MANUAL ON GUIDELINES FOR REHABILITATION OF COASTAL FORESTS DAMAGED BY NATURAL HAZARDS IN THE ASIA-PACIFIC REGION

H.T. Chan & S. Baba

International Society for Mangrove Ecosystems
and
International Tropical Timber Organization

MANUAL ON GUIDELINES FOR REHABILITATION OF COASTAL FORESTS DAMAGED BY NATURAL HAZARDS IN THE ASIA-PACIFIC REGION

H.T. Chan & S. Baba

International Society for Mangrove Ecosystems (ISME),
c/o Faculty of Agriculture, University of the Ryukyus,
1 Senbaru, Nishihara, Okinawa, 903-0129 Japan

International Society for Mangrove Ecosystems
and
International Tropical Timber Organization

© International Society for Mangrove Ecosystems (ISME) and International Tropical Timber Organization (ITTO), 2009

All rights reserved. No part of this publication may be reproduced or stored in any form that can be retrieved or transmitted in any form or by any means, electronic or mechanical, including photocopy, recording or any other means, without written permission from the publishers.

Citation:

Chan, H.T. & Baba, S., 2009. *Manual on Guidelines for Rehabilitation of Coastal Forests damaged by Natural Hazards in the Asia-Pacific Region.* International Society for Mangrove Ecosystems (ISME) and International Tropical Timber Organization (ITTO), 66 pp.

Published by:

International Society for Mangrove Ecosystems (ISME) and International Tropical Timber Organization (ITTO)

Printed by:

City Reprographic Services, No. 2, Jalan Vivekananda, Brickfields, 50470 Kuala Lumpur, Malaysia (cityrepro@yahoo.co.uk)

ISBN: 978-4-906584-13-0

Copies are available from the International Society for Mangrove Ecosystems (ISME), c/o Faculty of Agriculture, University of the Ryukyus, 1 Senbaru, Nishihara, Okinawa, 903-0129 Japan (isme@mangrove.or.jp)

Cover photographs:

General view of the Andaman mangroves in India by K. Tsuruda

Young plantation of *Rhizophora mucronata* in Malaysia by K.H. Tan

Women planting *Terminalia cattapa* in the Maldives by S. Yamagami

Fringing belt of planted *Rhizophora stylosa* in Kiribati by T. Suzuki

CONTENTS

PREFACE

The ISME/ITTO Pre-Project on *Restoration 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)] was implemented by the International Society for Mangrove Ecosystems (ISME) from January 2008 to March 2009.

The *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* was the first output of the Pre-Project. Edited by Chan, H.T. & Ong, J.E., and published in November 2008 as *ISME Mangrove Ecosystems Proceedings No. 5*, the document was a compendium of a meeting and workshop. The meeting, organised by ISME and ITTO in collaboration with University of the Ryukyus was held in Okinawa, Japan from 15-16 June 2007. It coincided with the 21st Pacific Science Congress held from 12-16 June 2007. The workshop was held in Bangkok, Thailand on 23 August 2008 in conjunction with the Seventh General Assembly of ISME. It was organised by ISME and ITTO in collaboration with Thailand Environment Institute (TEI) and Department of Marine and Coastal Resources (DMCR) of Thailand.

Another output of the Pre-Project was the *Proposal on Rehabilitation and Sustainable Management of Mangrove Forests subjected to Commercial Harvesting for Woodchips in Sabah, Malaysia*. Prepared by ISME for submission to ITTO by the Government of Japan, the main objectives of the proposal are to assess the state of the mangrove forests in Sabah previously harvested for woodchips and to prepare a five-year Mangrove Rehabilitation Management (MRM) Plan for rehabilitation of these degraded mangroves. Outputs of the project will include: 1) An assessment report on the degree of degradation and recovery of the forests; 2) Establishment of six one-hectare pilot plots for demonstrating best practice rehabilitation techniques; and 3) A five-year MRM Plan for the affected forest areas. The project will also provide hands-on training to the staff of the Sabah Forestry Department involved. A graduate from Japan and another from Sabah, both engaged under the project, will be given the opportunity to pursue their M.Sc. using data and information from this project.

The present *Manual on Guidelines for Rehabilitation of Coastal Forests damaged by Natural Hazards in the Asia-Pacific Region* is the final output of the Pre-Project. The manual includes introductory chapters on coastal forests (mangrove forests, beach and dune forests, and forests of coral islands), natural hazards (tsunamis, tropical cyclones, coastal erosion and sea-level rise), and the protective roles of coastal forests. The main chapter provides an overview (concepts and rationale of rehabilitation, and rehabilitation efforts), and guidelines for rehabilitation of mangroves and other coastal forests. The guidelines include the rationale for rehabilitation; choice of species; site selection and preparation; propagation and planting; monitoring and tending; and case studies. The case studies provide useful lessons of success and failure of past and on-going projects in coastal forest rehabilitation.

Chapter 1

TYPES OF COASTAL FORESTS

1.1 Mangrove forests

Mangroves are tidal forests of tropical and sub-tropical shores. They thrive in sheltered coastal areas with relatively calm waters such as estuaries, accreting shores, bays and lagoons (e.g. Spalding, 2004; Duke, 2006; Cochard, 2008). They are also found in areas protected by sand bars, islands, coral reefs and/or sea grass beds. Under sheltered conditions, they contribute to land accretion by colonising and stabilising mud banks with their extensive rooting systems. Trees of *Sonneratia* and *Avicennia* are the main pioneer species. On firmer and more compact sediments along the banks of creeks, bays and lagoons, trees of *Rhizophora* with stilt roots (Fig. 1) and *Bruguiera* with knee roots are the dominant species. Fringing large rivers, mangroves may occur upstream for tens of kilometres, depending on tidal range, freshwater discharge and topography (Giesen *et al*., 2007). Upstream mangroves include *Barringtonia asiatica*, *Sonneratia caseolaris* and *Nypa fruticans*.

Globally, mangroves occur in 114 countries and territories (Spalding *et al*., 1997; Spalding, 2004). The total global area has been estimated at 181,000 km^2 (Table 1). The centre for mangrove biodiversity is in Southeast Asia with up to 45 species of flora. In the Pacific Islands, many of which are atolls, 31 species of mangroves and five hybrids have been reported (Ellison, 2008). Common species found on these islands are *Heritiera littoralis*, *Sonneratia alba*, *Lumnitzera littorea*, *Rhizophora stylosa*, *Bruguiera gymnorhiza*, *Excoecaria agallocha* and *Xylocarpus granatum*.

Table 1. Estimation of global mangrove areas (Spalding *et al*., 1997)

Region	Area (km^2)	Percent
South and Southeast Asia	75,173	41.5
Australasia	18,789	10.4
Americas	49,096	27.1
West Africa	27,995	15.5
East Africa and Middle East	10,024	5.5
Total	181,077	100

Mangrove vegetation typically displays zonation patterns dominated by one or two species (e.g. Giesen *et al*., 2007; Twilley, 2008). Succession in mangroves is often equated with zonation which has been attributed to a number of factors. Biological factors include salinity tolerance, seedling dispersal patterns and inter-specific competition. Physical factors include soil types, wave actions, salinity, freshwater inflow and tidal influence.

Mangroves have developed specialised adaptive features to live in the tidal environment which is characterised by saline, water-logged and anaerobic soils. All mangroves are able to exclude salt from sea water (Spalding, 2004). Most species have an ultra-filtration process at the root endodermis that is highly efficient in excluding salt. Examples are species of *Bruguiera*, *Lumnitzera*, *Rhizophora* and *Sonneratia*. Species of *Aegialitis*, *Aegiceras* and *Avicennia*, which are less efficient in salt exclusion, actively secrete salt from their leaves through salt glands. Another morphological feature for which mangroves are best known is the development of aerial roots. Prop or stilt roots are characteristic of *Rhizophora*, knee roots of *Bruguiera*, pneumatophores of *Avicennia* and *Sonneratia*, and plank-like buttress roots of *Xylocarpus* and *Heritiera*.

Mangrove forests have been categorised into various classes based on the frequency of inundation by tides (Watson, 1928). The classes include those inundated by all high, medium and normal high tides, and those inundated only by spring and equinoctial tides (Table 2). Common tree species found in these inundation classes are listed in Table 3.

Table 2. Inundation classes of mangroves (Watson, 1928)

Class	Flooded by	Height above chart datum (m)	Flooding frequency (times/month)
1	All high tides	0 < 2.4	56 – 62
2	Medium high tides	2.4 < 3.4	45 – 59
3	Normal high tides	3.4 < 4.0	20 – 45
4	Spring high tides	4.0 < 4.6	2 – 20
5	Equinoctial tides	4.6 +	< 2

Table 3. Common species found in the various inundation classes of mangroves

Inundation class	Common tree species
1. Deeply inundated by all high tides (seaward shores)	*Avicennia alba*, *Avicennia marina* and *Sonneratia alba*
2. Inundated by all high tides (banks of tidal creeks)	*Rhizophora mucronata*
3. Inundated by normal high tides (central mangroves)	*Bruguiera gymnorhiza*, *Bruguiera cylindrica*, *Bruguiera parviflora*, *Bruguiera sexangula* and *Rhizophora apiculata*
4. Inundated only by occasional spring tides (back mangroves)	*Excoecaria agallocha*, *Ficus microcarpa*, *Instia bijuga*, *Lumnitzera littorea*, *Lumnitzera racemosa*, *Xylocarpus granatum* and *Xylocarpus moluccensis*
5. Inundated only by very rare equinoctial tides (riverine mangroves)	*Cerbera manghas*, *Cerbera odollam*, *Nypa fruticans*, *Oncosperma tigillarium* and *Sonneratia caseolaris*

Mangrove species can be categorised into true mangroves and mangrove associates (Selvam, 2007). Plants that occur in the coastal environment and also found within mangroves are considered as mangrove associates. True mangroves are species which are adapted to the mangrove environment and do not extend into other coastal plant communities. True mangroves consist of a core group of some 30-40 species (Spalding, 2004). They are the most important, both numerically and structurally, and are found in almost all mangrove communities.

Mangroves occur in ecological conditions that approach its limit of tolerance with regard to soil salinity and inundation regime (Blasco *et al*., 1996). If the durations of daily inundation were to be modified, mangrove species either re-adjust to the new conditions through recovery or succumb to the unsuitable conditions through mortality.

The socio-economic values of mangroves have been well documented (e.g. Clough, 1993; Spalding, 2004; Walters *et al*., 2008). Most of the people living in or adjacent to mangrove areas derive their livelihood from forestry and fisheries. *Rhizophora* trees are harvested for pole, firewood and charcoal production. Mangrove wood is also used for construction of houses and fish traps. Fronds of *Nypa fruticans* are particularly valued in Southeast Asia for use as thatch for roofing. Sap from its inflorescence is tapped for producing sugar or alcoholic beverages.

The linkage of mangroves and associated fisheries is well recognised (e.g. Robertson & Duke, 1990; Walters *et al.*, 2008). Fisheries include species that spend their entire life-cycle in mangrove systems, species that are associated with mangroves during at least one stage in their life-cycle, and species that are sporadic users of mangroves. The fry of penaeid shrimps enter the mangrove environment, where they feed and grow into juveniles and sub-adults before migrating back to the sea to complete their life cycle. Fish species, which have a close association with mangroves, include the grouper, snapper, sea-perch, mullet, catfish and milkfish. Mangroves also support many mollusc species that constitute an important *in situ* fishery. Edible species of oysters, mussels, cockles and gastropods are collected for the local market. The cockle *Anadara granosa* is commercially cultured in mangrove estuaries of Southeast Asia.

In recent years, mangrove ecosystems have become popular destinations for ecotourism and nature education. Visitors are fascinated by the range of species of flora and fauna that can be easily observed from boardwalks. Boat tours for photography, and for watching of birds, primates and fire-flies are now generating significant revenue for local communities.

Mangrove ecosystems have important ecological and environmental values (e.g. Clough, 1993; Kaly & Jones, 1998). They play a role in the out-welling of nutrients to adjacent near-shore areas, and can function as a cleansing system for sediments and nutrients in estuaries.

Mangroves also play an important role in stabilising coastal sediments and in protecting coastal areas from storm damage (Spalding, 2004; Braatz *et al.*, 2007). This role is frequently overlooked until major storm events hit coastlines where mangroves have been removed. The massive and devastating cyclones that regularly impact the coastline of the Bay of Bengal have drawn particular attention to these issues (Blasco, 2008). Some countries e.g. Bangladesh have established mangrove plantations to stabilise sediments and to reduce the impact of storm surges (Saenger & Siddiqi, 1993).

1.2 Beach and dune forests

Beaches and dunes occur in tropical and temperate coastal areas worldwide. They are among the most dynamic landscapes, shifting with the winds, incoming waves and storm tides (e.g. Craft *et al.*, 2008; Cochard, 2008; Moreno-Casasola, 2008). Dunes are formed from sand delivered to the beach from the near-shore by waves. The exposed sand, dried by the sun, is then transported inland by wind to form dunes. Formation of dunes requires a source of sand, usually carried from the beach by onshore winds, and vegetation to trap and stabilise the sand.

Coastal dunes serve as reservoirs of sand to re-nourish the beach during storms as erosion transports the sand offshore where it is deposited on sand bars to be returned gradually by the tides (Craft *et al*., 2008). They act as a buffer to winds and waves, and they shelter communities in the hinterland (Moreno-Casasola, 2008). They are also important habitats for plants and animals including the nesting of sea turtles.

Dunes are stressful environments characterised by shifting sand that abrades vegetation, salt spray, and soils with extreme temperatures, low water holding capacity and poor nutrient content, especially nitrogen (e.g. Cochard, 2008; Craft *et al*., 2008; Moreno-Casasola, 2008).

Plant communities of coastal dunes (Fig. 2), also referred to as strand vegetation, consist of three zones (e.g. BPA, 2004; Craft *et al*., 2008). They are: 1) the pioneer zone with primary stabilising plants of mainly herbaceous species; 2) the shrub zone with secondary stabilising plants consisting of shrubs, herbs and grasses; and 3) the forest zone consisting of shrubs and trees. Common plant species found in the various zones of coastal beaches and dunes are shown in Table 4.

Strand vegetation plays an important part in the formation and stabilisation of coastal dunes (BPA, 2004). Pioneer plants trap and hold wind-blown sand in the fore-dune and help create conditions which encourage the establishment and growth of other plant communities such as scrub and heath forests. All plants have a role in the development of vegetative cover and together they bring about dune stabilisation. Sand trapped in the fore-dune by strand vegetation serves as a reservoir of sand for the beach during periods of erosion. In the absence of dune vegetation, sand from the beach moves inland, resulting in coastline recession.

Table 4. Common plant species found in the various zones of coastal beaches and dunes

Zone	Common plant species
Pioneer	*Ischaemum muticum*, *Canavalia rosea*, *Wedelia biflora*, *Ipomoea pes-caprae* and *Sesuvium portulacastrum*
Shrub	*Spinifex littoreus*, *Vitex trifolia*, *Wedelia biflora*, *Pandanus odoratissimus*, *Pandanus tectorius*, *Scaevola taccada*, *Pemphis acidula*, *Hibiscus tiliaceus* and *Thespesia populnea*
Forest	*Calophyllum inophyllum*, *Terminalia cattapa*, *Barringtonia asiatica*, *Melaleuca cajuputi* and *Casuarina equisetifolia*

Establishing vegetation cover will reduce wind speed and thereby stabilises the dunes by trapping sand (Cochard, 2008). Shading by foliage increases water retention of the sand substrate and improves its binding capacity. Specialised flora of creeping herbs (e.g. *Ipomoea pes-caprae* and *Canavalia rosea*) sedges and grasses (e.g. *Spinifex littoreus*) plays an important role in fore-dune stabilisation. The richness of plant species of strand vegetation can be used as an indicator of dune stability.

In Southeast Asia and the Pacific Islands, two formations of strand vegetation are commonly associated with sandy beaches and dunes (Wibisono & Suryadiputra, 2006; UNEP, 2007; Giesen *et al*., 2007; Hanley *et al*., 2008). They are:

Pes-caprae formation

This formation is dominated by the creeper *Ipomoea pes-caprae*, which is a common cover crop of dune strands. If the substrate is stable, the plant will grow rapidly and dominate the back part of the beach. Establishment of this creeper is usually followed by the growth of grasses such as *Spinifex littoreus, Cyperus maritime* and *Ischaemum muticum*, and herbs such as *Canavalia rosea*, *Desmodium umbellatum*, *Vigna marina*, *Crotalaria striata* and *Calopogonium mucunoides.*

Barringtonia formation

This formation occurs behind the *Pes-caprae* formation. Common tree species are *Barringtonia asiatica*, *Cerbera odollam*, *Terminalia cattapa, Artocarpus altilis*, *Morinda citrifolia*, *Erythrina variegata*, *Hibiscus tiliaceus*, *Hernandia peltata* and *Casuarina equisetifolia.* Shrub species include *Pluchea indica*, *Desmodium umbellatum*, *Sophora tomentosa*, *Pemphis acidula* and *Ximenia americana.*

People have always appreciated the beauty and recreational values of beaches and dunes (Moreno-Casasola, 2008). Many would crowd the beaches as they are perfect tourist destinations for sun, sea and sand (Wong, 2003). Of all the coastal systems, the dunes have suffered the greatest degree of human pressure. Many have been irreversibly altered by human activities such as tourist resorts, golf courses and urban growth. Development of the shore often leaves no room for dunes to migrate inland, as occurs when sea-level rises (Craft *et al*., 2008). The combination of changing environmental conditions and urban encroachment makes coastal dunes a globally endangered ecosystem.

1.3 Forests of coral islands

Atolls consist of a raised rim of carbonate sand and gravel, surrounded by submerged reefs on the ocean side, and enclosing a lagoon (e.g. Solomon & Forbes, 1999; Woodroffe, 2008). The rim may be continuous, but it usually consists of a series of coral islands separated by channels, which allow exchange of water between the lagoon and the ocean.

Coral islands are formed by a combination of current and wave activities. They are very low-lying with elevations of 3-5 m asl (Solomon & Forbes, 1999). The substrate is ill-consolidated coralline material of sand and gravel, piled up over a reef platform (Mueller-Dombois & Fosberg, 1998). Coral islands show variations in the soil substrate. The inner or lagoon beach is sandy with the interior having higher humus content. At the outer or ocean beach, the substrate consists of broken coral rocks, gravel and coarse sand. Among the Pacific Islands, Tuvalu, Kiribati, Tokelau and Marshall Islands are true atolls, while the Federated States of Micronesia and Cook Islands are volcanic islands with atolls (Ellison, 2008).

Unlike continental islands which have a full or partial complement of plant species of the continent before they became isolated, oceanic islands such as atolls are formed without plant life (Gillespie, 2007). As such, coral islands do not have much topographical features and they harbour relatively few plant species with little endemism.

The vegetation of coral islands is essentially the same as strand vegetation of beaches and dunes. In the Pacific, herbaceous cover of creeping plants of *Ipomoea pes-caprae*, *Canavalia rosea* and *Wedelia biflora* are found, including sedges and grasses at the high tide level (Mueller-Dombois & Fosberg, 1998). Further inland, shrubs of *Scaevola taccada*, *Pandanus tectorius*, *Pemphis acidula* and *Hibiscus tiliaceus* occur alongside trees of *Barringtonia asiatica*, *Terminala cattapa*, *Calophyllum inophyllum* and *Casuarina equisetifolia*. In the Maldives, tree species found include *Terminalia cattapa*, *Hibiscus tiliaceus*, *Thespesia populnea*, *Calophyllum inophyllum*, *Pemphis acidula, Barringtonia asiatica, Pongamia pinnata* and *Scaevola taccada* (Jagtap & Untawale, 1999).

Low-lying coral islands on the rim of atolls are perceived as fragile ecosystems that are particularly vulnerable to the impacts of sea-level rise. Anticipated effects of sea-level rise are shoreline erosion, tidal inundation and salt water intrusion (e.g. Mimura, 1999; Wong, 2003; Gillespie, 2007). Other coastal hazards include damage by winds, waves and flooding during tropical cyclones (Solomon & Forbes, 1999).

For many people, coral islands surrounding lagoons are the perfect conditions for an ideal tourist destination (Wong, 2003). Attractions are full privacy, all-year sunshine, warm water, white sandy beaches and coral reefs. Besides sun, sea and sand, one can also experience sunrise and sunset. The Maldives have developed the one-island one-resort concept for small islands (Naseer, 2007). When an island is developed as a resort, the whole reef ecosystem surrounding the island effectively comes under the jurisdiction of the resort's management. Besides tourism, fishing is another important industry of coral islands. Activities include offshore and near-shore reef fishing.

Fig. 1. Mangrove forest of *Rhizophora* species fringing the banks of a creek

Fig. 2. Typical sandy beach and dune strand vegetation in the tropics

Chapter 2

NATURAL HAZARDS AFFECTING COASTAL FORESTS

2.1 Tsunamis

Tsunamis are series of waves caused by a large displacement of the ocean bed due to an earthquake or volcanic eruption (King, 2008). The effects of tsunamis can be devastating due to the immense volume of water and energy involved. It has been recognised as one of the deadliest natural hazards (Osti *et al*., 2008).

In the deep ocean, tsunami waves can travel at speeds of more than 750 kph, with wave heights of less than a metre (Solomon & Forbes, 1999). However, when they approach shallow waters, they slow down and increase in height dramatically. This effect is more pronounced on gradual and shallow shores (Wells *et al*., 2006). Tsunamis can cause substantial damage to locations protected from wind-generated waves, as they can accelerate through channels and inlets, rapidly increasing in height. When reflected by obstacles, they can also travel in different directions.

The 2004 Indian Ocean tsunami caused severe economic and ecological damage to 13 countries in Asia including Africa (Kathiresan & Rajendran, 2005; Chandrasekar & Ramesh, 2007; Osti *et al*., 2008). The sea waves were generated by a massive earthquake in the ocean bed that measured 9.3 on the Richter scale. Located close to northwest coast of Sumatra, the epicentre of the earthquake (3.7ºN, 95ºE) generated waves that travelled in all directions with speeds up to 900 kph. The gigantic waves killed more than 200,000 people, made about two million people homeless and resulted in property loss of US$ 6 billion.

The following are descriptions of the disastrous effects of the 2004 tsunami on coastal areas of five countries bordering the Indian Ocean:

Indonesia

With the earthquake epicentre less than 40 km from the northwest coast of Sumatra, Indonesia was the worst affected (Srinivas & Nakagawa, 2008). Extending 1-2 km inland, some 600 km of the coast of Sumatra were damaged (Shofiyati *et al*., 2005). In areas with flat topography such as Banda Aceh, the width of the corridor reached 4 km inland. The city was one of the worst hit areas with 74% of 3,860 ha of settlement area destroyed. Besides the massive human toll of more than one million killed or displaced, the economic and environmental damage was extensive. Coral reefs, mangroves, coastal forests, agricultural crops and aquaculture ponds were adversely affected. The total area destroyed in Sumatra was estimated at 120,300 ha, of which 22% was settlement and 28% was agricultural land. In the Province of Aceh, the total area of mangroves damaged was estimated at 32,000 ha with 15 districts and towns affected (Wibisono & Suryadiputra, 2006).

Damage to coastal vegetation in Aceh occurred at two stages (Wibisono & Suryadiputra, 2006). The first stage was caused by the energy of the tsunami, which directly struck the coast, and destroyed mangroves and other coastal forests including cash crop plantations. This happened extremely fast and the coastal vegetation was damaged instantly with trees uprooted or branches of trees torn off by the brutal force of the waves (Fig. 3). The second stage was caused by the inundation of sea water brought by the tsunami. The saline soils gradually killed the coastal vegetation as can be seen by the withering of leaves, crown die-backs and standing dead trees (Fig. 4).

Thailand

Much of the impact on Thailand was along the Andaman coast, affecting the coastal provinces of Phuket, Phang Nga, Krabi, Ranong, Trang and Satun (Harakunarak & Aksornkoae, 2005). The tsunami killed at least 5,300 people, affected 490 fishing villages and left tens of thousands homeless. Damage to mangrove forests was considerably less than in other countries, with less that 1% affected (Srinivas & Nakagawa, 2008). Mangrove forests in Phang Nga significantly mitigated the impact of the tsunami. They suffered damage at the seaward fringe, but reduced the tsunami wave energy and provided protection to the mangrove forests further inland.

Paphavasit *et al.* (2007) reported that only 390 ha of mangrove forests in Thailand were impacted by the tsunami. Mangrove forests in Phang Nga were slightly damaged with only 90 ha in Ranong severely damaged. The area impaired was relatively small when compared with other coastal ecosystems such as coral reefs (690 ha) and sandy beaches (990 ha). The most severely affected beach forests were in Ranong and Phang Nga. Beach resorts at Khao Lak were badly damaged (Fig. 5).

Sri Lanka

The first wave reached the east coast of Sri Lanka about 1.5 hour after the earthquake, with a surge height of 5.5-6.5 m (Srinivas & Nakagawa, 2008). Over two-thirds of the 12 districts were affected. The impact was not uniform due to varying topography and bathymetry. The presence of houses and other buildings at the sea-front increased the overall damage and destruction to infrastructure and property.

The Maldives

Many of the coral islands of the Maldives were in the direct path of the tsunami about three hours after the earthquake (Srinivas & Nakagawa, 2008). The low human casualty was attributed to protection by the surrounding reefs. Most of the damage was on coastal infrastructure including villages (Fig. 6), harbours and resorts. There was some damage to coastal vegetation but beach erosion and sea water intrusion were extensive. The tsunami displaced more than 10,000 people with three islands totally evacuated (Naseer, 2007). Economic sectors adversely affected were tourism, fisheries and agriculture.

Peninsular Malaysia

Although located close to the epicentre of the tsunami, Peninsular Malaysia was shielded from the initial waves by Sumatra and was only impacted by reflected waves (Tan & Ong, 2008). Whilst there was some loss of lives and damage to property, all mangrove forests remained intact. The secondary waves only arrived after the direct waves hit the Andaman coast of Thailand farther north. As such, the waves were mild and resulted in minor damage in the north-western coast of the peninsula.

Following the 2004 Indian Ocean tsunami, two more tsunamis occurred. They affected Java in 2006 and Solomon Islands in 2007 (Fig. 7) with estimated death tolls of 800 and 50, respectively (Osti *et al.*, 2008). Several years prior to the Indian Ocean tsunami were the tsunamis of Pakistan in 1999 and Papua New Guinea in 1998.

2.2 Tropical cyclones

Tropical cyclones are formed between latitudes of 10º and 25º, and they differ from temperate cyclones by being seasonal and having smaller whirlwinds (Mueller-Dombois & Fosberg, 1998). They are called hurricanes when wind speeds exceed 64 knots. Hurricanes are called typhoons in countries such as Guam, Taiwan, Philippines and Japan.

Cyclones are intense atmospheric depressions in which the winds whirl around a small calm ‘eye’ (BPA, 1999). In coastal areas, cyclones bring the hazards of large waves and storm surges in addition to strong winds and torrential rain. The intense winds of cyclones are capable of generating very high seas. A temporary rise in the sea level is known as a storm surge. The major part of the surge is usually caused by strong onshore winds which exert a stress on the sea surface, causing the water to accumulate. As a cyclone moves into shallow coastal waters, the near-shore bed and coastline modify the surge, resulting in a substantial amplification of its height. The great loss of human lives due to cyclones has often been a result of high storm surges that led to drowning.

The large waves that accompany cyclones can cause severe damage to coastal areas (Coch, 1994; BPA, 1999). The extent of erosion depends on the storm surge at the time of greatest wave attack. High water levels allow large waves to reach the dunes and cause erosion as sand is moved offshore by the backwash of breaking waves. Cyclones can substantially erode beach and dune systems and can wreck infrastructure if they are located too close to the beach. Strong winds can damage dune vegetation and expose the sand to wind erosion. Where sand is permanently lost, the beach and frontal dunes become susceptible to erosion.

The following are descriptions of the impacts of cyclones on coastal areas of Australia, Bangladesh and Myanmar:

Cyclone Winifred hit the coast of Queensland, Australia, from 29 January to 1 February 1986 (BPA, 1986). With winds gusting up to 200 kph, the cyclone generated waves of 1.5 m and a storm surge of 1.8 m. No human death and significant loss of property were report except for beach erosion and the over-topping of frontal beach ridges in some areas.

Cyclone Larry lashed the Queensland coast 60 km south of Cairns in the morning of 20 March 2006 with wind up to 300 kph (Williams *et al*., 2007). Although there was damage to buildings, forests and cash crops, there was no loss of human lives. Commercial, recreational and naval vessels in the port of Cairns were protected from the destructive winds by docking in the sheltered creeks of the Trinity Inlet mangroves.

Cyclone Sidr hit Sundarban in Bangladesh on 15 November 2007 (Akhter *et al*., 2008). With heavy rain, winds of 220 kph and tidal surge of 3-4 m, the cyclone caused serious damage to forest vegetation, wildlife and infrastructure in the south-eastern part. Total forest area damaged was 133,000 ha or 22% of Sundarban. Forests of *Sonneratia apetala* were highly affected while those of *Heritiera fomes* and *Excoecaria agallocha* were moderately affected. Slightly affected areas were along river banks and in the northern part of Sundarban which are dominated by *Excoecaria agallocha.*

Cyclone Nargis (Fig. 8) slammed Myanmar from 2-3 May 2008 with gushing winds of 190-230 kph and waves up to 3.5 m, causing severe damage to the Ayeyarwady delta (Than, 2008). The official death toll was 77,700 with 55,900 reported missing. Due to the immense magnitude of the cyclone and associated tidal surges, most of the mangrove forests in the delta were destroyed, especially in the core areas. The extent of natural forests and plantations damaged in the Ayeyarwady and Yangon Divisions was 14,000 ha and 21,000 ha, respectively. Physical damage to mangrove forests included uprooting of trees, damage to crowns and branches, and crown defoliation. Damaged forests in some areas of the core zone have yet to recover as the cyclone adversely affected the flora and fauna. The broken forest canopy encouraged colonisation of invasive light-demanding plant species such as *Acanthus ilicifolius*, *Phoenix paludosa* and *Acrostichum aureum.* New nesting mounds of the crocodile (*Crocodylus porosus*) were found in the mangrove plantations where it has never come to nest, as their natural nesting sites have been destroyed.

2.3 Coastal erosion

Mangrove forests are stable, accreting or eroding (e.g. Chan *et al*., 1993; Giesen *et al*., 2007). An accreting mangrove shore typically has a low crop of pioneer species of *Avicennia* moving seawards as the plants colonise the newly formed mud flats. A stable shore is one that is neither accreting nor eroding. An eroding shore is characterised by the general lowering of the near-shore profile, formation of retreating scarps due to scouring of mangrove substrate (Fig. 9), collapsing of mangrove trees (Fig. 10) and deposition of sand cheniers (Fig. 11). Comprising mostly shell fragments, these cheniers are mobile and highly abrasive, and can cause trees to die. The lowering of the shore profile leads to the generation of strong wave actions which accelerate the erosion process.

Globally, retreating coastlines have been reported to exceed advancing coastlines (Bird, 1985). About 20% of the world's coastlines are sandy; of these, more than 70% experienced net erosion over the past few decades, less than 10% showed accretion, and the remaining 20% was stable. There is increasing evidence that coastal erosion is an escalating environmental threat of global concern. Factors influencing coastal erosion are natural or human induced. Climate change and sea-level rise are seen as major factors causing coastal erosion.

It is anticipated that the problem of coastal erosion would be most severe for low-lying and small coral islands. The causes of beach erosion are increased wave energy, interruption to littoral transport, deprivation of sediment input, human activities and sea-level rise (Bird, 1996). Human activities which contribute to shoreline erosion include mining of beach sand, poorly designed seawalls and revetments, and destruction of coastal vegetation.

Measures of shore protection to combat coastal erosion are well known (Ghazali, 2006). They include hard engineering structures such as seawalls, groins and breakwaters. Of the soft engineering measures, beach nourishment is most widely practised. The construction process involves dredging, transport and placement of sand onto the eroding beach. It is considered semi-permanent and requires periodic replenishment of sand.

The following are descriptions of the extent and severity of coastal erosion in several countries of South and Southeast Asia:

Thailand

Coastal erosion in Thailand has intensified during the past decade (Thampanya *et al.*, 2006). The coastline of the Gulf of Thailand in the east was more dynamic than the Andaman coastline in the west. Erosion rates were 3.6 and 2.9 m per year versus accretion rates of 2.6 and 1.5 m per year, respectively. It was observed that areas with mangroves had less erosion while accretion occurred at sheltered river mouths and in bays. Erosion was severe in areas with extensive shrimp farms (Fig. 12). Erosion of the Bang Khun Thien mangroves in the Gulf of Thailand has been attributed to the construction of coastal dikes and dams, and to local subsidence due to ground water withdrawal (Winterwerp *et al.*, 2005).

Sri Lanka

Sri Lanka's coastline is retreating with the problem most severe in the west and southwest (Samaranayake, 2007). The degree of erosion varied between locations with maximum rates of up to 12 m per year. The average rate was 0.5 m per year. In some areas, the rate of retreat has increased due to human activities.

Peninsular Malaysia

In Peninsular Malaysia, the problem of coastal erosion was realised since the 1980s. A national coastal erosion study was conducted to assess the severity of coastal erosion, to map the locations of eroding shores and to recommend remedial measures (EPU, 1986). Erosion was categorised as critical, significant or acceptable (Table 5).

Table 5. Classification of coastal erosion in Peninsular Malaysia (EPU, 1986)

Category of erosion	Description of category
Critical	Eroding shoreline is in a state where shore-based facilities and infrastructure are in immediate danger of collapse or damage
Significant	Shoreline is eroding at a rate whereby public property and agriculture land of value will become threatened within 5-10 years unless remedial action is taken
Acceptable	Shoreline is experiencing erosion but with no or minor consequent economic loss if left unchecked

Critically eroding areas were reported to be 131 km or 41% of the total coastline in 1986 (EPU, 1986). A follow-up study conducted in 2006 by the Drainage and

Irrigation Department showed that the problem got worse with 256 km or 78% of the total coastline experiencing critical erosion.

Once erosion threatens urban and agricultural property, hard engineering structures such as rock and concrete revetments are constructed (Fig. 13). Typically constructed from quarry rocks or concrete units, these seawalls are constructed parallel to the shoreline forming a barrier between the coast and the sea (Ghazali, 2006). Although they prevent further loss of landward material, reflected waves cause scouring at the toe of the seawall. This eventually lowers the shore profile and generates stronger wave actions. In recent years, sand-filled geotubes have been constructed in some near-shore areas to protect against coastal erosion (Fig. 14). These breakwaters create a calmer wave environment at the leeward side for gradual build-up of substrate which is conducive for natural regeneration of mangroves.

Erosion affecting mangrove areas in Peninsular Malaysia is often associated with the construction of coastal bunds to prevent seawater ingression and to divert freshwater for agriculture (Chan *et al*., 1993). Of the west coast states, coastal erosion is the most severe in Selangor as much of the coastline has been bunded for agriculture and industrial development.

2.4 Sea-level rise

Climate change refers to the increase in global mean temperature leading to sea-level rise (Wong, 2003). The effects of sea-level rise include accelerated coastal erosion and more extensive flooding of low-lying coastal areas. The severity of coastal storms is expected to increase in some tropical areas. Small and low-lying atoll nations in the Pacific and Indian Oceans will be most vulnerable to sea-level rise (Woodroffe, 2008). Already these islands are already experiencing inundation during the highest tides and flooding during storms events. With sea-level rise, inundation will be exacerbated as sea-level rise of atolls is comparable to the global average rate of 1.4 mm/yr (Church *et al*., 2006).

Ong and Tan (2008) asserted that mangroves have survived sea-level changes through geological time. The difference now is that man-made barriers along the coast will prevent mangroves from migrating inland, so a significant reduction in the area of mangroves may be expected. Even so, the expected loss of mangroves to sea-level rise in the next 50 years is not expected to be anywhere close to the loss of mangroves due to alienation in the past 50 years.

In response to sea-level rise, the Inter-governmental Panel on Climate Change (IPCC) proposed three adaptation strategies (IPCC, 1990). They are: 1) retreat and resettle inland; 2) continue occupancy but with some adjustments; and 3) protect using both hard structures and soft measures.

Fig. 3. Mangrove trees at Aceh torn off or uprooted by the 2004 tsunami (L)
Fig. 4. Standing dead mangrove trees at Aceh after the 2004 tsunami (R)

Fig. 5. Beach chalets in Thailand damaged by the 2004 tsunami (L)
Fig. 6. Village in the Maldives damaged by the 2004 tsunami (R)

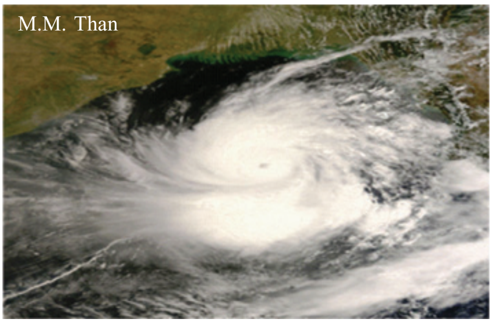

Fig. 7. House in Solomon Islands damaged by the 2007 tsunami (L)
Fig. 8. Cyclone Nargis that hit Myanmar in May 2008 (R)

Fig. 9. Retreating scarps formed due to scouring of mangrove substrate (L)
Fig. 10. Collapsing of mangrove trees and deposition of sand cheniers (R)

Fig. 11. Cheniers of abrasive shell fragments along eroding shores (L)
Fig. 12. Severe coastal erosion threatening shrimp farms in Thailand (R)

Fig. 13. Rock revetments constructed to safeguard against coastal erosion (L)
Fig. 14. Sand-filled geotubes constructed to protect eroding shores (R)

Chapter 3

PROTECTIVE ROLES OF COASTAL FORESTS

3.1 Overview

A technical workshop on *Coastal protection in the aftermath of the Indian Ocean tsunami: What role for forests and trees?* was convened by FAO in Khao Lak, Thailand from 28-31 August 2006. The objective of the workshop was to improve understanding of the role of coastal trees and forests in protecting populations and assets from natural hazards, including not only tsunamis but also cyclones, erosion, and wind and salt spray. The workshop brought together the best available knowledge and experience to give a clearer picture of the roles that forests and trees play in protection against natural hazards. Conclusions of the FAO workshop (Braatz *et al.*, 2007), which are considered the most authoritative statements on the protective functions of coastal vegetation, were:

- Coastal forests and trees can, under certain conditions, act as bio-shields to protect lives and valuable assets against coastal hazards, including: tsunamis, cyclones, wind and salt spray, and coastal erosion.
- The degree of protection offered by coastal bio-shields depends on a number of variables, including characteristics of the hazard itself (e.g. type, force, frequency); features of the site (e.g. bathymetry, coastal geomorphology); and characteristics of the bio-shield (e.g. type of forest/tree, width, height and density of the forest).
- Care must be taken to avoid making generalisations about the protective role of forests and trees based on evidence from one or a few areas; the many factors that influence the protective role of forests/trees must be understood and taken into consideration before lessons can be learned and applied elsewhere.
- Coastal forests and trees are not able to provide effective protection against all hazards (e.g. extremely large tsunami waves, flooding from cyclones and certain types of coastal erosion); provisions for other forms of protection and (in extreme events) for evacuation must be relied upon. Care must be taken not to create a false sense of protection against coastal hazards.
- The importance of incorporating coastal protection as an integral part of coastal area planning and management is recognised.
- Options for protection include soft and hard solutions, and a hybrid of the two. If none of these is appropriate and viable, it may be necessary to zone coastal land-use to prevent (further) settlement and construction of valuable assets in the vulnerable zone.

- It is important to match species with the site in order to avoid high mortality and low performance of the planted trees. Some forest types and tree species cannot survive or thrive in areas exposed to specific coastal hazards. They are not candidates for protective measures.
- Development of bio-shields is not possible in all situations owing to *inter alia* biological limitations, space constraints, incompatibility with priority land-uses and prohibitive costs.
- The level of knowledge and understanding of the functions of forests and trees in coastal protection is still insufficient. There is a lack of multi-disciplinary research in this field. Specific areas needing further attention include research in non-mangrove coastal forests, collection of data, and development of models on interaction between physical and ecological parameters.
- There is a need to recognise that many years are required to establish and grow bio-shields to a size and density that could offer protection against coastal hazards.
- Considerable research and field initiatives related to forests and coastal protection have been carried out over the past several years; they provide a useful foundation for further work to improve understanding of the protective role that forests can offer.

Based on the impacts of past tsunamis, Harada and Imamura (2005) reviewed the mitigation effects of coastal forests. According to them, the four main protective functions of coastal forests are: 1) Reduce damage by stopping drifts and boats carried by a tsunami; 2) Reduce the overall tsunami energy; 3) Form sand dunes that provide protection from tsunamis as well as high waves; and 4) Catch persons carried back by a tsunami to the sea. However, they cautioned that the protective functions of coastal forests would be destroyed if the tsunami waves exceed 4 m in height.

3.2 Mangrove forests

Mangroves are considered as natural barriers protecting the lives and property of coastal communities from storms, cyclones, flooding, and coastal erosion (Walters *et al.*, 2008). This remains a principal reason for planting mangroves along many low-lying coasts. Construction of engineering structures such groins and breakwaters to protect the coastline are expensive and may not be as effective.

Areas with mangroves sustained much less damage from the 2004 Indian Ocean tsunami than areas where mangroves have been removed and where coastal development has reached the seafront areas (e.g. Kathiresan & Rajendran, 2005; Danielsen *et al.*, 2005). Mangrove deforestation compounded the effects of the tsunami. These reports albeit anecdotal have been supported by evidence of satellite images taken before and after the tsunami. Results showed that areas with mangroves or tree cover were less susceptible to tsunami damage. Mangrove vegetation is considered more effective in mitigating the impacts of tsunamis than other coastal vegetation.

Although the 2004 tsunami had severe impacts on affected coasts, loss of human lives and the degree of damage to property and infrastructure were less in places with healthy mangrove or coastal forests, such as the Andaman and Nicobar Islands and parts of Tamil Nadu in India (Osti *et al*., 2008).

Despite some controversy over whether the presence of mangroves saved lives during the 2004 tsunami, Wolanski (2006) concluded that mangroves and other coastal forests do provide tangible coastal protection to the extent that the establishment of coastal green belts as buffers against storm and tsunami events is justified.

The protective role of planted mangroves in dissipating wave actions has been reported (e.g. Mazda *et al.*, 1997; Kogo & Kogo, 2004; Wolanski & Richmond, 2008). In the district of Thai Thuy, Vietnam, a seaward belt of *Kandelia candel* trees planted at close spacing was established. Six years after planting, a 1 m wave entering the forest was reduced to 0.05 m at the shoreline. Without the sheltering effect of the planted mangroves, the resultant waves would be 0.75 m.

Studies have shown that for mangroves and other coastal forests to effectively buffer against storm surges and tsunamis, they should be at least 100 m in width (Mazda *et al.*, 1997) or have 400 trees per 10 m of shoreline in density (Hiraishi, 2008). However, it has been envisaged that once the height of waves impacting a coast reaches 2 m or more, the forest will usually fail, and the trees themselves become part of the debris that causes damage further inland (Hanley, 2007).

Cochard (2008) supported the argument that mangroves and other coastal vegetation play a minor role in buffering against tsunami waves. Whether or not vegetation does provide protection depends on many factors, including stand size, density, species composition, structure and homogeneity. The most important predictor variables of the tsunami hazard are distance from the tsunami source and coastal topography, in particular near-shore bathymetry. In locations, far from the tsunami source, coastal vegetation probably provided some protection. In many other locations, however, the vegetation provided no protection. In some cases, they may even have aggravated the problem e.g. by contributing to flow debris and by channelling water flows. The establishment of tsunami greenbelts should not be treated as an alternative to early warning systems. Greenbelts may only be considered as economical and multi-functional means to provide relative hazard protection for material assets such as infrastructure and agriculture.

Since the 2004 tsunami, the general picture emerging is that mangroves are not the main factor influencing the extent of damage on the coastline (Wells *et al*., 2006). Near-shore bathymetry and coastline profile are probably the key factors determining the force of tsunami waves at any particular location. Shores adjacent to deep water tended to be less affected than those next to shallow and gradually sloping shelves. The shape of the coastline is another factor, with headlands providing protection while bays and inlets act as funnels, restricting and focusing the force of the waves. More research is required before it will be possible to predict where, and in what way, mangroves will help to reduce the impact of a tsunami.

The role of mangroves in protecting the shoreline from coastal erosion remains unclear. Blasco *et al.* (1996) pointed out that mangroves do not prevent coastal erosion but their elaborate root structures are likely to slow down the process considerably. Although mangroves can provide limited protection against erosive forces, Hanley *et al.* (2008) emphasised that mangroves typically colonise sheltered areas where fine sediments are deposited by coastal processes. Once established, they can enhance the process of sedimentation by increasing the rate of deposition. Mangroves do not, however, initiate sedimentation and are not able to colonise or persist at high energy shorelines. Natural hazards such as storms, cyclones, floods and tsunamis create severe erosion and in many cases mangroves can reduce the scale of these impacts. However, if episodes are frequent enough then the coastline will recede and eventually the mangroves will disappear.

3.3 Other coastal forests

It has been suggested that pure stands of *Casuarina equisetifolia* trees with little undergrowth provide limited resistance against the hazardous tsunami waves (Cochard *et al*., 2008). The dense, multi-layered strand formation of *Barringtonia asiatica*, *Pandanus tectorius* and *Scaevola taccada* probably provides better protection. In many locations, strand vegetation has been replaced by coconut groves which afford the least physical protection.

Compared to mangrove forests, strand vegetation may not provide adequate protection against tsunami (Kathiresan & Rajendran, 2005). Field observations following the 2004 tsunami showed that most of the beach and dune vegetation was affected with browning of canopies and trees shedding their leaves. However, they would hold good as wind-breakers during coastal storms.

Strand vegetation has been reported to provide protection of beaches and dunes against coastal erosion. For example, trees of *Scaevola taccada* serve as a protective barrier for the beaches of Kerala in India (Sundaresan, 1993). Natural vegetation belt of *Scaevola taccada* and *Pandanus odoratissimus,* with their masses of exposed roots and branches, have been effective in reducing wave energy and coastal erosion on Bintan Island in Indonesia (Wong, 2003).

Chapter 4

GUIDELINES FOR REHABILITATION OF COASTAL FORESTS

4.1 Overview

Concepts and rationale

Rehabilitation of coastal forests can be defined as the act of partially replacing their structural or functional characteristics that have been diminished or lost (Field, 1998a). This would mean re-establishing some of the ecological attributes. Restoration of coastal forests is the act of bringing them back, as nearly as possible, to their original condition. By implication, all the key ecological processes and functions including all the former biodiversity are re-established (Wells *et al*., 2006). The creation of plantations of a few coastal species does not equate to restoration. As restoring a coastal forest ecosystem to its original undisturbed condition is not realistic, rehabilitation is the preferred term to use.

The shortage of productive land in developing countries has resulted in coastal forests being converted for development. The rapid alienation of coastal forests has prompted a worldwide movement to plant new forest areas (Field, 1998a). Another impetus behind the rehabilitation of coastal forests is the spectacular rise of environmental consciousness in recent decades. The devastation of coastal areas by the Indian Ocean tsunami in December 2004 and cyclone Nargis in May 2008 has presented yet another rationale for establishing plantations of coastal forests for protection against natural hazards.

If the rationale of rehabilitation is to establish protective coastal belts to safeguard against natural hazards, there are no valid reasons for planting coastal species at fixed spacing along lines as traditionally done in plantation forestry. Other options such as cluster planting and phased planting can be tried out.

Cluster planting may be favoured in heterogeneous habitats (e.g. seaward tidal flats) where some sites are unsuitable for rehabilitation. Efforts should focus on establishing clusters of trees in favourable sites. Over time, these clusters would establish themselves and serve as mother populations to seed up the remaining sites through natural regeneration. The concept is essentially planting to assist in the natural recovery process.

Phased planting may work well in difficult habitats with harsh environmental conditions (e.g. coastal dune formations). Initial efforts will focus on planting pioneer herbaceous plant species to stabilise the site and to ameliorate site conditions. The planting of woody tree species will only commence after the site has stabilised and conditions improved.

Finally, if all initial trials failed in a given coastal area, the best option would be to do nothing and allow the shore to change naturally without intervention. As shore changes are usually cyclical, the site conditions may gradually improve to levels where rehabilitation becomes feasible.

A report by the Environmental Justice Foundation has rightly asserted that mangrove forests may recover without active rehabilitation efforts, once stresses to them have been removed (EJF, 2006). Rather than to launch straight into massive replanting programmes, at high cost and with a low probability of success, it may be far more sensible for governments of tsunami-affected countries to concentrate on the natural regrowth and recovery of remaining mangroves. Undoubtedly, this advice also applies to other coastal forests.

Rehabilitation efforts

The two main criteria for assessing the success of a coastal rehabilitation programme are the effectiveness and efficiency of the planting (Field, 1998b). The former can be considered as the closeness to which the new mangrove forest meets the original goals of the planting programme. The latter can be measured in terms of the amount of labour, resources and material that were used. In most cases, the effectiveness and efficiency of rehabilitation are not always quantified.

With every rehabilitation effort of coastal forests, there is always a high degree of uncertainty over the success of meeting its objectives (Yap, 2000). The level of difficulty varies with the different forest types and site conditions, and so does the associated expenditure in terms of manpower and financial resources. It is generally acknowledged that mangroves are easier to rehabilitate compared to other coastal forests.

Following the aftermath of the Indian Ocean tsunami, governments of countries in South and Southeast Asia have pledged their support for mangrove rehabilitation (Check, 2005). Malaysia has allocated $25 million to replant 4,000 ha of mangroves. Indonesia has pledged $22 million and has already planted 300,000 seedlings in Aceh. The Thai government has expressed its support for mangrove and coastal forest rehabilitation. The government of India has pledged $8 million to supplement an on-going programme to rehabilitate mangroves damaged by cyclones.

As many as 124 international NGOs participated in the reconstruction and rehabilitation of Aceh and Nias (Wibisono & Suryadiputra, 2006; UNEP, 2007). About 20 of them were involved in coastal rehabilitation programmes. They included

Oxfam International, Islamic Relief, Mercy Corps, GTZ, FAO and Wetlands International. More than 430 national NGOs participated but less than 20% were involved in coastal rehabilitation. In Aceh, over 10,000 ha of mangroves have been planted by the Board of Rehabilitation and Reconstruction of the Ministry of Forestry in areas affected by the tsunami (Triswanto, 2006).

Elsewhere in the region, post-tsunami projects were also implemented. An example is the mangrove rehabilitation project in Sri Lanka and Thailand (Qureshi, 2008). Funded by the Ministry of Environment of Spain, the project was implemented by IUCN from September 2005 to December 2007. In Phang Nga, more than 200 ha of mangroves damaged by the tsunami have been rehabilitated by the Department of Marine and Coastal Resources (DMCR) in collaboration with local residents (Paphavasit *et al.*, 2007). DMCR also planted 3,000 seedlings of *Cocos nucifera*, *Casuarina equisetifolia*, *Barringtonia asiatica* and *Pandanus odoratissimus*. In Peninsular Malaysia, although hardly affected by the tsunami, about 150 ha of mangroves and 18 ha of beach forests have been planted in the various states by the Forestry Department in 2005 (Mohd Ridza, 2006).

4.2 Mangrove forests

Rationale for rehabilitation

Mangroves have been planted for various purposes including: a) wood production to support commercial or small-scale forestry; b) shoreline and storm protection for coastal settlements; c) fisheries, aquaculture and wildlife enhancement; and d) ecological restoration (Field, 1996; Yap, 2000; Walters *et al.*, 2008).

Since the Indian Ocean tsunami and with more intensified coastal erosion, there is increased interest in planting mangroves for coastal protection (Check, 2005). In Thailand, concern over mangrove deforestation by shrimp farms has motivated many coastal households to participate in mangrove rehabilitation programmes (Barbier, 2006).

In the past, mangroves are considered easy to rehabilitate. Viviparity of their seedlings enables direct planting of propagules which are available in abundance, and planted seedlings often have good survival and growth rates. Reforestation programmes have been successful in many countries of the Asia-Pacific region (Field, 1996).

Recently, many post-tsunami mangrove rehabilitation projects have failed or achieved limited success as exemplified by those implemented in Aceh (e.g. Check, 2005; Wibisono & Suryadiputra, 2006; UNEP, 2007; Hanley *et al.*, 2008). Lessons learnt from these failed projects included planting too soon, wrong choice of species, planting in the wrong places, and the lack of monitoring and tending after planting.

Erftemeijer and Lewis III (1999) emphasised that during low tides, the intertidal mud flats serve as important feeding grounds for migratory shore birds and as habitats for local people to collect bivalves and crabs. Any attempts at mangrove restoration on mud flats would represent a form of habitat conversion.

Past attempts in planting mangroves on tidal flats to mitigate coastal erosion in Malaysia and Thailand have failed. In Selangor, Malaysia, Chan *et al.* (1988) reported that several planting trials of *Avicennia officinalis* on an exposed mud flats seaward of an eroding shoreline were not successful. Among the factors adversely affecting survival and growth of mangrove plants are strong wave actions, high soil salinity, barnacle infestation, prolonged inundation and lack of tidal flow. At Ban Don Bay in southern Thailand, mangroves were planted on newly-formed mud flats (Angsupanich & Havanond, 1996). Seedlings of *Avicennia alba* and *Sonneratia caseolaris* died within eight months while those of *Rhizophora mucronata* died within a year. Seedling mortality was attributed to severe infestation by barnacles and frequent immersion in seawater during high tide.

Choice of species

For the rehabilitation of mangroves, the choice of species and their propagation methods described here are by no means exhaustive. The species have been selected because some knowledge is available on their silviculture and they have potentials for coastal protection. The species, and their life-forms, habitat types, salinity ranges and inundation classes are listed in Table 6.

Table 6. List of mangrove species, and their life-forms, habitats, salinity ranges and inundation classes

Choice of species	Life-form	Habitat type	Salinity range (ppt)	Inundation class*
Acrostichum aureum	Fern	Back mangroves	< 15	4
Avicennia marina	Tree	Seaward shores	> 25	1
Bruguiera gymnorhiza	Tree	Central mangroves	15 – 25	3
Ceriops tagal	Tree	Central mangroves	15 – 25	3
Nypa fruticans	Palm	Riverine mangroves	< 15	5
Rhizophora apiculata	Tree	Central mangroves	15 – 25	3
Rhizophora mucronata	Tree	Banks of tidal creeks	15 – 25	2
Rhizophora stylosa	Tree	Central mangroves	15 – 25	3
Sonneratia alba	Tree	Seaward shores	> 25	1

* Refer to Table 2 for description of inundation classes

References to information of these mangrove species are mainly from Tomlinson (1986), Kitamura *et al.* (1997), Duke (2006), Giesen *et al.* (2007), Selvam (2007) and Hanley *et al.* (2008).

Acrostichum aureum

Acrostichum aureum (Pteridaceae) is a mangrove fern that grows to 4 m in height. Stems of fronds are stout, erect and covered with large scales. Tips of fertile leaves are rusty-brown, maturing dark brown during spore release. Spores are large and tetrahedral in shape. Tips of sterile leaves are blunt with a short tip. Leaf venation is net-like. It can be distinguished from *Acrostichum speciosum* by being taller, with young fronds being reddish and leaves with blunt tips. In open, degraded and inland mangrove areas that are seldom inundated, the species forms tall dense thickets (Fig. 15). The species can easily be propagated by rhizomes. Considered a weed which stifles the regeneration of commercial tree species by foresters, eradication by uprooting the fern is difficult as the exposed rhizomes can still sprout.

Avicennia marina

Avicennia marina (Avicenniaceae) is a tree that grows to 10 m tall and is characterised by its pencil-like pneumatophores. The bark is smooth, grey, mottled green and peeling in patches. Leaves are single, opposite, leathery, yellowish-green and silver-grey below with pointed apex. The under surface of leaves has special salt secreting glands. Flowers are small, sessile, fragrant and pale yellow. Fruits are heart-shaped, rounded or sometimes shortly beaked and greyish with fine hairs. It grows throughout the intertidal zones of estuaries, lagoons and backwater. It prefers fine clay and alluvial soil, and tolerates a wide range of soil salinity. The species can be easily propagated by propagules. Collected from trees or from the forest floor, propagules are soaked in brackish water to facilitate shedding of their outer coat. When sowing in the nursery, the radicle part of the propagules is lightly pushed into the soil. Nursery-raised seedlings of about 30 cm can be out-planted.

Bruguiera gymnorhiza

Bruguiera gymnorhiza (Rhizophoraceae) is a moderate-sized tree that grows to 15 m, occasionally up to 30 m tall. It has short buttresses and characteristic knee-shaped breathing roots. Bark is dark grey to black and conspicuously fissured. Leaves are simple, opposite, leathery and dark green with long leaf stalks. Flowers are single and axillary in position. Calyx is reddish to scarlet with 10-14 pointed lobes (Fig. 16). Petals are orange-brown in matured flowers and bi-lobed with each lobe having 3-4 long bristles. Propagules are cigar-shaped, 15-25 cm in length, 2 cm in diameter, stout with blunt apex. When mature, they are reddish-brown or greenish-red. The species is capable of growing well in somewhat dry and well-aerated soils. It is one of the most shade-tolerant mangrove species and seedlings may grow under a full forest canopy. It is propagated from propagules. Direct planting of propagules has been successful. Nursery-raised seedlings of 35 cm in height can be out-planted.

Ceriops tagal

Ceriops tagal (Rhizophoraceae) is a small tree that grows to 6 m in height. It has short buttresses and knee-like breathing roots. The bark is pale grey to reddish-brown, smooth in young trees and deeply fissured in old trees. Leaves are simple, shiny, opposite and ovate. Leaves are dark green in shade and bright greenish-yellow in full sun. Leaf apex is rounded or notched. Inflorescence is a condensed cyme and axillary with 5-10 flowers. Calyx is deeply sunken and divided into five green lobes. Petals are five in number and white turning brown, two-lobed and ending in 2-4 bristles. Propagules are slender and yellowish-green, warty, ribbed and widest at the distal half (Fig. 17). Surface of the propagules is warty and ridged. Mature propagules are recognised by their yellow collar and brownish-green hypocotyl. Freshly plucked from mother trees or collected from the ground, they can be used for direct planting. Nursery-raised seedlings 20 cm in height can be used for out-planting.

Nypa fruticans

Nypa fruticans (Arecaceae) is a stemless palm with branching underground rhizomatous roots. Growing to 10 m tall, fronds are erect and slightly recurved with a stout stalk that is strongly flanged at the base (Fig. 18). Each frond has 100-120 leaflets with a shiny green upper surface and a pale lower surface. The midrib of each leaflet is marked by brown scales. The species is monoecious with female flowers forming a spherical head of congested flowers. The bright yellow male flowers are catkins, located below the female head of flowers. The fruiting body is a spherical aggregate of individual brown fruits which are obovate, angular and fibrous. Each fruit contains a white, egg-shaped seed. The species is monotypic and occurs on soft, fine-grained substrates at the upper limits of tidal waterways where there is a regular supply of fresh water. It grows gregariously forming pure stands. Propagation is by sowing seeds in the nursery and out-planting of seedlings after several months.

Rhizophora apiculata

Rhizophora apiculata (Rhizophoraceae) is a large-sized tree that grows to 30 m in height with 50 cm trunk diameter. It is characterised by the presence of stilt roots, which are looping from the base of the trunk, and occasionally has aerial roots emerging from lower branches. The bark is grey to dark grey and sometimes longitudinally fissured. Leaves are simple, opposite and narrowly elliptic with fine black dots on the under surface. The inflorescence is axillary and a two-flowered cyme (Fig. 19). The peduncle is stout and grey. The calyx is four-lobed, greenish-yellow inside and reddish-green outside. Petals are four in number and white. Viviparous propagules are 25-30 cm long, greenish-brown, warty or relatively smooth. The species can be easily propagated from propagules. Matured propagules are characterised by a prominent red collar at the junction of the fruit and hypocotyl. Propagules can be stored for several days by soaking in brackish water. They can be directly planted in the field. Seedlings can be raised in the nursery before out-planting. After 4-5 months, seedlings of about 30 cm in height and with two pairs of leaves can be out-planted. The survival rate of nursery-raised seedlings is higher than those from directly planted propagule but at a higher planting cost. The species starts producing flowers and propagules 5-6 years after planting.

Rhizophora mucronata

Rhizophora mucronata (Rhizophoraceae) is a tree that reaches 25-30 m in height. Trees are characterised by stilt roots looping from the base of trunks. The bark is dark grey and horizontally fissured. Leaves are single, opposite, leathery, broadly elliptic to oblong with clear black dots on the under surface. The inflorescence is axillary and a dichotomously branched cyme, with 4-8 flowers (Fig. 20). The peduncle is slender, yellow and 2-3 cm long. Flowers are creamy white, fleshy and fragrant. Calyx is deeply four-lobed and pale yellow. Petals are four in number, light yellowish in colour with dense hairs along the margin. Viviparous propagules are 50-70 cm long, cylindrical, warty and yellowish-green. The species grows well along creek banks in deep soft mud, which is rich in humus. It is easily propagated from propagules. Mature propagules have a prominent yellowish collar at the junction of the fruit and hypocotyl. They can be out-planted directly or raised in the nursery prior to planting in the field. Growth is generally vigorous and planted trees are reproductive 3-4 years after planting.

Rhizophora stylosa

Rhizophora stylosa (Rhizophoraceae) is a small tree with single or multiple trunks. It grows to 10 m tall with 10-15 cm trunk diameter. The bark is smooth, reddish-brown to pale grey and fissured. It has stilt roots with aerial roots emerging from the lower branches. Leaves are broadly elliptic, leathery, with spots at the lower surface and an extended pointed tip. The inflorescence is axillary, forking 3-5 times with 5-8 bisexual flowers (Fig. 21). The four pale yellow calyx lobes, remaining on the fruit, are re-curved. The four yellowish to whitish petals have densely woolly margins. Each flower has eight stamens and a 4-6 mm long style. The fruit is elongated, pear-shaped and brown when mature. Flowers and fruits are produced throughout the year. This pioneer species grows in a variety of tidal habitats including tidal flats and coral islands.

Sonneratia alba

Sonneratia alba (Sonneratiaceae) is a tree that grows to 20 m tall. The bark is cream to brown and smooth with fine longitudinal fissures. Arising from underground cable roots are stout conical pneumatophores. Leaves are simple, opposite, leathery, ovate and bear vestigial glands at the base of leaf stalks. Bisexual flowers occur either solitarily or in groups of three (Fig. 22). The 6-7 persistent sepals are green outside and red inside. Flowers have an attractive display of numerous long and white stamens that soon shed following anthesis. Flowering occurs all year round. The fruit is a flattened round berry with persistent sepals at its base and contains many seeds. The species is a pioneer found in seaward habitats of consolidating mud and sand. It also occurs on rocky shores and on coral islands.

Site selection and preparation

It is crucial to determine the site conditions before embarking on any mangrove rehabilitation project (e.g. Ong, 1995; Kaly & Jones, 1998). Abiotic factors include shore dynamics e.g. exposure to storms and wave actions; shore profile e.g. eroding, accreting or stable; soil properties e.g. salinity and pH; amount and type of sedimentation; frequency and degree of tidal inundation; and availability of freshwater inputs. Biotic factors include availability and quality of planting material; incidence of pests e.g. barnacles; and presence or absence of natural regeneration of tree species and associated fauna.

If the conditions of a particular site are unfavourable, the best option would be to defer planting and to select other more suitable sites. It should be emphasised that mangroves typically colonise sheltered coastal areas with deposition of sediments and freshwater inputs. Priority should therefore be accorded to sheltered estuaries particularly in the enrichment of degraded forest areas. Tidal flats at the seafront with deep mud that are exposed to the vagaries of storms and wave actions, deeply inundated during high tide, and devoid of any life forms, should be avoided (Fig. 23). Tidal flats with some early colonising individuals of pioneer species are more suitable for rehabilitation (Fig. 24). In cases of uncertainty, small-scale feasibility trials to assess site suitability can be conducted. Failing which the best option would be to do nothing and allow the shore to change naturally without intervention. Too many attempts have failed when planting mangroves in such exposed habitats.

In the Philippines, planting of mangroves on seaward tidal flats had only 10-20% survival (Primavera & Esteban, 2008). In former mangrove areas that have been bunded and tidal flow restricted, it is crucial to re-establish the tidal drainage (Wolanski & Richmond, 2008). Too often, mangrove seedlings have been planted without re-establishing tidal flow. Where water stagnates, the seedlings invariably stop growing and gradually die. The more successful mangrove rehabilitation projects are those located in areas with low-energy and with an appropriate elevation within the intertidal zone (Yap, 2000).

Following damage to mangroves of the Ayeyarwady delta in Myanmar by cyclone Nargis in May 2008, it was reported that the damaged canopy encouraged the colonisation of invasive light-demanding species such as *Acanthus ilicifolius*, *Phoenix paludosa* and *Acrostichum aureum* (Than, 2008). These species form dense thickets and would require site treatment prior to planting. A cost-effective technique has been reported by Chan *et al.* (1987). It involved cutting lines through the thickets using a saw-edged disc cutter before planting mangrove propagules. The competition for light would encourage more rapid growth of the mangrove plants.

Propagation and planting

Direct planting of propagules

Direct planting of propagules is by far the most widely used technique for mangrove rehabilitation (Chan, 1996). Its timing largely depends on the availability of propagules and hence planting is often carried out during the fruiting season. Gathering of fresh-fallen propagules from the forest floor is preferred as this will ensure their maturity. The plucking of pre-dispersed propagules from mother trees is discouraged. Not only the process is more tedious, there is every possibility that immature propagules are collected. Only sound propagules are selected for planting with those damaged by beetles or rough handling rejected.

Direct planting of propagules of *Rhizophora*, *Bruguiera* and *Ceriops* is simple and can be done by untrained labourers. It involves inserting the elongated propagules into the often soft and moist mud. The depth of planting would depend on the length of propagules. In plantation forestry, planting is carried out along predetermined lines and at fixed spacing by the planting crew. Planted trees of *Rhizophora mucronata* and *Rhizophora apiculata* are reproductive 3-4 years and 5-6 years after planting, respectively. Although direct planting of *Avicennia* propagules is rarely done, techniques of broadcasting or burying propagules (several per hole) can be tried out. For *Sonneratia* species, direct planting of portions of mature fruits with enclosed seeds may be worth trying.

Planting of potted seedlings

Collected propagules are 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. For convenient transportation of seedlings, the nursery may be located at the planting site. Nursery seedlings require a growth period of 5-6 months before they can be out-planted in the field. By then, they would have acquired 2-3 pairs of leaves. Polythene bags should be removed before the seedlings are planted. Besides having higher survival rates, 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 (Chan, 1996). In view of the higher cost of planting, the use of potted seedlings should be restricted to more problematic sites.

Planting of wildings

Natural regeneration of mangrove species is often bountiful. Wildings are readily available in the vicinity of mother trees, can therefore be used as planting stock for rehabilitation. The planting of bare root wildings is not recommended as survival is low. The planting of rooted wildings has been shown to be effective (Chan, 1988; Chan, 1996). The technique of collection is simple and essentially involves extracting wildings of 0.5-1.0 m in height using a specially designed steel corer of 10 cm diameter. 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.

Monitoring and tending

At Aceh, seedling survival of many of the post-tsunami mangrove rehabilitation projects was very low (Wibisono & Suryadiputra, 2006; UNEP, 2007). This was partly attributed to the lack of monitoring and tending of planted seedlings. Rehabilitation work was considered completed as soon as the seedlings had been planted. Neither monitoring nor tending was deemed necessary.

Monitoring and tending of mangrove plantations are crucial as they provide useful information for future projects. Many lessons can be learnt based on the growth performance of planted seedlings. They include site selection, choice of species, causes of mortality, and effectiveness of silvicultural treatments such as replanting and pest control.

Case studies

Mangrove afforestation in Bangladesh

In 1966, the Forest Department of Bangladesh initiated a mangrove afforestation programme to protect coastal areas from cyclone damage (Saenger & Siddiqi, 1993). Initial planting of *Sonneratia apetala* and *Avicennia officinalis* at 320 ha per year was highly successful in protecting and stabilising coastal areas. This led to a large-scale mangrove afforestation initiative. Funded by the World Bank, the Mangrove Afforestation Project planted 120,000 ha of mangroves from 1980-1990.

During the cyclone of April 1991, many of the mangrove plantations were damaged. Young plantations seemed to have suffered most. Several months later, most of the plantations showed signs of recovery. Damage to non-mangrove trees planted on the coastal embankments was significantly higher. The susceptibility of non-mangroves to wind-throw was attributed to their less developed root systems. Subsequently, it was acknowledged that the most significant benefit of mangrove plantations was their ability to recover from storm damage through self-repair. The establishment of mangrove plantations has contributed to coastal stabilisation and protection in Bangladesh.

Post-tsunami mangrove rehabilitation in Aceh, *Indonesia*

According to a report by FAO, many of the post-tsunami mangrove rehabilitation projects in Aceh were generally sub-standard due to various reasons (Hanley *et al.*, 2008). They include the following:

- Limited areas planted - in many cases a few hundred seedlings have been planted in a very small area.
- Seedlings were planted too close together - distance between seedlings of 50 cm was common and there were examples of seedlings planted just 10 cm apart.
- Seedlings were planted without removal from polythene bags - it is possible that some plants may survive, but most plants will die.
- Poor site selection - many seedlings were planted in inappropriate sites.
- Typically, only seedlings of *Rhizophora apiculata* were planted. Those of *Rhizophora mucronata* were also present at some sites but there was little evidence of species being matched to sites with respect to shore elevation, substrate type, salinity, etc.
- Often seedlings were planted among debris which damaged seedlings when moved by the tide and freshwater flow.
- There was little or no community commitment to maintenance of the seedlings - many NGOs undertook planting as cash-for-work schemes and were not expected maintain the plantations.

According to UNEP (2007), 30 million mangrove seedlings covering 27,500 ha had been planted in Aceh since the tsunami. Unfortunately, most of the mangroves were planted in damaged pond areas and many seedlings were destroyed by the heavy machinery used in repair work. Other mangrove planting areas were destroyed by the construction of infrastructure, suggesting a lack of coordination among the various actors. The need to avoid such poor planning in planting efforts is one of the lessons learnt, the others being:

- Short-term, project-based, cash-for-work schemes in which local people worked as paid labourers. With limited supervision, training or education, there was little after-care of planted seedlings and mortality rates of seedlings were high.
- With most of planted seedlings being *Rhizophora mucronata*, the resulting mangrove monocultures lack structural and taxonomic diversity and zonation, which may render them vulnerable to environmental shocks and diseases
- Importing seeds and seedlings from Java to relieve local supply shortages meant that many (35-50%) died during shipping, and the rest were stressed and weakened
- The use of mature seeds and seedlings is essential to high survival rates after planting
- The choice of site for nurseries is important to seedling production, the best sites being tidal, flat and sheltered from the wind
- The use of growth media with little mud content causes seedlings to die
- A 1-2 month hardening period is needed before planting, during which the seedlings are progressively deprived of fresh water and shade
- Seedlings were often planted in the wrong sites i.e. in sandy areas, in areas prone to drying out, and in high-energy locations vulnerable to currents and wind
- Planting in privately-owned areas without the owner's permission may result in the seedlings being removed later
- Various technical errors can kill or weaken seedlings, including planting at the hottest times of day, transporting seedlings with bare roots, and planting seedlings still in their polythene bags
- Young seedlings are vulnerable to pest attack especially by barnacles, crabs and mud lobsters
- Seedlings need to be protected against browsing livestock

The study by UNEP (2007) concluded that key priorities were stakeholder coordination, full long-term community participation, awareness of the correct techniques, sites and species matching, and biological indicators. Educational and awareness-raising activities are important, and diversification of species planted should also be encouraged.

Another study on lessons learnt from mangrove rehabilitation efforts in Aceh was conducted by the Wetlands International – Indonesia Programme (WIIP) jointly with UNEP (Wibisono & Suryadiputra, 2006). It was reported that only a small fraction of rehabilitation efforts has been successful. The rest has failed based on the low survival rate of plants in the field. Among the reasons given were:

- Mistakes in the selection of planting sites and unsuitable choice of plants
- Insufficient preparation and inadequate guidance
- Low capacity of human resources and limited amount of community involvement
- No tending of the plants as rehabilitation activity is considered completed after planting
- Emphasis was on the number of seedlings planted and not on the number that survived

Mangrove planting projects in Aceh, *Indonesia*

WIIP has been implementing mangrove planting projects in Aceh by negotiating agreements with villagers (Check, 2005). Villagers are committed to plant an agreed number of seedlings they collect from the wild. In return, the programme provides support staff and loan to enable the villagers to initiate businesses such as chicken and goat farms. If 70% of the seedlings planted are still alive after five years, the villagers can keep the money; otherwise they have to repay part of the loan. These negotiated agreements encourage villagers both to plant and care for the forests, making them more likely to survive. Villagers have planted 350 ha along 3.5 km of the coast through these arrangements.

Post-tsunami mangrove planting in Peninsular Malaysia

The following case studies on post-tsunami planting of mangroves in Peninsular Malaysia have been reported by Ong (2007), and by Tan and Ong (2008).

On the northwest coast of Penang, *Rhizophora apiculata* seedlings were planted under an already good cover of *Avicennia marina* forest. Most of the planted seedlings died probably due to inadequate light and high soil salinity. This activity raises the fundamental question as to the purpose of planting, apart from obtaining funds to carry out the work.

On the southwest coast of Penang, dredged spoils from earthworks carried out soon after the tsunami, were piled on one bank of the estuary. There were not enough culvert openings to provide the necessary hydrological circulation for the mangrove community dominated by *Avicennia marina* and a patch of mangroves died behind the bund. Again, mangrove seedlings were introduced to the dead patch of *Avicennia*. As the seedlings planted were *Rhizophora apiculata*, most of them died. This is another example of knee-jerk reaction by simply planting mangrove seedlings.

Another mangrove rehabilitation project was near Pulau Sayap in Kedah. *Rhizophora apiculata* seedlings grown in PVC tubes, presumably to protect the shoreline from coastal erosion, were planted on the mud flats seaward of an existing mangrove forest of mainly *Avicennia marina*. Within weeks, most of the seedlings had disappeared and their PVC tubes were strewn everywhere by wave actions (Fig. 25). Subsequent attempts at planting *Rhizophora mucronata* seedlings in bamboo tubes were also unsuccessful (Fig. 26). Even if waves are not a problem, mud flats are certainly not the correct places to plant mangroves. Mangroves cannot survive on exposed low-elevation tidal flats.

MANGREEN – Ecological mangrove restoration in India

The coastline of Tamil Nadu or Land of the Temples in southern India was hit by the 2004 tsunami. Through the initiatives of DEEPWAVE (Initiative for the Protection of the High Seas) and OMCAR (Organization for Marine Conservation, Awareness and Research), the MANGREEN project was initiated (Balaji & Gross, 2006; GNF, 2007). In September 2005, Ecological Mangrove Restoration (EMR) sites for natural and artificial regeneration were established in two fishing villages, Keezhathottam and Velivayal, located at Agni estuary in the northern Palk Bay. These sites have been established after careful study on soil quality, species suitability, natural recruitment, land elevation, water sources, grazing effect and land-use. The villagers have been recruited for excavation of water channels, fencing, seed collection, plantation and maintenance. More than 10,000 mangrove seedlings have been planted and 4,000 saplings have been raised in nurseries. It was reported that nursery-raised seedlings showed higher survival rates than direct planting of propagules.

Mangrove rehabilitation project in Kiribati

The Republic of Kiribati comprises 16 atolls with low-lying coral islands of less than 4 m asl surrounding lagoons (Mueller-Dombois & Fosberg, 1998). The soils are coarse textured, alkaline with pH of 8.2-8.9 and deficient in trace elements. Principal food crops are *Cocos nucifera*, *Artocarpus altilis*, *Pandanus tectorius* and *Cyrtosperma chamissonis*. Beach strand vegetation consists of *Scaevola taccada*, *Terminalia littoralis*, *Calophyllum inophyllum*, *Hernandia nymphaeifolia* and *Thespesia populnea*. Mangrove species include *Rhizophora stylosa*, *Sonneratia alba*, *Bruguiera gymnorhiza* and *Lumnitzera littorea* (Fig. 27).

With support from the local Ministry of Environment, Land and Agriculture Development, and the Ministry of Education, Youth and Sports, the International Society for Mangrove Ecosystems (ISME) has implemented a mangrove rehabilitation project in Tarawa, Kiribati since 2005 (Baba *et al.*, 2008). Funded by Cosmo Oil Company Ltd. Japan, the objectives of the project are to establish coastal green belts especially along the banks of causeways using simple planting techniques, to create suitable grounds for fisheries resources, and to educate school children and youths on the importance of mangrove ecosystems.

Propagules of *Rhizophora stylosa* were collected locally and planted in groups of three propagules each at close spacing of 0.5 x 0.5 m (Fig. 28). Some 31,000 propagules have been planted in nine sites. As the substrate is mainly coral gravel, small iron rods were used to dig planting holes. These planting programmes were participated by school children and youths (Fig. 29). In successful sites, survival was 80% a year after planting and 50% three years after planting (Fig. 30). Besides the poor nutrient contents of soils and the lack of freshwater supply, other factors adversely affecting seedling growth are prolonged tidal submersion, strong wave actions, barnacle infestation and seaweed entanglement.

4.3 Other coastal forests

Rationale for rehabilitation

Beaches and dunes

Strand vegetation is critical to the formation and stabilisation of beaches and dunes (Craft, 2008; Cochard, 2008). Selection of suitable plant species is of paramount importance when rehabilitating vegetation on bare dunes. Dune plants must be able to survive sand blasting, sand burial, salt spray, saltwater flooding, heat, drought and limited soil nutrient. Only a few plant species can tolerate these stresses. Most post-tsunami attempts at planting tree species on beaches and dunes have failed due to poor site and species selection, grazing by livestock and no maintenance after planting (Wibisono & Suryadiputra, 2006).

It is therefore essential to adopt a prudent approach when rehabilitating beaches and dunes. Planting programmes can be implemented in two stages. Initial planting of primary sand-colonising herbaceous plants should be undertaken. They include creeping herbs (e.g. *Ipomoea pes-caprae* and *Canavalia rosea*), sedges and grasses (e.g. *Spinifex littoreus*) for fore-dune stabilisation. Only when the dunes have an adequate cover of ground vegetation, will the planting of woody tree species commences. Progressively, natural regeneration will also play a role in the development of the strand vegetation.

Coral islands

For many years, agro-forestry has become an integral component of the traditional subsistence of people living on coral islands (Manner, 1993). Agro-forestry practices, a sustainable land-use system, include wetland taro agriculture, mixed tree gardening, backyard or kitchen gardens, and intermittent tree gardening. The local communities know which varieties of food and native plants grew well or poorly on their atolls, how to propagate them, and where they grew best (Stone *et al*., 2000). They recognise the problems of inadequate rainfall in some years and poor soil fertility in many places when growing plants on atolls. They have addressed these limitations by planting tolerant plants such as coconut and *Pandanus* species, and by the intensive use of organic fertilizers from debris and household wastes.

Recognising the vulnerability of coral island to natural hazards such as tsunamis, hurricanes and sea-level rise, efforts in rehabilitation of these islands should take cognition of the limiting environmental factors and the wealth of local traditional knowledge in growing plants on atoll soils. The use of indigenous tree species and organic fertilizers is strongly encouraged. Small-scale planting trials to assess growth performance are essential before embarking on large-scale rehabilitation projects.

Choice of species

For the rehabilitation of other coastal forests, the choice of species and their propagation methods described here are by no means exhaustive. They serve as a guide and have been selected because some knowledge is available on their silviculture. They are important forest trees and/or major food crops and they can play a role in coastal protection. The species, and their life-forms, habitats and propagation methods are listed in Table 7.

Table 7. List of coastal species, and their life-forms, habitats and propagation methods

Choice of species	Life-form	Habitat	Propagation
Artocarpus altilis	Tree	Atoll	Seed/root sucker
Barringtonia asiatica	Tree	Dune/atoll	Seed
Calophyllum inophyllum	Tree	Dune/atoll	Seed
Canavalia rosea	Creeper	Beach/dune	Seed/cutting
Casuarina equisetifolia	Tree	Dune/atoll	Seed
Cocos nucifera	Palm	Dune/atoll	Seed
Hibiscus tiliaceus	Tree	Dune/atoll	Seed/cutting
Ipomoea pes-caprae	Creeper	Beach/dune	Seed/cutting
Melaleuca cajuputi	Tree	Dune	Seed
Pandanus odoratissimus	Herb	Dune/atoll	Seed/cutting
Scaevola taccada	Shrub	Dune/atoll	Seed/cutting
Spinifex littoreus	Grass	Dune	Seed/cutting
Terminalia cattapa	Tree	Dune/atoll	Seed
Thespesia populnea	Tree	Dune/atoll	Seed/cutting
Vitex trifolia	Shrub	Dune	Seed/cutting

References to information of these coastal species are mainly from Kitamura *et al.* (1997); Stone *et al.* (2000), BPA (2004), Giesen *et al.* (2007), Selvam (2007), Craft *et al.* (2008) and Hanley *et al.* (2008).

Artocarpus altilis

Artocarpus altilis (Moraceae) or breadfruit is a tree that grows to 30 m in height. Leaves are alternately arranged, thick, leathery and deeply fissured with 5-11 pointed lobes (Fig. 31). The upper leaf surface is dark glossy green with conspicuous yellow veins. Being monoecious, male and female inflorescences are present on the same tree. Male flowers are arranged densely on drooping, cylindrical or club-shaped spike. Female inflorescences are upright and cylindrical with numerous embedded flowers. Fruits are compound, ovoid to oblong in shape and vary from 10-35 cm in length. The outer skin of the fruit is thin and patterned with irregular, 4-6 sided faces, each of which has a minute, black pointed but flexible spine in the centre. Fruits are green when young and yellowish-green or yellow when ripe. All parts of the tree exude white latex. The species is an important staple food of the Pacific Islands. In the Maldives, fruits are eaten raw, boiled, steamed or roasted. Among the food crops grown on coral islands, breadfruit is the least tolerant to soil salinity. The species is normally propagated by transplanting root suckers. Trees grown from root suckers will bear fruit in five years and will be productive for more than 50 years. Seeded varieties are propagated in the nursery and seedlings are out-planted when they are 0.5 m tall.

Barringtonia asiatica

Barringtonia asiatica (Lecythidaceae) or sea putat is a small- to medium-sized tree with heights ranging from 7-20 m. Leaves, spirally arranged in rosettes, are obovate, thick and leathery. Flowers are large (10 cm in diameter) and scented with greenish-white petals and showy white stamens with pink tips (Fig. 32). Fruits are large (10-15 cm in diameter), cubic and have a broad square base that tapers towards the tip which carries two persistent calyx lobes. Green when young and yellowish brown when mature, the fruit has a tough fibrous husk and contains one large seed. The species occurs from Madagascar to South and Southeast Asia, and from northern Australia to the Pacific. The species is often planted as a shade tree along boulevards and avenues along the sea, and grows well when planted inland. It is a littoral species occurring on sandy and rocky shores, and occasionally in mangroves. It forms a dense forest with overlapping crowns. It can be grown as windbreak, wave barrier and shade trees. It is considered as one of the early colonisers of coral islands. It can be propagated in the nursery with partial shade by embedding fruits with single seeds in polythene bags with sandy soil. Seedlings with at least two pairs of leaves and more than 30 cm in height are hardened before they are out-planted at 2-4 m spacing.

Calophyllum inophyllum

Calophyllum inophyllum (Guttiferae) or laurel wood is a spreading tree of 10-30 m in height. It has a pale grey bark with shallow longitudinal grooves. Stems exude sticky yellow or white latex when cut. Leaves are glossy, opposite, dark green above and characterised by fine and dense parallel veins and a pale midrib. Flowers (2-3 cm in diameter) occurring in clusters are showy, white and fragrant with numerous yellow stamens. Fruits are round, single-seeded berries (3-4 cm in diameter) that hang from a long stalk (Fig. 33). Seeds are round and brownish-orange when mature. The species occurs on sandy beaches and non-swampy coastal areas and is distributed from East Africa through South and Southeast Asia to Polynesia. The species is hardy and thrives well on sandy well-drained sites and is resistant to salt spray. It is useful for shade, shelter and wind-breaks. Its fine timber is widely used for boat building. It is quick to establish and is effective in stabilising coastal dunes. Seeds may be sown directly or seedlings can be raised in the nursery before out-planting. To improve the rate of germination, ripe fruits may be soaked in water overnight. Nursery-raised seedlings should be hardened for 1-3 months before out-planting at 2-4 m spacing.

Canavalia rosea

Canavalia rosea (Fabaceae) or sea bean is a perennial creeper of sandy beaches and rocky shores. It is easily recognised by its round, trifoliate leaves and lilac flowers (Fig. 34). Flowers are sweet scented and have a white streak in the middle to attract pollination by bees. Fruits are 6-15 cm long, bean-like pods with 2-10 seeds. Flowers are used for flavouring, and young pods and seeds are edible after boiling. The species is suitable as ground cover against soil erosion of sandy beaches and dunes. Its long, creeping and branching stems with roots at the nodes spread over the sand surface to form dense blankets. Being a legume, it can fix nitrogen from the atmosphere. It often forms dense ground cover when growing in combination with *Spinifex littoreus* and *Ipomoea pes-caprae*, and is a useful species for mixed plantings on the frontal dune. It can be propagated from seeds which are directly sown. Seeds with seed coat scarified germinate well in the nursery and nursery seedlings can be out-planted. It can also be propagated from stem cuttings with at least two rooted nodes for successful establishment.

Casuarina equisetifolia

Casuarina equisetifolia (Casuarinaceae) or she-oak is a fast-growing tree that reaches 20-30 m in height. It resembles pine trees with their long-drooping needles and small cones (Fig. 35). Trunks are straight, cylindrical, 5-8 m in height and buttressed in older trees. The bark is smooth and greyish-brown when young, turning to thick, fissured, flaky and dark brown when old. Whorls of tiny male flowers are borne on branches which eventually drop off. Female flowers occurring as globular clusters are borne on permanent branches. After pollination, the female flowers form cones which are green when young and brown when mature. These woody cones eventually shed small shiny brown winged seeds. The species is native to Australia, Malaysia and the Pacific Islands. Although the species is a non-legume, it can fix atmospheric nitrogen. This process improves the nitrogen content of the sandy soils and enables other more nutrient-demanding species to establish. This salt-tolerant and wind-resistant species is a valuable sand-binder. It grows in pure stands and provides protection for the landward vegetation. It produces good firewood and charcoal. It is propagated mainly by seeds which are collected from mature cones. Seeds are sown in the nursery and out-planted when seedlings are about 0.3-0.5 m tall. Seeds can be sown without any pre-treatment and seeds germinate within two weeks. Seedlings can be planted singly or in groups of 3-4 seedlings at 3-5 m spacing.

Cocos nucifera

Cocos nucifera (Arecaceae) or coconut palm is a tall tree with a stout, straight or slightly curved trunk, rising from a swollen base surrounded by a mass of roots. Trunk is greyish-brown, smooth with rings of leaf scars. Tall varieties may attain heights of 20-30 m. Fronds are pinnate, up to 6 m long and 1.5-2.0 m wide with 200-250 leaflets arranged on either side of the rachis. Male and female flowers are borne on the same inflorescence called a spadix that develops within a woody canoe-shaped sheath and have 10-50 branchlets or spikelets. Male flowers are small, light yellow, numerous and found at the tips of branchlets. Each spikelet has up to three large female flowers at the base. Fruits are ovoid in shape and occur in bunches (Fig. 36). Each fruit has a thick, fibrous husk surrounding a spherical nut with a hard hairy shell. Three sunken holes or ‘eyes’ of soft tissue are present at one end of the nut. Inside the shell is a thin, white, fleshy kernel. There are tall and dwarf varieties of coconut with the former commonly cultivated around the world. The species is well adapted to a wide variety of soils in the coastal areas. It grows well in deep loamy and clayey soils with good drainage, and tolerates saline and infertile soils but is intolerant to drought. It is a multiple-use palm which is considered as one of the ten most useful trees in the world. It plays an important role in the economy, and food security of many countries. It can only be propagated by seeds collected from mature nuts with husk turning brown from green. Mature nuts are stored in a shaded nursery and after 3-4 months, sprouted nuts are out-planted. The hole is half filled with organic materials such as coconut husks. After placing the sprouted nut, the hole is topped up with soil. Mature nuts can also be planted in the nursery by burying two-third of their length in the soil to reduce desiccation. Germination occurs 4-6 weeks after sowing and continues over an eight-week period. Regular watering during this period is necessary. Nuts with fully developed compound leaves are the best to be transferred to the field. Seedlings should be out-planted not later than six months.

Hibiscus tiliaceus

Hibiscus tiliaceus (Malvaceae) or sea hibiscus is a fast-growing tree that reaches 15 m tall. Leaves are leathery, hairy beneath, heart-shaped and have 1-3 nectary glands at the base of the underside mid-rib. Flowers occurring singly are bell-shaped, each with a maroon heart and stigma (Fig. 37). Flowers are yellow in the morning, turning orange-red in the evening. The species is a coastal plant of the tropics and sub-tropics. It is commonly found along the sandy shores of tropical Asia and Australia, and is abundant in the Pacific Islands. It can withstand drought and tolerate a wide variety of soils on coral islands. Soils range from coralline to swampy soils. It is propagated from seeds and stem cuttings. Seeds, collected when the capsules split, are scarified by lightly nicking their coats. Seedlings, 5-6 months old and 25 cm in height, are suitable for out-planting. Stem cuttings, 2-3 m long and collected from straight branches, are commonly used for propagation.

Ipomoea pes-caprae

Ipomoea pes-caprae (Convolvulaceae) or goat's foot convolvulus is a perennial creeping vine with milky sap. Roots are produced at the nodes. Leaves are alternate and oval-shaped resembling the footprint of a goat. Flowers are attractive, pink or purple and bell-shaped resembling those of the morning glory (Fig. 38). Fruits are a flattened capsule with four black and densely hairy seeds. The species is common along sandy beaches of Southeast Asia. It is a primary sand-stabilising species, being one of the earliest plants to colonise the sand dunes including the seaward dune slopes. Growing in association with *Spinifex littoreus*, this plant is a useful sand-binder, thriving under conditions of sand blast and salt spray. It is propagated from seeds or stem cuttings.

Melaleuca cajuputi

Melaleuca cajuputi (Myrtaceae) or paper bark tree grows to 25 m tall. The bark is thick, whitish and flaky (Fig. 39). The crown is dense and green, with silvery new leaf flush. Leaves are dull green and stiff with pointed tips. Flower spikes are white or creamy, and fluffy resembling a bottlebrush. Capsules are grey-brown, broadly cylindrical, thick-walled and contain numerous very fine seeds. The species is sand- and salt-tolerant, and grows well in low-lying swamps, landward of frontal dunes. Propagation is usually from seeds. Seedlings can be raised in the nursery and out-planted when they are 30-40 cm tall.

Pandanus odoratissimus

Pandanus odoratissimus (Pandanaceae) or screw pine is an erect and coarsely branched plant. Growing to 15 m in height, the plant resembles a candle-stick holder. Stems are usually pale grey-brown, hollow, ringed by leaf scars and produce prop roots at the base. Leaves are sword-like and arranged spirally in three rows (Fig. 40). At the basal underside of leaves are two clear pale green strips, one on either side of the midrib. The leaf apex is long and flagella-like. Under exposed conditions, leaves hang downwards giving the plants a characteristic drooping appearance. The species is dioecious with male and female flowers occurring in separate plants. Male flowers are tiny, white, fragrant and last only for a day. Female inflorescences are composed of free or joined carpels. Fruits, resembling pineapples, are globular with tightly bunched, wedge-shaped fleshy drupes. They are green when young and orange-red when ripe. Ripe fruits are eaten raw, drank as juice and used in various food preparations. The species is commonly found growing in groves along sandy and rocky shores. It an important food crop of the Pacific Islands and the Maldives. It is propagated from seeds and branch cuttings. Seeds can be collected from intact drupes. After soaking in water for several days, viable phalanges will float. They can then be sown directly or propagated in a nursery. Seedlings, 4-12 months old, can be out-planted. Stem cuttings (20-40 cm) with some intact roots can be planted immediately after collection to enable higher rate of establishment.

Scaevola taccada

Scaevola taccada (Goodeniaceae) or sea lettuce is a sprawling perennial shrub that grows in dense stands to 3 m tall. Leaves are spoon-shaped, yellowish-green, thick and spaced at 2 cm along the stem (Fig. 41). Stems are woody, slightly succulent and crooked. Flowers are white, fragrant and petals are arranged in a 1.5 cm wide fan. Fruits are a shiny, succulent and globular drupe, 2 cm in diameter, and white or purple. The species is an effective sand-binder and is one of the early colonisers of beaches. It grows in sites protected from strong winds and sand blasting. It can be raised from seeds or stem cuttings. Both methods need shade and regular watering. A dense stand can be established by planting seedlings or rooted cuttings at 1 x 1 m spacing.

Spinifex littoreus

Spinifex littoreus (Poaceae) or sand spinifex is a stout perennial grass with strong creeping runners which produce roots and rigid, spiny leaves at the nodes (Fig. 42). The species is dioecious with male and female inflorescences borne on different plants. Male inflorescences consist of stalked racemes while female inflorescences consist of large, spiny and spherical head of stalkless racemes. The species is fairly common along sandy shores and dunes from South and Southeast Asia to Taiwan and southern Japan. It is a pioneer sand-stabilising species. The plant is salt-tolerant and has the ability to grow in wind-blown sand. It grows well on frontal dunes and is the dominant species colonising the seaward dune slopes. It is the main species used in planting programmes for re-vegetating frontal dunes and is the most successful sand-trapping plant colonising dunes along most of the coastline of

Queensland, Australia. It can be propagated from seedlings raised from seeds in the nursery. Stem cuttings of 40-60 cm long can be directly planted in the field at a depth of 20-30 cm.

Terminalia cattapa

Terminalia cattapa (Combretaceae) or Indian almond is a deciduous, moderate-sized tree, 10-25 tall, with horizontal branching when young (Fig. 43). Leaves are spirally-arranged and oval-obovate with 6-9 pairs of widely-spaced veins. Fruit pods are angular and flattened. They are hard and green when young, turning red when mature. Seeds contained in each pod are elliptic, tapering at both ends. Native to Southeast Asia, the species is commonly found throughout the tropics and sub-tropics. The species occurs on sandy and rocky shores and is commonly planted as a shade tree. It grows on silty, loamy and clayey soils, and tolerates slightly saline soils and moderate drought. It is an important timber tree in some countries. The outer flesh and nut of the fruit are eaten fresh or dried. The species can be readily propagated from seeds. Seeds, collected from mature fruits, should be sown within 4-6 weeks. No pre-treatment is needed. Seedlings grow rapidly in the initial stages. Seedlings, four months of age or about 25 cm in height, can be used for out-planting. Stem cuttings of 20-30 cm can be rooted in the nursery before planting.

Thespesia populnea

Thespesia populnea (Malvaceae) or tulip tree is a small, evergreen tree, 6-10 m in height with short and often crooked trunk. The crown is round, broad, dense and regular. The bark is brownish or greyish and fissured. Leaves are simple, alternate, broadly ovate, pointed at the tip and slightly heart-shaped at the base. Leaves are fleshy and shiny with palmate veins, turning yellow and red before falling. Flowers are large, bell-shaped and axillary. Petals are five in number, broad, rounded, overlapping and yellow with a maroon heart at the inside base of the corolla. Flower colour changes from yellow to purplish as the day progress. Fruits are rounded but flattened capsules. Mature capsules are brown to grey and exude a bright yellow resin when cut. Seeds are brown and hairy. The species can be propagated from seeds and stem cuttings. Seeds, collected from mature capsules by crushing, are soaked in water overnight before sowing. Nursery-raised seedlings, 40-50 cm in height, are hardened before out-planting. Stem cuttings are rooted in the nursery before planting.

Vitex trifolia

Vitex trifolia (Lamiaceae) or coastal vitex is a low sprawling shrub with radiating stems. The shrub produces adventitious roots and short, erect, flowering branches at nodes along the stems. Leaves are greyish-green and flowers borne on erect inflorescences are purplish-blue or lilac (Fig. 44). The species is widely distributed throughout the tropics and sub-tropics. It can withstand moderate salt spray and sand blasting. It grows well when planted behind the frontal dunes where it can form dense stands. Being able to tolerate partial burial by wind-blown sand, it is a useful secondary sand-stabilising species because of its sprawling growth habit and sand-binding ability. It is propagated from nursery-raised seedlings or rooted cuttings. Seeds germinate well in the nursery. Seedlings or rooted cuttings planted in moist sand should produce a dense stand.

Site selection and preparation

In dune areas devoid of any vegetation, sand fences are often erected to trap sand and to initiate dune building before planting can be undertaken (Craft *et al*., 2008). Fences may be built using wooden pickets, bamboo, reeds or branches that deflect and slow the wind. Guidelines for using fences include: 1) fences with 40-50% porosity are most efficient in trapping sand; 2) install fences parallel to the shoreline; and 3) a single row of fence is suitable for sites with lower wind speed and double fences may be needed for sites with higher wind speed. As the dune builds, continued sand trapping and dune growth are facilitated by installing additional fences atop the original fences as they become buried. Planting can commence once sand-binding pioneer species begin to colonise the site.

Seedlings should be planted in a manner to reproduce the natural vegetation zonation (BPA, 2004). Guidance can be obtained by observing similar adjacent undisturbed sites. Tree seedlings should not planted seaward of the fore-dune which can only be colonised by the herbaceous pioneer plants. *Casuarina equisetifolia* can be planted on the crest and landward slope of the fore-dune while other coastal species can be planted in more sheltered areas landward of the fore-dune crest.

Post-tsunami planting of coastal species in Aceh included *Terminalia cattapa*, *Casuarina equisetifolia*, *Cocos nucifera* and *Calophyllum inophyllum* (Wibisono & Suryadiputra, 2006; UNEP, 2007). Survival rate was only 20-50%. The major reason for the low survival was poor selection of planting sites which included open, labile and inundated sandy beaches and dunes. Open sandy beach is very difficult to rehabilitate. Apart from being labile as the sand is easily moved by the wind, it is highly saline and stores heat from the sun. It would seem obvious that such an area is unsuitable for planting as nothing is growing on it. Nevertheless, planting has been attempted on these sites and, as a result, most of the seedlings died. For coastal species, inundation especially by saltwater is detrimental to plants. Some projects have failed because coastal species were planted in places that were inundated.

Propagation and planting

Seed collection, storage and treatment

Seed should be collected from mother trees growing on coastal dunes or atolls. It is important to collect seeds from mature fruits (BPA, 2004). Collected fruits are dried in the sun to release the seeds. Seeds of fleshy fruits are removed from the pulp before drying. After drying, the seeds can be stored in airtight jars, kept under cool, dry and dark conditions, or in a refrigerator. Seeds of dune plants with a hard outer coat have to be treated by nicking with a sharp blade or by dipping in hot water.

Raising seedlings in the nursery

Small seeds should be germinated in seed beds before seedlings are transplanted into pots (BPA, 2004). Seeds can be sown evenly over the potting mixture before covering with a thin layer of vermiculite. Larger seeds can be directly sown in polythene bags. Several seeds are usually sown into each bag and later culled to leave one plant. The sown seeds are kept moist by watering.

Seedling hardening

Nursery seedlings for dune or atoll planting must be hardened by exposing them to full sun, wind and moderate moisture stress (BPA, 2004). Hardening usually takes 2-6 weeks. It is good practice to prune off some foliage of the seedlings during out-planting to reduce excessive moisture loss.

Planting time and method

High temperature and low moisture of soils in planting sites are the major causes of mortality of planted seedlings (BPA, 2004; Craft *et al*., 2008). Planting should commence at the onset of the rainy season to avoid high soil temperatures and to give the plants adequate soil moisture to colonise the site. There is much greater flexibility in time of planting if the seedlings can be watered during the critical establishment period.

At planting sites, the soil should be kept moist and the planting hole dug deep enough to allow the root system to be completely buried (BPA, 2004). It is also important to check that the root system of seedlings is healthy and is sufficiently well-developed to hold the potting mixture firmly when the polythene bags are removed. Seedlings are placed into planting holes and topped up with soil, which is tamped down to complete the planting operation. Seedlings should be watered before and after planting.

Stems cuttings of sand-binding primary species such as *Spinifex littoreus*, *Ipomoea pes-caprae* and *Canavalia rosea* can be collected for direct planting in the field. Cuttings with several rooted nodes should be planted obliquely into moist soil so that the growing end projects above the soil surface (BPA, 2004). Some form of surface stabilisation such as brush matting may be required for sites exposed to wind erosion. Because the stem cuttings are planted before their root system has grown, some losses are common. Plant spacing ranges from 0.5-1.0 m depending on the amount of planting material available.

Fertilizer application

The dune environment is harsh as sandy soils hold little water and are poor in nutrients especially nitrogen (Craft *et al*., 2008). Dune vegetation responds favourably to fertilizer which is applied 2-3 months after planting and in several applications spread over the growing season.

For planting on atoll soils, the use of organic manure and/or household food waste is recommended (Stone *et al*., 2000). Another source of fertilizer is compost from leaves and coconut husks. These plant materials can be dumped into pits dug at sites intended for planting.

Monitoring and tending

Poor survival of seedlings planted on dunes is often due to the moisture stress in the first few weeks (BPA, 2004). This problem can be greatly reduced if the seedlings are pruned and watered during this critical early stage. It is essential to keep planted sites free of vehicular and foot traffic (Craft *et al*., 2008). In some areas, fencing or caging of planted seedlings may be necessary to overcome the problem of browsing by livestock. This would incur additional costs to the rehabilitation effort.

For plants grown on atoll soils, water supply to the plants relies solely on the rain which is scarce during periods of drought (Stone *et al*., 2000). On some atolls, rain water runoff from roofs is stored and used for watering. Even waste water from bathing and household washing is diverted to the plants. Sometimes, weeding and mulching of plants are carried out to conserve soil moisture.

Case studies

Coastal rehabilitation project in the Maldives

The Republic of Maldives consists of some 1,190 low-lying coral islands, including 26 atolls (Jagtap & Untawale, 1999). Most of the islands (2 m asl) are enclosed by coral reefs with shallow lagoons and deep channels. The soil is young, shallow and composed mainly of coral debris and sandy loam with some surface humus. It is alkaline with high calcium content and poor water retention capacity.

Common mangrove tree species found in the Maldives are *Rhizophora mucronata*, *Bruguiera cylindrica* and *Lumnitzera racemosa* (Jagtap & Untawale, 1999; Selvam, 2007). Other coastal tree species include *Terminalia cattapa*, *Hibiscus tiliaceus*, *Thespesia populnea*, *Calophyllum inophyllum*, *Pemphis acidula, Barringtonia asiatica, Pongamia pinnata* and *Scaevola taccada*.

With support from the local government, ISME has implemented a coastal rehabilitation project in the Maldives since 2006. Funded by the Japan Fund for Global Environment, the project is aimed at rehabilitating coastal forests in the wake of the 2004 tsunami, severe coastal erosion and anticipated effects of sea- level rise. The project is on-going with local communities participating in all activities of fruit collection, seed processing, raising of seedlings in the nursery and planting in the field (Baba & Yamagami, 2007). The project is located on Mulaku Atoll, and on the islands of Boli Mulah, Dhiggaru and Maduvvari.

Coastal species planted were *Terminalia cattapa*, *Calophyllum inophyllum*, *Barringtonia asiatica* and *Pometia pinnata*. Nursery seedlings of these species were raised successfully (Fig. 45). About 1,000 seven-month old seedlings of *Terminalia cattapa* were planted on a beach of coral sand (Fig. 46). Although about 85% of the seedlings were washed away by strong waves during high tide, the remaining seedlings grew healthily after five months. Planting trials showed some promise as the seedlings were neither watered nor fertilised. Future planting will include the use of stakes to anchor the seedlings. Results of initial planting trials of the other species showed that seedlings of *Barringtonia asiatica* had outstanding growth.

Post-tsunami rehabilitation in Aceh, Indonesia

Following the 2004 tsunami, government agencies and NGOs had implemented planting projects on beaches and dunes. The total number and area planted were 403,400 seedlings and 29,000 ha, respectively (Wibisono & Suryadiputra, 2006; UNEP, 2007). Of the total, 109,000 seedlings and 150 ha were planted through small grants of the Green Coast Project coordinated by WIIP. Species planted were *Cocos nucifera*, *Terminalia cattapa*, *Casuarina equisetifolia*, *Azadirachta indica* and *Calophyllum inophyllum*.

Among the reasons for the failure of rehabilitation in some areas were planting on labile and bare sandy beaches (Wibisono & Suryadiputra, 2006; UNEP, 2007). In such sites, planted seedlings were exposed to winds, waves, saline soils and tidal inundation. Other reasons included browsing by livestock, and the lack of monitoring and evaluation. It was recommended that labile and bare sandy beaches should be avoided, and planting should commence from the back to the front of the beach.

Natural regeneration in Lhok Nga, Aceh, Indonesia

Several years after the 2004 tsunami, coastal strand vegetation started to regenerate naturally in Aceh (Wibisono & Suryadiputra, 2006). Mangroves performed poorly with some localised regrowth of *Nypa fruticans* and *Avicennia* species. Compared to mangroves, the natural regeneration of other coastal species was much better. Shrub forests consisting of a variety of plant species started to establish.

Lhok Nga in Aceh, famous for its scenic sandy beaches and *Casuarina* forests, was impacted by the 2004 tsunami (Wibisono & Suryadiputra, 2006). Two years later, most of the dune areas had very good natural regrowth of *Casuarina equisetifolia* trees with dense ground cover of *Ipomoea pes-caprae*. A survey conducted by WIIP in July 2006 showed densities of 3,800 saplings per hectare with heights ranging from 0.5-3.5 m.

Fig. 15. Dense thicket of *Acrostichum aureum* ferns (L)
Fig. 16. Wasp visiting flowers of *Bruguiera gymnorhiza* (R)

Fig. 17. Propagules of *Ceriops tagal* (L)
Fig. 18. Gregarious stand of *Nypa fruticans* (R)

Fig. 19. Inflorescences of *Rhizophora apiculata* (L)
Fig. 20. *Rhizophora mucronata* in flower (R)

Fig. 21. Leaves, inflorescences and flowers of *Rhizophora stylosa*

Fig. 22. Butterfly visiting flower of *Sonneratia alba*

Fig. 23. Tidal flat with deep mud is exposed to the vagaries of storms and wave actions, deeply inundated, and devoid of any life forms

Fig. 24. Tidal flat with some early colonising individuals of pioneer species

Fig. 25. PVC tubes strewn on the mudflats due to strong wave actions (L)
Fig. 26. Unsuccessful planting of *Rhizophora* seedlings in bamboo tubes (R)

Fig. 27. Forests of *Bruguiera gymnorhiza* (a), *Sonneratia alba* (b) and *Rhizophora stylosa* (c) in Kiribati (L)
Fig. 28. Line planting of *Rhizophora stylosa* propagules in groups of three in Kiribati (R)

Fig. 29. School children participating in mangrove planting in Kiribati (L)
Fig. 30. One-year-old stand of *Rhizophora stylosa* planted in Kiribati (R)

Fig. 31. The breadfruit tree *Artocarpus altilis* (L)
Fig. 32. Flowers of the sea putat *Barringtonia asiatica* (R)

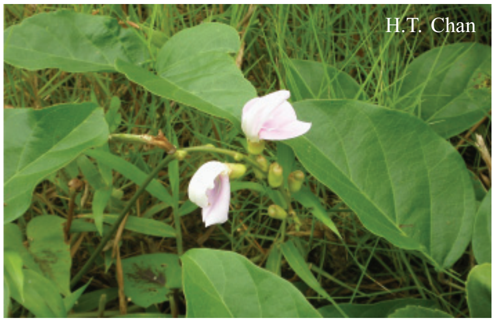

Fig. 33. Fruits of *Calophyllum inophyllum* (L)
Fig. 34. The sea bean *Canavalia rosea* (R)

Fig. 35. Mono-specific stand of *Casuarina equisetifolia* (L)
Fig. 36. The coconut palm *Cocos nucifera* (R)

Fig. 37. The sea hibiscus *Hibiscus tiliaceus* (L)
Fig. 38. The beach creeper *Ipomoea pes-caprae* (R)

Fig. 39. Flowers, trunk and bark of *Melaleuca cajuputi* (L)
Fig. 40. The screw pine *Pandanus odoratissimus* (R)

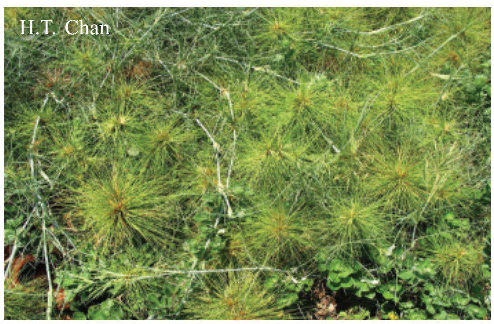

Fig. 41. The sea lettuce *Scaevola taccada* (L)
Fig. 42. The sand-stabilising grass *Spinifex littoreus* (R)

Fig. 43. The sea almond *Terminalia cattapa*

Fig. 44. The beach shrub *Vitex trifolia*

Fig. 45. Seedlings of *Terminalia cattapa* (L) and *Calophyllum inophyllum* (R) in the nursery

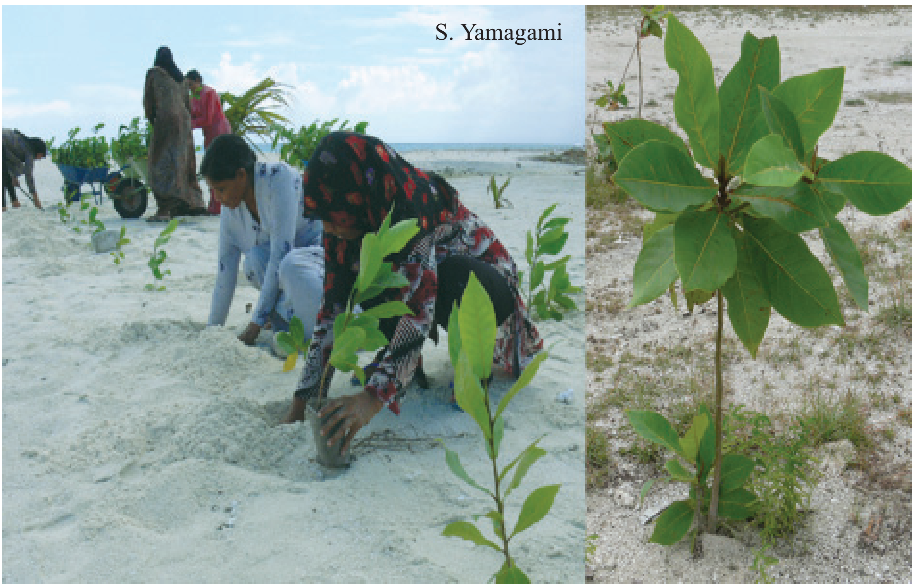

Fig. 46. Women planting seedlings (L) and healthy planted seedling (R) of *Terminalia cattapa*

REFERENCES

Akhter, M., Iqbal, M.Z. & Chowdhury, R.M., 2008. ASTER imagery of forest areas of Sundarban damaged by cyclone Sidr. *ISME/GLOMIS Electronic Journal* 6: 1–2.

Angsupanich, S. & Havanond, S., 1996. Effects of barnacles on mangrove seedling transplantation at Ban Don Bay, Southern Thailand. In: *Proceedings of the FORTROP '96: Tropical Forestry in the 21st Century*, 25-28 November 1995, Kasetsart University, Bangkok, Thailand, pp. 72–81.

Baba, S. & Yamagami, S., 2007. *Progress of restoration of coastal forests for local communities and coastal environment in small islands of Republic of Maldives.* Unpublished report of ISME submitted to the Japan Fund for Global Environment (in Japanese), 23 pp.

Baba, S., Suzuki, T. & Nakao, Y., 2008. *Progress of mangrove planting in Tarawa, Republic of Kiribati.* Unpublished report of ISME submitted to the Cosmo Oil Eco Card Fund (in Japanese), 6 pp.

Balaji, V. & Gross, O., 2006. *MANGREEN - Mangrove restoration and ecology in India.* Deepwave Report No. 4/06, 40 pp.

Barbier, E.B., 2006. Natural barriers to natural disasters: replanting mangroves after the tsunami. *Frontiers in Ecology and the Environment* 4: 124–131.

Bird, E., 1985. *Coastline Changes: A Global Review.* John Wiley and Sons, 219 pp.

Bird, E., 1996. *Beach Management.* John Wiley and Sons, 281 pp.

Blasco, F., 2008. Impacts of recent natural hazards on mangrove ecosystems in the Bay of Bengal. In: Chan, H.T. & Ong, J.E. (Eds.) 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. *ISME and ITTO Mangrove Ecosystems Proceedings No. 5*, pp. 97.

Blasco, F., Saenger, P. & Janodet, E., 1996. Mangroves as indicators of coastal change. *Catena* 27: 167–178.

BPA, 1986. *Report on cyclone Winifred.* Beach Protection Authority, Environmental Protection Agency of Queensland, 18 pp.

BPA, 1999. Cyclones and their effects on beaches. *Coastal Technical Series 3*, Beach Protection Authority, Environmental Protection Agency of Queensland, 4 pp.

BPA, 2004. Coastal Dune Management. *Coastal Technical Series 1-5*, Beach Protection Authority, Environmental Protection Agency of Queensland.

Braatz, S., Fortuna, S., Broadhead, J. & Leslie, R. (Eds.), 2007. *Proceedings of the Regional Technical Workshop on Coastal Protection in the Aftermath of the Indian Ocean Tsunami: What role for forests and trees?* Khao Lak, Thailand, 28-31 August 2006.

Chan, H.T., Husin, N. & Chong, P.F., 1987. Is there a need to eradicate *Acrostichum speciosum* prior to planting of *Rhizophora mucronata* in logged-over mangrove forest areas? *FRIM Occasional Papers* 1/87, Forest Research Institute Malaysia.

Chan, H.T., 1988. Rehabilitation of logged-over mangrove areas using wildings of *Rhizophora apiculata*. *Journal of Tropical Forest Science* 1(2): 187–188.

Chan, H.T., Chong, P.F. & Ng. T.P., 1988. Silvicultural efforts in restoring mangroves in degraded coastal areas in Peninsular Malaysia. In: Proceedings of the International Symposium on Conservation and Management of Coral Reef and Mangrove Ecosystems. *Galaxea* 7: 307–314.

Chan, H.T., 1996. Mangrove reforestation in Peninsular Malaysia: a case study of Matang. In: Field, C. (Ed.) *Restoration of Mangrove Ecosystems.* International Society for Mangrove Ecosystems, Okinawa, Japan, pp. 64–75.

Chan, H.T., Ong, J.E., Gong, W.K. & Sasekumar, A., 1993. The socio-economic, ecological and environmental values of mangrove ecosystems in Malaysia and their present state of conservation. In: Clough, B. (Ed.) *The Economic and Environmental Values of Mangrove Forests and their Present State of Conservation in South-East Asia/Pacific Region*. ISME, ITTO and JIAM Mangrove Ecosystems Technical Reports, pp. 41–81.

Chandrasekar, N. & Ramesh, R., 2007. Tsunami damage to the south eastern coast of India. In: Murty, T.S., Aswathanarayana, U. & Nirupama, N. (Eds.) *The Indian Ocean Tsunami.* Taylor & Francis Group, LLC, pp. 351–363.

Check, E., 2005. Natural disasters: roots of recovery. *Nature* 438: 910–911.

Church, J.A., White, N.J., Hunter, J.R., 2006. Sea-level rise at tropical Pacific and Indian Ocean islands. *Global and Planetary Change* 53: 155–168.

Clough, B. (Ed.), 1993. The Economic and Environmental Values of Mangrove Forests and their Present State of Conservation in South-East Asia/Pacific Region. *ISME, ITTO and JIAM Mangrove Ecosystems Technical Reports Vol. 1*, 202 pp.

Coch, N.K., 1994. Geologic effects of hurricanes. *Geomorphology* 10: 37–63.

Cochard, R., 2008. The 2004 tsunami in Aceh and Southern Thailand: a review on coastal ecosystems, wave hazards and vulnerability. *Perspectives in Plant Ecology, Evolution and Systematics* 10(1): 3–40.

Craft, C.B., Bertram, J. & Broome, S., 2008. Coastal zone restoration. In: *Jorgensen, S.E. & Fath, B. (Eds.) Encyclopedia of Ecology*, 2008 Elsevier Ltd., pp. 637–644.

Dahdouh-Guebas, F., Jayatissa, L.P., Di Nitto, D., Bosire, J.O., Lo Seen, D. & Koedam, N., 2005. How effective were mangroves as a defence against the recent tsunami? *Current Biology* 15(12): R443–R447.

Daniel, M. & Alongi, D.M., 2008. Mangrove forests: resilience, protection from tsunamis, and responses to global climate change. *Estuarine, Coastal and Shelf Science* 76(1): 1–13.

Danielsen, F., Sorensen, M.K., Olwig, M.F., Selvam, V., Parish, F., Burgess, N.D., Hiraishi, T., Karunagaran, V.M., Rasmussen, M.S., Hansen, L.B., Quarto, A. & Suryadiputra, N., 2005. The Asian tsunami: a protective role for coastal vegetation. *Science* 310: 643.

Duke, N.C., 2006. *Australia's Mangroves. The authoritative guide to Australia's mangrove plants.* University of Queensland, Brisbane, 200 pp.

EJF, 2006. *Mangroves: nature's defence against tsunamis - a report on the impact of mangrove loss and shrimp farm development on coastal defences.* Environmental Justice Foundation, London, UK, 32 pp.

Ellison, J.C., 2008. Wetlands of the Pacific Island region. *Wetlands Ecology and Management*, DOI 10.1007/s11273-008-9097-3.

EPU, 1986. *National Coastal Erosion Study – Final Report.* Report prepared for the Economic Planning Unit of the Prime Minister's Department Malaysia by Stanley Consultants, Moffat & Nichol, and Jurutera Konsultant (SEA) Sdn. Bhd.

Erftemeijer, P.L.A. & Lewis III, R.R., 1999. Planting mangroves on intertidal mudflats: habitat restoration or habitat conversion. Paper presented at the *ECOTONE-VIII Seminar on Enhancing Coastal Ecosystem Restoration for the 21st Century*, 23-28 May 1999, Ranong and Phuket, Thailand.

Field, C. (Ed.), 1996. *Restoration of Mangrove Ecosystems.* International Society for Mangrove Ecosystems, Okinawa, Japan, 250 pp.

Field, C., 1998a. Rehabilitation of mangrove ecosystems: an overview. *Marine Pollution Bulletin* 37(8-12): 383–392.

Field, C., 1998b. Rationale and practices of mangrove afforestation. *Marine and Freshwater Research* 49: 353–358.

Giesen, W., Wulfraat, S., Zieren, M. & Scholten, L., 2007. *Mangrove Guidebook for Southeast Asia.* FAO and Wetland International, 769 pp.

Ghazali, N.H.M., 2006. New innovations and technologies in coastal rehabilitation. In: Phang, S.M. *et al.* (Eds.) *Innovations and Technologies in Oceanography for Sustainable Development*. University of Malaya Maritime Research Centre, pp. 141–156.

Gillespie, R.G., 2007. Oceanic islands: models of diversity. In: Levin, S.A. (Ed.) *Encyclopedia of Biodiversity*, 2007 Elsevier Inc., pp 1-13.

GNF, 2007. *Mangrove Rehabilitation Guidebook*. Published in the framework of the EU-ASIA PRO ECO II B Post Tsunami Project in Sri Lanka, Global Nature Fund, 68 pp.

Hanley, J.R., 2007. Integrated land management to improve long-term benefits in coastal areas of Asian tsunami-affected countries. In: Broadhead, J.S. & Leslie, R.N. (Eds.) *Proceedings of the Workshop on Area Planning and Management Tsunami-affected Countries*, 27-29 September 2006, Bangkok, Thailand, pp. 253–286.

Hanley, R., Mamonto, D. & Broadhead, J., 2008. *Coastal Forest Rehabilitation Manual for Aceh Province and North Sumatra.* Food and Agriculture Organisation of the United Nations (FAO), Bangkok, 66 pp.

Harada, K. & Imamura, F., 2005. Effects of coastal forest on tsunami hazard mitigation – a preliminary investigation. In: Satake, K. (Ed.) *Tsunamis: Case Studies and Recent Developments* © 2005 Springer, pp. 279–292.

Harakunarak, A. & Aksornkoae, S., 2005. Life-saving belts: post-tsunami re-assessment of mangrove ecosystem values and management in Thailand. *Tropical Coasts* July 2005, pp. 48–55.

Hiraishi, T., 2008. Effectiveness of coastal forests in mitigating tsunami hazards. In: Chan, H.T. & Ong, J.E. (Eds.) 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. *ISME and ITTO Mangrove Ecosystems Proceedings No. 5*, pp. 65–73.

IPCC, 1990. *Strategies for Adaptation to Sea Level Rise.* Coastal Zone Management Subgroup, The Hague: Ministry of Transport and Public Work.

Jagtap, T.G. & Untawale, A.G., 1999. Atoll mangroves and associated flora from republic of Maldives, Indian Ocean. *Mangrove Ecosystem Technical Reports, ISME* 5: 17–25.

Kaly, U.L. & Jones, G.P., 1998. Mangrove restoration: a potential tool for management in tropical developing countries. *Ambio* 27(8): 656–661.

Kathiresan, K. & Rajendran, N., 2005. Coastal mangrove forests mitigated tsunami. *Estuarine, Coastal and Shelf Science* 65: 601–606.

King, D., 2008. Beach and shoreline. In: Lerner, B. & Lerner, K. (Eds.) *Climate Change: In Context*. Detroit: Gale, 1: 119–120.

Kitamura, S., Anwar, C., Chaniago, A. & Baba, S., 1997. *Handbook of Mangroves in Indonesia – Bali and Lombok*. Ministry of Forestry Indonesia, JICA and ISME, 119 pp.

Kogo, M. & Kogo, K., 2004. Towards sustainable use and management for mangrove conservation in Vietnam. In: Vannucci, M. (Ed.) *Mangrove Management and Conservation*. United Nations University, pp. 233–248.

Manner, H.I., 1993. A review of traditional agroforestry in Micronesia. In: *Proceedings of the Workshop Methodologies and Applications for Pacific Island Agroforestry*, 16-20 July 1990; Pohnpei, Federated States of Micronesia, pp. 32–36.

Mazda, Y., Magi, M., Kogo, M. & Phan, N.H., 1997. Mangroves as coastal protection from waves in Tong King Delta, Vietnam. *Mangroves and Saltmarshes* 1: 127–135.

Mimura, N., 1999. Vulnerability of island countries in the South Pacific to sea level rise and climate change. *Climate Research* 12: 137–143.

Mohd Ridza, A., 2006. Coastal forest rehabilitation and management in Malaysia. Presented in the *Workshop on Coastal Forest Rehabilitation and Management*. Bangkok, Thailand, 26 September 2006.

Moreno-Casasola, P., 2008. Ecosystems: Dunes. In: *Jorgensen, S.E. & Fath, B. (Eds.) Encyclopedia of Ecology*, 2008 Elsevier Ltd., pp. 971–976.

Mueller-Dombois, A. & Fosberg, F.R., 1998. *Vegetation of the Tropical Pacific Islands*. Springer-Verlag, 733 pp.

Naseer, A., 2007. Pre-and post-tsunami coastal planning and land-use policies and issues in the Maldives. In: Broadhead, J.S. & Leslie, R.N. (Eds.) *Proceedings of the Workshop on Area Planning and Management Tsunami-affected Countries*, 27-29 September 2006, Bangkok, Thailand, pp. 147–164.

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

Ong, J.E., 2007. Pre- and post-tsunami coastal planning and land-use policies and issues in Malaysia. In: Broadhead, J.S. & Leslie, R.N. (Eds.) *Proceedings of the Workshop on Area Planning and Management Tsunami Affected Countries*, 27-29 September 2006, Bangkok, Thailand, pp. 131–146.

Ong, J.E. & Tan, K.H., 2008. Mangrove and sea-level change. In: Chan, H.T. & Ong, J.E. (Eds.) 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. *ISME and ITTO Mangrove Ecosystems Proceedings No. 5*, pp. 89–96.

Osti, R., Tanaka, S. & Tokioka, T. (2008). The importance of mangrove forest in tsunami disaster mitigation. *Disasters* 33: 203–213.

Paphavasit, N., Chotiyaputta, C. & Siriboon, S., 2007. Pre-and post-tsunami coastal planning and land-use policies and issues in Thailand. In: Broadhead, J.S. & Leslie, R.N. (Eds.) *Proceedings of the Workshop on Area Planning and Management Tsunami-affected Countries*, 27-29 September 2006, Bangkok, Thailand, pp. 199–227.

Qureshi, M.T., 2008. Rehabilitation of mangroves in Sri Lanka and Thailand after the 2004 Indian Ocean tsunami. In: Chan, H.T. & Ong, J.E. (Eds.) 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. *ISME and ITTO Mangrove Ecosystems Proceedings No. 5*, pp. 15–20.

Robertson, A.I. & Duke, N.C., 1990. Recruitment, growth and residence time of fishes in a tropical Australian mangrove system. *Estuarine, Coastal and Shelf Science* 31: 723–743.

Saenger, P. & Siddiqi, N.A., 1993. Land from the sea: the mangrove afforestation program of Bangladesh. *Ocean & Coastal Management* 20: 23–39.

Samaranayake, R.A.D.B., 2007. Pre-and post-tsunami coastal planning and land-use policies and issues in Sri Lanka. In: Broadhead, J.S. & Leslie, R.N. (Eds.) *Proceedings of the Workshop on Area Planning and Management Tsunami-affected Countries*, 27-29 September 2006, Bangkok, Thailand, pp. 167–198.

Selvam, V., 2007. *Trees and Shrubs of the Maldives*. FAO Regional Office for Asia and the Pacific, Bangkok, Thailand, RAP Publication 2007/12.

Shofiyati, R., Dimyati, R.D., Kristijono, A. & Wahyunto, 2005. Tsunami effect in Nanggroe Aceh Darussalam and North Sumatra Provinces, Indonesia. *Asian Journal of Geoinformatics* 5(2): 1–16.

Solomon, S.M. & Forbes, D.L., 1999. Coastal hazards and associated management issues on South Pacific Islands. *Ocean & Coastal Management* 42: 523–554.

Spalding, M.D., Blasco, F. & Field, C.D. (Eds.), 1997. *World Mangrove Atlas*. International Society for Mangrove Ecosystems, Okinawa, Japan, 178 pp.

Spalding, M., 2004. Mangroves. In: Burley, J. (Ed.) *Encyclopedia of Forest Sciences*, 2004, Elsevier Ltd., pp. 1704–1712.

Srinivas, H. & Nakagawa, Y., 2008. Environmental implications for disaster preparedness: Lessons learnt from the Indian Ocean Tsunami. *Journal of Environmental Management* 89: 4–13.

Stone, E.L., Migvar, L. & Robison, W.L., 2000. *Growing Plants on Atoll Soils.* Lawrence Livermore National Laboratory, University of California, UCRL-LR-137517, 33 pp.

Sundaresan, J., 1993. Protection of tropical barrier beaches – a potential remedial measure. *Environmental Geology* 22: 272–275.

Tan, K.H. & Ong, J.E., 2008. Coastal vegetation rehabilitation for the mitigation of coastal hazards – The Malaysian experience. In: Chan, H.T. & Ong, J.E. (Eds.) 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. *ISME and ITTO Mangrove Ecosystems Proceedings No. 5*, pp. 57–63.

Thampanya, U., Vermaat, J.E., Sinsakul, S. & Panapitukkul, N., 2006. Coastal erosion and mangrove progradation of southern Thailand. *Estuarine, Coastal and Shelf Science* 68: 75–85.

Than, M.M., 2008. Devastation of the 2008 cyclonic storms on mangrove and other coastal ecosystems in Myanmar. In: Chan, H.T. & Ong, J.E. (Eds.) 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. *ISME and ITTO Mangrove Ecosystems Proceedings No. 5*, pp. 31–36.

Tomlinson, P.B., 1986. *The Botany of Mangroves*. Cambridge University Press, 413 pp.

Triswanto, A., 2006. Coastal forest rehabilitation and management in Indonesia. Presented in the *Workshop on Coastal Forest Rehabilitation and Management*. Bangkok, Thailand, 26 September 2006.

UNEP, 2007. *After the Tsunami Coastal Ecosystem Restoration: Lessons learnt.* United Nations Environment Program, 55 pp.

Walters, B.B., Ronnback, P., Kovacs, J.M., Crona, B., Hussain, S.A., Badola, R., Primavera, J.H., Barbier, E. & Dahdouh-Guebas F., 2008. Ethnobiology, socio-economics and management of mangrove forests: a review. *Aquatic Botany* 89(2): 220–236.

Watson, J.G., 1928. Mangrove Forests of the Malay Peninsula. *Malayan Forest Records No. 6*, 275 pp.

Wells, S.M., Ravilious, C. & Corcoran, E., 2006. In the front line: shoreline protection and other ecosystem services from mangroves and coral reefs. *UNEP-WCMC Biodiversity Series, No. 24*, 33 pp.

Wibisono, I.T.C. & Suryadiputra, I.N.N., 2006. *Study of Lessons Learned from Mangrove/Coastal Ecosystem Restoration Efforts in Aceh since the Tsunami*. Wetlands International – Indonesia Programme, Bogor, 83 pp.

Williams, M.J., Coles, R. & Primavera, J.H., 2007. A lesson from cyclone Larry: an untold story of the success good coastal planning. *Estuarine, Coastal and Shelf Science* 71: 364–367.

Winterwerp, J.C., Borst, W.G. & De Vries, M.B., 2005. Pilot study on the erosion and rehabilitation of a mangrove mud coast. *Journal of Coastal Research* 21: 223–230.

Wolanski, E., 2006. Protective functions of coastal forests and trees against natural hazards. In: Braatz *et al.* (Eds.) *Coastal protection in the aftermath of the Indian Ocean tsunami: What role for forests and trees?* 28-31 August 2006, Khao Lak, Thailand. Bangkok, FAO, pp. 5–32.

Wolanski, E. & Richmond, R.H., 2008. Estuary restoration. In: Jorgensen, S.E. & Fath, B. (Eds.) *Encyclopedia of Ecology*, 2008 Elsevier Ltd.

Wong, P.P., 2003. Where have all the beaches gone? Coastal erosion in the tropics. *Singapore Journal of Tropical Geography* 24(1): 111–132.

Woodroffe, C.D., 2008. Reef-island topography and the vulnerability of atolls to sea-level rise. *Global and Planetary Change* 62: 77–96.

Yap, H.T., 2000. The case for restoration of tropical coastal ecosystems. *Ocean & Coastal Management* 43: 841–851.

International Society for Mangrove Ecosystems (ISME),
c/o Faculty of Agriculture, University of the Ryukyus,
1 Senbaru, Nishihara, Okinawa, 903-0129 Japan

ISBN 978-4-906584-13-0