urgent need to integrate natural ecosystems in these ongoing reconstruction processes.
- Maintaining the security of Asia's coastal settlements and livelihoods requires reversing past damage and ensuring that mangroves are re-established in areas where they have been cleared, as well as taking action to prevent their future loss and degradation.

3. Project goal and objectives

This project responds to these urgent needs - within the immediate context of supporting post-tsunami reconstruction, and in a broader framework of strengthening the conservation of coastal biodiversity and ecosystems through Protected Areas. The goal of the project is to restore mangroves in and around priority Protected Areas that were affected by the tsunami as a mechanism to strengthen ecosystem conservation and reduce the vulnerability of coastal populations in Sri Lanka and Thailand.

Its objectives are:

1. To support and facilitate mangrove and coastal forest rehabilitation in and around priority Protected Areas.
2. Document and share policy and technical information and lessons learned in order to promote the integration of mangrove conservation and rehabilitation into post-tsunami reconstruction and coastal management processes.

4. Geographical focus

The project focuses on demonstrating and piloting on-the-ground approaches to mangrove rehabilitation and conservation in two countries which contain important and threatened mangrove resources, and which were among the worst affected by the tsunami: Sri Lanka and Thailand.

Within each country, at least one Protected Area (including its buffer zone and immediate surrounding area) will be selected for piloting mangrove rehabilitation activities. In Sri Lanka, the Yala East National Park (Fig. 1) and the Bundala National Park have been identified as priorities for mangrove rehabilitation, and in Thailand, the Laemson National Park.

Fig. 1. Damaged mangroves in the Yala East National Park, Sri Lanka

These sites have been prioritised in consultation with government and other partners in Sri Lanka and Thailand based on their biodiversity and ecological importance, perceived role in providing coastal protection and socio-economic services, degree of tsunami damage, and level of current and future threat. They are also located in areas where IUCN is active in supporting other elements of post-tsunami reconstruction, and is undertaking longer-term work programs in support of protected area planning, and ecosystem and livelihoods support.

5. Target beneficiaries

The ultimate target beneficiaries of this project are the communities who live in coastal areas, who depend on natural resources for their livelihoods, and whose settlements and infrastructure have been affected by the recent tsunami. A particular emphasis is given to poorer and more vulnerable groups. The project will involve and benefit various government and non-government agencies and sectors involved in post-tsunami reconstruction, coastal management and Protected Areas in Sri Lanka and Thailand.

6. Rehabilitation of mangroves in Thailand

This is the major part of the project. It deals with reforestation of denuded and tsunami affected areas employing different planting techniques such as seed sowing, transplanting of container plants, pit sowing etc.

6.1 Methods

Four sites were selected for planting, namely, Tung Nam Dam, Bang Kluay Nok, Cheme and Koh Yai coastal villages and Laemson National Park. Several mangroves species (*Avicennia alba, A. marina, Rhizophora apiculata, R. mucronata, Xylocarpus granatum, Ceriops tagal, Bruguiera cylindrica* and *Aegiceras corniculatum*) were tried in the field and nursery. In addition, some inland species such *Nypa fruticans, Ficus, Acacia, Casuarina* and *Derris* were raised in a beach nursery in Laemson National Park and Cheme village nursery. The mangrove planting has been done by local communities under the technical guidance of DMCR and National Park staff in the project areas. In some cases, other groups such as women folk and students have also participated in planting activities. So far, over five hectares of mangroves have been established in all the planting sites with 30-45% success. Especially in Tung Nam Dam sites, seedlings and saplings are sickly and unhealthy due to strong sea currents and wind pressures, whereas the mangrove plantations of other sites are surviving very well.

6.2 Management

This deals with taking care of existing mangroves stands in affected area. Most of the villages have their own conservation groups which have helped in management of the natural resources. It has been particularly helpful to the Department of Natural Parks for protection of biodiversity. Local communities have also restocked mangroves in blank areas in December 2006.

6.3 Community development

Efforts are being made to uplift the economy of the local people especially in Cheme Village. The fishermen cannot afford to rehabilitate or maintain mangroves as they are poor and under heavy debt. Most of the people do not know the importance of mangroves and also consider mangroves as an inexhaustible resource. The IUCN team is educating them through involvement in the mangroves replanting efforts. They are also encouraged to initiate income generating programs by raising *Nypa* plantations near their villages.

6.4 Recommendations

Before a possible redirection of the project can take place in the follow-on project, we strongly recommend that OANP should continue to support two main areas of the project, i.e. planting of mangroves, and creating awareness and encouraging community participation in mangroves conservation. The recommendations are grouped in the following categories, namely, mangrove planting, research, awareness, and training and community development.

Mangrove planting

Looking at the size of mangrove plantations which were established under the project, in no way can they be helpful to mitigate the natural disaster in future. Ideally, the protective plantations should be linear and should not be less than 10 hectares in areas exposed to tidal action. Planting of mangroves is an activity which needs to be continued in the affected areas. We however, emphasize that planting should concentrate on a mix crop of *Avicennia alba, A. marina, Rhizophora mucronata, R. apiculata* and *Sonneratia* spp. in areas prone to tsunami. For establishing mangroves plantations on high-lying areas in the frontage or back water, an irrigation system needs to be developed in order to maintain regular flushing of sea water.

Research

In view of the fact that basic scientific research is very limited in the area, it is recommended that significant funds be allocated for studies pertaining to local fisheries, food web dynamics, geochemistry of mangroves, soil and water etc. However, basic research could be considered separately from the current project as IUCN is most capable of community-related activities than basic research which could be carried out by research institutions. Beside, IUCN strongly believes that social-related issues are more immediate and pressing.

Awareness and training

Community awareness and sharing of responsibilities for their betterment should be encouraged and a working relationship should be maintained between them and IUCN. Some good results have been achieved and one could see several new small mangroves plantations near villages raised by local populations. The project team should extend all support to NGOs in this regards. One cannot have sound management policy for mangroves unless the local residents are ready to cooperate. IUCN is also very able to produce education and public awareness materials. Such material will be an asset for raising awareness among all stakeholders. Effective community participation will need time and credible advice will be the key to long-term cooperation.

Community development

Income-generating activities such as bee keeping, establishing *Nypa* plantation for thatching may be encouraged. The project team has already made successful attempts in this regards.

7. Rehabilitation of mangroves in Sri Lanka

A plantation of *Rhizophora apiculata* has been successfully established in the estuary. Over 300,000 container plants from IUCN mangrove nursery were successfully grown in a close spacing. The selection of site and the choice of species were correct and because of closeness to the village, the maintenance was minimal. The only threat to the young plantation was from the stagnant water which needs to be pumped out. Alternatively, the mouth of creek should be opened by deploying the earth moving machinery, so that the sea inundation could be resumed. A coastal plantation of *Casuarina* has also been raised in an adjoining area. Due to grazing pressure some saplings have been damaged and the remaining stock needs to be protected by erecting tree guards.

7.1 Identification of mangroves species

Typical mangrove species such as *Rhizophora*, *Avicennia*, *Excoecaria*, *Lumnitzera*, *Sonneratia*, *Xylocarpus* and *Aegiceras* and associates of *Tamarix*, *Acanthus* and *Sphaeranthus* are distributed along the coast of Sri Lanka. *Bruguiera cylindrica* and *Nypa* are found only on the west coast. Within the mangrove formation, different species occupy different zones. In places where the shore is not very steep, species such as *Lumnitzera* and *Avicennia* also come to the edge of the formation along *Rhizophora*. Further inland, where the water stagnates during high tide, a variety of species such as *Avicennia*, *Ceriops*, *Bruguiera*, *Excoecaria*, *Luminitzera* and *Aegiceras* are found.

Avicennia marina is a pioneer species that is tolerant to extremely saline conditions. It has a profuse root system that holds onto the ground firmly. It grows best when regularly inundated by the tide and hence the optimum growing zone is along the banks of creeks and lagoons. This is where the tallest trees are found, sometime approaching 10 m height. These species have been selected for planting in all sites in the Panama lagoon and East Yale National Park. *Rhizophora mucronata* and *B. gymnorhiza* are found as a dominant crop in lagoons on the east coast. Here, there is practically no wave action, the water level rises during rain. Trees of *R. mucronata* attain a height of 15 m serve as a shelter belt against wind erosion and cyclonic storms.

7.2 Physical environment

The soil of different composition ranges from sandy to sandy loam of varying depths. Tidal range is comparatively small, averaging about one metre. Because of this, the mangrove belts are rather narrow. The salinity level is variable depending on location, proximity to fresh water source and tide levels. Because of small variation in tide levels, there is little variation in inundation, except during monsoon periods when some sections remain inundated for prolonged periods.

7.3 Mangrove plantations

The main rationale of mangrove rehabilitation on the east coast of Sri Lanka is to mitigate the adverse impact of tsunami. Unfortunately, the work involving afforestation and protection operations has very recently started. As a result little expertise has developed within the Forest Department. But, the participation of local populations in mangrove rehabilitation has become productive and useful.

Site selection

Intensive surveys of the area have to be undertaken before mangrove planting. The operation cannot be done on every blank site or empty mudflat, since the topographical and environmental conditions limit the sustainability of many mangroves. In our case, there are many blank areas either because mangrove have been degraded by tsunami or cleared by local fishermen for fuel wood. These sites have been selected for planting under the rehabilitation program.

Choice of species

Avicennia marina, a hardy and colonizing species has been selected in all areas which are degraded by tsunami. *Rhizophora mucronata* and *B. gymnorhiza*, individually or mixed, are best suited for plantation along the banks of creeks. Sites down to the low water line have been selected. However, with trenching, *R. mucronata* can be planted in more elevated inland areas.

Nursery techniques

Seeds of *Avicennia* are raised in plastic bags and seedlings are transplanted in the field after 3-4 months. Propagules of *R. mucronata* can be planted directly into a field or raised in the nursery. Nurseries are sometimes protected by an earth embankment against wind and water currents. For ease and minimizing the risk of damage of the seedlings during transportation, nurseries should be located near the planting site.

Planting methods

Seeds of *A. marina* can be raised by three methods, namely, deep pitting, trenching and broadcasting. In sites with grass cover, the broadcasting method is economical and effective. The trench method is appropriate when the area has been degraded due to tree cutting and grazing. Propagules of *R. mucronata* are directly transplanted into deep pits in high lying areas. Under the project, all these three planting techniques have been applied.

8. Lessons learnt from rehabilitation efforts

Mangrove ecosystems are varied and their structure and functions depends heavily on the nature of prevailing environment. The approach adopted depends on the local conditions and the rationale for rehabilitation. It is therefore very difficult to generalise on the techniques that should be adopted for the rehabilitation at a particular site. However, there are some general principles that should be followed when rehabilitating a particular site. Above all, it is necessary to have a clear understanding of the nature and dynamics of locally occurring mangrove ecosystem, this will be the best guide to any rehabilitation program. It should be noted that plantation forestry is a long-term enterprise and would only start to yield results at least after five years.

Rehabilitation of mangroves and other coastal forests damaged by tsunami and other natural hazards in Australasia

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1. Introduction

This paper reports on mangrove rehabilitation and related mangrove management activities associated with extreme climatic and geophysical events that have or may impact on mangrove and maritime forest ecosystems in Australasia. This region includes Australia, New Guinea, New Zealand and some Pacific island nations e.g. Cook's and Tolelau Islands, which for political purposes are part of New Zealand. The focus will be on current issues and actions which relate to the perceptions of mangroves in New Zealand today. Australian examples will be used, where relevant, to give perspective to the New Zealand situation, as it existed in 2007. Mangrove rehabilitation and management is quite well documented in Australia (Hutchings & Saenger, 1987; Field, 1996; Saenger, 1996) and no obvious changes were reported by Mazda et al (2007). In the Asia-Pacific region, there exists a substantial body of literature on mangrove management and rehabilitation principles (Aksornkoae, 2004; Baba, 2004; Vannucci, 2004).

Biogeographically, Australasia is diverse and extensive with some 31 species of trees and shrubs including one species of fern represented in the mangrove flora. Endemic species are lacking in Australia and Papua New Guinea, being part of what some botanists describe as the "Indo-West Pacific' (Van Steenis, 1979). In Australia, maximum mangrove biodiversity occurs in the North East where a combination of climatic factors and geo-morphological conditions are most favourable (Hutchings & Saenger, 1987). Debate and discussion still exist as to the exact number and distribution of mangrove species in the Australian region, but from a rehabilitation standpoint, the patchy pattern of occurrence is noteworthy. These disjunctions of some 18 major species point to variations in ecology between species and this may influence species choice in rehabilitation schemes.

In broad terms, perhaps temperature tolerance may be a key factor in distribution patterns (tropical north to warm temperate south) and this should be taken into account in rehabilitaion. However, even today, the idea that only one mangrove species, *Avicennia marina,* exhibits cold tolerance is still widespread in the literature (Maxwell, 2007) despite efforts by Saenger (2002) to counter this viewpoint. Clearly, more work needs to be done on this aspect of mangrove biology. Perhaps rehabilitation work provides an opportunity and although much current 'climate change' literature points to global warming, this is not certain (e.g. Carter, 2007) and another major volcanic episode could rapidly reverse what seems to be the trend in global temperature patterns. It is wise therefore to keep an open mind on both 'global warming' and subsumed ideas such as the latitudinal extensions of tropical mangrove species or, alternatively, the invasion of *Avicennia marina* and *Kandelia candel* as two of the best known cold tolerant mangroves into coastal habitats now beyond the temperature tolerance of mangrove vegetation.

The impressive review of the physics of mangrove environments by Mazda *et al.* (2007) does not mention the effects of tsunami or cyclone on Australian mangrove ecosystems, likewise with New Zealand. The recent Indian Ocean tsunami of 26 December 2004 is given thematic attention, as it should be, but no specific Australian tsunami or cyclone cases are mentioned. This indicates a general absence of such hazards in living memory, especially with respect to spectacular or significant mangrove damage. To date, any details of mangrove destruction and associated coastal ecotones in areas near to northern Australia have not become easily available and do not appear in Mazda *et al.* (2007).

Key considerations of this regional report would focus on contemporary perceptions of mangrove ecosystems and on their potential to mitigate tsunami and cyclone forces in future. Sections include the following: 1) A summary of Australian mangrove restoration activities: Case study and model; 2) Changing mangrove perceptions in New Zealand: Models in motion and paradigm competition; and 3) Mangrove management: Methods and guidelines distilled from inter-jurisdictional uncertainty.

2. Australian mangrove restoration activities

2.1 Overview

As an examination of numerous coastal development projects will indicate, the coastal zone of Australia remains a magnet for settlement and life-style pursuits. Two main viewpoints dominate the thinking and activities here. They are conservation versus development (i.e. change to suit a human-made coastal landscape). Restoration may occur in such man-made landscapes but scientific eco-restoration of natural mangrove ecosystems is not an easy option as that of Brisbane International Airport case demonstrated (Saenger, 1996). As Field (1996) wisely cautioned, scientific eco-restoration is a daunting task and may be an impossible dream. He reminded us that the dilemma in such restoration is how much of the original mangrove ecosystem has to be restored to ensure sustained production and function.

This Brisbane International Airport (BIA) mangrove restoration project offers a very good case study for Australia. The thinking, selection, planning and monitoring methods are, in my assessment, a useful regional model.

2.2 Summary of BIA mangrove restoration project

Facilitation of rapid natural regeneration was the primary objective of the BIA mangrove restoration project with enhancing and protecting existing mangroves and improving biodiversity as secondary objectives (Saenger, 1996). The primary aim was related to bioengineering – using mangroves to protect the sides of new drainage canals, an important engineering aspect of this new airport spanning large portions of a mangrove habitat.

Many candidate species were considered, as might be expected in subtropical Brisbane located at 27°S. However, two ecologically, versatile (tolerant or hardy in Saenger's terms) Australian species were selected: *Avicennia marina* and *Aegiceras corniculatum.*

Nursery-grown seedlings were grown from freshly fallen or mature propagules detached from parent trees. Such established seedlings had better survival rates than dispersed propagules. The biology of propagule availability was very favourable too. *Avicennia marina* propagules being available in the Brisbane area from July to September and those of *Aegiceras corniculatum* from January to March.

Transplantation of shrubs between 0.3 to 1.5 m tall was found to be very successful. Plants less than 30 cm in height with a 20 cm diameter root ball had survival rates of more than 80% for at least three months. Planting involved placing the transplant in a prepared hole with care taken to avoid damage to and burying of pneumatophores. Costs can be highly variable with propagule collection, supply and planting the cheapest (~A$0.50 each) and transplants more expensive (~A$4.50 each). These costs translated into ~A$2,000/ha for propagule planting and ~A$18,000/ha for transplants. The encouraging natural mangrove regeneration and colonization which followed the restoration activities meant that extended restoration, repair and replacement problems were overcome. Saenger (1996) concluded that a self-maintaining mangrove community had been established.

In practical terms, I believe that the main lessons demonstrated from this BIA mangrove restoration project were:

a. Transplanting established seedlings of ~30 cm in height performed very well with low mortality. They play a bio-engineering role and can quickly function as stabilizers of canals.
b. *Avicennia marina* and *Aegiceras corniculatum* while lacking the large, elongate, easily planted propagules of Rhizophoraceae, are ecologically virile and their pioneering ability to colonise new mud surfaces.
c. There is evidence that the substantial below ground biomass of *A. marina* and *A. corniculatum* (Maxwell, 1993) may also enable them to cope with erosive forces associated with boat-wash from recreational fishing activities.
d. The BIA restoration project was not cheap and, as Saenger (1996) pointed out the restoration area was only 11 ha out of 13,720 ha of mangroves in the greater Moreton Bay of Brisbane. This is just 0.08% of the total mangrove area but at a cost of ~A$23,000 per ha in 1980. The project was, however, a success and did both protect and stabilize the banks of canals and, one could argue, used mangroves in a sustainable way.
e. This was an encouraging demonstration of the positive, productive and creative use of mangroves combined with their eco-restoration.

3. Changing mangrove perceptions in New Zealand: Models in motion and paradigm competition!

3.1 Overview

New Zealand has about 20,000 ha of mangrove forest (Hackwell, 1989). This figure is dynamic with some habitat loss due to reclamation, episodic frost damage and, overall, mangrove expansion due to sedimentation (Maxwell, 2005) and the ability of the sole New Zealand mangrove species, *Avicennia marina* to opportunistically exploit new mud flat habitats (Chapman, 1976; Maxwell, 2000; Maxwell, 2005).

Over the past 30 years, there has been a dramatic change in the viewpoints held by various groups in the New Zealand society on mangroves. Two polarised views now dominate. One wants, respects and seeks to save mangroves. The other, desires their demise. There is strong evidence in the media, in varies regional and community councils (local Government) and, of course, in many political parties which exist in New Zealand today, that the feelings about mangroves are at least mixed or, at worst, shifting from 'love' to 'hate'. I feel that these polarized perceptions are best characterized as mangrove models in motion and paradigm competition.

New Zealand is, in some ways, an extreme democracy; a country in which the opinions of anyone and everyone can contribute to environmental decisions. While this may be seen as good by some, it can often dilute the quality of science, especially ecology, on which environmental assessments are based. At times, inter-jurisdictional competition occurs with one local governmental authority competing with another (Taylor, 2007). In one of the two case studies to be outlined below, this process and the polarized perceptions of New Zealand mangroves have become an over-riding factor with serious implications for the future of mangrove ecosystems in New Zealand.

3.2 The Hauraki Plains: A low-lying, very productive dairy farming landscape protected by mangroves and estuarine stop-banks

The Hauraki Plains is famous in the rich agricultural region of Waikato for productive dairying country, currently worth more than NZ$14,000 per ha with the market value of farms typically reaching NZ$20,000 per ha. Much of this productive area is low-lying at 0.6-1.8 m above sea level (Maxwell, 1971 & 1976). The area is protected from seaward and estuarine river invasion by a complex of stop-banks. The seaward edges of this man-made network are protected by mangrove vegetation. Here the New Zealand sole true mangrove, *Avicennia marina* var. *resinifera*, is providing important and still poorly recognized bio-engineering service. Additionally, the mangrove ecosystem here in the Firth of Thames and its twin rivers of Piako and Waihou, also supports both recreational and commercial fin fishing and seasonal, wild duck hunting (Maxwell, 1971 & 1977). The mangrove area covers about 700 ha.

Both *Avicennia marina* propagules and seedlings were used in stop-bank protection and repair at several eroding sites along the estuarine reaches of the Waihou River. Propagules were grown to 4-6 leaf stage (~20 cm in height) in 500 ml biodegradable paper cups filled with estuarine mud. They were initially watered with estuarine water on two occasions, after which tap water was used as soil salinity can slow seedling growth. Old car tyres filled with estuarine mud and anchored with wooden battens were planted with propagules and seedlings of *Avicennia marina*. Survival rates varied from 50-90%. Some 100 tyres were used and a measure of stop-bank stabilization was achieved along with mangrove rehabilitation. Once the pneumatophores and base ground biomass were well established, the *Avicennia marina* shrubs held their own against estuarine and riverine water currents (Maxwell & Druitt, 1992).

It may take an extreme geophysical event such as a tsunami to re-affirm mangrove importance as coastline and, in the case of the Hauraki Plains, farmland protective systems. This mangrove is extensive and includes mudflats over one kilometre in width on which mangrove seaward expansion occurs. The field work alone reported by Mazda *et al.* (2007), underscores the potential importance of these systems.

4. Conclusion

This paper, of necessity in my view, focused on current issues and situations which exist in most of Australasia today. The Brisbane International Airport mangrove restoration project was used as a model system to illustrate how ecologically and practically sound eco-restoration projects may be structured. New Zealand examples were used to show that mangrove resources may not always be treated as assets and how the potential role of these ecosystems in tsunami mitigation can seem to be a distant non-reality. However, New Zealand is geo-physically unstable. Thus the potential importance of extensive belts of *Avicennia marina* mangroves in New Zealand coastal sites such as the Hauraki District in protecting valuable farmland from storm wave invasion should always be strongly appreciated.

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Problems and challenges of the rehabilitation of mangrove ecosystems in Indonesia after the 2004 Indian Ocean tsunami

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Abstract

In Indonesia, mangrove ecosystems are distributed throughout the archipelago. For centuries, Indonesian people have utilized mangroves for firewood, charcoal, tanning dye, timber for construction, etc. It has been estimated that the area of mangrove ecosystem is about 4.25 million hectares. However, due to population pressures and increasing demands on land for development activities in recent years, the mangrove area has been drastically reduced. Mangrove rehabilitating efforts were not so successful. The rate of degradation and conversion is much faster than that of rehabilitation. On 26 December 2004, Indonesia and some countries of Southeast and South Asia experienced a very strong earthquake of 8.9 Richter scale magnitude followed by a devastating tsunami. In the Aceh province, North Sumatra, alone, hundred of thousands of lives perished. Destruction of infrastructures, buildings, houses and other public facilities in coastal areas were extensive. Until June 2007, efforts of rehabilitation and reconstruction have not yet been completed. The Indian Ocean tsunami had served as the turning point for mangrove ecosystems in Indonesia, in particular for replanting mangrove trees for physical protection along coastal areas. Many provinces, districts, cities and villages have allocated funds to replant mangrove trees. Some of these efforts were successful, but many failed due to several factors, among others, the suitability of the land, species and the quality of mangrove seedlings, techniques of replanting, lack of caring after planting, and the lack of participation of local communities in the affected areas. This paper briefly describes the problems, challenges, manpower development and community participation in the efforts of rehabilitation of mangrove ecosystems in Indonesia after the tsunami.

Post-tsunami mangrove rehabilitation: An assessment

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Abstract

The protective role of mangrove and other coastal ecosystems was given much attention after the 26 December 2004 Indian Ocean tsunami. Many mangrove rehabilitation efforts were initiated with the objective to protect the coast from future tsunami. This paper documents the failures and successes of various mangrove rehabilitation projects at different sites, ranging from exposed coastlines to abandoned shrimp ponds. This assessment focuses mainly on the objectives of planting, selection of planting sites and mangrove species, and planting techniques and approaches. This paper also highlights the links between information, knowledge and policies. It identifies knowledge gaps and research priorities for the future needs. Standard guidelines to provide knowledge-based decisions will enhance the success of future mangrove rehabilitation projects. Future rehabilitation efforts should also take into consideration the effects of sea-level rise and climate change.

Devastation of the 2008 cyclonic storms on mangrove and other coastal ecosystems in Myanmar

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Abstract

Myanmar, with a total land area of 676,577 sq. km, is the largest country in mainland South East Asia. It has a total length of 2,832 km of coastline, and the extent of mangroves is 785,000 ha. The Ayeyarwady delta, with an area of about 35,000 sq. km, lies at the southern part of the country. The delta, where four million people lived, was devastated by Nargis cyclone in early May 2008. The official death toll was 77,738, with 55,917 reported missing. The United Nations estimated that some 2.4 million people were affected, mostly in the delta region. Apart from a huge death toll, most of the mangroves and coastal forests were destroyed, especially in core areas affected by the cyclone. The extent of natural forests and plantations damaged by storms in the Ayeyarwady and Yangon Divisions were reported to be 14,000 ha and 21,000 ha, respectively. Damaged forests in some areas have yet to recover. The Myanmar Forest Department is planning to rehabilitate the forests through artificial regeneration. The reforestation program will cover 170,000 ha, involving seven townships of the delta. It will be implemented in collaboration with the local communities and non-governmental organizations.

1. Introduction

Myanmar, with a total land area of 676,577 sq. km, is the largest country in mainland South East Asia. It has a total length of 2,832 km of coastline, and the extent of mangroves is 785,000 ha. The Ayeyarwady (AYWD) delta, with an area of about 35,000 sq. km, lies at the southern part of the country (Fig. 1).

Cyclone Nargis slammed into Myanmar on the nights of 2 and 3 May 2008 with gushing winds between 190 and 230 kph and waves up to 3.5 m high, causing much damage to the coastal region. The official death toll was 77,738, with 55,917 reported missing. The United Nations estimated that 2.4 million people were affected, mostly in the AYWD delta. Damage has been estimated at US$10 billion, which made it the most devastating cyclone ever recorded in the history of the country.

People of this region are mainly engaged in agriculture and fishery. The farming and fishing communities suffered lost of livestock, crop seedlings, equipment, boats, nets etc. Besides the loss of human lives, hundreds of thousands of people were left homeless.

Most of the mangroves and coastal forests were destroyed, especially in core areas affected by the cyclone. The extent of natural forests and plantations damaged by storms in the AYWD and Yangon Divisions were reported to be 14,000 ha and 21,000 ha, respectively. Damaged forests in some areas have yet to recover.

Although mangroves are a crucial resource of timber and food security, they also play an important role in coastal protection against natural hazards. Nevertheless, they are being destroyed at an alarming rate over the years. Unlike tropical moist forests, however, much of the conversion of mangroves is based upon the perception that mangroves are wastelands that are of no value until they have been converted for development. In Myanmar, overexploitation of timber for firewood

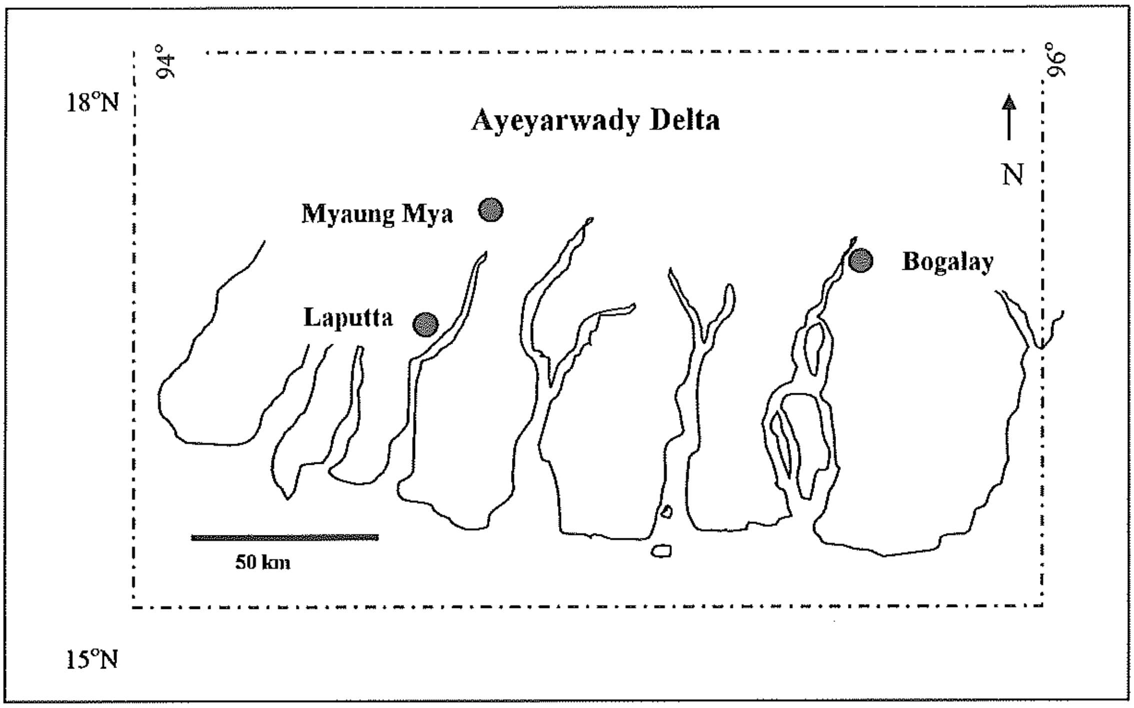

Fig. 1. Location of three mangrove areas in Myanmar and Ayeyarwady delta

and charcoal is a main cause for the deforestation, followed by conversion to paddy fields, salt fields, shrimp ponds and settlement areas.

The extent of mangroves in the AYWD delta has been estimated to be 177,330 ha some 15 years ago (Pe Thein, 1989). An area of 249,000 ha was estimated when the annual mangrove deforestation rate was assessed (Sit Bo, 1992). Between 1975 and 1989, the rate of mangrove deforestation in AYWD delta was about 7,780 ha per year. It was three times that of inland high forests. The Myanmar Forest Department reported the extent of mangrove forests in Myanmar to be 250,000 ha in 2003.

In addition to mangroves, other coastal vegetation grows on sand ridge areas. Trees of these beach and dune forests have been cut for timber. They include species such as *Streblus asper*, *Casuarina equisetifolia* and *Calophyllum inophyllum*. It is imperative to replant these species for protection of local inhabitants against destructive winds and waves.

The degradation and denudation of mangrove forests in Myanmar are a major concern for the people living along the coastal area. The socio-economic and environmental conditions of coastal community will be greatly affected. Unless proper remedial measures are immediately adopted, these forests will soon disappear. The impact of cyclone Nargis indicated the alarming situation of mangrove and coastal forest depletion in the delta region.

2. Coastal forests and storms

Many studies have highlighted that mangroves along with beach and dune forests help protect the coastline from erosion, storm damage and wave action by acting as buffers and trapping alluvial sediments. The degree of protection offered by coastal forests depends on many factors related to the characteristics of the hazard, the site and the forest. Mangrove forests have proven to be the most effective barriers to natural disasters resulting from storms and tsunamis. The case study of two coastal villages in Sri Lanka hit by the December 2004 tsunami was a good example. According to researchers from IUCN, only two persons died in a village with dense mangrove and scrub forest cover. In another village, with little or no coastal vegetation, up to 6,000 people lost their lives.

A tsunami impact reduction study found a 100 m wide mangrove forest could reduce a tidal wave's height by 50% and the wave's destructive power by 90% (Samabuddhi, 2005).

Cyclones that hit Myanmar in the past were not as strong as Nargis that brutally devastated the AYWD delta in the early of May. The lack of experience and expertise in managing a natural disaster of such magnitude might have contributed to the high death toll and great loss of human property. In addition, the vulnerability of the coastal line of the delta to storms and waves might also be due to the noticeably sparse mangrove vegetation in many areas.

In the case of cyclone Nargis, many survivors escaped the brutal storm surge by gripping onto branches and stems of trees in or near their villages. They would not have survived without these trees and many people became aware of the importance of mangrove including beach and dune forests in mitigating the impacts of natural storm hazards.

3. Impacts on mangrove, and beach and dune forest ecosystem

3.1 Effects on structure of forests

Disturbance and change, particularly over long periods of time, are part of all ecosystems. Natural disturbances such as storms and waves can alter ecosystem characteristics. Mangrove species differ in their degree of tolerance and recovery to damage.

Due to the immense magnitude of cyclone Nargis associated with tidal surges, most of the mangrove forests in the delta were seriously destroyed, especially in the core areas of the cyclone (Fig. 2). Damage outside the core zone was less severe.

Avicennia forest on Byone Mwe Island

Damaged stand of *Avicennia*

Sonneratia forest in Laputta

Damaged *Sonneratia* plantation

Fig. 2. Mangrove forests of the Ayeyarwady delta before (left) and after (right) Nargis

Table 1. Damage of trees inside core zone of cyclone Nargis

Type of damage	Seriously damaged (%)			Moderately damaged (%)			Slightly damaged (%)			Average (%)
	Plot 1	Plot 2	Plot 3	Plot 1	Plot 2	Plot 3	Plot 1	Plot 2	Plot 3	
Defoliation	20	15	30	35	40	40	60	65	45	38.9
Branches damaged	10	5	10	15	25	30	60	60	60	30.6
Crowns damaged	10	10	20	20	15	10	10	15	5	12.8
Trees uprooted	80	85	70	65	60	60	30	25	35	56.7

A total of nine 15 x 15 m plots representing seriously, moderately and slightly damaged sites were established in the core zone to investigate the intensity of damage on trees. As shown in Table 1, the average rate of defoliation was 38.9%. Trees with branches damaged, and with crowns damaged were 30.6% and 12.8%, respectively. About 56.7% of the trees were uprooted.

Similarly, nine 15 x 15 m plots were established outside the core zone to assess the degree of tree damage. Table 2 indicates the severity of tree damage outside core zone. Average defoliation was 55.6% while trees with damaged branches, trees with broken crowns and uprooted trees were 42.7%, 19.8% and 4.2%, respectively. Outside the core zone, standing trees having minor damages were found to be 33.3%. In contrast, none of trees in the nine plots established inside of core zone were free from storm damage.

Table 2. Damage of trees outside core zone of cyclone Nargis

Type of damage	Seriously damaged (%)			Moderately damaged (%)			Slightly damaged (%)			Average (%)
	Plot 1	Plot 2	Plot 3	Plot 1	Plot 2	Plot 3	Plot 1	Plot 2	Plot 3	
Defoliation	80	95	50	80	95	40	20	10	30	55.6
Branches damage	60	49	65	71	62	77	Nil	Nil	Nil	42.7
Crown damage	28	51	22	26	38	13	Nil	Nil	Nil	19.8
Trees uprooted	12	Nil	13	3	Nil	10	Nil	Nil	Nil	4.2
Standing trees with minor damage	Nil	Nil	Nil	Nil	Nil	Nil	100	100	100	33.3

Due to tree falls in the core zone, many small gaps were created. The open canopy may encourage natural regeneration of light demanding tree species such as *Avicennia*, *Sonneratia* and *Rhizophora*. However, growth of these tree species may be stifled by the rapid colonization of invasive species such as *Acanthus illicifolius*, *Phoenix paludosa* and *Acrostichum aureum*.

Table 3. Survival and growth of plantations before and after cyclone Nargis

Species	Age	Diameter (cm)	Average height (cm) Before Mar 08	After May 08	Height difference (cm)	Survival (%) Before Mar 08	After May 08	Mortality (%)
B. sexangula	8		147.8	157.8	10.0	82	82	
A. marina	8	1.3	239.2	239.4	0.2	80	80	
H. formes	6		206.1	212.5	6.4	68	68	
R. apiculata	7	6.5	879.0	810.0	-69.0	88	88	
S. apetala	9	9.4	917.4	833.9	-83.5	70	67	3
A. officinalis	9	8.7	943.1	877.9	-65.2	74	73	1

A survey was conducted on the survival and growth performance of mangrove plantations before and after cyclone Nargis. These plantations ranged from 6 to 9 years of age. As shown in Table 3, *Bruguiera sexangula, Avicennia marina* and *Heritieria fomes* showed positive height growth and no mortality. Damage was not discernable. With an average height of only 2 m, these trees are likely to be more resilient to storm damage.

On the contrary, plantations of *Rhizophora apiculata*, *Sonneratia apetala* and *Avicennia officinalis* were much more susceptible to storm damage. Trees showed height reductions of 65 to 84%. It is likely that the trees which are taller in height were snapped during the storm. Trees of *S. apetala* and *A. officinalis* showed minimal mortality of 3 and 1%, respectively.

3.2 Effects on seed production

Usually, flowering and fruiting of most mangrove species occur in rainy season, from middle of May to end of September. The period of Nargis coincided with the flowering of *Avicennia* and *Sonneratia*. It is anticipated that there will be a short supply of mangrove seeds for natural and artificial regeneration as a result of the vast injury inflicted on parent trees. It is hoped that species such as *B. sexangula*, *Bruguiera gymnorhiza*, *Ceriops decandra* and *Lumnitzera racemosa*, that were not in flower when Nargis hit, will be able to produce sufficient seeds and propagules for reforestation activities of the existing year.

3.3 Pest attack after recovery of trees

Some species of *Sonneratia* and *Avicennia* started to produce flushes of new leaves within two weeks after cyclone Nargis. Field observations showed that *A. officinalis* trees were susceptible to defoliation by beetles and caterpillars feeding on new leaves.

3.4 Effects on wildlife

Due to high intensity of winds of Nargis, tree canopies were damaged during the Nargis. Stress that reduces tree height and canopy coverage also destroys habitats for wildlife, especially birds. When the trees are defoliated, the substrate condition below the dead stand may also change. The fauna living in such substrate may be adversely affected. Similarly, many living organisms must have been affected in terms of changes in habitats and functions because of enormous natural disturbance.

The outstanding example is that new mound nests of crocodiles (*Crocodylus porosus*) were found in the mangrove plantations where it has never come to nest before Nargis. The first reason may be that their natural nesting sites have been destroyed. The second reason may be that mangrove reforestation has provided habitats for the crocodile as well as other fauna. Investigations on the effects of Nargis on wildlife in the delta are pertinent to restore the ecosystem.

4. Coastal erosion and deposition of sand

Because of cyclone Nargis, coastal erosion was seen in some areas of the AYWD delta. Magnitude of erosion varied between places depending on storm surges. About 40 m of the coastline of Laputta township has started to erode. Sand up to 20 cm in depth is deposited some 200 m inland. This has caused mortality of natural regeneration of trees. In addition, aerial roots of some mangrove species were buried by the sand deposition, and these trees died eventually.

5. Rehabilitation of mangrove ecosystem after Nargis

There are many things to be undertaken in the post Nargis period in terms of restoration of mangrove and coastal forests. The Myanmar Forest Department is planning to rehabilitate the forests through natural and artificial regeneration (MFD, 2008). The extent of reforestation to be conducted is 177,308 ha involving seven townships of the AYWD delta (Table 4). The program will be implemented in collaboration with the local communities and non-governmental organizations.

Table 4. Extent of mangrove reforestation to be conducted in the AYWD delta

Township	A/R	N/R	Private	CF	Riverbank	Conservation
Laputta	80,100	56,270	25,860	20,000	2,650	
Bogalay	59,600	15,560	12,000	8,000	1,750	31,115
MawKyun	8,560	1,000			700	
Ngaputaw	600				550	
Pyapon	75,600	47,320	13,000	12,000	700	
Daydeye	1,200				150	
Kyaiklatt					100	
Total (acre)	225,660	120,150	50,860	40,000	6,600	31,115
Total (ha)	90,264	48,060	20,344	16,000	2,640	12,446
Grand total (ha)						177,308

A/R: Artificial regeneration; N/R: Natural regeneration; CF: Community forestry
Source: Working Plan Division, Myanmar Forest Department

International organizations such as ITTO and JICA will also contribute the reforestation activities to be conducted in the delta. FREDA, in collaboration with the Forest Department, has plans to establish 750 ha of mangrove plantations from 2009 to 2014 with the support of ACTMANG from Japan.

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Conceptual model on capacity building of fishing communities in post-tsunami mangrove rehabilitation

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Abstract

This project is aimed at applying research-based knowledge to the integrated post-tsunami mangrove rehabilitation and management plan for the coastal fishing communities in the Andaman coastline of Thailand. The project was undertaken after the royal initiatives of the beloved the King and Queen of Thailand on self-sufficiency for sustainable development and the three-well concept, respectively. Three phases of the mangrove rehabilitation scheme have been proposed, namely, immediate, short-term and long-term phase. The immediate phase will concentrate on ecological risk assessment impacts. The short-term phase will involve the comparison of field surveys and the predicted risk assessment, and drawing up rehabilitation plans which are site-specific. The project proposed under the long-term phase will be for four years. The Participatory Research Approach will be adopted in all four components of the project. Site-specific designs of mangrove plantations have been proposed for each selected area based on suitable species selected and planting techniques in relation to the enhancement of coastal fishery. Assessment of mangrove resilience and recovery capacity to disturbances will also be carried out. Public awareness and participation in the coastal resource conservation and rehabilitation will also be encouraged throughout the project. Self-reliance in terms of biological productivity and fishing communities are the two prime factors to sustain the rehabilitation and conservation of coastal resources. Capacity building scheme proposed not only concentrated on the local fishermen themselves but on trilateral cooperation, local communities with emphasis on the younger generations, new generations of researchers working on sites and graduate students in mangrove ecology.

1. Introduction

On 26 December 2004, a tsunami disaster struck six provinces of the Andaman coastline in Thailand. It caused great loss of human life and property. But the mangrove forests have proven their ecological role as barriers against winds, waves and erosions, helping to lessen the loss. Of the coastal ecosystems, about 386 ha of mangrove forests were reported to be impacted by the tsunami. Only 89 ha in Ranong Province were reported to be severely damaged. Mangrove forests in Phan-nga Province were slightly damaged but over a large area. The damaged area of mangroves was small when compared that of other coastal ecosystems such as coral reefs (690 ha) and sandy beaches (990 ha). However, these impact assessments were based only on physical alterations. The assessment on ecological functions, being permanent habitats, feeding and nursery grounds, and nutrient transports between mangrove forest and coastal waters, have not been carried out. Having multi-disciplinary researchers in our team both in the field of science and social science, we feel that this "crisis" could turn into an "opportunity" for us to apply our research-based knowledge to the integrated post-tsunami mangrove rehabilitation and management plan for coastal communities of the Andaman coastline.

2. Royal initiatives of mangrove rehabilitation and management plan

In term of sustainable development, His Majesty King Bhumibol Adulyadej of Thailand is the solitary leader. His vision on self-sufficiency is the important step towards a balanced development that will sustain both human beings and the natural environment (Paphavasit *et al.*, 2000). The concept of self-reliance concentrated on the principles of producing enough to live on while preserving the integrity of the environment which is most essential for sustainable development. For both the King and Queen of Thailand, the success of forest rehabilitation required the full understanding of how different elements, both natural and human, interact. The assessment of the existing biological productivity and the necessity of maintaining ecological processes is one of the most important elements to determine the self-reliance of the ecosystem. This demonstrates the resilience and response of the ecosystem to environmental changes. Public awareness and participation in the coastal resource conservation and rehabilitation is another important element of self-reliance apart from the biological productivity of the area. These two major elements play important roles as the internal driving forces to sustain the rehabilitation and conservation of coastal resources. His Majesty the King has laid down the principles toward self-sufficiency (self-reliance). First step is "Respect the local landscape and culture: Listen to the people, let them be your teachers. Think far and wide, but remember that the final goal is the well-being of the people". Second step, the King has stated that "Change must come from within to attain sustainability, every part of the society must move along in unison towards common goals. Foster the spirit of unity and pause, only to go forward."

Her Majesty Queen Sirikit laid down the three-well concept under the royal initiatives which is applicable to mangrove rehabilitation and management plan. Well-being of the people is Her Majesty's prime concern. People should be living in harmony with the forest under the guidance of His Majesty on self-sufficiency. The right to conserve and utilize the forest land should be provided for the people to enjoy the well-to-do condition for their families. Well-knit principle is to foster the spirit of unity for the locals to conserve and rehabilitate the forest. On the other hand, the well-knit principle implies how the people and the forest have inter-twined in harmony. Taking the royal initiatives into account, our research team has drawn up the framework of transforming these into a working reality of a mangrove post-tsunami rehabilitation and management plan.

3. Fishing communities as the target group

Several studies of mangrove forest communities in Thailand provide evidence that the fishermen way of life is a paradigm to follow His Majesty's guidance on self-sufficiency. The fishing communities demonstrate the moderate and reasouable standard of living. They have followed the concept of self-reliance by producing enough to live on while preserving the integrity of the environment. The problem of mangrove deforestation has pronounced impacts on the fishing communities. Increased coastal erosion resulting from vanishing mangrove areas has forced many fishing households along the coastlines to move inland to settle. The rate of moving landwards is quite rapid in recent years as coastal land areas become scarce and expensive. Due to this limitation of coastal land, very high-density fishing communities occur along the coastlines. This is a good indicator of poverty in fishing communities (Siriboon, 1998; Suwannodom *et al.*, 1999; Suwannodom *et al.*, 2000). The fishermen have faced major obstacles in pursuing their livelihoods, namely, the degradation of coastal ecosystem, declining fishery production, and conflict of interests between commercial fishery and small-scaled fishery. It can be concluded that the small-scaled fishermen were mostly affected by the mangrove degradation, which in turn, resulted in the reduction of fishery resources. They were driven into hardship and poverty due to the scarcity of fishery resources.

It is evident that the fishermen themselves are often more aware of the values and benefits of mangrove forests. They are also well aware of how the changes in these forests would affect them. They realized that mangrove reforestation/afforestation will help to lessen their burden. They believe that if these mangrove forests could appear once again along the coast, the quality of life of small-scaled fishermen would be better (Suwannodom *et al.*, 2004). It was found that those who received direct benefits from the mangrove forest in particular the fishermen were more determined than others to participate in rehabilitation programs (Siriboon, 2000). We feel that changes in mangrove productivity will be a major factor in sustaining the fishing communities and their livelihood. In turn, the prosperity of the fishing communities is a good indicator of coastal productivity.

4. Framework for integrated post-tsunami mangrove rehabilitation

Our research team has proposed three phases in the mangrove rehabilitation scheme. As mentioned, we strongly feel that this disaster has given us an "opportunity" to do things the right way. The mangrove rehabilitation scheme needs to be carefully drawn based on the royal guidelines. Mangrove rehabilitation schemes can be divided into four major stages: 1) drawing the goals and objectives of mangrove rehabilitation in each site; 2) outlining the activity and operation plan based on ecological processes in human interactions which play important roles in mangrove rehabilitation; 3) defining the criteria for the monitoring/assessment of mangrove rehabilitation, and 4) management plan. The major goals and objectives of mangrove rehabilitation are to select the protocols for mangrove plantations to enhance the coastal productivity and fishery. The reforestation techniques, mangrove species chosen and magnitude or scale of mangrove reforestation should be drawn based on scientific knowledge. Based on our previous studies, we would like to concentrate on two protocols of mangrove plantations in Nakhon Si Thammarat and Samut Songkram Provinces, respectively. Our assessment is on the positive influence of multi-species mangrove plantations in abandoned shrimp farms on coastal fishery. It would take not less than five years for the recolonization process to take place and thus enhance coastal fishery (Teratanatorn, 2002; Paphavasit *et al.*, 2002; Paphavasit *et al.*, 2004). The three phases in the post-tsunami mangrove rehabilitation scheme are outlined as in Figure 1. The immediate phase concentrates on the ecological risk assessment impacts. The short-term phase involves the comparison of field surveys with the predicted risk assessment. Site-specific rehabilitation plans will be drawn accordingly to the landscape and public needs. The long-term phase is proposed to commence 6-8 months after the implementation of the mangrove rehabilitation plan on selected pilot sites. The project will have a duration of four years.

5. Capacity buildiug in fishing communities

Pilot fishing communities will be selected based on the ecological risk assessment, mainly the severity of damaged forest, size of fishing communities and degree of mangrove dependency by the communities. Two important target groups involved in the project are the fishermen themselves in particular the younger generation of 15-24 years old. Another target group is other stakeholders such as community leaders, government sectors, non-government sectors and public participations. This latter group should play active roles in building awareness and cooperation in planting and conserving the mangrove forests.

Participatory Research Approach is focused in all four components of the project. Before initiating the project, the site and the people, who will be affected, should be studied, based on first-hand knowledge of the landscape and culture. The site specific design of mangrove plantations are proposed based on suitable species selected and planting techniques in relation to the enhancement of coastal fishery. Self-reliance of the mangrove forest was dependent on the existing biological productivity and their maintenance processes as the aftermath of the Tsunami disaster. Public awareness and participation in the mangrove rehabilitation is another important elements of self-reliance apart from the biological productivity of the area. Quantitative survey as well as in-depth interview and focus group discussion will be carried out to determine the local awareness on the ecological functions and values of mangrove forests. Their perception on the changes in mangrove area and their rehabilitation efforts will be sought. This will also determine the local community cooperation and organization to participate in the management of the forests.

Program intervention phase is the integration of the scientific and socio-economic aspects when drawing a specific rehabilitation plan that is suitable to the landscape and fulfills the needs of the local people. Monitoring is one of the integral parts of the rehabilitation activity. This will also involve the public participation as well as the capacity building program for the locals, field officers, and young scientists to monitor and assess the progress of the project. This involves the monitoring of planting, growth and survival studies of mangrove species and maintenance protocols. Protocols for seed germination and seedling cultivation are also included for the maintenance of the mangrove forests which would be community-based. Environmental monitoring as well as the coastal fishery will also be monitored. Certain indices for the recovery of mangrove forests will be determined. Outcome evaluation will be included to determine the success of the project not only in terms of the enhancement of coastal productivity and fishery, but also to determine the community capacity to sustain the on-going mangrove rehabilitation scheme.

6. Preliminary results on the ecological risk assessment

Results of the impact assessment of tsunami on the mangrove forests of the Andaman coastline in Thailand are shown in Table 1. The degree of impacts depends on the location of the forest. Severely damaged forests are those at the seafront. Mangroves fringing riverbanks and small canals are usually protected. Physical alterations revealed seawater intrusion in mangrove areas of Ranong, Phang-nga, Phuket, Krabi and Satun Provinces. Changes in direction and in the depth of canals and water channels were evident in the provinces of Phang-nga, Phuket and Satun. Increased turbidity of mangrove waterways were observed with offensive odour in certain areas.

Table 1. The impact assessment from tsunami on the mangrove forests of the Andaman coastline in Thailand

Impact on Mangrove Ecosystem	Province					
	Rano	Phang-nga	Phuket	Krabi	Trang	Satun
1. Physical alterations						
1.1 Water quality						
- seawater intrusion in mangrove forest	0-1	0-2	0-2	0-1	0	0-1
- channel fill-up	0	0-1	0-2	0-1	0	0-1
- changes in waterways	0	0-3	0-2	0	0	0-1
- increase channel depth due to erosion	0	0-2	0-2	0	0-1	0-1
- increase turbidity	0-1	0-3	0-3	1	0-1	0-1
- changes in seawater coloration	0	0-4	0-1	1	0	0-1
- increase in offensive odours	0-1	0	0-3	0	0	0-1
1.2 Sediment quality						
- increase sedimentation in mangrove area	0	0-4	0-3	0	0	0-1
- soil erosion	0-1	0-3	1-3	1	0-1	0-1
- changes in sediment coloration	0-1	0-2	0-1	1	0	0-1
- increase in offensive odours	0-1	0-1	0-2	0	0	0-1
2. Biological alterations						
2.1 Mangrove flora						
- loss of mangrove area	0-1	0-3	0	0	0	0
- loss of seedlings area	0	0-2	0	0	0	0
- mangrove regenerations	0	0-2	0-1	0	0	0
- increase damages on mangrove shrubs	0	0-2	0-3	0	0	0
2.2 Mangrove fauna						
- decline in fishery resources	0-1	0-3	1-2	0-1	0	0-1
- increase in fishery resources	0	0-2	0	0	0	0-1
3. Socio-economic aspects (fishing communities)						
- decline in catches	0	0-3	0-1	0-1	0-1	0-1
- decline in fishing boats	0	0-4	0-2	0-2	0-1	0-1
- decline in fishing families	0	1-4	0-2	0-2	0	0
- occupational shifts	0-1	0-4	0-2	0-1	0	0-1

0 = not affected ; 1 = 1-25% alteration; 2 = 26-50% alteration; 3 = 51-75% alteration;
4 > 75% alteration

Loss of mangrove area was observed in Ranong Province (8 ha) and Phang-nga Province (319 ha). Natural regeneration in the Phang-nga area was severely damaged. Most provinces reported declines in fishery production. The fishermen in Phang-nga Province were affected by this disaster. Table 2 summarises the impacts of tsunami on the fishing industry of the Andaman coastline.

Table 2. Impact assessment from tsunami disaster on the fishery occupation in six provinces on the Andaman coastline

Province	Damage (recorded from field survey)								Total cost (Baht)
	Aquaculture (No.)			Fishing Boats (No. of boats)		Fishing Gears (No.)			
	Fish cages	Fish ponds	Hatchery	Small	Large	Stake traps	Nets	Traps	
Phang-nga	1,733	7	67	390	473	-	477	517	913,549,000
Krabi	890	2	-	1,034	10	345	643	402	191,697,000
Phuket	529	2	209	968	473	-	649	72	320,504,000
Ranong	1,229	-	-	420	356	56	522	267	170,738,000
Trang	470	-	-	815	1	8	600	483	14,980,000
Satun	1,126	-	1	1	30	274	580	584	119,394,000
Total	5,971	11	277	3,628	1,343	683	3,471	2,322	1,730,862,000

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Guidelines on the assessment of mangrove rehabilitation efforts as mitigation to natural hazards: Thailand's experiences

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Abstract

Mangrove rehabilitation in Thailand has emerged as a viable mechanism to mitigate natural hazards in particular coastal protection in the aftermath of the Indian Ocean tsunami. Current rehabilitation activities in some area have failed to achieve the objectives and goals as efforts were not sustained. Failures to recover the pre-disturbance mangrove structure and function have increased the need for rehabilitation guidelines and assessments. The proposed guidelines for mangrove rehabilitation efforts as mitigation to natural hazards have been designed to address the effects of rehabilitation that are of ecological and social importance. The assessment program has taken into account the linkage of several ecological indicators as the measurement of mangrove rehabilitation success and the ecosystem services provided for the coastal communities. The program is also designed to enhance the capacity building among local communities in monitoring and evaluation which form an integral part of mangrove rehabilitation. Most importantly, there should be two-way communication flows when drawing up the mangrove rehabilitation plan in order to ensure the success and sustainability of rehabilitation efforts.

1. Introduction

The 2004 Indian Ocean Tsunami has cost death and destruction in six coastal provinces on the Andaman coast. The tsunami affected 407 villages of which 47 were almost completely destroyed. Phang-nga and Krabi provinces were the most severely affected. About 386 ha of mangrove forest were reported to have been impacted by the tsunami. Since then, mangrove rehabilitation in Thailand has emerged as a possible option to protect coastal area against natural hazards such as tsunami and coastal erosion (Paphavasit *et al*, 2007; Siripong, 2007; Wachrinrat, 2007). Severe coastal erosion in the Gulf of Thailand in particular Samut Prakarn, Samut Sakhon, Samut Songkram and Nakhon Si Thammarat Provinces resulted from degradation of mangrove forests due to shrimp farming, land subsidence, reduction of sediment runoffs, coastal construction and coastal sand mining. Mangrove reforestation programs have been viewed as counter-measure efforts to coastal erosion. Assessment on public awareness and participation in mangrove rehabilitation programs as revealed by Siriboon (2007) showed that the level of participation was highly correlated to degree of mangrove dependency, degree of threats to community well-beings and quality of life affecting their occupations and also the size of remaining forest. Once the communities are no longer related to the forest, the less they are willing to volunteer and participate in mangrove rehabilitation efforts. The statistics in Table 1 exemplified these relationships. The high percentage of public awareness and participation in mangrove rehabilitation in Phang-nga Province was a quick response to the tsunami aftermath.

Table 1. Public awareness and participation in mangrove rehabilitation program in Thailand

Public awareness and participation	Percentage of respondents: Samut Sakhon (N = 770)	Nakhon Si Thammarat (N = 728)	Phang-nga (N = 115)
Need for mangrove rehabilitation			
- Yes	75.2	84.5	93.9
- No	24.8	15.5	6.1
Participation in mangrove reforestation			
- Full cooperation	36.5	53.8	88.7
- Some cooperation	22.7	10.4	3.5
- Occasionally	32.2	35.3	6.1
- No	8.6	0.4	1.7

N = Number of households

2. Failures and success of mangrove rehabilitation in Thailand

Current mangrove rehabilitation activities in Thailand have failed in some areas and the efforts were not sustained. Our studies in several coastal provinces indicated that although the rehabilitation projects involved participation of the coastal communities in terms of conservation and rehabilitation activities, they were not involved in terms of planning and drawing up the integrated mangrove management plans (Paphavasit *et al.*, 2006, Siriboon & Paphavasit, 2006). Public awareness and participation play a vital role in determining the success of mangrove rehabilitation. Other factors contributing to failures of such programs included designs that were not suited to local needs and also incompatible with natural recovery processes. Large-scale mangrove rehabilitation is often technically unfeasible and difficult to manage.

3. Needs for rehabilitation guidelines and assessment

The assessment of mangrove rehabilitation efforts should be designed to address the three related objectives as adapted from selecting estuarine indicators (Toth, 2005; Hameedi, 2005; Jordan & Smith, 2005). The assessment should document the effects of mangrove rehabilitation that are of ecological and social importance. What we are looking for is whether the mangrove rehabilitation really rehabilitated the mangrove structure and function and thus providing the ecosystem goods and services to the coastal communities. Secondly, the assessment is to ensure that the rehabilitation process is conducted to minimize any impacts to other coastal resources. The assessment will help to prove that we are doing the right thing, unlike the Thai expression "not with good intentions but wrongdoings". Lastly, the rehabilitation assessment should provide information for sound management and wise use of mangrove resources.

4. Rehabilitation guidelines: Moving on the road of success

Sustainable development of mangrove resources should not be the government's sole responsibility. Local communities also have the responsibility to conserve mangroves as well as the right to utilize the forest and its resources. With different goals and objectives for mangrove rehabilitation, the same basic blue print cannot be drawn. There is a need for the design of mangrove rehabilitation scheme which is site-specific to suit the objectives of the coastal communities. The design should also enhance the natural recovery processes. Coastal green belts were introduced in order to provide an open-end framework to bring together key stakeholders to collaborate in supporting the protection and rehabilitation of affected coastal area in post-tsunami mitigation efforts. However, Parish (2005) concluded that poor design and management of coastal green belts reduced their effectiveness. Selected mangrove species, their complex root system and tree density as well as spacing must be considered in designing an effective green belt. Planting techniques as well as selection of mangrove species are the key component in the rehabilitation. Protocols for seed germination and seedling cultivation are essential.

In our post-tsunami monitoring and assessment in the Phang-nga and Phuket Provinces, we recommended site-specific mangrove reforestation schemes based on the comprehensive understanding of the complex ecological-social-economic linkage. Coastal green belts were proposed for Ban Nam Khem, Phang-nga Province on the basis that rapid recolonization of plant communities is expected in the short term. Ban Nam Khem village was one of the hard hit areas by the 2004 Indian Ocean tsunami. Mangrove rehabilitation to enhance coastal fisheries was recommended for Ban Rong fishing village in Phuket Province (Paphavasit *et al*., 2006).

Introducing different mangrove species is the key to re-establishing the forests as a viable ecosystem. This is based on the principles of colonization and secondary succession in plants and benthic communities in order to build the predictive model of ecological recovery. This can also be used as guidelines for an adaptive management strategy. Several studies on the stability assessment of mangrove reforestation in Thailand demonstrated that the ecological recovery required longer periods of time. Paphavasit *et al.* (2002) found that the recolonisation of benthic fauna on mangrove afforestation in the tidal mudflat in Samut Songkram Province as the indication of stability would take more than 7 to 11 years depending on the degree of sedimentation and the availability of natural seedlings in the area (Figs. 1 and 2).

It would take no less than five years for the recolonization process in natural succession forests to take place (Fig. 3) depending on the degree of disturbances in the sediment and of human interferences. Different selected mangrove species demonstrated different time frames to stabilize. Similar studies were carried out in Nakhon Si Thammarat Province on the stability assessment on *Rhizophora* planted on newly accreted mudflats (Fig. 4) and in elevated abandoned shrimp farms (Fig. 5). Paphavasit *et al.* (2004) reported that multi-species or mixed plantations in abandoned shrimp farms at Pak Nakhon, Nakhon Si Thammarat Province showed a similar pattern as natural succession forests without human intervention (Fig. 6). It would take more than five years for the benthic fauna to recolonize. The opportunistic species mainly small crustaceans, such as amphipods, tanaidaceans and polychaetes would replace previous benthic groups. As forest succession progresses, major benthos such as brachyurans, gastropods, bivalves and polychaetes would replace the opportunistic species. They would then serve as food sources for fishery resources.

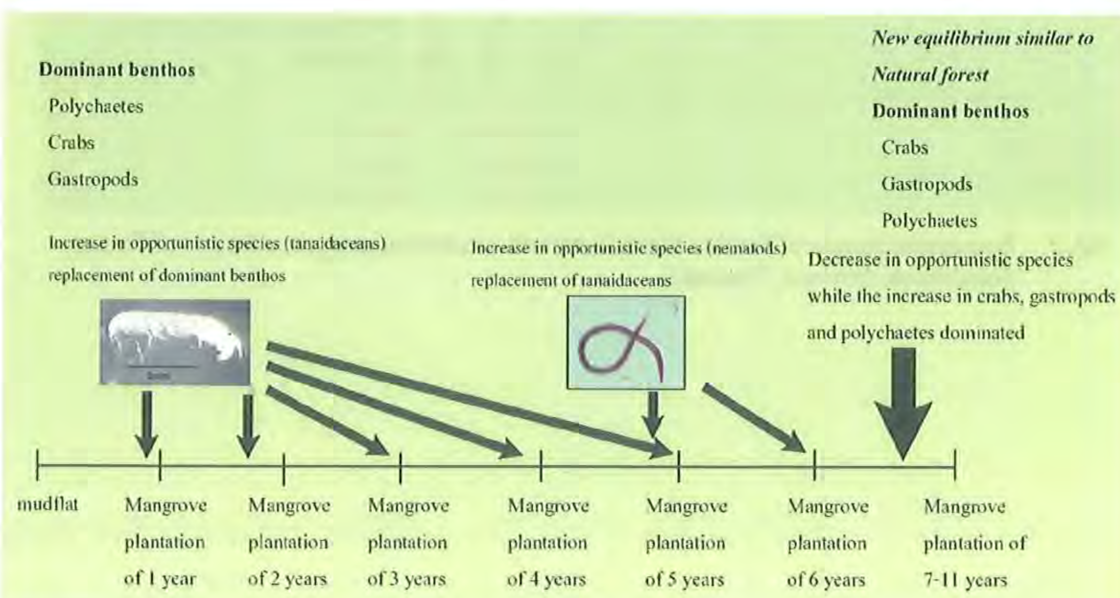


Fig. 1. Succession pattern of benthic fauna in *Avicennia* plantations established on tidal mudflats of Samut Songkhram Province, Thailand

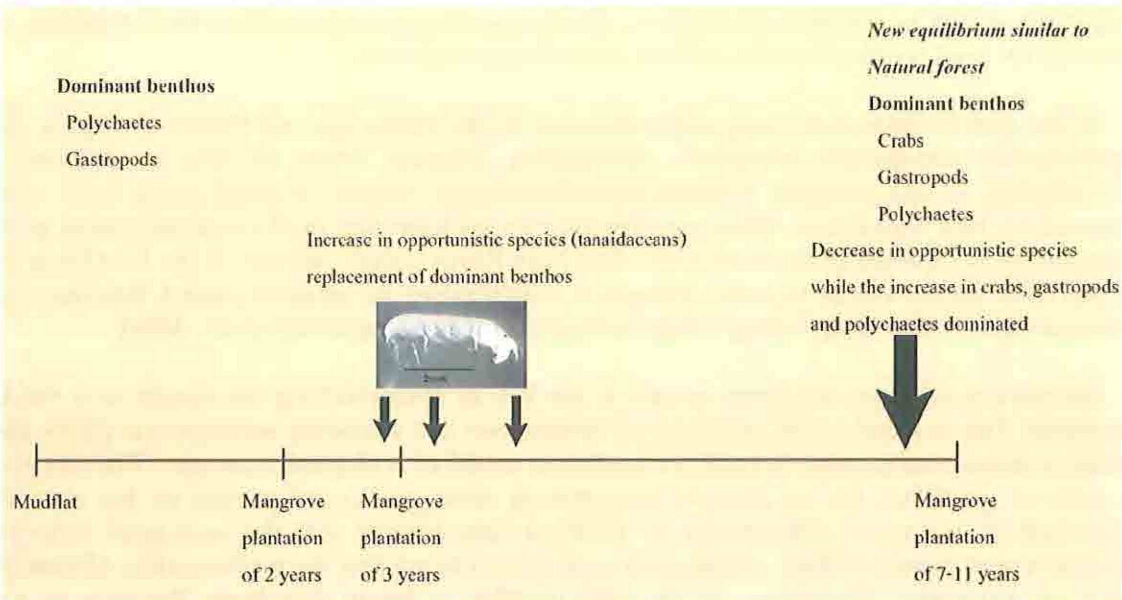


Fig. 2. Succession pattern of benthic fauna in *Sonneratia* plantations established on tidal mudflats of Samut Songkhram Province, Thailand

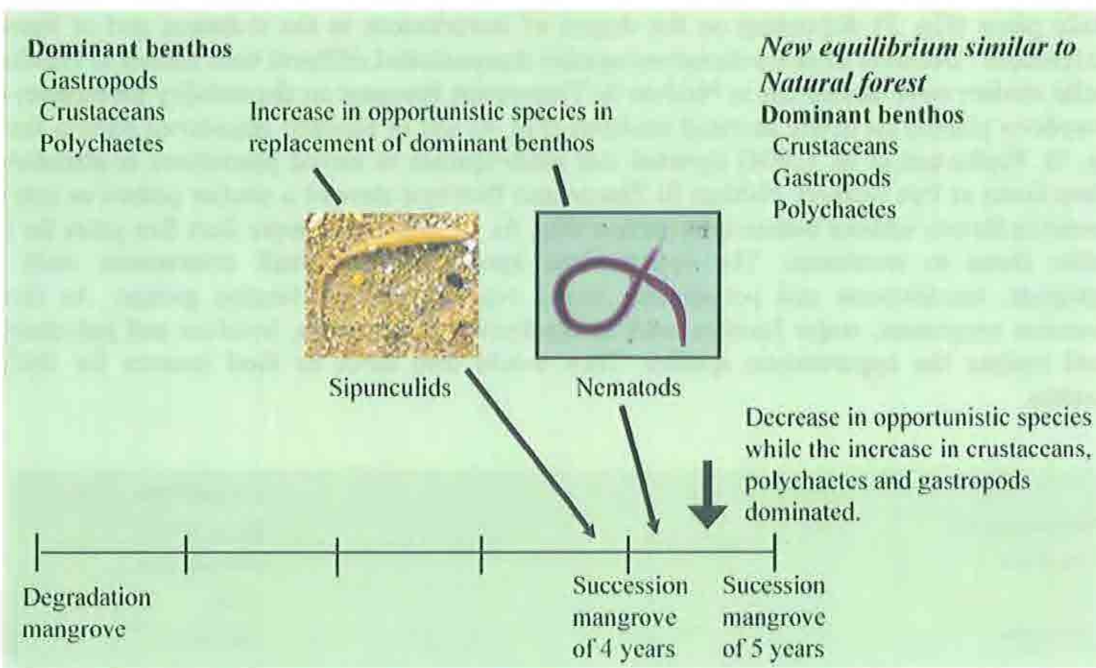


Fig. 3. Succession pattern of benthic fauna in natural succession mangrove forests of Samut Songkhram Province, Thailand

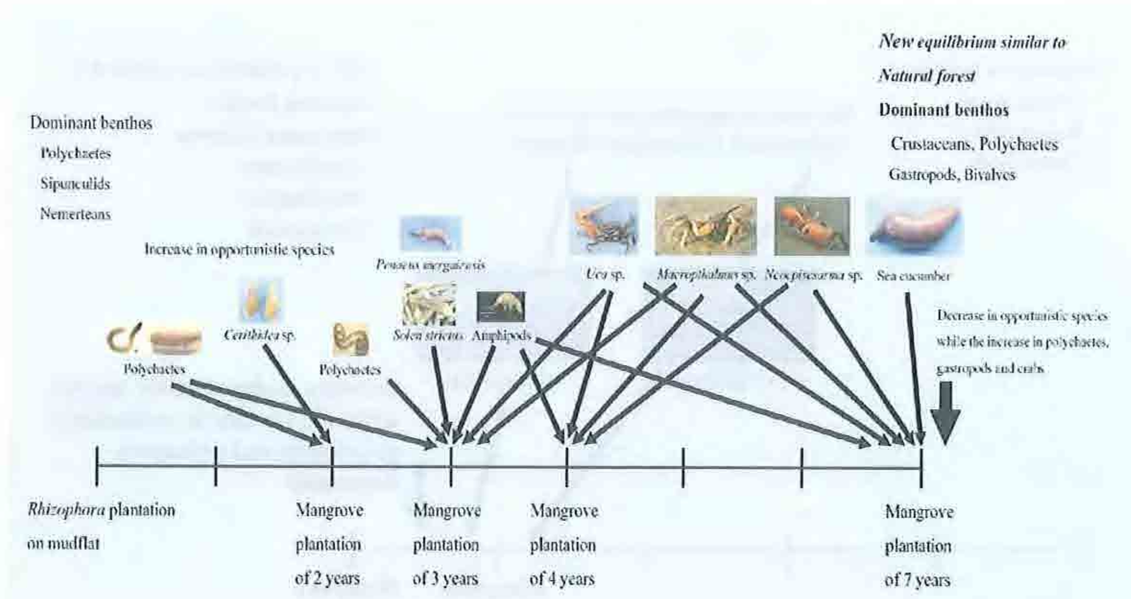


Fig. 4. Succession pattern of benthic fauna in *Rhizophora* plantations established on newly accreted mudflats of Nakhon Si Thammarat Province, Thailand

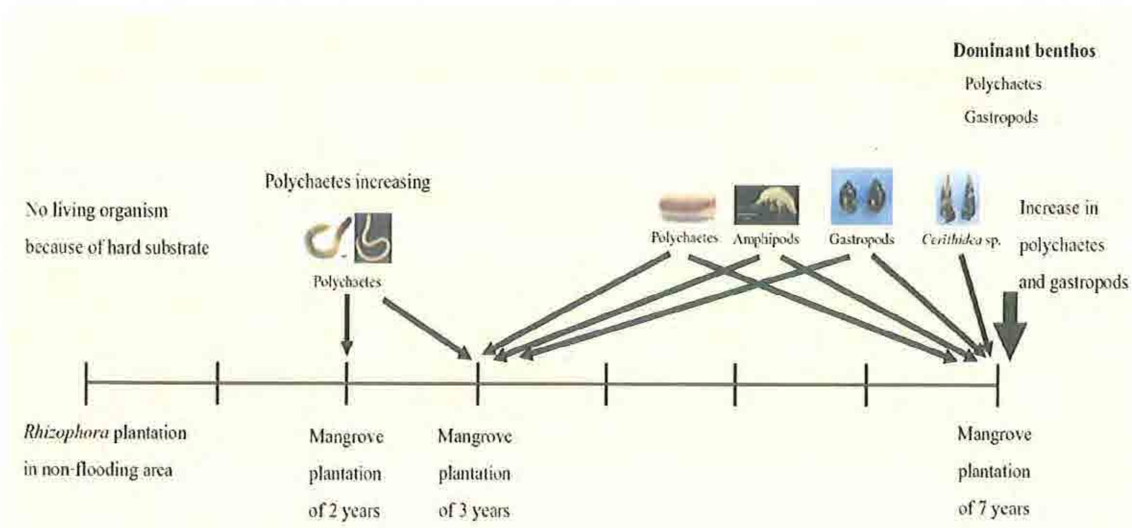


Fig. 5. Succession pattern of benthic fauna in *Rhizophora* plantations established in elevated abandoned shrimp farms at Nakhon Si Thammarat Province, Thailand

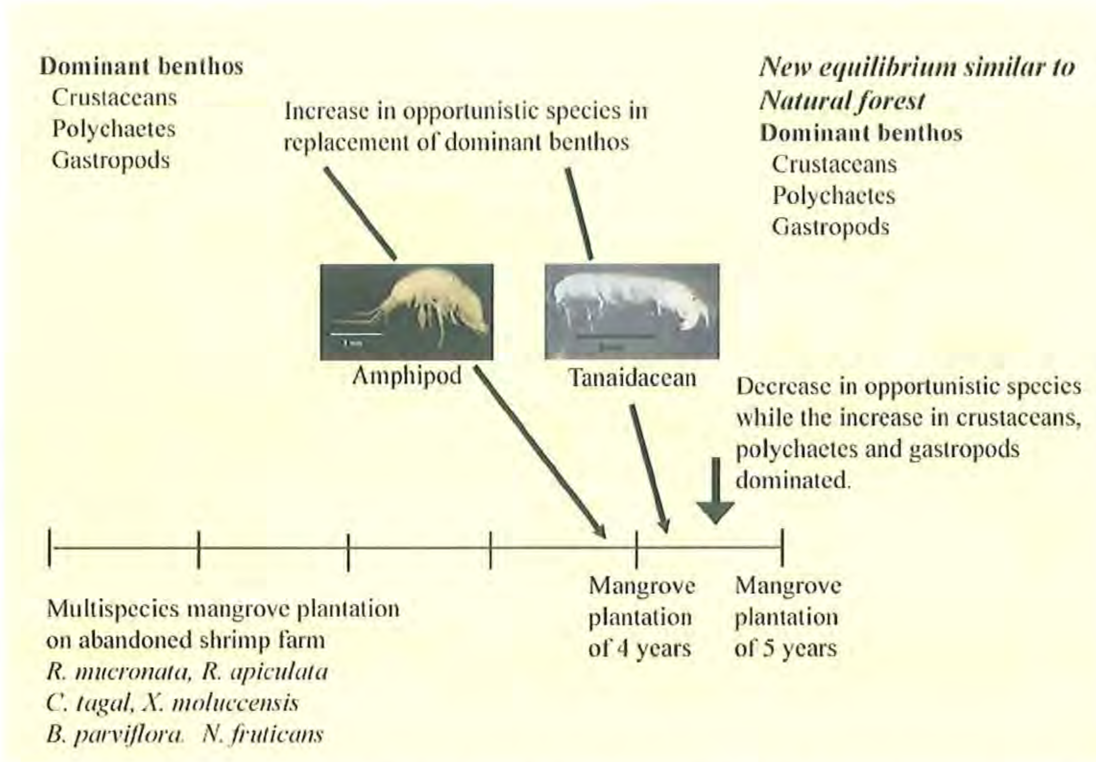


Fig. 6. Succession pattern of benthic fauna in muti-species or mixed plantations established in abandoned shrimp farms at Pak Nakhon, Nakhon Si Thammarat Province, Thailand

5. Criteria for assessing the success of mangrove rehabilitation

Once a site-specific design for mangrove rehabilitation has been drawn up, it is necessary to choose the criteria to assess the rehabilitation. Development of ecological indicators should be based on the linkage of ecosystem components. Ecosystem integrity implies balanced, healthy and productive characteristics of the ecosystem. Collective data on flora and fauna as well as ecological processes should be compiled to demonstrate their tropho-dynamic relationships. The complexity of mangrove food webs can be used as the ecological indicator of a balanced ecosystem (Fig. 7).

Estuarine health index is another way to demonstrate the health of the ecosystem. Environmental qualities such as dissolved oxygen concentration and plankton indicators can be used to indicate the eutrophic condition of the coastal system. The benthic composition and indicators can also be used as ecological indicators of successful mangrove rehabilitation. Certain key benthic indicators such as mud crabs, grapsid crabs and red gastropod snail, *Assiminea brevicula*, can be used to indicate that the mangrove forest has regained its function in providing habitats and food sources for these fauna.

Fish composition and diversity is another good ecological indicator of the health of mangrove forests (Shinnaka *et al.*, 2007; Tongnunui *et al.*, 2007; Wongchinvit *et al.*, 2007; Satapoomin & Karnchanapaiharn, 2007; Termvichakorn *et al.*, 2007). Fish production or fish catch and selected target fish species are powerful indicators. Fish data in particular fish larvae and their abundance provide useful indicators for adaptive management. From these data, it is necessary to allocate the nursery and breeding grounds for selected target species in the mangrove management plan.

6. Selection of indicators for socio-economic assessment

Indicators on ecosystem functions provided for coastal communities and assessment of community capacity to sustain on-going mangrove rehabilitation programs are two important components. Funding is often a major determining factor. Mangrove rehabilitation programs often lack continuous support in terms of funding from both local authorities and the central government. Major problems in the coastal communities are the lack of strong local leaders and the lack of cooperation among themselves (Siriboon & Paphavasit, 2006). Although inputs of the coastal communities are on voluntary basis, the opportunity for them to be involved in planning and drawing up the management plan is not provided. Monitoring and evaluation as an integral part of the plan is also absent.

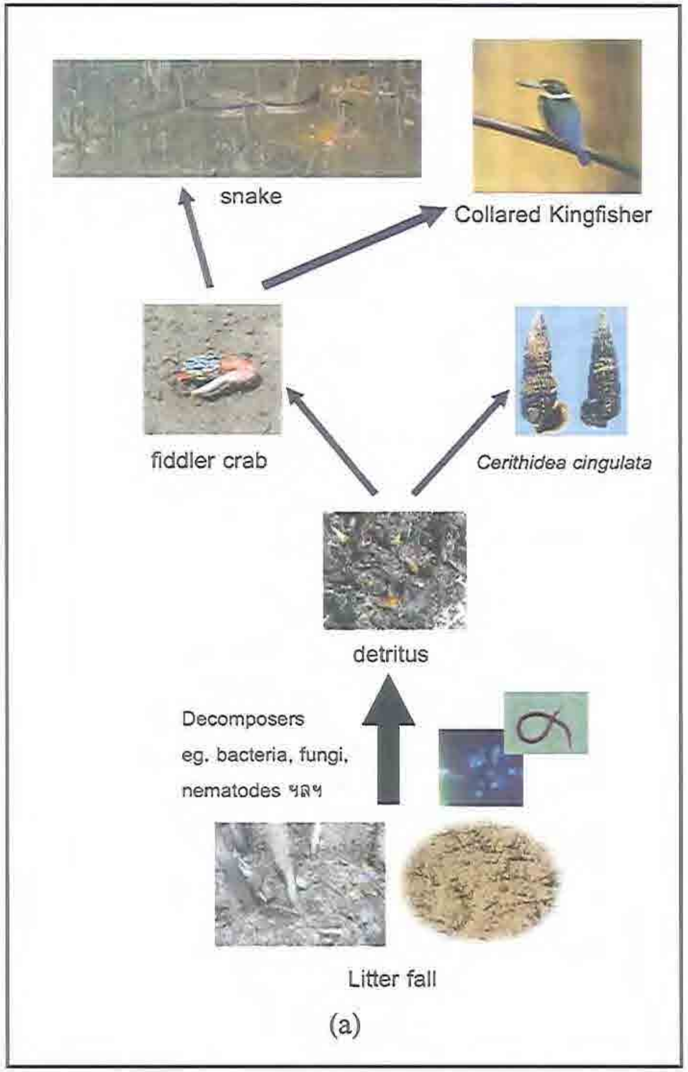
Monitoring and evaluation of the mangrove rehabilitation program will provide evidence and insights supporting the success of the process. It will also provide data for public awareness on the importance of mangrove rehabilitation and conservation. Data or guidelines for adaptive management are provided. Lessons learned from the failures and successes of the program can also be compiled. The assessment will also provide data relating to the responsibility of those involved in the rehabilitation program in particular who is doing his share of responsibility and who is not.

7. Public participation and community-based management

There are several success stories on mangrove rehabilitation in Thailand where mangrove rehabilitation activities have been implemented on a sustainable basis. The community-based rehabilitation program at Bang Rong mangrove forest, Phuket Province is one good example (Siriboon & Paphavasit, 2006). In Ban Rong, the mangrove forests were managed for wood production based on two rotation cycles from 1976-2001. Prior to the beginning of the second rotation cycle in 1986, the forests were deteriorating with predominance of small trees of mainly *Rhizophora mucronata*, *R. apiculata*, *Ceriops tagal* and *Bruguiera cylindrica*.

The Royal Forestry Department, together with the Petroleum Authority of Thailand, launched a mangrove reforestation program in 1996. The program was a success in Bang Rong due to community-based management incorporating a "social capital" system of natural resources, human resources, budget, social control and social wisdom. Utilization of natural resources in this community followed the concept of sufficiency economy. Increasing capacity of coastal resources by releasing crabs and fish larvae were carried out regularly. In term of human resources, the community has placed emphasis on education as the process of building awareness through extra-curriculum such as religious classes and reforestation activities. As funding is a limiting factor, the Ban Rong community generated income through ecotourism. Meetings during religious and social events were often held to discuss problems related to mangrove management. They also agreed on bans on certain destructive fishing gear. Social wisdom is the path to capacity building in community-based management.

Fish abundance was used as a tool to evaluate the effectiveness of community-based management at the Ban Tong Tasae mangrove community forest (Sudtongkong *et al.*, 2007). Compared was made with Ban Tab Jak, a non-mangrove community forest in Trang Province. At Ban Tong Tasae, fish community showed higher abundance and greater species diversity. The community-based management in Ban Tong Tasae has placed emphasis on ban of illegal fishing, control over fishing period as off season and declaration of fishing grounds.



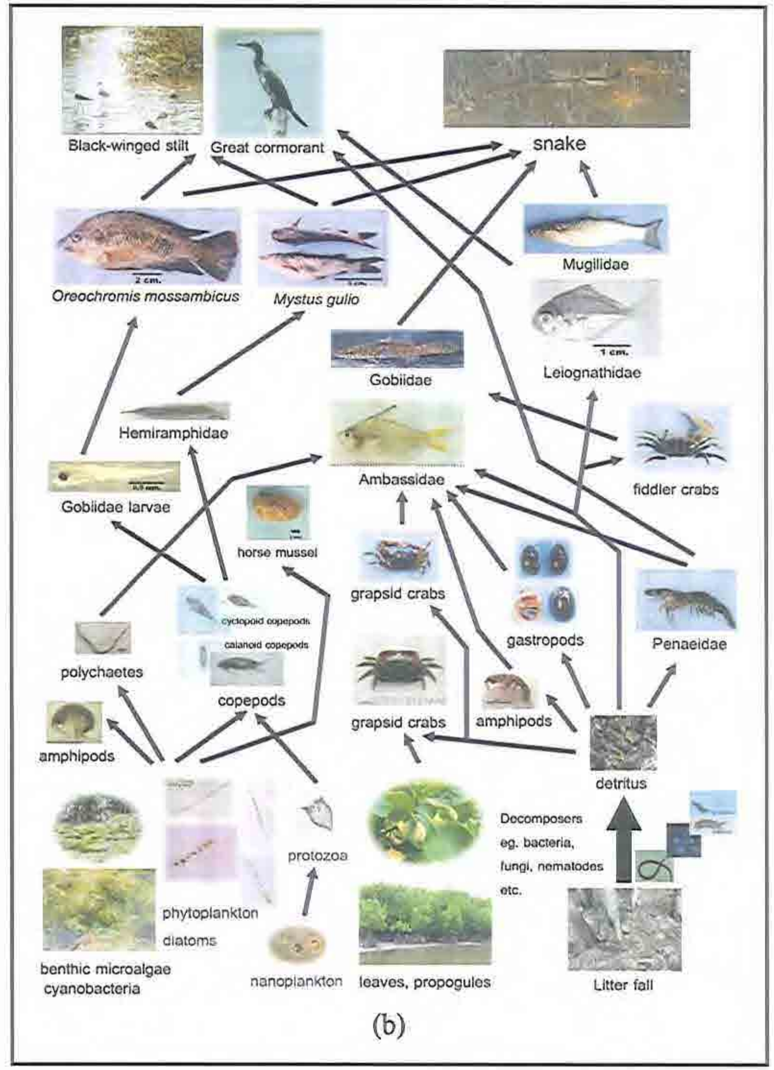


Fig. 7. Comparative food webs in (a) abandoned shrimp farm and (b) natural mangrove forest at Pranburi, Phachuap Khiri Khan Province, Thailand

8. Staying on track the road to success in mangrove rehabilitation

Sustainable development of mangroves should not solely be the government responsibility. Local communities have the responsibility to conserve mangroves as well as the right to utilize the forest and its resources. Site-specific design to meet the need of coastal communities is essential. Goals and objectives need to be clearly defined to select the appropriate criteria to assess the success of mangrove rehabilitation. The linkage of ecological indicators and ecosystem services provided for coastal communities must be taken into account. Capacity building in monitoring and evaluation of the rehabilitation program is essential. In order to conserve and maintain long-term sustainable yields from mangrove resources, government, non-government and public participation is essential.

The six REs namely revalue, restrategy, reprocess, restructure, recondition and research have been proposed as underlying factors determining sustainable development of mangrove resources (Siriboon & Paphavasit, 2006). Revalue is based on the concept of self-sufficiency as promoted by His Majesty King Bhumibol Adulyadej. His Majesty's vision on self-sufficiency is the important step toward a balanced development that will sustain both human being and the natural environment. Two-ways communication flows when drawing up mangrove rehabilitation plans should replace top-down management or centralization as the restrategy. Reprocess, calls for co-management which requires the active participations from all stakeholders with joint responsibility. Restructure is the most important driving force in changing from public cooperation to full participation. Recondition requires site-specific designs of mangrove management. Research provides the knowledge-base data and information for formulating the mangrove management plan.

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Coastal degradation and rehabilitation in Thailand

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Abstract

Thailand has two long coastlines. The east coast stretches into the Gulf of Thailand from Trat Province to Narathiwat Province, covering a length of 1,653 km. The west coast bordering the Andaman sea stretches from Ranong Province to Stun Province, covering a length of 1,014 km. Severe coastal erosion is occurring in the upper Gulf of Thailand, involving six provinces, namely, Chachoengsao, Samut Prakran, Bangkok, Samut Sakhon, Samut Songkram and Petchaburi. Many types of hard and soft structures were applied to protect the coastline. Mangrove rehabilitation has been carried out to protect the coastline. However, coastal development and mangrove rehabilitation should be done based on integrated multi-disciplinary knowledge, such as oceanography, soil structure, sedimentation, forest plantation, coastal engineering, resilience of human being, etc. The investigation on specific site conditions of coastal ecosystems prior to rehabilitation is necessary.

Coastal vegetation rehabilitation for the mitigation of coastal hazards – The Malaysian experience

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Abstract

This paper attempts to document the experience of many years of coastal vegetation research and rehabilitation in Malaysia, and make this information available to guide on-going and future rehabilitation efforts. We briefly describe the natural coastal vegetation setting, coastal processes and changes, coastal development pressures, coastal hazards (coastal erosion, storm surges resulted from monsoons, typhoons and tsunami), and coastal protection measures to mitigate coastal hazards with special reference to mangroves and casuarina trees. The number of coastal vegetation rehabilitation projects has increased significantly in tandem with the increase of critical coastal erosion areas and attention generated by the recent Indian Ocean tsunami. We assess these rehabilitation projects based on objectives of planting, site selection, choice of species, planting techniques and approaches, and cost implications. These projects have yielded both successes and failures, and provided opportunities for learning useful lessons.

Although Malaysia is located close to the epicenter of the 2004 Indian Ocean earthquake, she was shielded from the initial waves of the tsunami by Sumatra and was only impacted by reflected waves. Whilst there was loss of life and considerable damage to property, all the mangrove forests remained intact. The Government allocated some $25 million to rehabilitate 4,000 ha of mangroves after the tsunami. We discussed the importance of understanding basic coastal processes such as tidal inundation, vegetation zonation, hydrodynamics and sedimentation. We then examined three different rehabilitation projects. The main problem was a lack of suitable areas for rehabilitation (since the tsunami did no damage). Planting in areas that already had mangrove cover is redundant. Mudflats appeared as an obvious choice and were often targeted but unless the level of sediments on the mudflats can be raised so that they are not inundated by all tides, mangrove vegetation will not establish. Despite the use of expensive geotubes to try to stabilize the mudflat, planting failed. This was perhaps due to a lack of a deep enough understanding of the basic principles involved. Although there a multi-disciplinary approach was attempted (engineering and forestry), a key discipline was missing (hydrodynamics) and the inter-disciplinary aspect was apparently lacking. Instead of trying to plant on sand and mudflats (which are unsuitable for planting without expensive engineering modifications), it is suggested that it may be more appropriate to at least initially rehabilitate abandoned or marginally profitable shrimp ponds. This can then be extended to even profitable ponds located in critical areas that need protection.

1. Introduction

Malaysia is situated on the stable Sunda Shelf and close to the equator. Its position, away from the centre of the plate means that earthquakes are mild. Being near the equator, means that typhoons that plague the region, are also rare and mild. The huge December 2004 earthquake off Aceh, Sumatra, and the massive tsunami that followed left hundreds of thousands dead and millions homeless in the region. The west coast of Peninsular Malaysia was shielded by Sumatra and was spared the direct impact of the tsunami. The secondary waves (which only arrived after the direct waves hit the Thai coast, farther north) were milder, resulting in less loss of lives and property. Compared to the other countries in the region, Malaysia is very lucky in being subjected to fewer and milder natural hazards.

The 2004 Indian Ocean tsunami has attracted much attention and funds (both international and national) flooded in for the rehabilitation of mangroves. This is mainly the result of anecdotal reports of the effectiveness of mangroves and other coastal vegetation in saving lives. This has attracted many international organizations, governments and non-government organizations to establish mangrove rehabilitation projects in the countries affected by the tsunami.

Apart from the perception (real or otherwise) that mangrove and other coastal vegetation help to save lives, there is also the perception that vast tracts of mangroves were destroyed by the tsunamis. In effect, apart from a few sites that bore the full impact, like around Bandar Aceh and parts of the Andamans, there was no very significant destruction of mangroves by the tsunami. Satellite data support this (Blasco & Auda, in this proceedings).

The terms 'rehabilitation' and 'restoration' are often used interchangeably. For instance, Yap (2000) has discussed the definition and use of these terms. Here, we prefer to use the term rehabilitation because: first, no two moments in time can be the same so restoration is a physical impossibility and second, giving the notion to managers (and governments) that ecosystems can be restored is tantamount to giving license to wanton destruction of ecosystems, since they cannot easily be restored.

Whilst Malaysia has not attracted international funding for the rehabilitation of its coastal vegetation, the Government of Malaysia has perceived the importance of mangroves (and other coastal vegetation) in protection from natural hazards. Check (2005) writing on the rehabilitation of mangroves in the aftermath of the 2004 Indian Ocean tsunami, reported that the Malaysian Government promised $25 million to replant 4,000 ha of mangroves whilst the Indonesia Government pledged $22 million (300,000 seedling already planted in Banda Aceh).

In this paper, we discuss aspects of the post-2004 Indian Ocean Tsunami rehabilitation of coastal vegetation (mainly mangroves) in Malaysia, its successes and failures and the possible lessons learnt.

2. Malaysian mangrove and other coastal vegetation

Malaysia has some 4,800 km of coastlines (Teh, 2001) of which about half are sandy beaches, a bit less are mangroves and the rest (only a few percent) rocky shores.

The mangroves (considered forests) have been managed by the various State Forestry Departments since the beginning of the last century. The 40,000 hectare Matang Mangroves are arguably one of the world's best managed (for forestry use) mangroves (e.g. Watson, 1923; Ong, 1982; Chan, 2001; Gan, 1995; Azahar & Nik Mohd., 2005). The management system includes the planting of areas (after harvesting) of areas where natural regeneration has been inadequate. Malaysia has thus a long experience with this type of mangrove rehabilitation. It must however be noted that this rehabilitation is confined almost entirely to the planting of just two species, *Rhizophora apiculata* and *R. mucronata.*

The sandy beaches on the other hand, being not under the jurisdiction of any particular State authority, are less well managed. The vegetation that grow on beaches are often referred to as strand vegetation and include species such *Barringtonia asiatica, Calophylum inophylum, Casuarina equisetifolia, Cocos nucifera, Ipomoea pes-caprae, Scaveola taccada* and *Terminalia cattapa.* There are hardly any pristine areas of strand vegetation left in Malaysia due mainly to tourism development (i.e. construction of beach resort hotels).

The few percent of rocky shores by and large have remained intact as they are more difficult to convert for other uses.

3. Coastal processes and change

In order to successfully replant coastal vegetation, it is important to understand the biological, chemical, physical and, for mangroves, especially the geo-morphological and hydrodynamic processes. The movement of sediment is an important aspect. Sediments are in constant motion, resulting in both erosion and accretion of sediments. Coasts (even the low energy mangroves coasts) are subjected to this natural dynamic process. The process is often cyclical, but the periodicity of these cycles, are very variable (from hours to tens of years).

It must be understood that mangroves occur in the mid-intertidal zone and are thus subject to the full brunt of the tidal and sediment processes. On the other hand, only the seaward fringe species (e.g. *Ipomoea pes-caprae* and *Scaevola taccada*) of strand vegetation are subject to occasional tidal inundation and are thus on more stable ground.

For the mangroves, understanding the tidal inundation process and its relation to mangrove species distribution is vital to the choice of the correct species to plant in the rehabilitation process. This is not new science and Watson (1923) remains an excellent source of information.

Data from the National Coast Erosion Study (EPU, 1985) and the Department of Irrigation and Drainage (unpublished) showed that the total length of eroding coastline was 1,366 m (or 28% of the total coastline) and in 2006 it was 1,415 km (29% of the total). The critically eroded length increased from 145 km in 1986 to 288 km in 2006. There was hardly any change in the "Acceptable Erosion" category between 1986 (975 km) and 2006 (933 km) whilst the "Significant Erosion" category showed a decrease from 1986 (246 km) to 2006 (193 km). A more balanced view would be to give equal emphasis to the other side of the same coin: accreting coastline.

Once the erosion prone areas have been identified, remedial measures are usually taken. Unfortunately, most of the time the remedial measures are based on hard engineering solutions and although soft solutions have been applied they have been few, and by and large not successful.

4. Rehabilitation sites

From our surveys of the various mangroves in Malaysia affected by the 2004 Indian Ocean tsunami, the damage is surprisingly negligible. At worst, only a few trees were damaged and these may even have been damaged earlier by other hazards such as erosion from bow waves and from shipping (e.g. Chan, 1985). So there are in fact no areas of mangroves that require rehabilitation. As stated earlier, the Malaysian Government has promised $25 million to rehabilitate 4,000 ha of mangroves but the vital question is: where are the 4,000 ha of destroyed or degraded mangroves that require rehabilitation? As far as we are aware this 4,000 ha is non-existent, unless shrimp ponds converted from mangroves are to be rehabilitated.

The mangrove rehabilitation projects we have seen are on tidal mudflats, under the canopies of already existing mangroves or on erosion control rock revetments.

Tidal mudflats (Inundation Class 5 of Watson, 1923) are unsuitable for the planting of mangroves (only the occasional *Rhizophora mucronata*, usually in the more riverine areas) will grow here. This is not a mangrove vegetation zone and is almost always free of any vegetation. Birds, often migratory ones, use these areas and artificially planting mangroves here is not only a waste of effort but also has an adverse effect on an ecosystem of trans-boundary significance.

4.1. Case 1: Planting mangroves on mudflats (Pulau Sayap, Kedah)

Considerable effort has been devoted to this project by both the Forestry Department as well as the Forest Research Institute Malaysia. The site is an exposed mudflat located near Pulau Sayap in the State of Kedah.

Geotubes

Initial planning included the installation of a geofabric tube (about two metres in diameter and a hundred metres long) filled with sand. The geotube was located just above the lowest tide mark, parallel to the shore. The reason for the installation of this geotube was to form a barrier to break the on-shore waves as well as encourage sedimentation on the shoreward side of the tube. The use of this rather expensive (~$75,000 per 100 metres) geotube has been described by Chan (2008).

The waves (both from storms as well as from bow waves from a large traffic of ships, since the Strait of Malacca is one of the world's busiest waterways) at this site can be relatively high (one or two metres) so the geotube may provide a wave-breaking function. From our observations on how the geotube has been positioned, it appeared to have caused an increase in flow of water from the northern side, causing sediments (including red lateritic soil used to reclaim land on the northern part of the site) to be eroded and washed down in a southerly direction and scouring of consolidated mud as well as bark of existing mangroves. This increased flow may also have been responsible for most of the PVC tubes used in the first planting to be dislodged. Another observation was that there was apparently no significant increase in sedimentation on the shoreward side of the geotube or any reduction in relative sea-level.

Our assessment of the use of geotubes (as also observed at another site in southern Johor, to provide protection mainly from bow waves) is that it is very important to understand water current and other hydrodynamic aspects of the site before the geotubes can be correctly positioned. Otherwise success will at best be limited and at worst, cause other problems (such as the increased in flow and erosion seen at the Pulau Sayap site). It must also be realized that the main source of sediments in the mangroves is not direct deposition of upstream sediments but that such sediments come from the sea. It is thus completely unrealistic to expect to see increased sedimentation on the shore side of geotubes placed parallel to the shore. A very good understanding of the hydrodynamics of the site is required so that the positioning of the geotube will cause increase sedimentation on the shoreward side.

Tidal inundation class

The site where the mangroves have been planted is in Watson's Inundation Class 1, i.e. Inundated by all tides and is thus a non-vegetated mudflat. At best, a few *R. mucronata* plants may survive, if wave action is not strong (like in the more sheltered riverine mudflats). *Rhizophora mucronata* and *R. apiculata* were used in the initial failed planting but in the subsequent planting *Avicennia marina* was also tried. Since this site is not suitable for any mangrove vegetation, it does not matter which species is planted as they will all fail. Planting can only be successful if sedimentation can be increased (by geotubes or other means) to the extent that the site falls into Watson's Inundation Class 2. It is clear that the extra elevation provided by either the PVC or longer bamboo tubes are of no help.

4.2. Case 2: Planting under existing mangrove canopies

The site is near Sungai Burung on the Island of Penang. The plants, *R. apiculata,* were planted under a canopy of mainly *A. marina*. Most of the plants were dead (perhaps through lack of light and high salinity). It seems to us that planting in an area that already has cover (even if the planting is successful) is completely redundant and a waste of resources and effort.

4.3. Case 3: Planting on rock erosion prevention revetment behind mangroves fringe

This site is also near Sungai Burung on the Island of Penang. There is a rock canal and revetment behind a fringe (about 20 m in width) of mixed species of mangroves.

The hard engineering structure was probably to prevent erosion as well as to prevent saltwater intrusion (hence the canal). *Rhizophora mucronata* and *R. apiculata* were planted between the rocks in areas that are often inundated by fresh and seawater. Initially some (possibly about half) died. After three years or so, the plants that survived reached a height or between two to three metres.

We do not know why this site was chosen but can only guess that there were no other places available for planting (apart from on the adjacent mudflat). This showed how tough mangroves can be and, given the right hydrological conditions, will not only survive but grow reasonably well, even between rocks.

5. Lessons learnt

Although the 2004 Indian Ocean Tsunami resulted in the loss of some 50 lives and millions of dollars of damage to property in Malaysia, there was no damage caused to mangroves. This zero loss of mangroves was apparently not perceived by the Government (or at least by the agencies that reported to the Government). Hence, there was a knee-jerk allocation of $25 million to rehabilitate 4,000 ha of mangroves.

With no suitable mangroves to rehabilitate, government agencies and non-governmental organizations were essentially left with only sand and mudflats to plant, without realizing that such areas are completely unsuitable for planting mangroves.

Although the Forestry Department has had over a century of experience with very successful planting mangroves where natural regeneration was inadequate in managed mangrove forest, there was a lack of understanding of the basic scientific principles when it came to planting in unfamiliar territory. Employing expensive technology (e.g. geotubes) is one thing but it is also necessary to understand what these structures are meant to do. There is no point in attempting to plant unless the site is suitable and conducive to mangrove growth or the site can be suitably modified to support mangrove growth. Suitable modification of site conditions is often complex and difficult. It requires a multi- as well as inter-disciplinary approach (e.g. hydrodynamics, ecological and engineering). It would appear that whilst there was a multi-disciplinary approach (e.g. in the Pulau Sayap Project) there may have been a lack of interaction between the disciplines. The lack of input from the hydrodynamics aspect may also be a factor. The bottom line is that better assessment of the situation and more adequate preparations involving a multi- and inter-disciplinary approach is needed to address such a problem.

6. Discussion

The concept of mangrove rehabilitation or restoration is not a new one. Over the years, there have been many books (e.g. Field, 1996), manuals (e.g. JAM, 1994) and papers (e.g. Turner & Lewis, 1997; Field, 1998; Kaly & Jones, 1998; Lewis, 2005) on this subject. Rehabilitation work after the 2004 Indian Ocean tsunami has already resulted in new manuals (e.g. Hanley *et al.*, 2008) and no doubt, more will appear. These are no magic recipes and, for successful rehabilitation there is a need for a thorough understanding as well as application of the basic scientific principles.

The basic requirement for successful rehabilitation of mangroves is a good understanding of the ecological requirements of the mangrove plant. It has long been known (e.g. Watson, 1923) that different mangrove species are found in the different tidal inundation zones. It is also known that sand and mudflats (perhaps with the exception of riverine flats, where *R. mucronata* may survive) that are inundated by all tides are by and large free of any mangrove vegetation. These flats form an ecosystem of their own and are often important feeding and resting sites for both resident and migratory birds.

In the Pulau Sayap case study, attempts were made to plant mangroves on the unvegetated tidal mudflats. One reason for doing this was perhaps that there had been some erosion at the site so planting mangroves there may alleviate the erosion problem. Erosion and accretion are natural processes that occur in all coasts. These often occur cyclically at indeterminate periods, even in sheltered coasts where mangroves usually form. Understanding this concept, and better still, also taking account sea-level change, means that good coastal zone managers will leave an adequate buffer zone that is free of human development activities. However, this is often ignored and the resultant "threat to property" may end up requiring expensive hard engineering solutions, often provided through public funds.

Since sand and mudflats are unsuitable sites, the alternative is to plant in shrimp ponds that were originally reclaimed from mangroves as suggested by Samson and Rollon (2008) for the Philippines.

Mangroves naturally regenerate in abandoned shrimp pond, especially after the bunds of the ponds are breached and the ponds are not deep. Filling up the deeper ponds is relative simple. The bottoms of some badly run old ponds may have become anaerobic as a result of contamination with excess feed, so these ponds may present some problems with planting.

Initially, abandoned shrimp ponds could be rehabilitated. This can then be followed by the closure and rehabilitation of shrimp ponds situated in critical areas. There are probably more that 4,000 ha of abandoned or marginally profitable shrimp ponds for this purpose. It however means more than just a financial commitment from the government as the revoking of licenses and the transfer of property would have socio-political implications.

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Effectiveness of coastal forests in mitigating tsunami hazards

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Abstract

Several field surveys have demonstrated the effectiveness of coastal vegetation (e.g. mangroves, coconut plantations and other coastal vegetation) in mitigating the damaging effects of the Indian Ocean Tsunami. Apart from hard engineering tsunami mitigation techniques such as tidal barriers, evacuation towers and offshore tsunami monitoring buoy systems, dense coastal vegetation serve as protective buffers in mitigating the adverse effects of tsunamis on coastal areas.

The numerical ratio of tsunami force reduction provided by coastal vegetation was evaluated. Main parameters determining vegetation effect were diameter of tree trunk, density of trees and width of coastal vegetation. A series of calculations of tsunami height, flow velocity and coastal vegetation demonstrated that a total of 400 trees per 10 m shoreline were necessary to reduce the tsunami force at vertical wall to the level of wooden houses. The flow velocity of tsunami at a gap between neighbouring planted vegetation increased when the gap width decreased.

1. Introduction

The 2004 Indian Ocean Tsunami had a catastrophic impact on coastal areas. Destruction of residential areas was widely reported. Some reports (e.g. Hiraishi *et al.*, 2005) analyzed the tsunami run-up height distribution. The other characteristic of tsunami damage was beach erosion and scouring at the foot of sea walls. The eroded volume became so large in the city of Banda Acheh, Indonesia that some coastal grounds disappeared after the tsunami. A field survey was conducted to measure the cross section of an eroded beach in order to study the relationship between tsunami height and beach erosion in Thailand.

Several recent reports (e.g. Hiraishi & Harada, 2003; Danielsen *et al.*, 2005) described the effects of coastal forests in reducing the force of tsunami impacting coastal villages. The importance of greenbelts (in the form of coastal forests or other coastal vegetation) as barriers against tsunamis had been demonstrated mainly in the model experiments. We also investigated the effectiveness of greenbelts in reducing coastal erosion. The criteria of building and housing damage due to tsunami inundation were discussed based on the field survey results. The numerical calculation for tsunami force reduction by the coastal vegetation was carried out to find its appropriate density and width to protect wooden houses in the South East Asian coasts. Finally an example of numerical prediction of effectiveness of coastal vegetation in a simple coastal topography was presented.

2. Damage of built structures

Coastal areas of the Indian Ocean were heavily damaged by the tsunami. Vulnerable buildings are resort hotels in Thailand, and block style houses in Thailand and Indonesia. Based on field surveys in Thailand and Indonesia, coastal structures and their damage levels were categorised as follows:

Types of structure:

A: Reinforced concrete houses and buildings (resort hotels in Khao Lak coast, Thailand are included)
B: Concrete and blocks structures (large storages in fishery harbours are included)
C: Wooden houses (almost all village houses in the coasts are included)
S: Sea walls (some coasts are protected by sea walls)
P: Piers and jetties (small piers are employed in Thai fishery harbours)

Damage levels:

1. Light (Window broken or wall slightly damaged)
2. Medium (Column remained but wall broken)
3. Heavy (Completely washed out or recovery impossible)

Structure type A: Damage level 2

Structure type P: Damage level 2

Fig. 1. Examples of structure types damaged by tsunami

Fig. 1 shows some examples of structures damaged by tsunami.Table 1 shows the relation of structural types and damage level. Wooden houses are very weak and are completely destroyed by the tsunami. The block-type houses are usually stronger than the wooden houses. As the tsunami run-up height was relatively large in Thailand and Indonesia, the damage level of block-type houses is about the same as that of wooden houses.

Structure type A is relatively stable to tsunami inundation. Reinforced concrete buildings were partially damaged when the tsunami run-up height was less than about 10 m. Damage to sea walls, piers and jetties was not so severe compared with damage to residential buildings. The improvement of housing style was effective in reducing tsunami hazard on land because the damage level depends on the structure type as well as the tsunami run-up height.

Table 1. Structure types and damage levels

Location		Structure		A	B	C	S	P
	R (m)	SW	D (m)	Damage level				
Ban Nam K h em Harbour	5.4	Y		2	3	3	1	2
Khao Lak Resort	8.8	N	2.5	2	3	3		
Cape Pakarang	9.8	N	1.1	3	3	3	3	
Kamala (Phuket)	6.0	Y	1.3	1	3	3	1	
Patong (Phuket)	3.4	Y	1.0	2	3	3	2	
Banda Aceh	10.0	Y	4.0	3	3	3	3	

D: Scoring depth (m); R: Tsunami run up height (m); SW: Seawall; Y: Existing; N: Non-existing

3. Field measurements

3.1 Land erosion

A field survey was carried out along the Khao Lak coast, Thailand to investigate the effects of coastal vegetation in reducing beach erosion due to tsunami. Soil erosion was observed in the hotel area while beach erosion was observed in the sandy coast in front of the hotel. The inland soil erosion was suspected to be caused by the rapid tsunami flow. The relationship between the strength of surface water flow and ground characteristics have not been studied because few studies have been carried out on the mechanism of ground erosion due to tsunami. We carried out a simple test to study the influence of ground soil properties to erosion by the tsunami.

Fig. 2 shows the arrangement of field test area at Khao Lak Orchid Resort Hotel, Thailand. In the figure, points (P.1 to P.4) represented sampling points for ground soil. Several large holes due to ground erosion were found in P.1. Fig. 3 shows one of the ground holes, about 5 m wide and 2 m deep. The photograph was taken a few days after the tsunami event. The area was filled with red earth clay three months later.

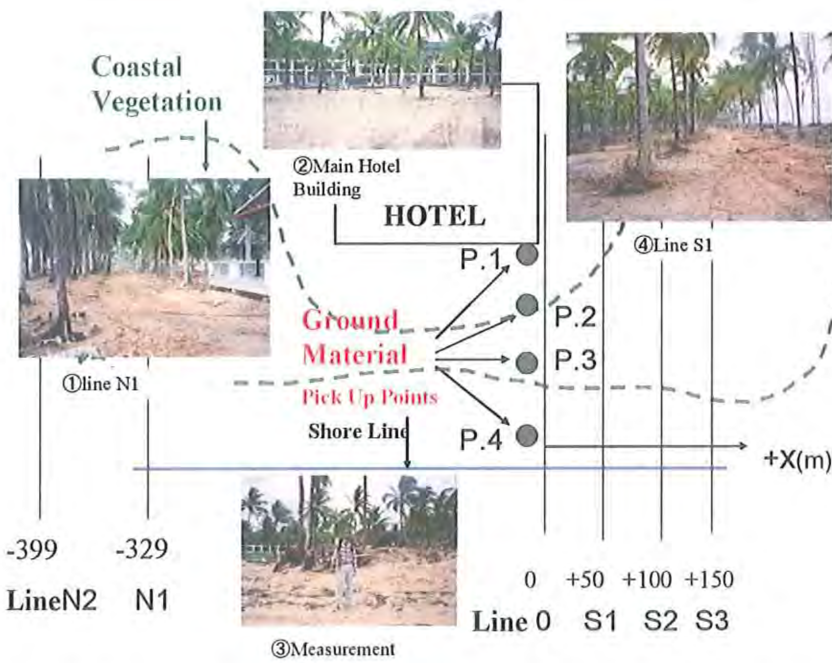


Fig. 2. Measurement line of beach cross section and soil sampling points

We conducted soil analyses using the collected material. The silt component was relatively large at P.1 located in the hotel garden where the ground erosion was observed. The sandy component was dominant in the beach (P.4) and sand dune (P.3) samples. The central diameter of soil captured at P.1 was 0.09 mm and its silt content was 48% while the diameter and silt content of the beach sand (P.4) was 0.44 mm and 0.3%, respectively. The beach and adjacent inland area were originally composed of sandy material, before construction of the hotel. The silt material was assumed to be brought from other areas for reclamation of the hotel ground. Such silt material was not stable for tsunami inundation flow and was susceptible to erosion. The stability of ground depends on the material property as well as tsunami run-up height.

(a) Ground erosion (b) Measurement of depth

Fig. 3. Ground erosion observed in Khao Lak beach, Thailand

3.2 Beach erosion

Assessment of erosion was carried out at the Khao Lak beach. Cross sections of lines (N2, N1, 0, S1, S2 and S3) were measured (Fig. 2). On line-0, *Casuarina* and coconuts trees were very few compared with those on the other lines because the trees were removed so as not to block the sea view from the hotel main building. The greenbelt remained without modification in the other lines. Therefore, the width of greenbelt in the N- and S-lines is thick and its width is about 100 m. The tsunami run-up height in the hotel area was about 10 m and the wooden cottages were completely washed out by tsunami flows. Damage to the reinforced concrete main building was not severe and the second and third floors suffered little or no damage.

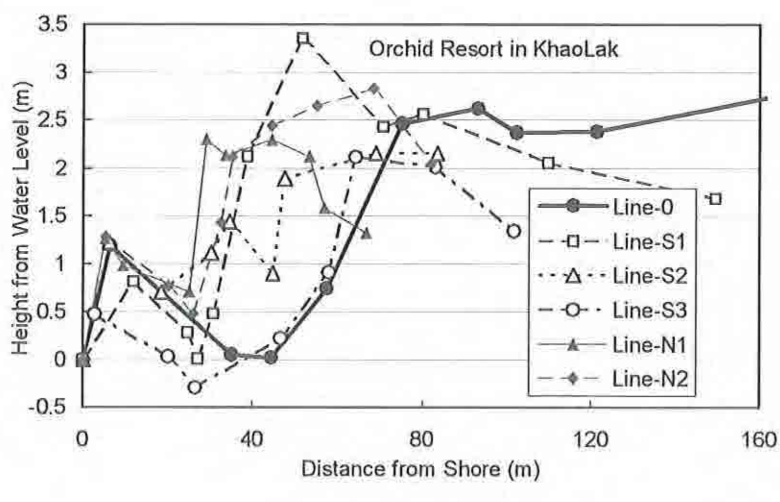


Fig. 4. Beach profiles measured in the damaged hotel area

The sandy beach in front of the main building was seriously eroded compared with neighbouring beaches. Fig. 4 shows the comparison of beach cross-sectional profile of line-0, lines-N and lines-S. Line-0 was at the front of hotel main building. Lines-N and -S were measurement lines north and south of the main building, respectively.

The coastal forest with coconut and *Casuarina* trees was assumed to be located uniformly along the beach before hotel construction. Fig. 4 demonstrates the erosion depth of line-0 was more than 2 m while that of lines-N and lines-S were shallower. The existence of greenbelts appeared to have reduced the erosion of the beach caused by the tsunami.

4. Effectiveness of coastal vegetation

4.1 Estimation of tsunami force reduction by coastal vegetation

The field survey on the greenbelt effect demonstrated that tsunami flow pressure was reduced by dense greenbelt and beach erosion depth was less in the beach with the greenbelt than in the beach without. The reduction of tsunami flow pressure is important to prevent the washing out of village houses. In the near future, we have to establish the greenbelt tsunami prevention technique to reduce the human life and property. I conducted a numerical study to estimate the effect of greenbelt to reduce tsunami flow pressures. The drag and inertia resistance in a hydraulic model test has been already done. The resistance force of greenbelt in a unit area is expressed as equation (1), and the drag C_D and inertia C_M coefficient in greenbelt is expressed as equation (2).

$$WF = \frac{1}{2} C_D \rho A_0 u|u| + C_M \rho \frac{V_0}{V} \frac{\partial u}{\partial t} \qquad (1)$$

$$C_D = 8.4 V_0 / V + 0.66$$
$$C_M = 1.7 \qquad (2)$$

where u = tsunami flow velocity, A_o = projection area of vegetation, V_o = volume of vegetation, and V = total volume under water. The projection area and volume of vegetation are determined by the number of trees per unit area and by the diameter of tree trunk D. The number of trees N in a unit area (10 m x 10 m = 100 m^2), determines the greenbelt density. Another dominant parameter is the total width of greenbelt B.

Compared with the inertia resistance, the drag resistance is much larger. A simple computation of drag resistance variation indicates the approximate effect of greenbelt to reduce the tsunami acting force. Fig. 5 shows the dimensionless tsunami force behind the greenbelt. The dimensionless tsunami force is estimated as the ratio of tsunami drag force behind the greenbelt to that in front of greenbelt. The dimensionless tsunami force decreases as the density of greenbelt N and the width B increase. When the tsunami run-up height is 5 m, the allowable force level for wooden house is 0.15. To prevent damage to wooden houses, the greenbelt should be wider than 200 m. The coefficient C_R represents the ratio of tsunami force acting an imaginary vertical wall behind the greenbelt to that in front of it.

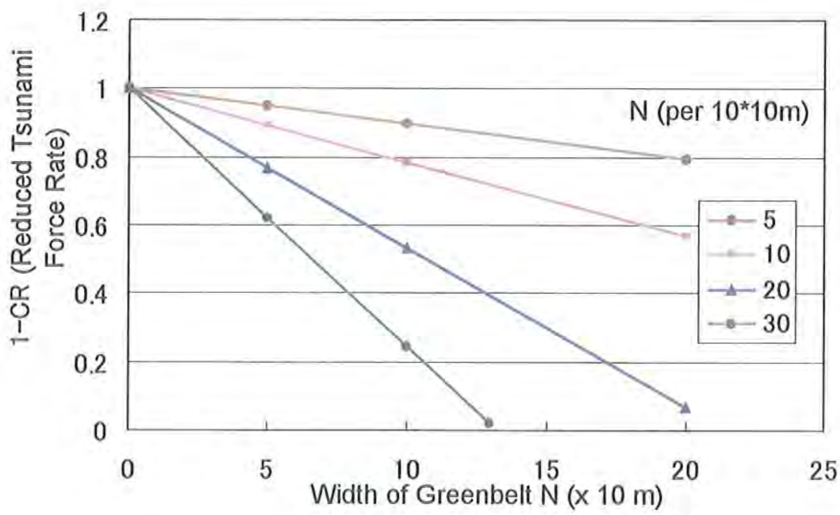


Fig. 5. Variation of dimensionless tsunami drag force of greenbelt

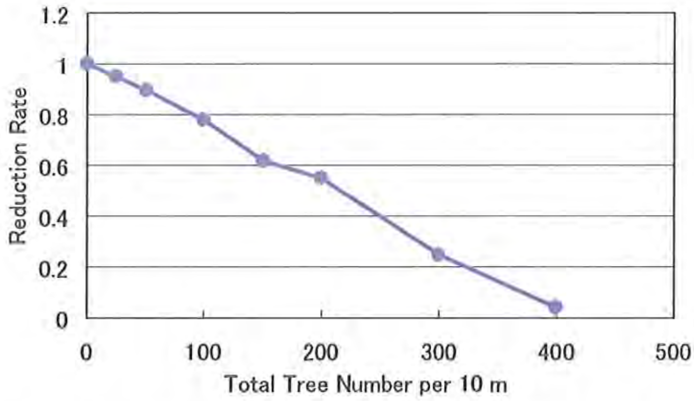


Fig. 6. Variation of averaged tsunami force reduction rate for number of trees per unit shore line

Fig. 6 shows the variation of the tsunami force reduction rate for each vegetation density N. The total tree number per unit shore line length is calculated as the product of density and width of greenbelt. Fig. 4 shows the variation of tsunami force reduction rate for total tree number per 10 m shore line. The reduction rate varies slightly according with the density and the figure shows the averaged reduction rate for the same total tree number with different densities.

4.2 Variation of tsunami flow velocity at vegetation gap

In the design of coastal vegetation, several access roads to the coast are necessary for the daily fishing and beach activities. Such access roads may serve as evacuation routes after a tsunami warning. The tsunami flow velocity in such gaps between neighbouring coastal vegetation areas becomes larger than the original tsunami flow velocity in plane coasts because parts of the flow are disrupted in the dense vegetation. The evaluation of flow velocity in the gaps is needed to determine safe evacuation routes.

Fig. 7 shows the image of determination of tsunami flow velocity in the gaps. The parameters are as follows:

W: Length of coastal vegetation along shore line
γ: Opening ratio of vegetation (dimensionless width of gap)
u_1: Original tsunami flow velocity
u_2: Flow velocity in backward of vegetation area
u_3: Flow velocity in gap

The total tsunami inundation volume is assumed to be constant and the velocity behind vegetation u_2 is calculated from the former equations. The variation of velocity in the gaps is expressed in Fig. 8.

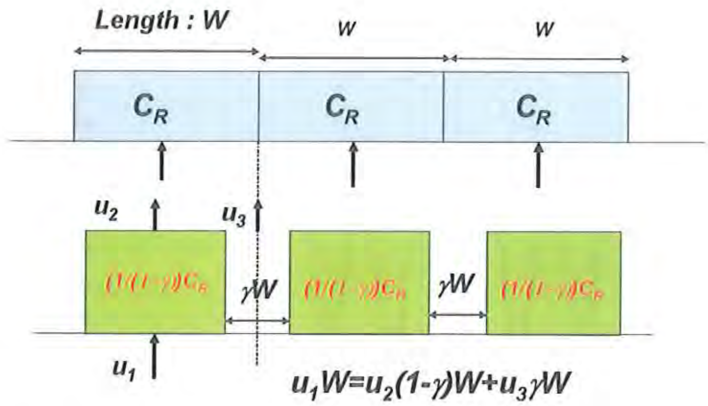


Fig. 7. Image of variations of tsunami flow velocity in coastal vegetation area

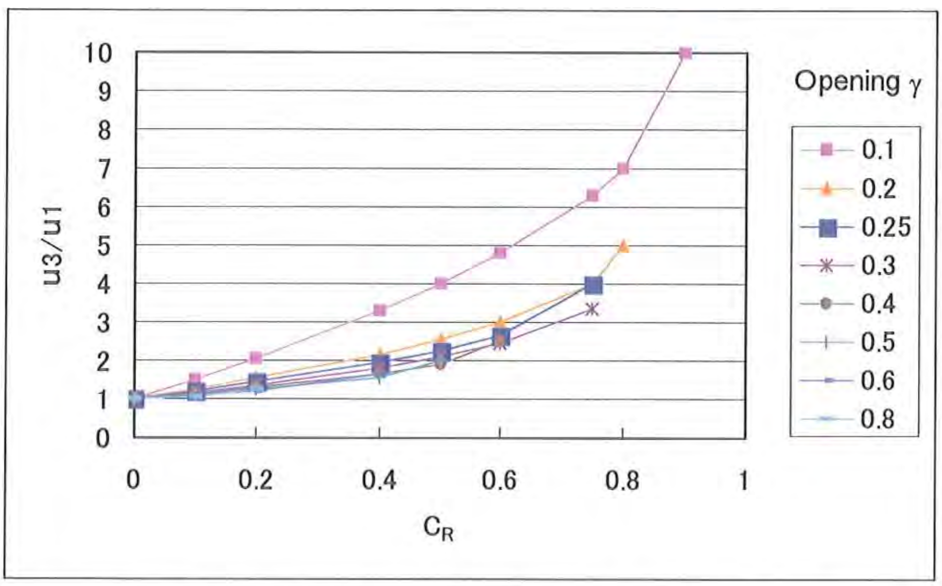
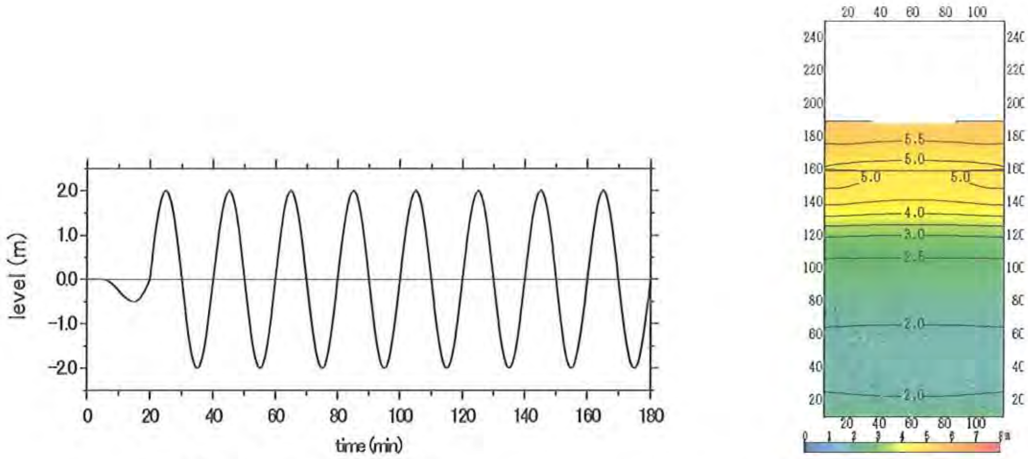


Fig. 8. Variations of tsunami flow velocity in vegetation gaps

The tsunami flow velocity in the gaps increases when the tsunami force reduction ratio becomes large and the opening ratio becomes small.

5. Evaluation of vegetation effect in a simple coast

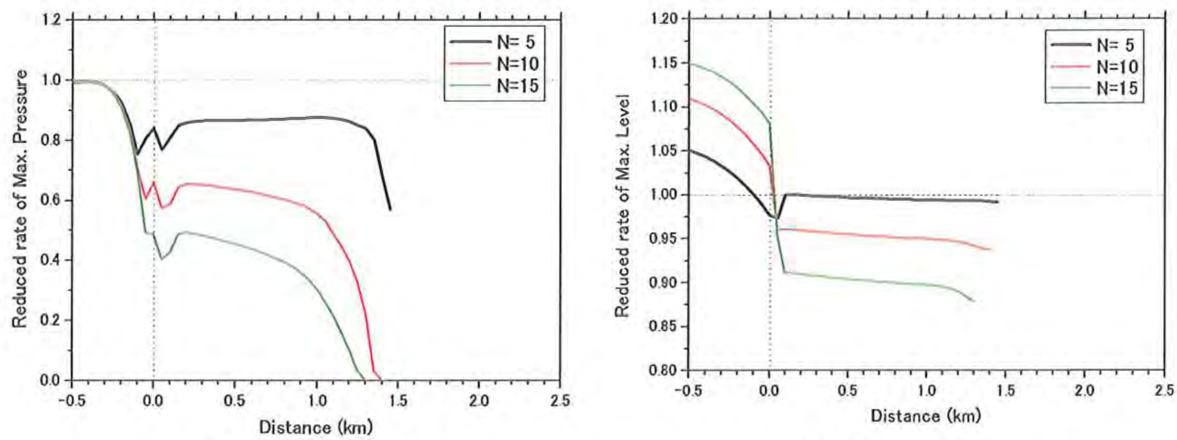
A numerical simulation of tsunami run-up was conducted to evaluate the greenbelt effect in a typical coastal topography. Fig. 9 shows the simulation condition in a straight coast. We assume that the sinusoidal tsunami with 4 m height and 20 min period incidents normal to the shore. Fig. 9(a) shows the profile of incident tsunami. Fig. 9(b) shows the contour of maximum water level in the shore. The inclination of sea bed and land surface is 1/125 and 1/250, respectively.



(a) Incident tsunami profile

(b) Tsunami run-up height

Fig. 9. Tsunami height variation in straight shape coast



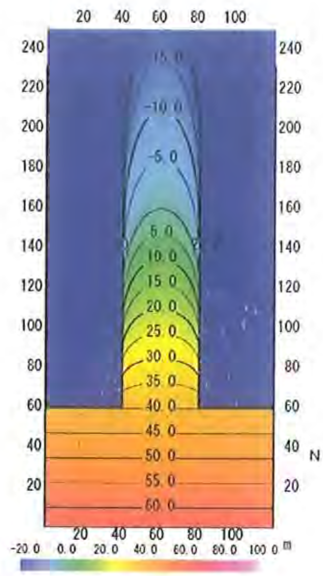
(a) Maximum water level

(b) Maximum flow pressure

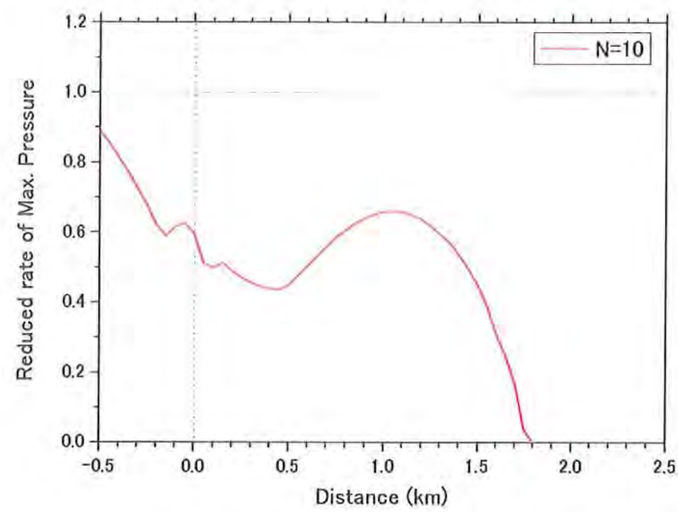
Fig. 10. Variation of dimensionless tsunami levels and flow pressures for greenbelt densities

Fig. 10 shows the dimensionless tsunami water level and force for the different greenbelt densities. The density is changed from 5 to 15.

The tsunami water level decreases slightly as the greenbelt density increases. Meanwhile the flow force decreases remarkably as the density increases. The effect of greenbelt to reduce the tsunami run-up height is relatively small but the greenbelt is applicable to reduce the tsunami force acting on the houses behind it.



(a) Depth contour of U-shape bay



(b) Variation of tsunami flow pressures

Fig. 11. Variation of tsunami flow pressures in U-shape bay

Fig. 11(a) shows an example of U-shape bay model for simulation. The greenbelt is located along the shore with a width of 100 m. The number of trees with 50 cm diameter in the unit area *N* is 10 in the simulation. Fig. 11(b) shows the variation of dimensionless tsunami flow pressures along centre line in the U-shape bay. The computed tsunami flow pressures are divided by that simulated at the centre and at a distance of 0.0 km for the case without greenbelt. The maximum pressure rate is reduced by the effect of greenbelt. The reduction rate decreases when the distance increases. However, the rate becomes higher when the distance is about 1.0 km from the shore. Therefore, the reduction rate of tsunami flow pressure varies with the location in the bay. Numerical simulation is necessary to determine the appropriate width and density of greenbelt.

6. Conclusions

a. The damage level due to tsunami differs with the type of structure.
b. Even reinforced concrete buildings may be severely damaged if the tsunami run-up height is greater than 5 m.
c. It is possible to calculate the effectiveness of coastal vegetation in mitigating tsunami damage.
d. The tsunami force reduction rate is determined mainly by the density and width of coastal vegetation.
e. The tsunami force is reduced to the level less than 15% of original behind coastal vegetation when the total number of trees per 10 m shore line is 400.
f. The tsunami flow velocity in the gap of coastal vegetation increases as the gap width decreases.
g. The tsunami force is reduced in the U-shape bay as well as the straight coast.

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Impact of the Indian Ocean tsunami and other coastal hazards on mangrove ecosystems as identified from space

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1. Introduction

Since the publication of the 1997 World Mangrove Atlas, two major coastal disasters have occurred i.e. the Indian Ocean tsunami in December 2004 and hurricane Katrina in August 2005. As mangroves seem to be very effective as defence against coastal hazards, it is legitimate to evaluate the present status of these ecosystems in coastal areas prone to frequent disasters, i.e. South East Asia, the Atlantic coast of Central America and the Caribbean. This study was carried out using a series of satellite data and completed by field surveys. The rapid regression of mangroves in these coastal areas were analysed and the main causes were identified.

2. Known rate of mangrove destruction

Since the publication of the first version of the World Mangrove Atlas (Spalding *et al.*, 1997), the major disastrous event in South East Asia was the Indian Ocean Tsunami which killed more than 200,000 people and left millions homeless, on the 26 December 2004. Around the same time, several severe cyclones, typhoons or hurricanes have caused disastrous situations in several parts of the world, especially in the Bay of Bengal, in South East Asia and in the Caribbean.

How effective were mangroves as a defence against the tsunami and other coastal hazards? Tens of papers published during the past few years concluded that the most popular and scientific views were:

- Where mangroves were in good condition, many people were saved from the fury of the tides as opposed to adjacent places where mangroves had been converted to other uses such as agricultural land or shrimp farming.

- Human activities, in general exacerbated the damage inflicted on the coastal zone by the tsunami. Some scientists even suggested the construction of a huge "Coastal Bioshield", especially along the Eastern coast of India (Selvam *et al.*, 2005).

We could expect to confirm, using data remotely sensed from space whether along the tropical coastlines, mangroves are now efficiently protected and rehabilitated in order to improve the physical barrier against tidal and oceanic influences.

Recent observations from space do not confirm this hope. On the contrary, the conversion of mangrove to shrimp aquaculture, the dramatic mass mortality of mangroves in coastal lagoons, the fantastic impacts of polluted areas and unexplained mangrove decay is expanding. Mangroves are preserved, primarily in those areas beneficial of the status of Forest Reserves with old and efficient Working Plans. The global areal extent of mangroves ecosystems in 1997 was 181,077 km^2.

Finally, the possibility of acquiring accurate data, for almost all mangroves of the world, has constantly increased, allowing the European Community, in the year 2000 (Aizpuru *et al.*, 2000) to publish an updated world-wide mangrove inventory. The conclusion was that the regression of mangrove ecosystems around the world was increasing at an average speed of 1,000 km^2 per year with remarkable exceptions in Papua New Guinea and Australia where most mangroves seem to remain practically untouched. If this figure is confirmed in the revised version of the World Mangrove Atlas, the total present extension of mangroves, including all types of mangroves (closed tall dense and low dense, open mangrove stands, fragmented mangroves, restored mangrove) would not exceed 172,000 km^2.

3. Technological evolution for mangrove monitoring

In 2007 the facts and events that can be monitored from space are the same as in 1997: erosion, degradation processes, human impacts, flooding, phenology and density of mangrove stands. This can be done primarily because each satellite makes regular overhead passes on a fixed orbit. Species distinction from space is practically impossible.

For the production of the first World Mangrove Atlas (Spalding *et al.*, 1997) we had at our disposal Landsat data (mainly Thematic Mapper) with a ground resolution of 30 m and 7 spectral bands including middle-infrared (1.57-1.78 µm) and thermal-infrared (2.10-2.23 µm). We also had SPOT data operating with a 20 m ground resolution in multi-spectral mode and at 10 m in panchromatic mode. Recently, several attempts to use radars have been made (ERS and Radarsat) with very limited success, even when radar data are processed in combination with optical data as one of the major issues is the suppression of the random noise associated with SAR data (the speckle), which induces strong limitations for the delineation of coastal units and land cover types (Kushwaha *et al.*, 2000; Phinn *et al.*, 2000; Proisy *et al.*, 2000).

At the end of the twentieth century, hyper-spectral scanning systems provided new types of data sets. They measure the intensity of the radiation received from coastal ecosystems in each of a large number of very narrow bands (50 to 300 bands, about 2 or 3 nm each). MODIS (MODerate resolution Imaging Spectroradiometer) was in space on EOS (Earth Orbiting System) satellite, launched in 1999. Several comparable airborne instruments could also be used: VIFIS (Variable Interference Filter Imaging Spectrometer) with 64 spectral bands, AVIRIS (Airborne Visible Infrared Imaging Spectrometer), CASI (Compact Airborne Spectrographic Imager) etc.

Since the beginning of the 21st century, the scientific community had new facilities to study the impacts of tsunamis and other coastal hazards. We have access at present to data provided by a generation of satellites operating in the optical mode, with almost metre resolutions (Ikonos, Quickbird, Corona, Spot series, IRS, Google Earth data, Digital Globe, Landsat 5 GISTDA etc.) (Adam *et al.*, 2006). The technical approach is rather simple; Landsat 5 imagery series are used as historical records of changes in mangroves, as indicators of pre-tsunami degradations; the assessment of damage to coastal communities is derived from very high resolution data (Quickbird and Ikonos) that are collected very soon after the coastal events. The discrimination of mangrove ecosystems always obeys the same physical rules. Usually the "mangrove signal" is distinct from others coastal ecosystems for two main reasons: (1) It is necessarily confined to the near-shore tropical intertidal zone (2) It is the result of two main signatures often recognised in the visible and near-infrared domains: the evergreen character of mangrove trees leads to strong reflectance in the near-infrared channel (0.7-1.1 µm), generally coded in red on a colour composite. Permanently wet mangrove soils have a noteworthy reflectance in the red channel (0.6-0.7 µm), generally coded in green on a colour composite.

This is why dense mangroves always appear dominantly in a reddish violet colour, turning to bluish violet in open mangrove stands. A given tall dense mangrove stand with *Rhizophora* sp. (Matang in Malaysia, Can Gio in Vietnam,) or with *Heritiera fomes* in the Ganges complex may have the same "signature" as a low thicket with *Avicennia marina* (New Zealand and Arabian Gulf). This is one of the major limitations of these technologies, especially in forestry in general, where one of the main goals is to discriminate the species of trees and to estimate the structure of the forest and the size of its components.

Recently, Garay and Diner (2007) reported that MISR instrument (Multi-angle Imaging Spectro Radiometer), on board of Nasa's Terra Satellite, was able to capture large waves along the eastern coast of India on the 26 December 2004. MISR provided accurate data on the location and characteristics of tsunami waves in near shore waters and an estimate of wave speed is being investigated to evaluate how far the instrument could offer practical monitoring facilities along the tropical coastal belts.

Another rather new technical capacity innovation (Curran *et al.*, 2006), is derived from a little used and presumably also little known instrument, MERIS, which is used by the European Space Agency (ESA). This Medium Resolution Imaging Spectroradiometer, on Envisat, produces interesting data concerning the mortality of mangroves, through the detection of a rapid decline of the chlorophyll content, thanks to its MTDC (Meris Terrestrial Chlorophyll Index). The senescence of mangrove trees can be due to several causes.

In 2007, remotely sensed imageries were used to update existing mangrove maps or to create new maps. New satellite data are available and the possibility to manipulate the synergy between optical and radar imageries increase the possibility to observe coastal areas where the cloudy cover is almost permanent (Papua New Guinea, Irian Jaya, Mouth of the Amazon, Pacific coast of Colombia, Mouth of the Orinoco) However, for complex technical reasons, the general methodology described in 1997 (Spalding *et al.*, 1997) remains basically valid in 2007, although a number of new methods of transferring the data to GIS or other software systems have been developed to easily correct geometric distortion and to undertake subsequent data analysis.

4. Some conspicuous and critical mangrove features discerned from space

In 1997, conversion of mangroves to shrimp ponds was a limited phenomenon in most countries of tropical America. It is now being exacerbated in most coasts of Central America, in Ecuador and Peru.

Along the Pacific coast of Mexico from 28°20' N, southward along the Baja California Peninsula, aquaculture is developing at an extraordinary pace. Today, many new striking examples are available, especially along the Culiacan coast, near Yaqui, Isla Lobos, Isla San Ignacio and Isla Altamura, indicating the total destruction of mangroves in many creeks and lagoons. Those lagoons which were mapped as examples of good mangrove areas in Mexico (Spalding *et al.*, 1997), i.e. Laguna Agua Brava and Laguna de Terminos have now almost lost their last mangroves. Another disappointing observation along the Atlantic coast of Mexico (which is often struck by hurricanes) is the extremely high rate of unexplained mass mangrove mortality in many of the numerous coastal lagoons. It is quite obvious that heavily polluted mangrove areas seem to be primarily affected by the oil industry.

In Guatemala, aquaculture is now developing rapidly, especially along the Pacific coast, at Champerico, Barra dre Vieja, Tecajote etc. In the Departamento de Atlantico Norte, space observations made in 2005 revealed a phenomenal mortality of coastal vegetation especially in coastal lagoons. Similarly, along the Atlantic coast of Honduras several examples of large stretches of mangrove mortality were observed, especially on the Gracias a Dios coast (Baltimore, Rio Platano, Brus Laguna, Lampira, Balcaca etc.). In the same manner, it was observed in El Salvador, that agricultural development is probably the oldest and major factor of mangrove destruction. However, in the last few years, the rapid expansion of aquaculture has become very significant, especially in the Departamentos of Usulatan and La Union.

The Pacific coast of Panama is also strongly affected by mangrove destruction due to the continuous expansion of agricultural activities and aquaculture. The Bay of the Isla Gobernadora, Los Santos, Chitre, Aguadulce coasts offer good examples. In this country also, impressive and unexplained coastal erosion processes are observed as exemplified at Isla Coiba.

At this stage we do not have a clear explanation to all of the mentioned cases of conspicuous and repeated cases of mangrove mortality. Oil spills and herbicides may have important destructive consequences (Duke *et al.*, 1997 & 2005). Another partial explanation could be an excessive fresh water diversion mainly for agricultural, industrial and urbanisation purposes. Along the Atlantic coast, some changes in Oceanic currents and/or in the frequency and intensity of hurricanes in the Caribbean have to be considered as potentially mangrove destroying parameters.

In Asia, Kalimantan and Sumatra (Indonesia) and Vietnam became focal points during the last 10 years. At the country level, Vietnam (2,500 km^2 of mangroves in 1997) is a part of the world where the fate of mangrove ecosystems is most seriously imperilled since 1997. Today, with the exception of Can Gio National Park, located near Saigon city, about 80% of the country's mangroves, including the Mekong delta, Central Vietnamese coast, Red River mouth (where *Kandelia candel* and *Aegiceras corniculatum* were dominant species), up to the Chinese border, have already been converted to shrimp ponds. Good patches of mangrove remnants are becoming rare. *Rhizophora apiculata* is planted in between shrimp ponds in the mouths of the Mekong River where mixed shrimp farming and mangrove mono-specific planting is practised (Tong *et al.*, 2004).

In West Africa, one of the largest mangrove ecological disasters is presumably found in the inaccessible Niger Delta where the oil industry and huge oil spills added to a permanent civil war in this southern part of Nigeria, have virtually transformed during the last ten years, the original 9,000 km^2 of mangroves into barren polluted mud.

5. Mangrove senescence, extreme winds and increasing salinity

Extreme winds events are reported every year on the Eastern façade of the continents with a latitude greater than about 5°C N or S. Regions particularly affected include the Caribbean, Eastern coasts of Central America, the Bay of Bengal, Vietnam, the Philippines, China, Japan etc. Some of these parts of the world are precisely those where mangroves have been depleted at the quickest pace. Mangroves usually bear the full brunt of such tropical storms described as hurricanes, typhoon or cyclones. As analysed by Saenger (2002), wind damage can be classified into several groups (mangrove trees are felled, twigs and leaves removed, broken trunks, standing dead etc.). In any case space observations do not produce any clear difference between wind damage (gusts up to 290 kph) and water damage due to long lasting floods, tsunamis etc.). The general response obtained with optical sensors is the absence of chlorophyll (no absorption in the red channel) and a strong absorption of the near infra red by water.

The excess of sodium chloride in mangrove soils, due to tidal intrusions or to the lowering of the water table when fresh water runoff decreases has strong physiological consequences on these ecosystems (Blasco *et al.*, 2004). Different genera behave differently with respect to the "salt parameter". Some species, called "salt excreting"; (e.g. those of the genera *Avicennia, Aegialitis, Aegiceras*) are able to accumulate (and to excrete salt) from salt glands present in their leaves. Species of *Rhizophora, Sonneratia, Lumnitzera* etc. do not allow salts to penetrate into the sap. In this last group, the amount of salt entering the vascular part of the individuals is controlled by a set of complex physiological and anatomical adaptation mechanisms which are studied since many years (Ball, 1988 & 2002; Lovelock, 2003; Parida, 2004; Ye *et al.*, 2005). Our field observations give the following data regarding optimal ecological requirements:

In Asia, *Heritiera fomes* and *Nypa fruticans* are extremely sensitive to minor increase in salinity (optimum about 10-15‰). *Sonneratia* is much more complex because the genus produces several little known hybrids. *Sonneratia alba* prefers highly saline waters (30 to 35‰); *S. ovata* is found upstream, where the salinity is low (<15‰); *S. apetala* also thrives well only where the salinity is <20‰; and *S. caseolaris* is common in areas with >20<35‰ salinity.

The highest salt tolerance is found in the *Avicennia* group of trees. *Avicennia officinalis* and *A. alba* in South East Asia grow best between 20 and 30‰ salinity (Mekong delta). *Avicennia* *germinans* along the Atlantic coast grow with salinities >40‰ (Mauritania) while *A. marina* (several varieties) thrives in areas >40‰ salinity (Red Sea, Arabian Gulf, N. Australia etc.).

Most of these studies are still at a research level (stomatal response, gas exchange in leaves, oxygen accumulation in pneumatophores, nitrogen fixation, potassium deficiency etc.) It is admitted that the growth and survival of all mangrove trees is limited by water salinities >90‰.

6. Contrasting cases of mangrove conservation and stability

In theory, most luxuriant mangrove habitats and best mangrove development (mangrove trees height >20 m) are found in protected coastal areas where upper tidal soils are exposed to a continuous supply of fresh water. The primary effect of the fresh water is to remove salt from the soil by leaching and to maintain salt water content below the permanent wilting point.

This occurs in three main bioclimatic settings: 1) Where the rainfall exceeds evaporation throughout the year (Malaysia, Papua New Guinea and Irian Jaya, Sumatra (Indonesia), Borneo, Gabon, mouth of the Amazon River, Pacific coast of Colombia etc.); 2) Where large fresh water catchments allow strong dilution of estuarine and deltaic waters, reducing salt additions to the soil (Gulf of Guyaquil in Ecuador, Mouth of the Orinoco River in Venezuela, Gambia River in West Africa); and 3) Where large fresh water catchments and heavy monsoon rains, provide regular and prolonged freshwater flooding of the tidal zone (Mekong in Vietnam, Gangetic delta in India and Bangladesh, Irrawady delta in Myanmar, Niger delta in Nigeria, Ranong and Phan Nga bays in Thailand etc.).

In these favourable mangrove habitats, all best mangrove stands are found only in protected areas such as Forest Reserves, National Parks, Nature Conservation, Wildlife Sanctuaries etc. Protected areas where mangroves are conserved, an almost constant acreage during the last 10 years are found in only a few countries such as Australia, Malaysia, Papua New Guinea, Phan Nga bay (Thailand), Gabon, mouths of the Ganges and of the Amazon River. In addition, silvicultural practices in the mangroves of the Pacific coast of Colombia, and in the Orinoco delta (Venezuela) are also well adapted, apparently to local ecological conditions.

It is noteworthy that in some coastal areas known to have very suitable climatic conditions as defined above, mangroves have been rapidly declining during the last 10 years. This is typically the case in Surinam, in Nigeria, in Gambia, in Ecuador, in the Mekong delta (Vietnam), in the Irrawaddy delta (Myanmar) and in Sumatra and Kalimantan (Indonesia).

7. Hypothetical global change symptoms?

How are present changes in meteorological and oceanic processes contributing to the observed disaster?

Human induced direct and indirect impacts on mangrove ecosystems can, to a certain extent, play in synergy with cryptic natural changes. Mangrove species which are usually remarkably resistant to most natural hazards, constraints and most humankind's activities (Clark *et al.*, 1997; Lacerda & Molisani, 2006), are extremely vulnerable to change in their hydrological conditions, especially to water logging. Other parameters which cannot be observed from space (decreasing rainfall in watersheds, increasing salinity and acidity all kinds of pollution, changing coastal currents etc.) may create a high level of ecosystems vulnerability.

In the year 2000 the coastal population living within 100 km of the coast was 38% in the Asian Region, 53% in the Central American, Caribbean and South American Regions, and 87% in the Oceania Region. The population density in the same coastal zone is expected to grow between 30 and 40% from 2000 to 2050 (Duedall & Maul, 2004). The constant and rapid human population growth in coastal areas is certainly the major cause, everywhere, of the accelerated destruction of mangroves.

Over the past 30 years or so, severe drought periods occur around the world were related to ENSO (El-Nino Southern Oscillation) (IUCN, 1993; Ong, 1993; Ellison, 1994; Diop, 2003; Cohen *et al.*, 2005). We noticed in West Africa, especially in Senegal, a vertical migration of salts by capillarity, from soil solution and shallow ground waters, and inundation by hypersaline waters from creeks and rivers. As a matter of fact the extension of blanks (or *tannes* in West Africa) is expanding due to an increment of the salinity. Its effects on mangroves are often underestimated simply because the decay is very gradual. The concentrations of salt in mangrove soil and water, control the selection of species, the germination of many species, the growth of seedlings, ion accumulation or nutrients utilisation and the global photosynthetic performance, which varies from one species to another.

The decrease of global rainfall in the watersheds has important effects on the salinity and may induce a higher acidity in some mangrove soils especially in those coastal areas with a pronounced dry season (6 to 9 consecutive dry months) during which the aeration of top soils may lead to the oxidation of pyritic sediments (FeS_2). The simplest and schematic expression of the phenomenon is:

$$FeS_2 + \text{oxygen} + H_2O \rightarrow H_2SO_4 \text{ (sulphuric acid)} + \text{iron and sulphur compounds}$$

It can be assumed that direct links exists between climatic changes, soil properties including their acidity and fluvio-marine ecosystems.

Are coastal lagoons increasingly becoming coastal lakes? Mangroves are thriving well in coastal lagoons, wherever the water circulation with the ocean is ensured. The existence of mangrove surviving in landlocked, tideless areas is rare and should be considered as local degenerate remnants. However when the stream drainage to the sea is blocked the water body becomes a coastal lake in which the survival of mangroves is seriously compromised because in supplying oxygen for the root respiration, soil aeration and tidal fluxes are essential for all mangrove species. Regular inundation by tides plays an essential role in the survival of mangrove ecosystems whereby their soils do not reach excessive levels. The physical mechanisms accelerating coastal processes including the accelerated growth of elongated spits in the direction of predominant alongshore drift are governed both by the changing terrestrial (human impacts) and marine characteristics including major coastal dramatic events.

Increasing sand accumulation in some mangrove areas is a noteworthy phenomenon first observed in the beginning of the 21^{st} century. The mangroves of Tulear along the southern coast of Madagascar, Eleuthera and Andros islands in the Bahamas, North Eastern coasts of Brazil, especially in the states of Piaui, Ceara and Rio Grande Do Norte etc. are surviving in areas where the accumulation of sand is spectacular. Hundreds of kilometres of mangrove coasts are affected by this poorly known coastal process. We do not know to what extent these enormous sandy drifts observed from space are actually reducing the mangrove resource. Are they due to quartz sand and heavy minerals reworked during rising sea levels leading to massive polycyclic accumulations of sand deposits? Are they mainly coastal sands marine carbonates originated from coral reefs? Most of the terrigenous sand is derived from denudation of the hinterland and transported to the coast by rivers and could be a consequence of the global deforestation.

8. Conclusion

In this quick mangrove survey, the existing very high resolution satellite imagery has not been used to their full potential. In addition, the analytical approach itself is limited by the fact that special emphasis has been put on rough satellite observations such as barren mudflats, obvious conversion of mangroves to other uses, sand intrusions, conspicuous pollution, urban expansion in mangrove areas etc.

However, the observed facts are doubtless. In spite of the recognized vital role of mangroves, current space observations indicate that their eradication has reached an unprecedented rate during the last ten years. Assuming that figures published in 1997 were the most reliable at that time and accepted by the community of mangrove specialists (i.e. about 181,000 km^2 of which about 60% were dense stands and the rest included open mangroves, fragmented types and mosaics), it appears that the average world mangrove regression exceeds 1,000 km^2 $year^{-1}$. Noteworthy exceptions are Australia (11,500 km^2), Papua New Guinea (4,100 km^2), Malaysia (6,400 km^2), India (5,700 km^2) and Bangladesh (6,300 km^2), Gabon and the United Arab Emirates which seem to have maintained the extent of their mangroves.

The great surprise, after the emotional shock created by the deadly Asian tsunami, in December 2004, and the universally admitted need to protect and to rehabilitate coastal forests, is that mangroves continue to disappear at an alarming rate, especially in those countries prone to destructive coastal hazards. The Philippines, Vietnam, Myanmar, North Western coast of Madagascar, islands of the Caribbean and the Atlantic coast of Central American countries are such cases.

Accelerated coastal population growth is probably the most powerful cause of mangrove degradation. However there are a lot of cryptic degradation processes which cannot be observed from space. Remote sensing specialists recognize that the technology has so far been less successful in coastal areas than in continental zones. The reasons lie in questions of spatial and temporal scales and on the physics of coastal signals often distorted by marine aerosols and warped by the proximity of the ocean.

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Impacts of tsunami on mangroves and other coastal ecosystems of Solomon Islands

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Abstract

The 2004 Indian Ocean tsunami had catastrophic effects on coastal areas. The protective effects of coastal vegetation in reducing the destructive forces of the tsunami on coastal villages have been reported. The importance of coastal greenbelts as barriers against tsunami has been demonstrated using model experiments and numerical simulations. On 2 April 2007, a tsunami generated by earthquake hit Solomon Islands. In June 2007, a field survey was conducted to assess the protective roles of greenbelts on Gizo Island, located in the western part of Solomon Islands. Data collected included damage in villages, variation in ground level, and density and size of vegetation. Results showed that damage in villages varied with the number and trunk diameter of coastal trees fronting the houses. The snrvey demonstrated that dense forest vegetation protected wooden houses on the island.

1. Introduction

The 2004 Indian Ocean tsunami had disastrous effects on coastal areas with great loss of human lives and properties. Several reports (e.g. Danielsen *et al.*, 2005; Kathiresan & Rajendran, 2005) had described the protective functions of coastal forests in reducing the tsunami force destroying coastal villages. The importance of greenbelts as barriers against tsunami had been demonstrated using model experiments and numerical simulations (Hiraishi *et al.*, 2005). In the present study, the numerical calculation for tsunami force variation due to coastal vegetation was carried out to determine its appropriate density and width to protect the wooden houses in coastal villages in South East Asia. A tsunami generated by earthquake hit Solomon Islands on 2 April 2007. A field survey was conducted in June 2007 and the protective effects of coastal vegetation against tsunami damage were evaluated.

2. Numerical results

2.1 Estimation method of tsunami force reduction due to coastal vegetation

The evaluation of drag and inertia resistance for coastal vegetation in a hydraulic model test has been already done by Hiraishi and Harada (2003). The resistance force of greenbelt in a unit area is expressed as equation (1), and the drag C_D and inertia C_M coefficient in greenbelt is expressed as equation (2).

$$WF = \frac{1}{2} C_D \rho A_0 u|u| + C_M \rho \frac{V_0}{V}\frac{\partial u}{\partial t} \quad (1)$$

$$C_D = 8.4V_0/V + 0.66, \quad C_M = 1.7 \quad (2)$$

where u = tsunami flow velocity, A_0 = projection area of vegetation, V_0 = volume of vegetation, and V = total volume under water. The projection area and volume of vegetation are determined by the number of trees per unit area and by the diameter of tree trunk D. The number of trees N in a unit area (10 m x 10 m = 100 m^2) determines the greenbelt density. Another dominant parameter is the total width of greenbelt *B*. The reduction effect due to coastal vegetation was employed to simulate the variation of tsunami profiles by non-linear long wave model.

2.2 Predicted effect of coastal vegetation

We used the data on coastal vegetation in a beach in Khao Lak in Thailand after the Indian Ocean tsunami (Fig. 1). The tree diameter *D*, density *N* and width *B* of the vegetation are 30 cm, 20 and 50 m, respectively. Fig. 2 shows the numerically estimated profile of the tsunami. The incident component, indicated in red line, is employed as the acting wave profile in the coastal vegetation zone.

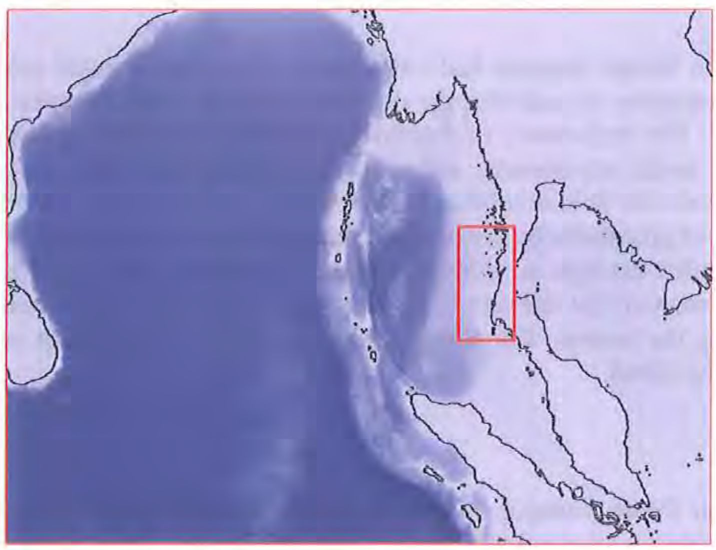


Fig. 1. Location of target beach in Thailand

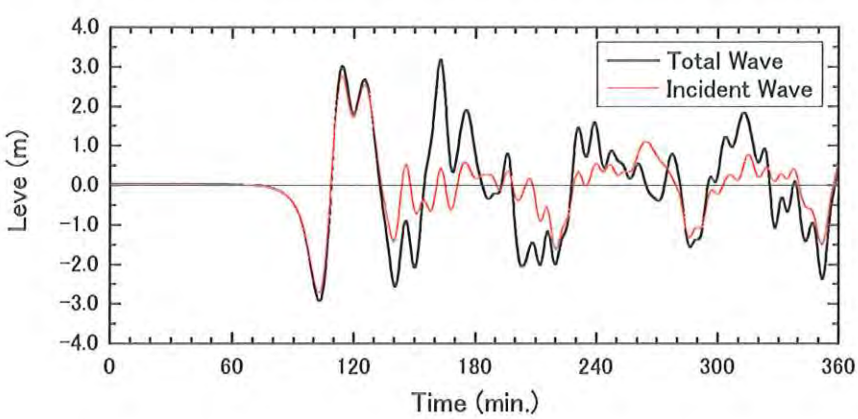


Fig. 2. Numerical estimated tsunami profile (total and incident component)

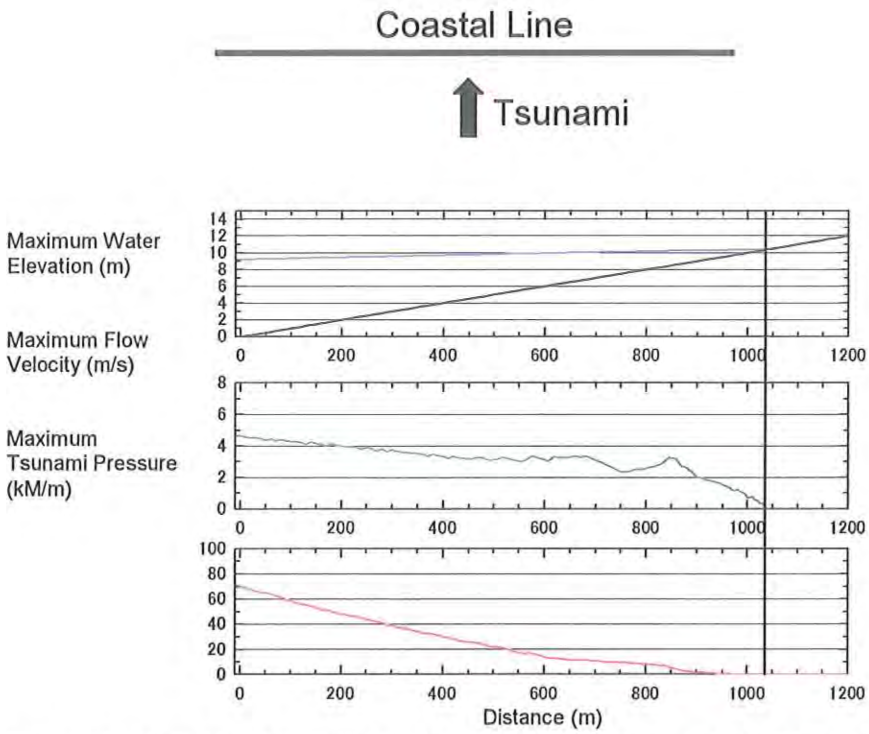


Fig. 3(a). Variation of tsunami height, velocity and pressure on beach (without greenbelt)

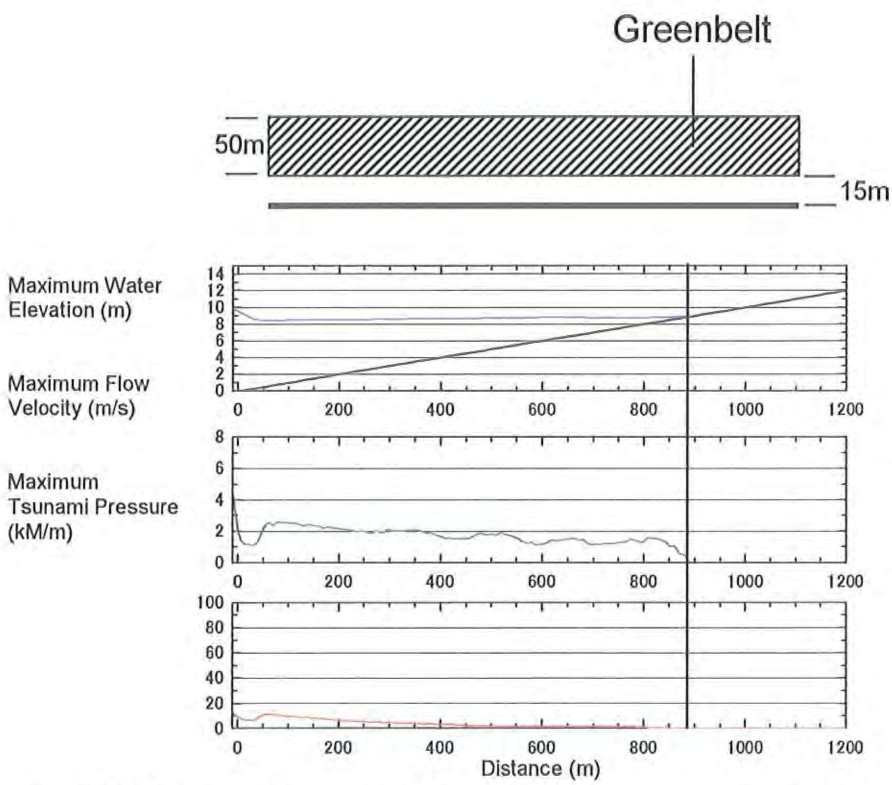


Fig. 3(b). Variation of tsunami height, velocity and pressure on beach (with greenbelt)

Fig. 3 shows the comparison of maximum water elevation, maximum tsunami flow velocity and maximum tsunami pressure along the distance from the shore line without and with coastal vegetation. Tsunami pressure was reduced to the level at which wooden houses remained without heavy damage after establishment of coastal vegetation with the width of 50 m.

3. Field survey of Solomon Islands

Damages in the villages of Suva, Vorivori and Titiana on Gizo Island in the western part of Solomon Islands due to the tsunami on 2 April 2007 were assessed. Data on variation of ground level and density of vegetation in these villages were collected in June 2007. Fig. 4 shows the situation in the devastated area (Line-2) and in the less damaged area (Line-1).

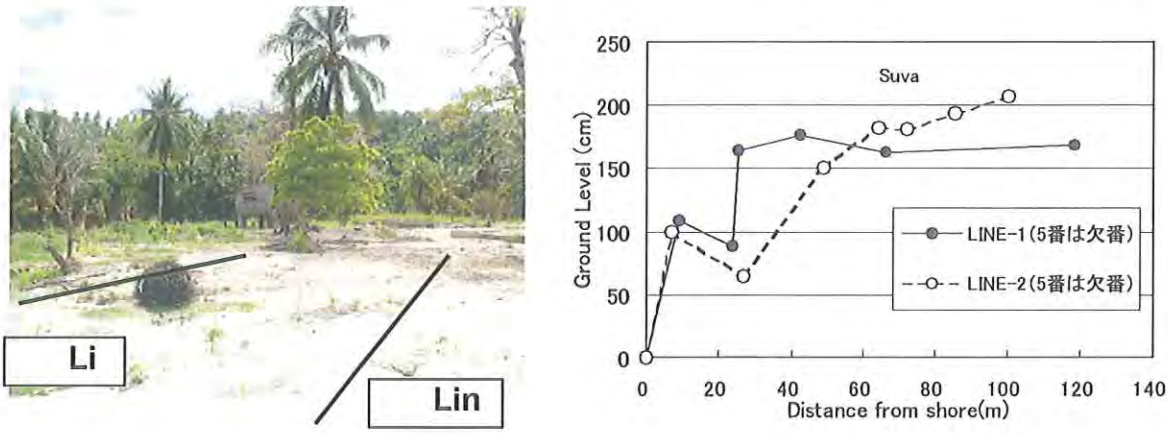


Fig. 4. Cross sections at Line-1 and Line-2 in Suva village

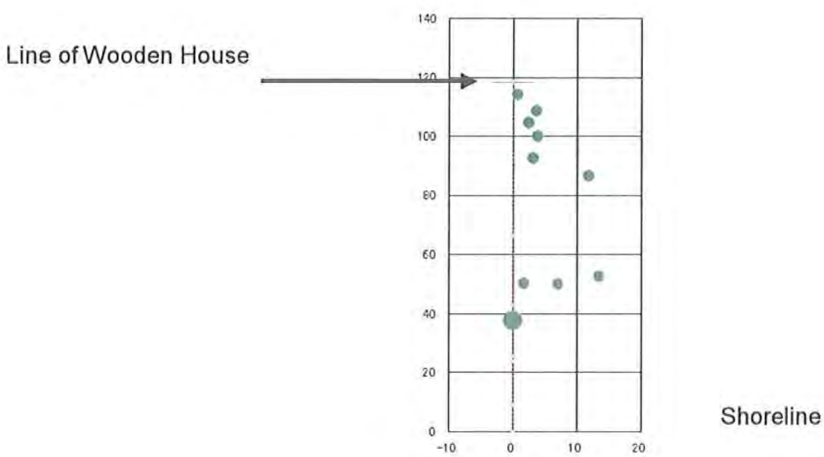
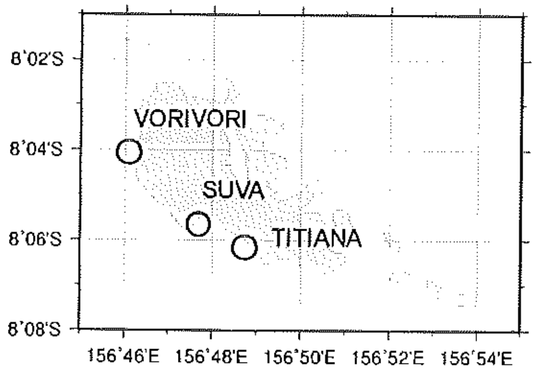
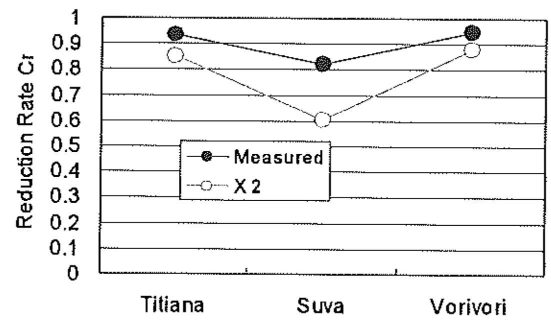


Fig. 5. Location of coastal trees (dotted) fronting a wooden house

Fig. 5 shows the location of coastal trees represented by green dots. The effects of coastal trees in reducing tsunami pressure were estimated using equations (1) and (2). Fig. 6 shows the dimensionless variation of maximum tsunami pressure acting on village houses on Gizo Island. The maximum tsunami pressure was expected to be reduced about 20% by the coastal vegetation. Results of the field survey revealed that dense forests protected wooden houses on Gizo Island when the 5 m tsunami hit Solomon Islands on 2 April 2007.



(a) Location of villages surveyed on Gizo Island



(b) Reduction rate of tsunami pressure

Fig. 6. Reduction rate of maximum tsunami pressure acting on village houses on Gizo Island (X 2 indicates the case including ground friction)

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Mangroves and sea-level change

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Abstract

Whilst it is true that the present increase in atmospheric carbon dioxide is alarming (and merits serious attention), the possible knock-on effects of global warming and, even more so, the consequent sea-level rise is perhaps not as clear as currently made out to be. We ask if the global warming debate is about "*An Inconvenient Truth*" or "*A Convenient Half-truth*", providing a more balanced perspective to our main discussion on sea-level rise and its effects on mangroves.

Sea-level change is site-specific, determined not only by eustatic sea-level change but also by tectonic change, sedimentation/erosion rates, auto-compaction as well as ground-water withdrawals. Measurement difficulties and the lack of reliable long-term data sets lead to uncertain predictions and generalisations.

Mangroves have survived rapid sea-level changes through geological time. The difference now is that human-built barriers will prevent mangroves from spreading inland so a significant reduction in the area of mangroves may be expected. Will governments, through implementation of new coastal policies, let mangroves expand or will they "protect" their land? Protection of mangroves through the implementation of a few coastal policies is suggested. Even so, the expected loss of mangroves to sea-level rise in the next fifty years is not expected to be anywhere close to the loss of mangroves in the past fifty years, so are we pursuing a red herring?

1. Introduction

Predictions of sea-level rise are based on the concern of rapidly increasing levels of atmospheric carbon dioxide. Carbon dioxide is a greenhouse gas, so any increase in atmospheric carbon dioxide would (with everything else remaining constant) result in a rise in global temperature. The consequence of global warming would result in a rise in ocean temperature and in turn would lead to its expansion. Global warming could also lead to melting of glaciers. These will lead to a rise in eustatic sea level.

In theory, at least, what has just been outlined in the previous paragraph is one scenario for the sea-level rise prediction. There are many assumptions in that scenario, as well as various feed-backs (especially of other greenhouse gases) to consider. We like to point out that whilst change is a certainty, the jury may still be out on the cause/s of climate change and certainly so on the even more tenuous link between anthropogenic atmospheric carbon dioxide and sea-level rise.

So, before we get into the discussion on sea-level change and mangroves, we think it appropriate to briefly provide at least a wider perspective, and hopefully, a more balanced one on climate change and its consequences. Change, whether it is climate or anything is a physical certainty. It is the direction and magnitude of change that is uncertain and very often difficult to predict with any reasonable degree of confidence.

In this presentation, which we must state is not intended as anywhere near a comprehensive review, we first take a quick look at increasing atmospheric carbon dioxide concentrations and its possible cause and the controversy of global warming. We then discuss the mechanisms sea-level change, before we go on to discuss the effects of sea-level change on mangroves. We also discuss measures that will mitigate or minimize the impact of sea-level rise on mangrove.

2. Atmospheric carbon dioxide and global warming

2.1 Increase in atmospheric carbon dioxide and its cause

Atmospheric carbon dioxide concentrations have increased dramatically over the past century. The excellent half a century time-series from Mauna Loa (Boden *et al.*, 1990; NOAA, 2006) is proof of the dramatic rise in concentration of atmospheric carbon dioxide in the last half a century. Few would deny this, but there are some who doubt that the cause of this rise in atmospheric carbon dioxide is an anthropogenic (through the use of fossil fuels and the manufacture of cement). Jaworowski (2007), for example, has this to say:

> *"Also not mentioned is that 97% of the total annual emission of CO_2 into the atmosphere comes from natural emissions of the land and sea; human beings add a mere 3%. This man-made 3% of CO2 emissions is responsible for a tiny fraction of the total green house effect, probably close to 0.12%."*

The point to be made here is that this small (3%) addition is an annual one that has taken place for over a century. If we assume that the natural emissions (e.g. from respiration and decomposition) has remained constant and have been naturally sequestered, then the human induced addition to atmospheric carbon dioxide over the past century or so is, in fact, extremely significant. Canadell *et al.* (2008) gave details on the numbers as well as the sequestrating capacity of the global system and provides a rebuttal of the Jaworoski's contention.

Our assessment is that not only is there an alarming rise in atmospheric carbon dioxide but that this rise is too much of a coincidence not to be attributed to the human use of fossil fuels and cement manufacture in the past century or so. This is no longer such a contentious issue. We are also of the opinion that urgent measures should be taken to stem this alarming rising atmospheric carbon dioxide tide but the measures taken should be well thought out and based on good science (some of which may yet be available).

2.2 Global warming

Whilst more and more are convinced about the reality of global warming, this issue, especially the causes of global warming is still a controversial one. Whilst we have witnessed the dramatic increase in atmospheric carbon dioxide, it must be remembered that carbon dioxide is but one of many greenhouse gases in our atmosphere. Water vapor, for example is not only more abundant and probably more important but has until recently been largely ignored, especially by climate modelers (Engelman *et al.*, 2008). Perhaps this is because water vapor is much more complex, since it is not only a greenhouse gas but also form clouds that lead to amongst others, albedo and changes in evaporation rates (e.g. Srinivasan & Gadgil, 2002; Wild *et al.*, 2007; Roderick *et al.*, 2007). These have various less understood feedback loops that make modeling much more complex and difficult.

Ice core data have provided us with very long-term records of atmospheric carbon dioxide concentrations and temperatures that date back hundreds of thousands of years. Such data sets, like the Vostok Ice-Core (e.g. Petit *et al.*, 1999), have provided impressive evidence of carbon dioxide change and its parallel temperature change. These data sets appear to give convincing evidence of the link between carbon dioxide concentration and temperature but one question that is very pertinent is if this link is one of temperature following carbon dioxide or the vice versa. This is a vital question and has serious repercussions as to how we tackle the atmospheric carbon dioxide problem. For example, Jaworowski (2007) strongly questioned if ice core data showed that temperature change followed carbon dioxide change. In fact, Petit *et al.* (1999) did mention that Fischer *et al.* (1999), also working on the Vostok ice core, had concluded:

"that CO_2 concentration increases lagged Antarctic warmings by 600 ± 400 years." Petit *et al.* (1999) nevertheless went on to say that *"considering the large gas-age/ice-age uncertainty (1,000 years, or even more if we consider the accumulation-rate uncertainty), we feel that it is premature to infer the sign of the phase."*

It is obvious that the interpretation of the ice core data was subject to a number of assumptions and high degree of uncertainties. There is as yet not enough confidence to determine the phase relationship between carbon dioxide and temperature. In short, the jury is still out on this issue.

3. Sea-level change

Sea-level change can be divided into two components: eustatic (or "global") change and site specific changes. At any particular site, the sea-level change that is seen is a "relative" change. It is a combination a eustatic and site specific changes. So, even if eustatic sea-level is rising, sea-level in a particular site may be falling (e.g. if sedimentation rate exceeds that of the eustatic rate).

Measuring sea-level change is a difficult and complex task. Traditionally, tide gauges or even simple tide poles are employed and, in theory, accuracy to a centimeter or so is attainable. The difficulty in such measurements is not with the instrument but more in how well the instruments are installed. Any vertical movement of the instrument will result in inaccuracies. Since sea-level change is relative (to a physical point of reference), the establishment of a reference point (also known as chart datum) is complex. Even with a well established chart datum, there is still a problem with tectonic and other site specific vertical movements. It must be noted that tide gauges do not measure eustatic sea-level change but a combination of eustatic and tectonic change. Only if the tectonic change at that site is known (e.g. by reference to satellite altimetry) can the eustatic change be calculated.

3.1 Eustatic (global) change

This is the change of sea-level on a global basis and is essentially caused by the change of volume of all the water in the world's ocean. Water volume change is mainly caused by rise or fall in water temperatures as well as the increase or decrease of glacial ice (icebergs that are floating in the sea do not cause significant changes to water volume, as seen when a glass of water with ice filled to the brim does not overflow when the ice melts).

In theory, the way to measure eustatic sea-level change would be to install tide gauges at a number of sites where the tectonic activity is very stable. In practice, there are possibly no completely tectonically stable sites. The alternative is to look at tidal data from more or less tectonically stable sites. With long enough time-series data sets it would be possible to at least establish broad trends. For example, time series data from 23 tide gauges over the past century or so showed (Wikipedia, 2008) a sea-level rise of some 20 cm (i.e. a mean of +2 mm yr^{-1}) but with a large variability (a range of 20 cm or more at any one point in time). The main problem would be that if the mean tectonic movements of these 23 sites showed a bias (which is difficult to know). Still, this is as close to the best that we have, with tide gauges.

More recently, satellite altimetry time-series data has become available (University of Colorado, 2008). Starting in 1992, with TOPEX/POSEIDON, followed by JASON 1 and just this year by JASON 2 (e.g. Nerem & Mitchum, 2001), we now have decadal scale time-series ocean level data. The mean tidal level change over the past 15 years or so is +3.2 ± 0.4 mm yr^{-1}. Satellite altimetry measurements are for oceanic waters and referenced to the centre of the Earth (Blasco, pers. com., Leuliette *et al.*, 2004).

With this background it is interesting to note that the IPCC (2001 & 2007) predicted a sea-level change with a huge range of +1 to +88 mm yr^{-1}.

On a longer time-scale, over the Holocene (e.g. Peltier, 2002; Douglas & Peltier, 2002), sea-level was -120 m at the last glacial maximum some 20,000 years ago. The mean rate of sea-level rise from some 12,000 years ago (when the sea level was -75 m) to 7,000 years ago (when it had more or less leveled at close to 0 m) was some +15 mm yr^{-1}. These are rates that are at least half an order of magnitude larger than the rates we are seeing over the recent century.

3.2 Site specific changes

Site specific changes include tectonic changes, sedimentation or erosion changes, auto-compaction and ground water withdrawal.

Tectonic

This is the result of the movement of the earth's plate. The plates push against each other which results in tilting. With tilting, one side of the plate will subside while the opposite side will rise. Some plates are more or less stable whilst others show more pronounced movements. Melting and melted glaciers results in reduced load and the plate will slowly rebound, causing a relative sea-level fall. Norway is an example where such a tectonic rebound is seen.

Atmospheric pressure

Changes in atmospheric pressure result in sea-level change and are not only site specific but also time specific. Increase in atmospheric pressures result in a drop in sea-level and low atmospheric pressures result in sea-level rise. Atmospheric pressure has also to be taken into account when measuring eustatic sea-level changes.

Sedimentation/erosion

Sediments from the land eventually end up on the coasts and add to the level of coastal flats. Sedimentation rates can range from millimeters to centimeters, which results in relative sea-level fall. Palembang was a coastal port on the island of Sumatra, Indonesia just over a hundred years ago but is today some tens of kilometres inland, as a result of heavy sedimentation (Macnae, 1968).

The other side of the sedimentation coin is erosion. High energy coasts are often subject to erosion and this result in a relative rise in sea-level.

Auto-compaction

Deltas are built on sediments and these sediments are subject to compaction (e.g. when buildings are constructed). Such auto-compaction will result in a relative rise in sea level and Bangkok, Thailand is an example.

Groundwater withdrawal

In many places there are reservoirs of underground fresh water. Cities often sit on top of these groundwater reservoirs so these are often pumped out for use. Excessive (unsustainable) withdrawal of groundwater results in more water being taken that being naturally replaced. This results in the sinking of the land and in coastal areas, or a relative rise in sea level. Bangkok in Thailand is again an example where groundwater withdrawal has resulted in a relative rise in sea-level.

4. Mangroves and sea-level change

Recently, Schwarzbach (2008) provided a bibliography of 100 papers (with abstracts) on mangroves and sea-level change. This, together with a very recent review (Gilman et al., 2008), provide a very convenient introduction to this subject.

One of the important factors for the occurrence of mangroves is low energy, accreting (or sedimenting coasts. Most mangroves occur in such situations and with the present eustatic sea-level rise of some 3 mm yr^{-1} sedimentation will more than likely keep up with or exceed eustatic sea-level rise. If the tectonic plate where the mangrove occur is stable (such as the case of the Sunda Shelf, where some third of the world's mangroves occurs) or there is upward tilting (such as the Sundabans, which has 3% of the world's mangrove), it is clearly safe to say, even though we do not have actual numbers, that with the present rate of sea-level rise, more than half the world's mangroves [sea-level change in Australia, where some 10% of the world's mangrove occur, is reported to be a slow 0.3 mm yr^{-1} (Mitchell *et al.*, 2000; quoted in Ellison, 2004)] will not be subject to relative sea-level rise but rather to sea-level fall. Still, a study to estimate the percentage of mangroves that will be subjected to relative sea-level rise or fall will be a useful one, in light of the present debate on global warming. However, mangroves on low islands (e.g. Ellison, 2001) on carbonate bases where sedimentation is low would perhaps be the most vulnerable.

Santilan and Wilton (2001) has, however reported the transgression of mangroves into salt marshes in Australia, suggesting sea level rise. Woodroffe (1995) however reported that different mangroves in Australia will respond differently to sea-level rise and that "broad plains have been able to prograde during the last 6,000 years of relatively stable sea level."

4.1 How mangroves react to sea-level change

Mangroves have survived numerous glacial cycles over millions of years. They have been subjected to relatively rapid (compared to the present rate) fall and rise of sea-levels from glacial to inter-glacial. The sea-level in the last glacial maximum, some 22,000 years ago was some 130 metres below the present sea-level. There was a slow rise in sea-level from then till about 15,000 years ago. There was then a rapid rise of approximately 40 metres in around a thousand years (i.e. a sea-level rise rate of some 40 mm yr^{-1}). Then, over the next seven thousand years or so the rise was some 75 metres (just over 10 mm yr^{-1}) before leveling off (rising only two metres or so i.e. around 0.3 mm yr^{-1}) for the past seven thousand years. There is paeleontological evidence that the sea-level (in the Sunda Shelf at least) rose to some five metres above the present level some five thousand years ago before falling back to the present level (Kamaludin, 1993; Kamaludin & Azmi, 1997). So, we at least know (e.g. Ong, 2001) that mangroves can handle a sea-level rise of at least a bit more than an order of magnitude of the present rate (3 mm yr^{-1}) of sea-level rise.

We like to once again stress that with the present rate of eustatic sea-level rise, local conditions (tectonic movement, sedimentation/erosion, auto-compaction and lowering of water table) are perhaps more important in determining if sea-level rise or fall is occurring. Global generalization does not make sense in this case. Governments have to determine for themselves what the risks are for their different sites in their countries and lay down their own mitigation strategies, if any.

However, should sea-level rise occur, mangroves will be able to move inland. The exceptions are when human pressures (built infrastructure and activities) get into the way (this is sometimes referred to as the coastal squeeze) or on low islands and atolls where there are no higher grounds.

4.2 Human pressures

Coastal squeeze

By and large, mangroves have been able to move inland with the rise in sea-level and seaward with the fall of sea-level over the millions of years that they have existed. However with the advent of *Homo sapiens* the scenario is now different. Humans favor coastal land for settlement and various activities. Mangroves have often been converted for various uses (from aquaculture to rice and oil palm cultivation to development to real estates). Bunds and levees are often built to prevent salt-water intrusion. Sometimes even the front (seaward sides) of mangroves is given hard engineering "protection" because of perceived erosion.

Should there be sea-level rise, the mangroves will have no place to migrate (Ong, 1995; Tan, 2005) and will be reduced (also known as "coastal squeeze"). Breaking down bunds will allow mangroves their natural migration but the question is whether governments will protect mangroves or property like land (often mangroves) previously converted to agriculture and aquaculture.

Government policies

In many countries (e.g. like those that were previously subjected to British laws) there are bye-laws and regulations that afforded protection to coastal areas. For example, a certain distance (e.g. 3 chains or 60 metres) from the highest tide mark or the mean tide mark, was designated as "Crown Property". Whilst some governments have rescinded such laws, others have more wisely retained them. One question is how effective such a law is. As we know, with ever changing sea-levels, the reference "highest tide mark" or "mean tide mark" is a moving target. If there is sea-level fall, coastal protection based on this law is not a problem but if there is sea-level rise, then Crown Property may intrude into private property and present a problem (Titus, 1998). One way to overcome this is to have a larger buffer zone (the size of the buffer zone being related to the rate of sea-level rise at the particular sites). Another way is to explore the adoption of some flexible coastal management policy such as the rolling easement policy which is implemented by several coastal states in United States.

Another problem is where there are already critical installations (e.g. ports, airports or valuable built-property). It is very unlikely that governments will sacrifice these for mangroves of other natural coastal ecosystems. They are almost certain to protect these by resorting to hard engineering solutions. Perhaps this can be balanced or mitigated with the "sacrifice" of less valuable and less critical agriculture and aquaculture land for the migration of natural coastal ecosystems and not allow the coastal squeeze to occur. Ultimately the solution may be an economic one of whether the government is rich enough to afford sacrificing agriculture and aquaculture land.

5. Discussion

The issue of global warming is not an easily fathomable one, with lots of opinions expressed as well as numerous scenarios presented. As was said earlier, change is a certainty but the magnitude and direction of the change is often very uncertain. Reliable long-term time series measurements are few and far between and yet these are what are needed for predictions with a high degree of confidence. For instance giving a prediction of sea-level rise that covers a range of two orders of magnitude, does not serve much practical purpose, except perhaps to be alarmist. It also does not help, not to mention up front, that sea-level change is site specific and that there are other factors than eustatic sea-level change.

In summary, we conclude that:

a. The increase in atmospheric carbon dioxide over the last century of so is real and very alarming. The evidence we adduced also pointed to an anthropogenic generated origin of the carbon dioxide.

b. Ice core data are impressive in their long time series record (going back some half a million years). The phases of the different parameters (e.g. atmospheric carbon dioxide concentration and temperature) are extremely uncertain and it is not possible to determine if temperature rise followed carbon dioxide rise or vice versa.

c. Tide gauge data go back just over a century but not all are on tectonically stable plates so measure relative sea-level change rather than eustatic change. Satellite altimetry provides a better measure of eustatic sea-level change but the data set is short.

d. For millions of years, over many glacial cycles, mangroves have been able to adapt and survive very drastic sea-level changes. The difference now is there will now be anthropogenic interference that would lead to "coastal squeeze" in many sites.

e. Even if the rate of eustatic sea-level rise increase over the next fifty to a hundred years the loss of mangroves from sea-level rise will be much less than from the loss of mangroves through human interference.

f. Some of the mitigating actions now being taken (e.g. the use of food for fuel in carbon trading) are not well thought through and may not only exacerbate the problem of an already malnourished human population but also reduce mangrove areas and species (as a result of peat swamp and mangrove land being used for oil palm plantations to produce biodiesel).

Consequently, for the present, we should concentrate our efforts on the prevention of any further loss of our already depleted & rare mangroves (Dodd & Ong, 2008) rather than follow the sea-level rise bandwagon which could well turn out to be a red herring.

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Impacts of recent natural hazards on mangrove ecosystems in the Bay of Bengal

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Abstract

The mangroves located around the Bay of Bengal and along the coast of South China Sea are of special interest for many reasons. Three major rivers (Ganges, Irrawaddy and Mekong) drain the area which has the world's largest single block of mangroves (the Sunderbans). The climatic conditions varying from sub-arid (Southeast India), to moist (coastal Myanmar), and the extreme diversity of human impacts in one of the world's highest population densities (West Bengal in India and Bangladesh), have created a mosaic of mangrove types that are floristically rich, with different histories, different ecological frameworks and distinct evolutionary trends. During the last 40 years, the scientific community has reiterated that mangrove ecosystems constitute an irreplaceable bioshield for coastal protection. In the course of the last four years (tsunami on 24 December 2004 and Nargis cyclone on 2 May 2008), at least 400,000 people have perished in the Bay of Bengal. In every country of this part of the world, the vulnerability of coastal dwellers to coastal hazards is increasing. Recent statistics are showing an almost linear correlation between mangroves depletion and loss of human lives. The approximate extent of mangroves in the Bay of Bengal was known since the publication of the World Mangrove Atlas. Using metric spatial resolution tools and traditional space borne sensors, the magnitude of ongoing deforestation in each country is discussed. The current location and status of mangrove forests in the affected area are described.

Bangkok Workshop: Conclusions and recommendations

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The Baugkok Workshop had two main themes, "Rehabilitation of mangroves and other coastal ecosystems" and "Impacts of global warming on mangrove ecosystems and their mitigation options".

At present, there is a tendency for engineers, foresters, fisheries personnel, oceanographers and socio-economists to work independently in the rehabilitation of coastal habitats, and in the design and implementation of interventions for mitigating the impact of natural hazards in coastal areas.

- There is an urgent need for greater cooperation between these groups with different skills and experience, to ensure a more multidisciplinary and integrated approach to rehabilitation and mitigation interventions
- It is also critical that local communities be involved in such activities

These two recommendations would aid greatly in avoiding failures and in ensuring that rehabilitation and hazard mitigation activities are environmentally, economically and socially compatible with national, regional and local aspirations, and needs.

Mangrove forests usually regenerate naturally if the site conditions are suitable and there is an adequate supply of seeds or other propagation materials. It may be desirable or necessary to carry out manual replanting in some areas where natural regeneration does not occur. Prior to undertaking manual replanting, it is important to identify and understand the reasons for the lack of natural regeneration because this will dictate whether or not it is possible to replant successfully, and whether or not site remediation is necessary before replanting.

Successful rehabilitation is critically dependent on the suitability of the site for rehabilitation and the selection of suitable species for the site conditions. Many failures in rehabilitation or restoration can be attributed to failure to evaluate the suitability of the site (mainly in terms of soil condition and hydrology) for rehabilitation and/or a mismatch between the species planted and site conditions. In particular, careful attention needs to be given to the slope of the site to ensure that there is sufficient drainage to avoid permanent water-logging. Extensive mudflats extending far seawards with little or no gradient are usually high risk sites for the successful planting of some mangrove species, notably *Rhizophora* species.

All rehabilitation projects should be monitored for at least a number of years to evaluate their success, and the reasons for failures need to be identified in order to ensure that others avoid similar mistakes. Since the results of rehabilitation projects are seldom published in scientific journals, some mechanism needs to be established to ensure that the experience gained from all rehabilitation projects is widely available to all those who are engaged in these types of activities.

Success is critical when working with local communities. They should be involved in monitoring to instill confidence in rehabilitation activities; unexplained failures lead to doubt and a lack of support for mangrove protection and management at a community level.

Mangrove ecosystems are naturally dynamic and exhibit changes in floristic composition and structure over time. Significantly more research is needed to identify and, if possible, quantify the underlying causes for changes in floristic composition and structure, particularly in areas where such changes are taking place rapidly.

It is important to recognize that the direct impact of tsunamis, storm surges and coastal erosion operate on different time scales. The direct impact of a tsunami usually lasts for a period of hours, storm surges may last up a few days depending on wind and tidal conditions, while the duration of coastal erosion involves years or even decades. These time scales need to be considered in the choice and implementation of mitigation options.

Coastal erosion tends to be a persistent problem, but the pattern of erosion along different sections of coastline may change over time, either naturally or through human interventions. It is important to understand the underlying causes of these changes, in order to implement the most cost-effective mitigation option.

Coastal forests of mangroves and other vegetation can help reduce the impact of tsunamis, storm surges and coastal erosion, but they may not prevent loss of life or property, and they cannot prevent flooding. The benefits of coastal forests in mitigating tsunamis and storm surges will depend on:

- Height of the waves
- Height, density and diameter of the trees
- Width of the tree belt

Mangroves are opportunistic colonizers of suitable sites and display a high degree of plasticity in response to environmental change. They have survived past changes in sea level over geological time frames and are likely to be able to adapt to the expected future rates of change in sea level, provided that man-made structures such as bunds, roads or other barriers do not restrict their landward progression.

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