

# **Mangrove restoration in Vietnam**

**Key considerations and a practical guide**

Marcel Marchand



Prepared for:  
WRU / TUD

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<b>Client</b>	WRU / TUD
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**Abstract**

In Vietnam mangrove rehabilitation has a long history and gained momentum after the war that destroyed huge forested areas, especially in the Mekong Delta. In addition, in various places mangrove have been and still are being planted specifically as a way to protect shorelines and sea-dykes from wave attack. The success of such projects highly depends on using the ecological knowledge describing the physical conditions under which mangroves thrive. The aim of this report is to provide in a nutshell the key considerations for a successful mangrove rehabilitation or planting project. It can be used as a practical guide to the planning of these projects.

Despite the many projects worldwide on mangrove restoration, there is a considerable shortage on documented evidences of their long term success. Recent studies from several countries show that the survival rate of young mangrove stands in rehabilitation projects is varied but sometimes extremely low. One of the main reasons for failure is that mangroves are planted in the wrong location, e.g. on lower intertidal mudflats or even subtidal zones (unsuitable for all species) or on sandy substrates of exposed coastlines where most mangrove species do not thrive. Of utmost importance for success is the combination of proper site selection and choice of the right mangrove species. Besides ecological and engineering issues, rehabilitation also involves important socioeconomic considerations. Local ownership and effective community participation are often crucial to achieve sustainable impacts.

**References**

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Annex 1

Glossary





# 1 Introduction

## 1.1 Why this report?

This report has been written for the project 'Technical Assistance for Sea Dike Research in Vietnam from the Netherlands', which is executed under the collaboration agreement between the Hanoi Water Resources University, Vietnam and the Delft University of Technology in the Netherlands. By letter dated 4 December 2008 CICAT agreed to contract Deltares for the production of this report, which was written by M. Marchand and reviewed by P. Erftemeijer.

Mangroves are disappearing worldwide at a fast rate. According to trend analyses of the available data, some 15.2 million hectares of mangroves are estimated to exist worldwide as of 2005, down from 18.8 million hectares in 1980 (FAO, 2007). Average losses are estimated to be 1 % per year over the last decade (Lewis III 2005). This fact alone justifies an increase in awareness regarding mangrove protection as well as mangrove rehabilitation. Furthermore, the potential of using mangrove forests for effective and efficient shore protection and storm attenuation has heightened interest in mangrove rehabilitation programmes throughout the Asian region.

The aim of this report is to provide in a nutshell the key considerations for a successful mangrove rehabilitation or planting project. It can be used as a practical guide to the planning of these projects, although it must be stressed that using this guide alone does not guarantee success. Equally important is to involve an appropriate mix of experts, both from the ecological and socioeconomic, engineering and juridical domains.



Figure 1 Mangrove restoration project in Banda Aceh, Indonesia after the Asian tsunami

After a brief introduction of mangrove forests and species in general (next section), the biogeography, restoration efforts and species list of the mangroves in Vietnam are presented in Chapter 2. The protective function of mangroves is briefly described in

Chapter 3. The successes and failures of mangrove restoration are reviewed in Chapter 4. Chapter 5 provides a step-by-step procedure that can be followed when implementing mangrove restoration. Chapters 6 and 7 deal with Monitoring and Costs of mangrove rehabilitation, respectively. Finally, some general conclusions are drawn in the last chapter.

## 1.2 What are mangroves?

Mangroves are tidal forests commonly observed along the sheltered shorelines of most tropical and few subtropical countries. Mangroves have no structural analogues at higher latitudes, where salt marshes occupy similar environmental conditions. Situated between land and sea, the mangrove forest is host to some 69 species of plants called mangroves. These plants are adapted to loose wet soils, saline habitats and periodic tidal submergence. More landward the mangrove tree species mix with freshwater-adapted species, which in truly freshwater or terrestrial environments outcompete the mangroves.

It is important to note from the start that mangrove trees are not very fond of saline water, although the opposite may seem true, as they are found always near the sea. The fact is that for mangroves, salt water is a physiological stress factor. The only reason that they can be found along the seashore is that they have found various mechanisms to cope with this stress, and therefore are in a competitive advantage over other plants. Most mangrove species, when kept under laboratory conditions, can perfectly survive in completely freshwater conditions.

### Growth and morphology

Mangroves are easily distinguished by their root systems which are highly adapted to their specific habitat. Root systems of different genera are depicted in Figure 2. The morphology of the roots relates to their function. More specifically, the whole root system can be regarded as an integrated whole, with the different but closely associated parts of the system having different functions. The above-ground parts, pneumatophores (e.g. *Avicennia*), prop roots (e.g. *Rhizophora*), buttresses (e.g. *Pelliciera*), root knees (e.g. *Bruguiera* and *Ceriops*), or plank roots (e.g. *Xylocarpus granatum*) allows gas exchange with below-ground parts. Gas exchange occurs by means of air holes or lenticels. Below-ground parts comprise the absorbing/anchoring component and cable roots which unify the former with the aerating parts (Kuyper, 1993).

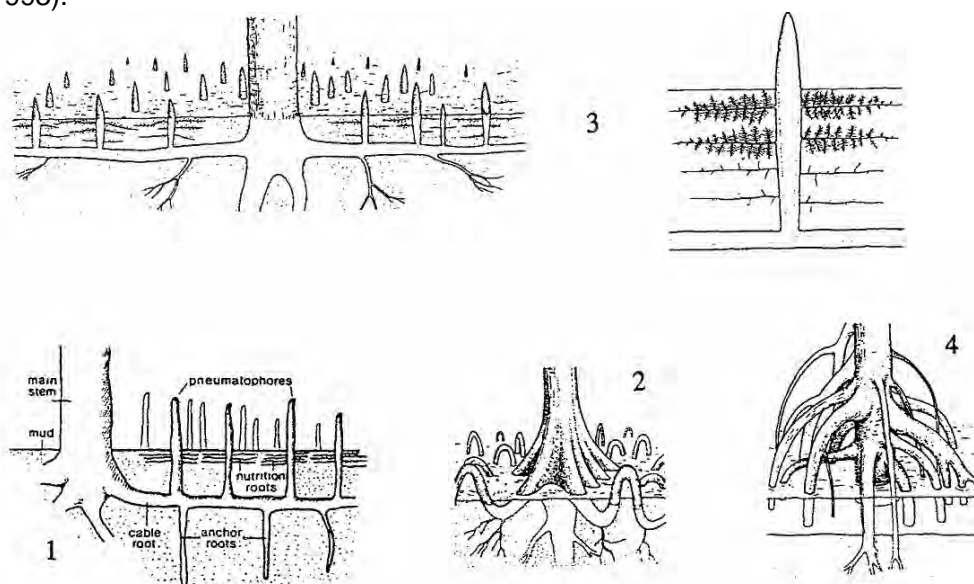


Figure 2 Typical root systems of *Avicennia* (1), *Bruguiera* (2), *Sonneratia* (3) and *Rhizophora* (4) (after King, 1981).

The growth rate varies among mangroves. The species which yield valuable timber are often slow growing. For example, in the Andamans, *Bruguiera gymnorrhiza* attains a height of 9-12 m and a girth of 23-30 cm in 15 years. In Thailand, *Rhizophora* species attain 14-18 m in height and 45-75 cm in girth in a period of 20-30 years (Walsh, 1974).

### Reproduction

Mangroves have little or no capacity for vegetative regeneration or vegetative spread, and no natural capacity for vegetative dispersal. Biological requirements for dispersal and establishment at a distance are met by floating seeds or seedlings (propagules), i.e. by sexual means (Figure 3). Flowering seems to occur throughout the year. Fertilized flowers develop propagules (fruits, seeds or seedlings). All mangroves are dispersed by water, and the propagule has some initial ability to float, even if for a limited time. In the most highly specialised types, represented by the mangrove genus *Rhizophora*, the unit of dispersal is the viviparously developed seedling. Here the embryo grows out of the seed coat and then out of the fruit while still attached to the parent plant. When the seedling falls from the tree it seems to plant itself in the sediment under the parent tree, but more often it is dispersed further away. Where the propagule finally is stranded it may establish itself (Tomlinson, 1986).

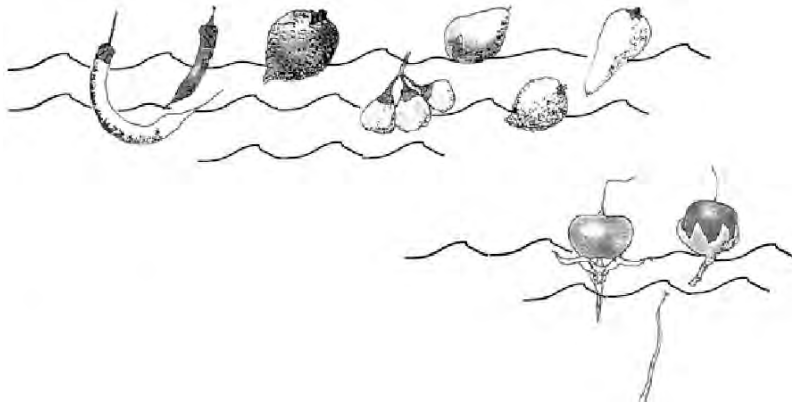


Figure 3 Drawings of propagules (from Brown & Lewis, 2006)

### Physiology

Mangroves have different mechanisms to cope with (high) salt concentrations. Mangroves have the ability to obtain freshwater required for physiological processes from the pore-water surrounding the absorbing roots. But this mechanism of salt exclusion at the roots is not hundred percent: a little amount of salt is taken up by the tree and will accumulate. Salt in high concentrations in plant tissues is toxic and must be largely excluded. All mangroves exclude most of the salt in seawater. The way they do this differs between those that secrete salt (secreters) and those that do not (non-secreters). In salt secreters (such as *Avicennia*) the absorbed salt is primarily excreted metabolically via salt glands in the leaves. In non-secreters, such as *Bruguiera*, *Rhizophora* and *Sonneratia* salt exclusion by the roots is more efficient. And although these non-secreters have no specialised mechanism for actively secreting salt, they lose some salt through the leaf surface (see Figure 4), possibly by transpiration. An additional mechanism for the elimination of salt in all mangroves is simply by loss of parts, notably leaves (Tomlinson, 1986).



Figure 4 Salt crystals on the leaf of *Avicennia*  
(Source: Wikipedia)

### **Biological environment**

In addition to the physical factors controlling the development and productivity of mangrove there are some biological factors which play a minor but evident role. These are competition, herbivory and bioturbation.

One example of how competition influences the mangrove environment is apparent in the settling stage of mangrove seedlings. There is a clear pattern among mangrove seedlings when they settle. This is called propagule sorting. It appears that propagules of a certain species are specialised in colonising particular environments. The success of settling is thus clearly related to physical factors such as flooding.

Grazing is a common feature in mangrove forests. For instance mangrove foliage is grazed by cattle, sheep, goats and camels. Widespread grazing by insects, isopods and crabs is also of considerable importance. Crabs of the family Grapsidae are common grazers (Kuyper, 1993).

Crabs and mud lobsters are important in reworking the sediments among the mangroves. Mud lobsters (*Thalassia anomala*) build large tunnelling burrows which are generally recognized by the mound of fresh mud up to 75 centimetres high around their entrances. These burrowing activities help to mix the soils and to change their surface characteristics. Other burrowing organisms have similar affects, although generally on a smaller scale. The burrows of fiddler crabs, mudskippers and mud crabs allow drainage, mixing and a degree of aeration of subsurface water in the mangroves, and in this way enhance the growth of mangroves.



Figure 5 Fiddler crab in a mangrove forest

The main importance of the mangrove forest to the adjacent marine ecosystem is through the export of dead organic material. This material drives a complex foodweb, an example of which is depicted in Figure 6.

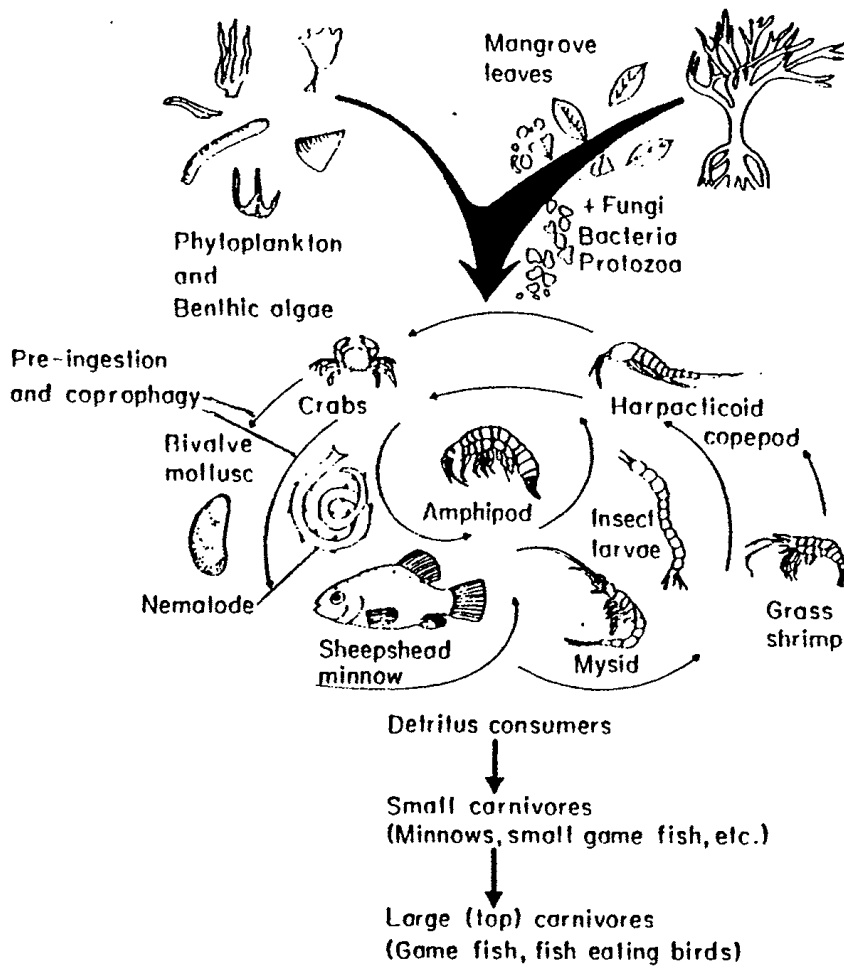


Figure 6 Food web of a mangrove forest (from Mann, 1982)



## 2 Mangroves in Vietnam

### 2.1 Distribution and biogeography

A recent survey conducted by the Institute of Forest Science of MARD and the UNEP/GEF East-Sea Project reported that Vietnam's mangrove forests have dwindled to 155,290 ha in 2007, a 50% drop from 1980. This reduction was mainly caused by the conversion of mangroves to aquaculture and farmland.

Hong & San (1993) divided the mangrove vegetation in Vietnam into 4 zones:

Zone I	Northeast coast from Ngoc cape to Do Son cape
Zone II	Northern delta from Do Son cape to Lach Truong river
Zone III	Central coast from Lach Truong to Vung Tau cape
Zone IV	Southern delta from Vung Tau cape to Ha Tien

#### Zone I: The Northeast coast

Of all the zones, zone I has the most complex geomorphology, hydrology and climatic conditions, of which some are suitable and others unsuitable for the growth and development of mangroves. The coastal mudflats are protected by a number of islands (such as Ha Long and Bai Tu Long) and are little affected by storms, high winds and waves. Accumulated alluvia make it easy for mangroves to settle. The main rivers have strong flows with steep slopes and carry alluvium down to the sea and estuaries.

There are unfavourable conditions in this zone that adversely affect the development of mangroves. During winter, for instance, due to the strong action of the northeast monsoon, there is a sudden drop in temperatures which affect tree growth and some species cannot adapt to it. In addition, the mudflats have less coarse sediments and consist mainly of fine sand. The rate of reduction from  $Fe_2O_1$  to FeO on the surface layer here is much higher than that observed in mangrove soils in southern Vietnam. In the deep layers, the sediments are acidic with pH values ranging from 4-6, the content of sulphur is high, the soil is poor in phosphorus and rich in nitrogen as well as  $H_2S$  due to the presence of decomposed mangrove material in the soil.

The mangroves in this zone have abundant flora comprised of euryhaline species with no brackish water species except those found on the swamps far inland, in areas such as Yen Lap and the southern part of Bach Dank river delta. Although the number of species here is relatively small as compared to southern Vietnam, some common species in this zone, such as *Rhizophora stylosa*, *Bruguiera gymnorrhiza*, *Kandelia candel*, *Aegiceras corniculatum* are less frequently found in mangroves in the south. On the other hand, many common species of the south are absent in Zone I.

#### Zone II: the northern delta

This zone is formed of the coastal areas accreted by Thai Bing and Hong rivers. The accreted flats are larger at the estuaries and the seashore, but are subjected to strong winds and waves. The salinity changes considerably during the year and ranges from 0.5 -5.0 ppt. A dense system of rivers, including the Hong and its tributaries, are found in this zone. The rivers have low gradients and carry a large water volume during the rainy season between May and October. As a result, brackish water remains in the estuaries for a long period of time. The decomposition of loam-clay sediments leads to localised expansion of land towards the sea.

The average temperature in the coldest month does not drop below 10° C. The zone is directly affected by storms, northeast monsoons and strong winds, resulting in high tides. In the northern portion there are no mangroves, except where the coast is protected by Do Son cape.

To protect sea dykes, people of Thai Thuy and Tien Hai (Thai Binh province) and Xuan Thuy (Ha Nam province) have planted stretches of pure *Kandelia candel* forests outside the sea dykes. These have provided protection for dykes and soil for the last several decades. The planting of *Kandelia candel* also helps in the natural regeneration of some species such as *Aegiceras corniculatum* and *Acanthus ilicifolius*. (Hong & San 1993)

### **Zone III: Central coast**

This zone covers a narrow strip of land including the coast of central Vietnam from Lach Truong to Vung Tau cape. At some locations mountains extend to the sea, as in Quang Binh, Quang Tri or from Nay cape to Dinh cape, while at other places the sea action is evident in the high sand dunes and sand bank which form bays or lagoons. The rivers in central Vietnam are unlike those in the coastal region of the north. Most of them rise from the Truong Son range and are generally precipitous. The alluvium carried by them is too little to form seashore swamps and any alluvium arriving at the estuary is swept away by the tides and waves.

Rainfall is high but unequally distributed. During storms it can reach levels of 400-700 mm over 2-4 days, causing floods. Like zone II, this zone is strongly influence by storms and monsoons. Due to these reasons, there are no mangroves along the entire seashore, except in areas protected by sand banks, between rivers. Narrow strips of brackish water mangroves can also be seen along river banks.

### **Zone IV: the coast of southern Vietnam**

This zone is mainly accreted by the river systems of Cuu Long and Dong Nai and is characterized by and even and low-lying topography where big river systems are connected by many intertwined canals. Millions of tons of alluvium, rich in plant nutrients, is carried to the coast each year, together with a huge volume of fresh water. There are no prolonged floods here and very few storms affect the coastline. Data from 55 years of observation shows that only 8 storms had hit this coast. However, the northeast monsoon often causes rises in sea levels and subsequent floods. The seashore has many sunny days and high radiation of 130 kcal/m<sup>2</sup>/year, which is favourable for the growth of phytoplankton. The zone is affected by two tidal patterns, namely semi-diurnal tides from the East sea with a tidal range of 3-4 m and diurnal tides from the Gulf of Thailand with a smaller range of only 0.5-0.8 m.

The ecological conditions are favourable for the extensive development of mangroves. Moreover, this zone is near the Indonesian and Malaysian archipelagos, the places of origin for many mangrove species. Due to the warm streams and south-western winds which carry samplings and seedlings to this zone, the composition is rich and the tree sizes are the largest in the country.

## **2.2 Mangrove restoration efforts in Vietnam**

Vietnam has a long history of mangrove restoration efforts. Especially in the Mekong Delta, the need for restoration was high, after the devastating effects of the use of herbicides such as Agent Orange during the war. Hong (2001) describes the restoration efforts in Can Gio:



'Between 1978 and 1999, some 21,400 of the original 40,000 ha of mangroves were rehabilitated in Can Gio, a district of Ho Chi Minh City in southern Viet Nam that was heavily affected by herbicide spraying during the war. The main species planted were the fast-growing *Rhizophora apiculata* (the main economic species) and other species such as *Nypa fruticans*, *Ceriops tagal* and *Rhizophora mucronata*. From 1978 to 1994, 18,120 ha of *R. apiculata* and 1,031 ha of *Nypa* palm were replanted. The reforestation in Can Gio was mainly done by youngsters and schoolchildren. Consequently, the technical aspects of reforestation were neglected and the survival rate was low. In the first years of the *R. apiculata* plantation, because of the lack of experience, the planting density was too high.'

'Through the 1980s, the success rate of the rehabilitation was limited by inadequate management, continued fuelwood collection and conversion to shrimp ponds (see section on management and protection, below). By 1996, nearly 35,000 ha of mangrove forest had been replanted in Can Gio; of these, about 20,000 ha are now growing well. The mangrove flora is now fairly similar to that before the herbicide spraying, although the amounts and distribution are not the same. There are 72 mangrove species reported, 30 of which are true mangroves (species that can only grow in areas inundated regularly with tidal water, even if only once a year) and 42 associated mangrove species. Besides the mangrove flora, 95 species belonging to 42 families of inland plants dispersed by humans and animals have been found. Today, the mangroves in Can Gio are more diverse in community structure than before the war. An explanation for this is that in these mangroves, replanted species have mixed with naturally regenerated species.'

Also in the Red River delta, mangrove restoration efforts have started some time ago. Here the main driver is shore protection against storms, which occur much more frequently than in the Mekong Delta. Already back in 1994 the Red Cross started planting mangroves as a buffer against storm surges (Vanessa Uy at [www.mangroveactionproject.org](http://www.mangroveactionproject.org) accessed 6 December 2008). In 1993 a Japan based NGO called ACTMANG (Action for Mangrove Reforestation) started a project in three districts in northern Vietnam, Thai Thui (Thai Binh province), Tien Lang (Hai Phong city) and Tinh Gio (Thanh Hoa province). A total of 1,100 hectares of mangrove area has been reforested (see Table 1).

Table 1 Mangrove restoration organised under ACTMANG

location	Year	activities
Thai Thui (Thai Binh prov.)	1994	planted <i>K. candel</i> (120 ha),
	1996	<i>R. stylosa</i> and <i>B. gymnorhiza</i> (70 ha)
Tien Lang (Hai Phong city)	1994	transferred nursery techniques
		planted <i>S. caseolaris</i> (800 ha)
Tinh Gio (Thanh Hoa prov.)	1999	planted <i>K. candel</i> , <i>R. stylosa</i> (120 ha)

Source: Kogo & Kogo, 2000

These projects were executed in close cooperation with the local communities, which had already experience with planting two mangrove species: *Kandelia candel* (through propagules sowing) and *Sonneratia caseolaris* (transplanting of wildlings). A high

planting efficiency was observed: 10 persons per day per ha for *K. candel* with a spacing of 1m x 1m and 8.5 persons per day per ha for *S. caseolaris* with a spacing of 2m x 1m. For *S. caseolaris* nurseries were installed as wildlings occur only in small numbers in the field (Kogo & Kogo, 2000).

### 2.3 Species list

Table 2 provides an overview of the main (true) mangrove plant species that can be found in Vietnam, including their hydrological and soil preferences and occurrence in the 4 different zones.



*Mangrove forest near Vung Tau, South Vietnam*

Table 2 Mangrove flora and distribution in Vietnam (only true mangrove species listed)

Scientific name	life form	inun- dation class	soil and position	Zone			
				I	II	III	IV
ACANTHACEAE							
<i>Acanthus ebracteatus</i>	US	4-5	Loam, clay on river banks	+	+	+	+
<i>A. ilicifolius</i>	US	4-5	Loam, slit-clay with fine sand on river banks and estuaries	+	+	+	+
AVICENNIACEAE							
<i>Avicennia alba</i>	T	1-2	Deep mud, sea-face, river banks				+
<i>A. lanata</i>	T	2-3	Sandy mud			+	+
<i>A. marina</i>	T/ST	1-4	Deep sandy mud, sea face	+	+	+	+
<i>A. officinalis</i>	T/ST	2-4	Loam clay on river banks on degraded soil			+	+
BIGNONIACEAE							
<i>Dolichandrone spathacea</i>	T	4-5	Loam clay on river bank				+
COMBRETACEAE							
<i>Lumnitzetra littorea</i>	T	4-5	Loam firm mud, river banks			+	+
<i>L. racemosa</i>	T/ST	4-5	Clay, sandy loam, firm mud on river banks	+	+	+	+
EUPHORBIACEAE							
<i>Excoecaria agallocha</i>	ST/T	4-5	Clay, firm mud on river banks	+	+	+	+
MELIACEAE							
<i>Xylocarpus granatum</i>	T	2,3-5	Stiff mud on river banks, loam	+	+	+	+
<i>X. moluccensis</i>	T	4-5	Clay, river banks			+	+
MYRSINACEAE							
<i>Aegiceras corniculatum</i>	S	1-2-4	wet, sandy mud, sea face	+	+	+	+
<i>A. floridum</i>	ST	2				+	
PALMAE							
<i>Nypa fruticans</i>	P	3-5	River bank, low brackish water			+	+
<i>Phoenix paludosa</i>	P	5	Clay/loam, firm mud, degenerated soil			+	+
RHIZOPHORACEAE							
<i>Brugiera gymnorrhiza</i>	T	3-4	Loam, sandy mud, foot of limestone	+	+	+	+
<i>B. cylindrica</i>	T	3-4	Firm mud, not far from sea				+
<i>B. parviflora</i>	T	2-3	Soft mud, along river banks				+
<i>B. sexangula</i>	T	3-4	Loam, river banks				+
<i>Ceriops decandra</i>	S/ST	3-5	Firm mud, river banks, land fringe				+
<i>C. tagal</i>		3-4	Quite firm mud, under Rhizo canopy			+	+
<i>Kandelia candel</i>	T/ST	2-4	Loam, sandy mud, river banks	+	+	+	+
<i>Rhizophora apiculata</i>	T	2-4	Deep soft mud, river banks			+	+
<i>R. mucronata</i>	T	1-4	Deep soft mud, river banks, sandy mud			+	+
<i>R. stylosa</i>	T	2-4	Sandy shore, sandy mud & firm mud on river bank	+	+	+	+
RUBIACEAE							
<i>Schyphiphora hydrophyllacea</i>	ST	4-5	Sandy mud, river banks & clearings	+		+	+
SONNERATIACEAE							
<i>Sonneratia alba</i>	T	1-3	Deep soft mud, sea face			+	+
<i>S. caseolaris</i>	T	1-4	Soft sandy mud, river banks, estuary	+	+	+	+
<i>S. ovata</i>	T	4-5	Soft mud, salt water, islands				+
STERCULACEAE							
<i>Heritiera littoralis</i>	T	4-5	Sandy loam, river banks	+			+

Key life forms: T = tree; S Shrub; ST = Shrubby Tree.

Source: (Hong &amp; San 1993)

Inundation class:

- 1 = land flooded by all high tides  
 2 = land flooded by medium high tides  
 3 = land flooded by normal high tides  
 4 = land flooded by spring tides only  
 5 = land flooded by normal or equinoctial tides

Zones:

- I = Northeast coast  
 II = North plain coast  
 III = Central coast  
 IV = South plain coast

### 3 Mangrove functions, with special reference to storm and erosion protection

Mangroves are widely recognised for their importance in providing direct uses for local communities as well as for their ecological and protective functions. Below an overview of functions of healthy mangrove forests is given.

Table 3 Functions of a healthy mangrove forest

---

Direct productive functions:

- High quality construction timber and poles
- Fuel wood (high calorific value)
- Pulpwood
- Fodder for domestic animals
- Non-timber-forest-products (tannin, medicines, adhesives, etc.)

Ecological functions:

- Spawning & nursery grounds for fish and crustaceans,
- Maintaining delta building process (land forming)
- Soil conservation (along river and creek banks)
- Habitat for wildlife (birds, otter, crocodile, etc.)

Protective functions:

- Storm protection (hydraulic resistance against storm surge)
  - Shelter
  - Shoreline protection
- 



Figure 7 Fisherman on Inhaca island, Mozambique

Of special interest for this report is the protective function of a mangrove forest against storm surges and high winds. A general word of caution must be made in advance, however, to avoid misunderstandings. As described in Chapter 1, mangroves are typically found in sheltered and muddy shores, they usually do not naturally occur in areas directly affected by storms (Hong & San 1993). Shorelines that are exposed directly to winds and waves usually have coarse, sandy sediment foreshores and beaches that are totally unsuited for mangrove trees. Instead, mangrove forests can be found mainly in sheltered coastal habitats, such as along estuaries, lagoons, behind barrier islands and spits.

Especially in delta and coastal areas where a large natural belt of healthy mangrove exists, a significant protection against storms is possible. A well known example is the Bangladesh coast. Since 1822, a total of 69 extreme cyclones landed on the Bangladesh coast of which 10 hit the Sundarbans mangrove forest. However, a cyclone that lands on the Sundarbans causes less damage compared to the likely damage caused the cyclone of equal magnitude lands on the central and eastern part of the coast. Most of the cyclone damage is caused by the surge. For example, a cyclone that landed on the Cox's Bazar coast generated 4.3 m surge caused deaths of 11,069 people in 1985. On the other hand, when a similar cyclone landed on the Sundarbans in 1988, the number of fatalities was just half of the 1985 cyclone (Millennium Ecosystem Assessment 2005).

The protective function of mangrove forests can be split up into three components:

- Wave attenuation, mitigation of the hydraulic forces of storm surges and tsunamis;
- Storm protection through windbreak;
- Shoreline stabilisation, sediment retention and erosion control

### **Wave attenuation**

Especially after the 2004 Asian tsunami many studies and discussions arose regarding the ability of coastal forests to reduce the impact of tsunamis and storm surges. Forbes & Broadhead (2007) in their review on tsunami mitigation by forests report: 'Evidence from post-tsunami surveys, field research and model simulations strongly support the notion that coastal forests can provide significant mitigation of tsunamis and storm waves. All forest types, with the exception of altered forests, demonstrate the ability to mitigate tsunami energy and force, reduce flow depth and velocity, and limit inundation area. These forests include mangroves, beach forests and plantations.

Healthy, undegraded natural forests offer good protection to coastal areas, but plantations of closely-spaced trees with low, widely-branching canopies or significant ground vegetation can also provide equally good protection. Altered forests found around homesteads, hotel resorts and other development areas, on the other hand, are generally too widely-spaced, lack ground vegetation, and have introduced trees species not adapted to coastal wind and wave forces, and so are structurally weaker.

Notwithstanding the positive role many coastal forests have played, other forests proved to be ineffective against the tsunami waves. Evidence shows that coastal forests failed where waves were very large; forest width was limited; or trees were widely spaced, of small diameter or without branches near ground level. Any forest type could be susceptible, though degraded natural forests, altered forests and plantations are more likely to be deficient in one respect or another' (Forbes & Broadhead 2007).

Quantitative data on the mitigating effect of mangroves is still limited. Coastal forest generally collapse by tsunami of over 4 m height. However, in case of tsunami wave height of 3 m, coastal forest with forest density of 30 trees per 100 m<sup>2</sup>, the diameter of trunk of 15 cm, and forest width of 200 m can reduce tsunami inundation depth to 50-60 % and flow velocity to 40-60 % (Nippon Koei, 2005).

It has to be realised that the mitigating effect on storm surges can be much higher than on a tsunami. Especially the energy of wind waves induced by hurricanes or typhoons can be dissipated significantly by mangroves.

**Windbreak**

Villages adjacent to the mangroves may benefit from wind protection. Forest shelter-belts may reduce wind speeds up to an area of about 20 to 30 times the height of the trees. Mangroves are generally not very tall (up to 10 m), hence their impact on wind velocity is considered limited to an area of about 0.25 km. However, with very high wind velocities occurring during cyclones and super cyclones, tall trees may bend, break or be uprooted, thus considerably reducing their wind break function. Shelter-belt wind breaks are most effective in normal conditions (Mohapatra & Bech, 2001)

**Erosion control and sediment retention**

Mangroves are capable of reducing coastal erosion due to their positive effect on local sedimentation. An important precondition for the sustenance of this feature is that the tidal movement of water in and out of the mangrove forest is not disturbed (e.g. by detached breakwaters). Research into the sediment retention properties of a mangrove along the upper Gulf of Thailand revealed the process of onshore sediment transport by tidal filling. The intertidal areas along the coast, covered with mangroves, are flooded at every high water. In particular during the Southwest monsoon the flood brings in sediment-laden water. These sediments are mobilised by the larger waves. As most of the suspended sediments settle in between the roots of the mangrove trees around slack water the ebbing water contains very little sediment. This process results in net accretion of the area (Winterwerp et al. 2005).

## 4 Successes and failures of mangrove restoration programmes

In Bangladesh, 120,000 ha of mangroves have been planted since 1966 (Saenger & Siddiqi, 1993, cited in Field, 1998). Nowhere else have mangroves been planted on such a large scale. In this case the mangroves were planted on newly accreted land. Two species of mangrove, *Sonneratia apetala* and *Avicenna officinalis*, dominate the mangrove plantations, usually as monospecific stands. According to Field, the planting of mangroves has been highly successful in protecting and stabilizing coastal areas and in providing substantial timber production (Field 1998).

However, Lewis (2005) states that 'in spite of the success in Bangladesh, most attempts to restore mangroves often fail completely, or fail to achieve the state goals' (Lewis, 2005, page 404). For instance:

- Between 1989 and 1995, 9,050 ha of mangroves were planted in West-Bengal, India, with only a 1.52% success rate (Sanyal, 1998 cited in Lewis 2005).
- In the Philippines, during the past 2 decades, more than 44,000 hectares, mostly non-mangrove mudflats, sandflats and seagrass beds had been planted with mangroves, using almost exclusively the genus *Rhizophora*. In these non-mangrove areas, seedlings experienced high levels of mortality and, in the few that survived (apparently through stubborn, expensive replanting), have displayed dismally stunted growth relative to the corresponding growth performance of individuals thriving at the high intertidal position and natural mangrove sites' (Samson & Rollon 2008). Despite heavy funds for massive rehabilitation of mangroves in the Philippines over the last two decades, the long term survival rates are generally low at 10-20% (Primavera & Esteban 2008).
- In Thailand, a massive 5-year mangrove replanting programme was launched by the Thai Government during 1991-1996, targeting to replant 40,000 ha. According to Suwannodom et al. (1998) this programme cannot be evaluated as successful, except in a few cases in Southern Thailand where a community-based management approach was followed (Erftemeijer & Lewis III 1999).
- An area of about 580 ha of muddy tidal flat on the seaward side of a sea dyke in Ha Tinh province, Vietnam, was planted with mangroves between 1989 and 1993 sponsored by various NGOs, to achieve a sustainable greenbelt for coastal protection against natural surges and erosion. Survival rates were around 40% (Hong, 1994 cited in (Erftemeijer & Lewis III 1999).
- In the case of the Xan Thui and Tien Ha coastal reserves in northern Vietnam, it was found that despite restoration efforts, the mangroves have become fragmented and survival rates for replanting efforts are low (Seto & Fragkias 2007).





Figure 8 Nursery in Banda Aceh, Indonesia

Primavera & Esteban (2008) attribute poor survival of mangrove stands mainly to two factors: inappropriate species and sites. With respect to the experiences in the Philippines, the favoured but unsuitable *Rhizophora* are planted in sandy substrates of exposed coastlines instead of the natural colonizers *Avicennia* and *Sonneratia*. More significantly, planting sites are generally in the lower intertidal to subtidal zones where mangroves do not thrive rather than the optimal middle to upper intertidal levels.

Mangrove planting on lower intertidal mudflats is to be discouraged or at least reconsidered (Samson & Rollon 2008). Erfteimeijer & Lewis (1999) report: *[...] mangrove afforestation on mudflats is not easy, it is often characterized by high mortality rates caused by factors such as barnacle infestation, smothering or burial from excessive sedimentation, wave action and so forth. [...] In areas where sedimentation is substantial and mudflats are accreting, such as in the case of Bangladesh and some localized estuaries, success rates are likely to be higher*.



Figure 9 Barnacles (*Chthamalus stellatus*) (source: Wikipedia)

Moreover, intertidal mudflats constitute an important habitat in themselves, supporting a high biodiversity and biomass of benthic invertebrates, sustaining productive fisheries, providing feeding grounds for migratory shorebirds and supporting the socioeconomic livelihood of many coastal villagers who collect shellfish and crabs (Erfteimeijer & Lewis III 1999).

The single most important factor in designing a successful mangrove restoration project, according to Lewis (2005) is determining the normal hydrology (depth, duration and frequency of tidal flooding) of existing natural mangrove plant communities (as a reference site) in the area in which one wishes to do restoration.

Samson and Rollon (2008) indicate a large number of reasons for failure of mangrove restoration projects in the Philippines, grouped into three clusters: ecological,



social/institutional and economic (see Table 4). Probably many of these factors also apply to mangrove restoration initiatives in other countries.

Table 4 Ecological, social/institutional and economic factors influencing success of mangrove reforestation initiatives in the Philippines (Samson & Rollon, 2008)

ecological	social/institutional	economic
Lack of baseline ecological assessment of the target areas prior to mangrove rehabilitation	Lack of clearly defined goals of mangrove management	Food security
Site and species unsuitability	Lack of sustainability mechanisms such as monitoring and evaluation system, maintenance and financing support	Low perceived economic values of mangrove habitats and hence aquaculture development was favoured
Monospecific forest ( <i>Rhizophora</i> spp.)	Aquaculture as a development strategy	Lack of funding for sustainability projects
Poor growth performance	Lack of coordination among concerned agencies	Long waiting time for economic returns
Infestations by barnacles and other pests	Weak law enforcement, especially on the moratorium on fishpond development and cutting of mangroves	Mismanagement of funds
Natural calamities	Lack of interest by the local community	
Domestic and agricultural pollution	Conflicting interests of various users	
Animal grazing	Reforestation contracts benefited only a few	
Sand accretion		

Besides the ecological requirements for successful mangrove restoration, socioeconomic aspects are also very important. Local ownership of a restoration project and effective community participation are considered crucial to achieve sustainable impacts (Erftemeijer & Bualuang 2002; Primavera & Esteban 2008).

A relatively new and potentially successful strategy is the revegetation of disused brackish-water fish and shrimp ponds (Stevenson et al. 1999; Samson & Rollon 2008; Primavera & Esteban 2008). The upper to middle intertidal sites that are ideal for mangroves are in many countries occupied by culture ponds. Disease problems have caused abandonment in India, the Philippines, Taiwan and Thailand. Poor water quality and poor site selection have caused production failure in Sri Lanka and Indonesia, and problems with acid sulfate soils have caused abandonment in Vietnam and Cambodia (Stevenson et al. 1999). In the Philippines, a large proportion of these ponds (in the thousands of hectares) are underutilized or totally abandoned.

Although there have been many attempts at restoration of mangrove in degraded habitats, there are few documented cases of pond restoration (cf. Macintosh et al. 2002). The application of the five steps to successful mangrove restoration outlined in

the next chapter is also applicable to disused aquaculture ponds. Especially the location and size of breaches in the dikes or bunds that allow reentering of the tides requires specific attention (see section 5.4).

## 5 Five steps for successful mangrove restoration

In this Chapter, five steps for mangrove restoration are summarized, based on the manual 'Five Steps to Successful Ecological Restoration of Mangroves', written by Ben Brown and Robin Lewis and was published by the Mangrove Action Project, in April 2006 in Yogyakarta, Indonesia. Readers are encouraged to use this manual as it shows many practical tips and drawings that can help making mangrove restoration or creation projects successful.

Five critical steps are necessary to achieve successful mangrove restoration:

1. Understand the autecology (individual species ecology) of the mangrove species at the site; in particular the patterns of reproduction, propagule distribution, and successful seedling establishment.
2. Understand the normal hydrologic patterns that control the distribution and successful establishment and growth of targeted mangrove species.
3. Assess modifications of the original mangrove environment that currently prevent natural secondary succession (recovery after damage).
4. Design the restoration program to restore appropriate hydrology and, if possible, utilize natural volunteer mangrove propagule recruitment for plant establishment.
5. Only utilize actual planting of propagules, collected seedlings, or cultivated seedlings after determining (through steps 1-4) that natural recruitment will not provide the quantity of successfully established seedlings, rate of stabilization, or rate of growth of saplings established as objectives for the restoration project.

### 5.1 Understand mangrove ecology

#### Mangrove reproduction and dispersal

After flowering and pollination, many mangroves develop viviparous seeds called propagules. Vivipary is a characteristic in which the propagules develop early and germinate while still on the parent tree receiving food to keep the propagule healthy for a long time after they fall into the water. This enables the propagule to float with the tides until it comes to rest in a good place to grow. The propagules then put down roots into the mud and use stored food to grow quickly into a young tree.

Like the coconut palm, mangroves have floating propagules. Because of their various shapes and sizes propagules of separate mangrove species float differently.

Small propagules such as *Avicennia* spp., *Aegiceras* spp. and small mangrove fruits such as *Sonneratia* spp. float far and wide on normal tidal currents. Because of their small size, these fruits and propagules easily reach new or disturbed areas and, if the soil conditions are right, become quickly established. These species are known as *colonizers*.

Large propagules such as *Rhizophora* spp. and large mangrove fruits such as *Xylocarpus* spp. are not as easily dispersed as smaller fruits and propagules. The larger propagules may have difficulty entering into areas where normal tidal exchange has been blocked such as is often the case in disused shrimp ponds.

Before addressing local issues concerning hydrology (Step Two), it will be useful to understand local mangrove seedling dispersal. Check for each species the season when seeds are dispersed and the distance from the rehabilitation site to the seed source.

Mangroves often occur in zones, which are groupings of the same species of mangrove within a whole mangrove forest. Zonation occurs because different species of mangrove need particular conditions to grow. Some species require more water than others. Some species are able to tolerate more saline soils than others. Which species occurring in a zone depends on:

- a) depth, duration and frequency of tidal inundation
- b) soil salinity
- c) amount of fresh water available

Using the information in Table 2, you may find out which types of mangrove species in your area are normally occurring and which soil and hydrological conditions these species need.

## 5.2 Understand hydrology

Step two deals with understanding the normal hydrologic patterns that control the distribution and successful establishment and growth of targeted mangrove species. The single most important factor in designing a successful mangrove restoration project is determining the normal hydrology (depth, duration and frequency of tidal inundation, and of tidal flooding) of existing natural mangrove plant communities (a reference site) in the area you wish to restore.

### Water Depth/ Substrate Height

- Each mangrove species thrives at a different substrate level which in some part dictates the amount of exposure the mangrove will have to tidal waters. For instance most *Avicennia* species thrive at lower substrate levels (deeper water) while *Heritiera* sp. thrive inland at higher substrate levels (shallower water)
- You will need to study tide charts for your area and begin to take measurements in healthy mangroves relating substrate height/depth to the various species of mangroves that exist at each depth.
- When rehabilitating a destroyed mangrove area, one of the keys is going to be to imitate the slope and topography (relative height) of the substrate from a nearby healthy mangrove forest.

### Frequency of Inundation

It will be essential to note the critical periods of inundation and dryness that govern the health of the forest. Among the most widely used approaches for mangrove zonation is the following scheme based on degree and frequency of tidal inundation developed by Watson (1928) from his work on Malayan mangroves Table 5.

Table 5 Zonation for mangroves based on flood characteristics

Class	Flooded By	Height above chart datum in feet (meters)	Flooding Frequency (times/month)
1	All high tides	0-8 (2.44)	56-62
2	Medium high tides	8-11 (3.35)	45-59
3	Normal high tides	11-13 (3.96)	20-45
4	Spring high tides	13-15 (4.57)	2-20
5	Abnormal (equinoctial tides*)	> 15 (> 4.57)	2

\*Equinoctial tides are extremely high or low tides which occur twice a year around March 21 and September 23.

An example of how Watson's inundation classes can be applied may help to clarify things. Below, Watson's "Inundation Classes" are applied to the mangroves of Vietnam (see Table 2 for the species list and their inundation class requirement).

**Class 1:** Mangroves in this class are inundated by all high tides. Predominant species found in these environments are *Rhizophora mucronata*, *Sonneratia alba* and *Avicennia alba*. *R. mucronata* prefers areas under greater freshwater influence. In Vietnam, pioneering *Avicennia* and *Sonneratia* forests may dominate this zone.

**Class 2:** Mangroves in this class are inundated by all medium-high tides. Predominant species are *Avicennia alba*, *A. marina*, *Sonneratia alba*, *Rhizophora mucronata*, *R. stylosa* and *R. apiculata*.

**Class 3:** Inundation by normal high tides. Most species thrive under these conditions. A large part of the mangrove ecosystem falls into this class which exhibits the highest biodiversity of mangroves. Common species are *Rhizophora* spp. (often dominate), *Bruguiera* spp., *Ceriops* spp. and *Xylocarpus granatum*.

**Class 4:** Inundation only during spring tides. Area generally too dry for *Rhizophora* spp., but it may be present in low numbers. Common species are *Bruguiera* spp., *Xylocarpus* spp., *Lumnitzera littorea* and *Exoecaria agallocha*.

**Class 5:** Inundation only during equinoctial or other exceptionally high tides. Predominant species are *Bruguiera gymnorrhiza* (dominates), *Lumnitzera* spp., *Nypa fruticans*, *Heritiera littoralis* and *Exoecaria agallocha*.

Below two examples of cross sections of mangrove forests are given, one for the northern Vietnam coast (Figure 10) and one from the southern coast (Figure 11).

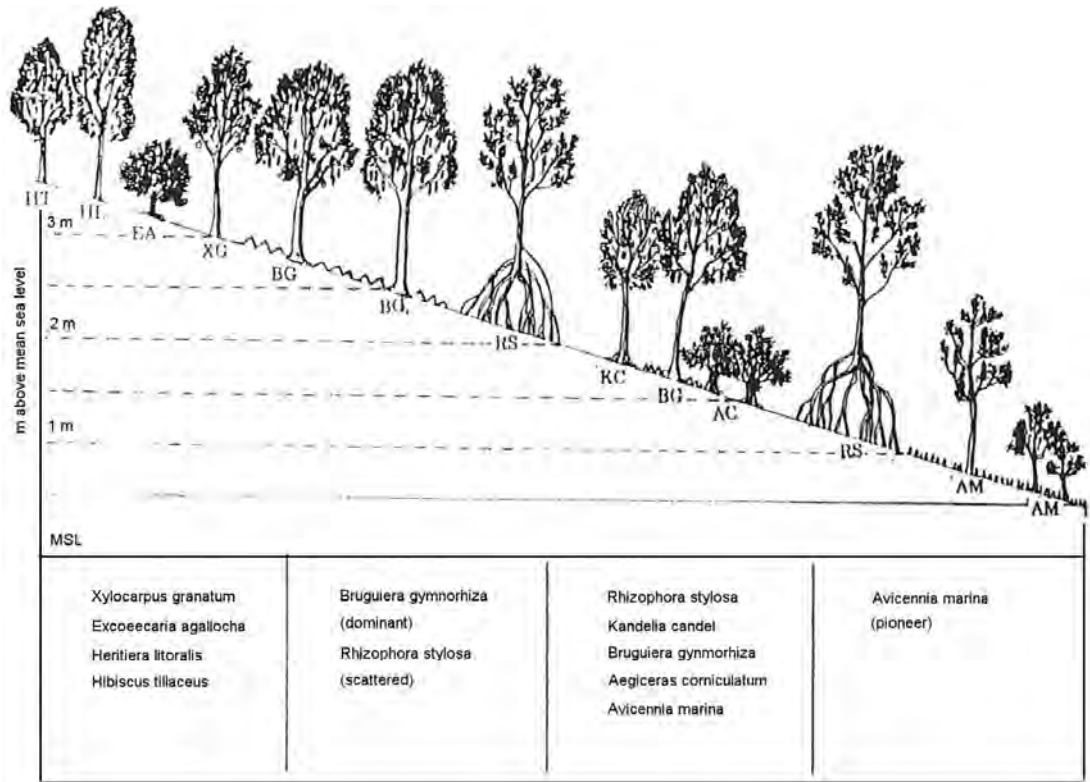


Figure 10. Cross section of the mangrove vegetation at Chua Cape, Tien Yen district, Quang Ninh (northeast coast). Source: Hong & San, 1993.

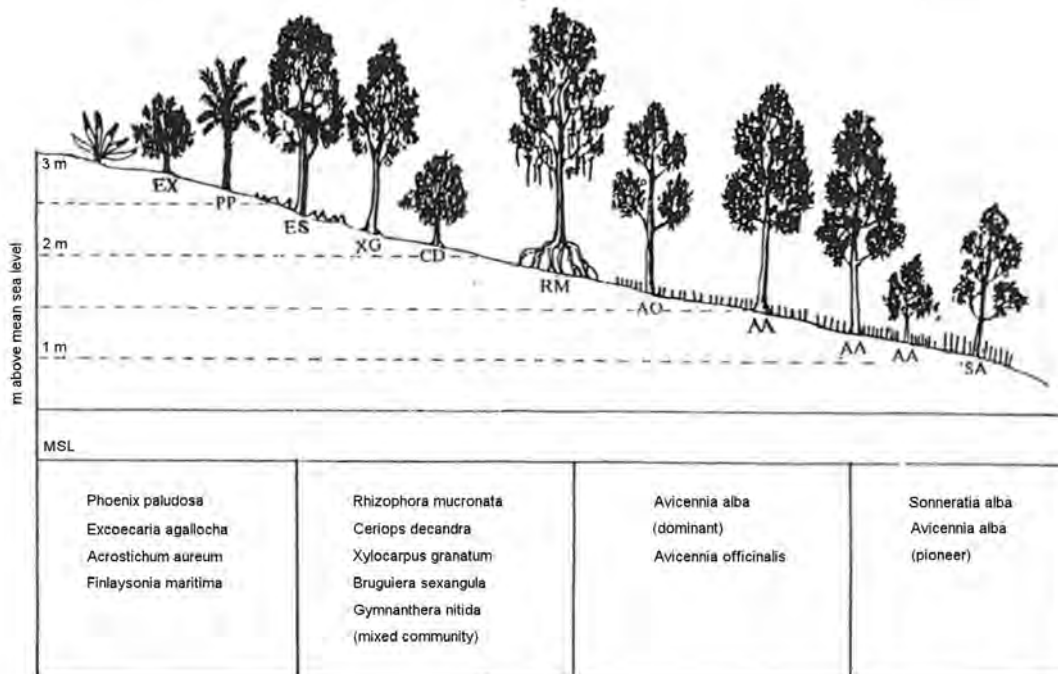


Figure 11. Cross section of the mangrove forest in the brackish water area of Ham Luong estuary (southeast delta). Source: Hong & San, 1993.

### 5.3 Assess what has changed (why no natural recovery or mangrove growth)

In Step 3 we assess any modifications of the original mangrove environment that currently prevent natural secondary succession. And for areas where there originally were no mangroves, we need to assess why there is no natural growth of mangrove.

#### Determining stresses

A restoration project should first look at the potential existence of *stresses* such as blocked tidal inundation that might prevent secondary succession from occurring, and plan on removing that stress before attempting restoration. Often, human activities have damaged or destroyed mangrove ecosystems. Disused shrimp ponds, clear-cut mangrove areas for charcoal production, or mangroves which are drying out as a result of nearby changes in hydrology (due to construction of dikes, levees, roads, upland deforestation) are all areas where mangrove rehabilitation may be attempted. In these cases, before planting mangroves or attempting another type of restoration it is imperative to determine if the area is presently suitable for mangrove growth. If not, what are the stresses preventing growth of mangroves? Work together with the local community to help determine how the mangrove area has changed over time and why.

Examples of Stresses:

- Lack of groundwater
- Blockage of tidal exchange
- Hypersaline or acid sulfate soils (usually after intensive shrimp farming)
- Overgrazing by goats, camels etc.
- Shoreline abrasion and lowered substrate level

### 5.4 Restore hydrology and allow natural recruitment

Step four involves the designing of the restoration program to restore appropriate hydrology and, if possible, utilize natural volunteer mangrove propagule recruitment for plant establishment.

#### Regrading substrate

One basic theory behind hydrological rehabilitation is to recreate a natural slope and substrate height which will support normal tidal flow, and the natural re-establishment and growth of mangrove seedlings. Dike walls of disused shrimp ponds need to be levelled, and ditches need to be filled. If you can not level dike walls entirely, opening strategic breaches may be enough to support the exchange of tidal waters and should lead to further degradation of the dike walls over time.

The final graded topography of a site needs to be designed to match that found in an adjacent reference forest and checked carefully by survey during and at the completion of construction.

#### Tidal streams

Tidal streams run through mangrove areas from the terrestrial edge to the sea. They are narrower upstream, widening as they meander to the coast. Tidal streams are fed from the landward edge by groundwater, springs, runoff and streams. Because they are connected to the sea, tidal streams facilitate the exchange of tidal waters in and out of the mangrove area. When tidal streams are disturbed, a mangrove may dry out, and die over time.

In the case of rehabilitating disused shrimp ponds, it may be enough to create “strategic breaches” in the dike walls. In this case, less rather than more cuts in dikes is better. The reason is that the *tidal prism* (the amount of water that can enter an opened pond

between high and low tide) needs to be channeled to the extent possible through a few key openings that are wider downstream than upstream. This mimics the normal operation of tidal streams in mangroves (see previous page). Fewer openings produce greater velocities as the flow is restricted, which in turn produces scouring, which keeps the human-made openings open and reduces the chances of siltation and closure. Too many openings distribute the tidal prism over many points, reduce the velocity, and induce less scour and more siltation.

### **5.5 Planting mangrove if there is no natural recruitment**

Only utilize actual *planting* of propagules, collected seedlings, or cultivated seedlings after determining (through steps a-d) that natural recruitment will not provide the quantity of successfully established seedlings, rate of stabilization, or rate of growth of saplings established as objectives for the restoration project.

#### **Assessing natural recruitment**

Determine by observation if natural seedling recruitment is occurring once the stress has been removed. This means monitoring. Are seedlings coming into the area? Are they taking root? What is the density of seedlings per hectare? You will probably want a minimum of 1000 seedlings per hectare with 2500 seedlings per hectare as a good figure. How are they growing? Have they survived the dry season?

*Note:* Even if mangroves survive for several years in your restoration area they may remain stunted or even die out unless hydrological conditions are truly supportive of mangrove growth.

If seedlings have established in the rehabilitation area, but at lower densities than hoped for, you may consider planting. But planting costs can double the overall cost of a project and may limit the biodiversity of the site due to competition from planted mangroves (usually only one or two species) with volunteer species (5-15 species).

If no seedlings have established in the area, even though a natural seed source is nearby, you will have to re-evaluate the effectiveness of your hydrological rehabilitation. Perhaps there are still blockages to normal tidal flow or there is a disturbance in the seed source.

#### **Planting considerations**

There are four sources of seeds/propagule for mangrove planting:

1. Raising seedlings in a nursery from local seed source
2. Direct planting of propagules
3. Transplanting of wild seedlings
4. Broadcast fruits/propagules directly on the water surface during incoming tides.

The collection and distribution by hand onto the water's surface of seeds or seedlings from natural collection areas stimulates natural re-growth of mangroves. Propagules and seeds suitable for collection are commonly found along high tide lines. If an area lacks natural seed sources, seeds may be collected from another area that has a lot of seeds, transported to the restoration site, and as the tide turns and flows into the restoration site, the seeds can be broadcast onto the water and allowed to float and find their own suitable location for germination. It is a good idea to do this on a series of different tides, like the neap, the spring, and several in between during the month of maximum availability of the seeds.

Additionally, more detailed guidelines on seed handling and planting requirements are given in Annex 1.



## 6 Monitoring and maintenance

Once the restoration programs have been completed, it is essential to monitor recovery processes (or lack thereof) of the plots. A summary of parameters to be monitored in a restoration project is given in Table 6. These are similar activities that would normally be taken in any forestry project. Three to five years is often specified as the monitoring period in small-scale rehabilitation programmes but more realistically ten years should be the monitoring period. For large afforestation projects up to 30 yr may be necessary (Field 1998).

Table 6. Monitoring and maintenance of mangrove rehabilitation programmes

Action	Comment
Take regular aerial photographs of the site	Effective way of getting an over view
Monitor mangrove species that develop	Checks correctness of original provenance of propagules and seeds. Mis-identification of seeds and propagules can lead to failure
Monitor growth as a function of time	Common measurements are: density of seedlings or trees (no. of trees ha per year), diameter at breast height (DBH) (cm), height (m) and volume (m <sup>3</sup> per ha per year). The annual increments of these parameters should be determined
Monitor growth characteristics	Determinations could include: stem structure, node production, phenology, fruiting and resistance to pests
Record level of failure of seedlings	Provide a scientific reason for lack of success
Record impact of pests and diseases	Note nature of pests and diseases and steps taken to eradicate the problem
Record level of rubbish accumulation	Note source of rubbish and steps taken to minimize the problem
Record impact of grazing, cutting, fish ponds and fishing	Note source of such external pressures and the steps taken to minimize the problems, e.g.: fencing; law enforcement
Adjust density of seedlings and saplings to an optimum level	The degree of thinning, replanting or natural regeneration should be noted in detail. Growth should be monitored
Estimate cost of rehabilitation project	The estimation of cost should include all aspects of the undertaking including the purchase of land and any legal costs
Monitor impact of any harvesting	This should be part of any long-term record of a rehabilitation project
Assess characteristics of a rehabilitated mangrove ecosystem	This involves detailed measurements of the fauna, flora and physical environment of the new mangrove ecosystem and comparison with nearby similar undisturbed mangrove ecosystems
Measure the success of the rehabilitation project against the original criteria that were established	This is rarely done but is an essential outcome

Source: (Field 1998)

## 7 Costs of mangrove restoration

In general, costs of mangrove reconstruction or creation are poorly documented (Lewis III, 2001). Obviously, the costs involved in mangrove restoration depend on the method of restoration. For instance, it makes difference if only preliminary hydrological preparation works are executed and natural regeneration is anticipated or if also mangrove seedlings are planted. The costs of mangrove restoration in Thailand was estimated at around 200 US\$ per hectare for hydrologic restoration, or 700 US\$ per hectare if planted (Lewis 2001).

Estimates of the costs of establishing rehabilitated mangrove stands are presented in Table 7. These costs are based primarily on the cost of labour for the activities described. Survey research was carried out in 1994. Planting of 1 hectare of mangroves required 95 work days or VND 522,000, as shown in the table. The estimates are averaged across three districts, with variations in costs dependent on where the seedlings were obtained. The planting and handling fees for seedlings obtained from forests in the area under rehabilitation are not significant compared to costs for collecting, handling and transportation for other areas which increase depending on the distance from the seedling source site to the planting site. The seed mortality rate between time of collection and time of planting adds an additional cost factor. For some mangrove species, such as *Sonneratia* sp., *Avicennia* sp., *Aegiceras* sp. and others, planting directly on mudflats is unsuccessful due to the exposure to strong wind and wave forces which wash away the seedlings. The cost of raising such species in a nursery and transplanting them at eight months old is relatively high, with fees for maintaining the nursery, care, protection and transportation adding to overall expenditure. The costs of establishing a stand, including planting, pruning & thinning and protection occur mainly in the first year. Maintenance from the second year on, incurs an estimated annual expenditure of VND 82,500 per hectare. The cost of thinning occurs in years 6, 9, 12, 15 20 and 25 (Tri et al. 1998).

Table 7 Costs of mangrove rehabilitation in Vietnam (data from 1994)

Activity	Cost (000 VND per ha)
seed collection	137.5
Transportation	110
Soil preparation and inputs	82.5
Planting	110
Maintenance	82.5
<b>TOTAL</b>	<b>522.5</b>

Source: Tri et al. (1996)

These costs seem rather low. For instance, based on a press release from the Ministry of Agriculture and Rural Development (see box), a huge rehabilitation project for 100,000 ha will require a budget of 2.5 trillion VND. This equals 25 million VND per ha, i.e. fifty times as much as the costs reported by Tri et al. (1996). Of course the data from Tri et al. are already 14 years old, and would need to be increased for accounting of the inflation rate to get current values.

**Box: Mangrove rehabilitation project announced.****Ministry plans to grow 100,000 hectares of mangrove forest**

(Intellasia | Saigon Times Daily Nov 8, 2008 )

The Ministry of Agriculture and Rural Development Vietnam has plans to plant 100,000 hectares of mangrove forest between now and 2015 to compensate for the loss of mangrove forest area over the last six decades. The project, which was submitted to the government last month and requires a total budget of 2.5 trillion dong, aims at raising the mangrove forest area from 209,000 to 307,000 hectares by 2015, said Nguyen Quang Duong, deputy director of the ministry's Forestry Department.

Macintosh & Ashton (2002) mention 320 US\$/ha for the direct planting of *Rhizophora* in the Mekong Delta, including land survey, site preparation and protection. For the Red River Delta, the costs of direct planting and protection of mainly *Kandelia* propagules, a figure of 84 US\$/ha is given. For all project costs included 164 US\$/ha is mentioned.

An analysis on a range of programs in the Philippines demonstrated that low-cost locally led projects have a much higher rate of success than high-cost government-led projects. Typical costs of mangrove rehabilitation projects in the Philippines are between 200 and 500 US\$/ha, but also low-budget project costs exist (in the order of 80 US\$/ha). Surprisingly these cheap projects have been among the most successful, which indicates that money alone is not sufficient. Aside from modest funding, these projects have shared a number of features, such as regular maintenance by local residents and co-management with local governments (Primavera & Esteban 2008).

## 8 Conclusions

Mangroves are a precious resource as they exhibit many useful functions for mankind. Unfortunately, this resource is under high pressure from coastal developments, such as aquaculture development, timber harvesting and alteration of the hydrologic regime. Therefore, the rehabilitation of mangrove forests has become an important coastal management measure.

In Vietnam mangrove rehabilitation has a long history and gained momentum after the war that destroyed huge forested areas, especially in the Mekong Delta. In addition, in various places mangrove have been and still are being planted specifically as a way to protect shorelines and seadykes from wave attack. The success of such projects highly depends on using the ecological knowledge describing the physical conditions under which mangroves thrive. From the information assembled in this report based on a brief desk study, the following conclusions can be drawn:

- Despite the many projects worldwide on mangrove restoration or afforestation, there is a considerable shortage on documented evidences of their long term success. Recent studies from several countries (e.g. Thailand, the Philippines) show that the survival rate of young mangrove stands in rehabilitation projects is varied but sometimes extremely low.
- One of the main reasons for failure is that mangroves are planted in the wrong location, e.g. on lower intertidal mudflats or even subtidal zones (unsuitable for all species) or on sandy substrates of exposed coastlines where most mangrove species do not thrive. Of utmost importance for success is the combination of proper site selection and choice of the right mangrove species.
- Most successful afforestation results are usually gained at places where mangroves previously existed, but were converted into other land use, for instance aquaculture. Provided that the original hydrology is restored, the rehabilitation of disused, abandoned or otherwise poorly producing shrimp or fish ponds, into mangrove forest can be very successful and highly sustainable and also leading to increased safety against storms.
- Using the five steps for mangrove restoration, as developed by Lewis (2005), provides a guidance for improved success. As the description of these steps indicate, its implementation implies some fundamental knowledge of mangrove ecology and hydrology, local knowledge on the hydraulic and sediment conditions and skilful engineering to restore or improve the shoreline conditions to favour mangrove growth.
- Furthermore, besides ecological and engineering issues, rehabilitation also involves important socioeconomic considerations. Local ownership and effective community participation are often crucial to achieve sustainable impacts (see Erfemeijer & Bualuang, 1998).
- Therefore, a successful mangrove project necessitates interdisciplinary teamwork, not only with various experts, but also in close cooperation with local stakeholders.

## 9 Reference List

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## ANNEX 1

Guidelines from: PCARRD, 1991. *The Philippines recommends for mangrove production and harvesting*. Los Banos, Laguna, 96 pp. (Philippine Council for Agriculture Forestry and Natural Resources Research and Development).

### Seed Collection

- Timing of seed production varies from place to place and tree species
- Collect local seeds to ensure survival and adaptation of young plants to planting site and reduce the incidence of seed damage because of handling and transport
- Collect only mature seeds (immature seeds often don't survive)
- Tree collection of seeds is easiest at high tide from a boat. Ground collected seeds have a higher incidence of insect attack and are to be used as little as possible

### Seed quality

- Discard abnormal and injured seeds.
- Eliminate seeds with holes (even pin sized) because these are usually infested by a beetle *Poecellips fallax*. Infested seeds can easily contaminate the other seeds

### Seed Handling and Transport

- Retain pericarp (brown cap structure in *Rhizophora*) to provide protection to the shoot
- Keep seeds under a shed and cover with green banana leaves to prevent excessive loss of seed moisture
- Bundle seeds in 50s or 100s to facilitate counting and handling
- Keep seeds horizontal and covered with moist sacks to properly protect from heat when transporting

### Seed storage

- Clean and treat the seeds with fungicide (e.g. Benlate) and insecticide (e.g. Azodrin) at manufacturers specification before storage
- Air dry seeds for one day
- Place seeds in plastic bags, seal and keep at room temperature (can keep like this for 1 to 4 months and still have 60-90% germination depending on the species)
- *Rhizophora* seeds can be kept in a shed under room temperature for two weeks without adversely affecting viability, as long as don't get wet

### Seedling production

- *Rhizophora* can be directly seeded by placing hypocotyl end vertically in mud and removing pericarp
- *Ceriops* and *Bruguiera* although have shorter propagules can be planted directly in less inundated areas
- *Sonneratia* and other small seed mangrove species should be raised in a nursery. Best *Sonneratia* germination obtained if fruits are soaked in tap water for 7 days, mashed and seeds sown on flooded seedbeds using waterlogged mangrove soil.
- In nurseries use mangrove forest top soil in polyethylene plastic bags, direct sow seeds, place under partial shade and irrigate daily with brackishwater
- *Avicennia* and other small seed mangrove species wildlings (wild seedlings) can be transplanted to planting site successfully. Best size range for *Avicennia* is 60 to 90 cm tall. Can be planted earthballed or bareroot. Bareroot collected wildlings must be placed in plastic bags to prevent roots drying

### Selection of Planting Site and Species

- Mangrove zonation results from the combined effects of tidal inundation, exposure to wind, waves and water currents, soil properties, morphology of species, salinity, light and

species association. Environmental factors and natural mangrove zonation should be taken into account in determining what species are particularly suited to the planting site.

- Seaward zone - daily inundated. Soil ranges from sandy to sandy loam, mudflat or coralline type. Usually inhabited with *Avicennia*, *Sonneratia*, *Aegiceras* and *Rhizophora mucronata*.
- Middle zone - daily inundated except during neap tides. Soil clayey, silty to silty clay. Usually inhabited with *Avicennia*, *Aegiceras*, *Bruguiera*, *Ceriops*, *Excoecaria agallocha*, *Lumnitzera racemosa*, *Scyphiphora hydrophyllacea* and nipa.
- Landward zone – unaffected by tidal inundation over long periods of time except during high Spring tides. Soil clayey to silt clay. Vegetation highly diverse because of the presence of mangrove associates, vines and epiphytes. Mangrove species similar to middle zone but can also include *Acanthus*, *Heritiera littoralis*, *Barringtonia racemosa*, *Hibiscus tilaceus* and *Thespesia populnea*
- Riverine fringes at mouths of rivers commonly have *Avicennia*, *Aegiceras* and *Rhizophora* species and in interior riverbanks these species and *Bruguiera* and *Xylocopus granatum* can be found

### Preparation of Planting Site

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

### Planting

- Use species that match zonation
- Direct seeding is recommended as entails less labour costs and has high survival rate.
- On soft ground push seeds 1/3 to 1/2 of the total length of the hypocotyls. On hard grounds firstly dig hole and plant 1/4 to 1/3 total length of hypocotyls. Best spacing 1 m x 1 m (Gan, 1995).
- Wildlings are directly planted on same day collected. Hole dug to freely accommodate earth and roots, ideal spacing 2 m x 2 m.
- Proper timing is critical for success. Should coincide with season of available mature seeds, calm weather and long days of low tide during the day

### Protection

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



- Diseases. Cuts can serve as entry for microorganisms. To prevent infection coat with coal tar or paint.
- Weeds. *Acrostichum* fern forms dense, tall thickets when canopy opens up. Natural colonization is difficult and survival of seedling reduced. Fern can be manually uprooted.

## Glossary

Alluvium	sediments deposited by a river
Autecology	The study of individual species in relation to its environment
Barnacle	a type of arthropod (Crustaceans) that lives in shallow and tidal marine waters, attaching themselves permanently to a hard substrate
Bioturbation	reworking sediments by living organisms, such as crabs and worms
Crustacean	a group of arthropod species, including various familiar animals, such as crabs, lobster, crayfish and shrimp
Epiphytes	plants that grown on other plants
Equinoctial	referring to the equinox (the astronomical event when the sun is directly above the equator)
Euryhaline	capable of tolerating a wide range of salt water concentrations
Fungicide	a chemical that kills fungi
Herbicide	a chemical that kills vegetation, e.g. by defoliation
Hypocotyls	the part of a germinating seedling bearing the embryonic leaves
Lenticels	pores on leaves and trunk of a plant that allow exchange of gas
Phenology	the study of the times of recurring natural phenomena, such as the date of leaf colouring and fall
Phytoplankton	unicellular plants that float in the water
Propagule	any plant material used for the purpose of plant propagation
Tidal prism	the amount of water that can enter a tidal creek or estuary between high and low tide
Viviparous seeds	seeds that germinate before they detach from the parent plant