CHAPTER 4
PROTECTION FROM COASTAL EROSION

Thematic paper: The role of coastal forests and trees in protecting against coastal erosion

Gegar Prasetya[1]

1 Introduction

Shoreline changes induced by erosion and accretion are natural processes that take place over a range of time scales. They may occur in response to smaller-scale (short-term) events, such as storms, regular wave action, tides and winds, or in response to large-scale (long-term) events such as glaciation or orogenic cycles that may significantly alter sea levels (rise/fall) and tectonic activities that cause coastal land subsidence or emergence. Hence, most coastlines are naturally dynamic, and cycles of erosion are often an important feature of their ecological character. Wind, waves and currents are natural forces that easily move the unconsolidated sand and soils in the coastal area, resulting in rapid changes in the position of the shoreline.

Excluding the impact of human activity, these processes are simply natural evolutionary phenonema. Human activities along the coast (land reclamation, port development, shrimp farming), within river catchments and watersheds (river damming and diversion) and offshore (dredging, sand mining) in combination with these natural forces often exacerbate coastal erosion in many places and jeopardize opportunities for coasts to fulfill their socio-economic and ecological roles in the long term at a reasonable societal cost.

Development within coastal areas has increased interest in erosion problems; it has led to major efforts to manage coastal erosion problems and to restore coastal capacity to accommodate short- and long-term changes induced by human activities, extreme events and sea level rise. The erosion problem becomes worse whenever the countermeasures (i.e. hard or soft structural options) applied are inappropriate, improperly designed, built, or maintained and if the effects on adjacent shores are not carefully evaluated. Often erosion is addressed locally at specific places or at regional or jurisdictional boundaries instead of at system boundaries that reflect natural processes. This anomaly is mostly attributable to insufficient knowledge of coastal processes and the protective function of coastal systems.

The costs of installing hard structures for coastal protection are very high; strong negative public reaction to rock emplacements along the coast often aggravate the problem (Bray *et al.*, 1995; Black, 1999; Clark, 1995; van der Weide, 2001). This has led to uncertainty among managers and local government authorities on how to treat shoreline erosion. It has become an issue for serious debate for politicians, coastal managers, land- and property owners, lawyers, bankers, insurers and fisherfolk, especially in areas of intensive use and rapidly rising coastal land value. Many of these stakeholders are resorting to planned retreat where houses or hotels are simply removed and the coast is left to erode. However, planned retreat can be expensive, unnecessary and sometimes impossible, especially in highly modified environments.

Increased interest in soft structures for coastal protection (including increased forest cover) and a combination of hard and soft structures is predominating and is consonant with advanced knowledge on coastal processes and natural protective functions. There is evidence that coastal

[1] Agency for the Assessment and Application of Technology, Indonesia.

forests and trees provide some coastal protection and that the clearing of coastal forests and trees has increased the vulnerability of coasts to erosion (Figure 4.1) — such as in Viet Nam (Mazda *et al.*, 1997; Cat *et al.*, 2006), Malaysia (Othman, 1994), Indonesia (Bird and Ongkosongo, 1980; Nurkin, 1994; Tjardana, 1995), Sri Lanka (Samarayanke, 2003), India (Malini and Rao, 2004; Gopinath and Seralathan, 2005) China (Bilan, 1993) and Thailand (Thampanya *et al.*, 2006). This paper will elaborate on and discuss the causes of coastal erosion induced by human activities; erosion management options; and the role of coastal forests and trees in protecting coastal areas against coastal erosion, as well as their socio-economic and environmental considerations.

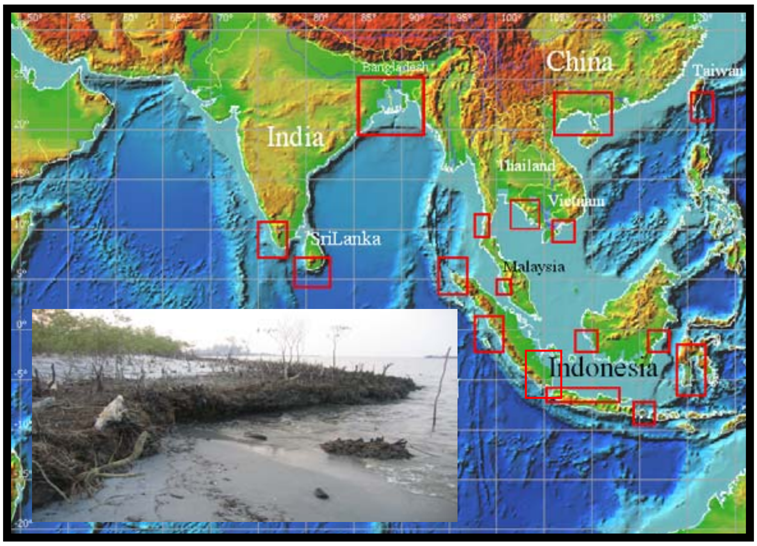

Figure 4.1 Coastal erosion sites reported in Asian and Indian Ocean countries; the inset indicates how clearing of coastal forest such as mangroves has increased the vulnerability of coasts to erosion (base map source from ITDB, 2004)

2 Coastal erosion: Extent and causes

Coastal erosion and accretion are natural processes; however, they have become anomalous and widespread in the coastal zone of Asia and other countries in the Indian Ocean owing to combinations of various natural forces, population growth and unmanaged economic development along the coast, within river catchments and offshore. This type of erosion has been reported in China, Japan, India, Indonesia, Viet Nam, Sri Lanka, Thailand, Bangladesh and Malaysia.

2.1 The extent of the coastal erosion problem in Asia

Bilan (1993) reported that the erosion rate in the northern part of Jiangsu Province in China is serious and as high as 85 metres/year; in Hangzhou Bay the rate is 40 metres/year, while in Tianjin it is 16–56 metres/year. Erosion persists even where preventive measures such as sea dykes are constructed. Beach scour has been found along coasts with sea-dyke protection. This erosion is attributable to many factors such as river damming and diversion, that leads to less sediment supply to the coast, and the clearing of mangrove forests, which makes coastal areas more susceptible to the hazard. Juxtaposing these phenomena, the intensification of typhoons and storm surges during the 42-year period between 1949 and 1990 has meant that storm surges with increasing tidal levels exceeding one and two metres have occurred 260 and 48 times respectively, thus exacerbating the erosion problem. Most of the sediment taken offshore by the storm waves has been returned in minimal quantities to the coast during normal conditions owing to the frequent storm intensity.

According to Othman (1994), nearly 30 percent of the Malaysian coastline is undergoing erosion. Many of these areas are coastal mudflats, fringed by mangroves. Behind the mangroves there are usually agricultural fields protected from tidal inundation by bunds (dykes). Locally, mangroves are known to reduce wave energy as waves travel through them; thus, the Department of Irrigation and Drainage has ruled that at least 200 metres of mangrove belts must be kept between the bunds and the sea to protect the bunds from eroding. However, the mangroves themselves are susceptible to erosion when the soil under their root systems is undermined by wave action that mostly occurs during periods of lower water level or low tide. The value of intact mangrove swamps for storm protection and flood control alone in Malaysia is approximately US$300 000/kilometre (http://ramsar.org).

In Viet Nam, most of the coastline in the south that is located in a wide and flat alluvial fan and bordered by tidal rivers fringed by wide mangrove swamps, has been eroded continuously at a rate of approximately 50 metres/year since the early twentieth century (Mazda *et al.*, 1997; Cat *et al.*, 2006). This massive erosion — mostly due to wave and current action — and vanishing mangrove vegetation is attributable to the long-term impacts of human activities since the late nineteenth century and also human-induced change within watersheds (dam construction that has reduced the sediment supply to the shore). Erosion still occurs in the central coastal zone of Viet Nam and preventive measures such as sea dykes, revetments, and tree plantations have been implemented in many coastal areas; however, in the southern coastal zone, mangrove plantations have mitigated wave action and prevented further erosion (Cat *et al.*, 2006).

The rapid erosion of the coast of Sagar Island in West Bengal, India, is caused by several processes that act in concert; these are natural processes that occur frequently (cyclones, waves and tides that can reach six metres in height) and anthropogenic activities such as human settlement and aquaculture that remove mangroves and other coastal vegetation. The erosion rate from 1996 to 1999 was calculated to be 5.47 square kilometres/year (Gopinath and Seralathan, 2005). The areas that are severely affected by erosion are the northeastern, southwestern and southeastern faces of the island. Malini and Rao (2004) reported coastal erosion and habitat loss along the Godavari Delta front owing to the combination of the dam construction across the Godavari and its tributaries that diminishes sediment supply to the coast and continued coastal land subsidence.

Sri Lanka’s experience with coastal erosion dates back to 1920 (Swan, 1974; 1984). It has become more serious because mangroves are being eradicated by encroachment (human settlement), fuelwood cutting and the clearing of coastal areas for intensive shrimp culture. Mangrove forest cover was estimated to be approximately 12 000 hectares in 1986; this dwindled to 8 687 hectares in 1993 and was estimated to be only 6 000 hectares in 2000 (Samrayangke, 2003). Approximately US$30 million has already been spent on breakwaters and other construction to combat coastal erosion on southern and western coasts (UNEP, 2006); however, coastal erosion still persists in some coastal areas.

In Indonesia, coastal erosion started in the northern coast of Java Island in the 1970s when most of the mangrove forest had been converted to shrimp ponds and other aquaculture activities, and the area was also subjected to unmanaged coastal development, diversion of upland freshwater and river damming. Coastal erosion is prevalent throughout many provinces (Bird and Ongkosongo, 1980; Syamsudin *et al.*, 2000; Tjardana, 1995) such as Lampung, Northeast Sumatra, Kalimantan, West Sumatra (Padang), Nusa Tenggara, Papua, South Sulawesi (Nurkin, 1994) and Bali (Prasetya and Black, 2003). US$79.667 million was provided by the Indonesian Government to combat coastal erosion from 1996 to 2004, but only for Bali Island in order to protect this valuable coastal tourism base (Indonesia water resource donor database:http://donorair.bappenas.go.id). A combination of hard structures and engineering approaches (breakwaters/jetties/revetments) of different shapes that fused functional design and aesthetic values, and soft structures and engineering approaches (beach nourishment) was used. They succeeded in stopping coastal erosion on Sanur, Nusa Dua and Tanjong Benoa beaches, but were neither cost effective nor efficient, because during low tide all of the coastal area was exposed up to 300 metres offshore; thus, these huge structures were revealed and became eyesores.

In Thailand, intensification of coastal erosion came to notice during the past decade (Thampanya *et al.*, 2006). Overall, the net erosion is approximately 1.3 to 1.7 metres/year along the southern Thailand coastline. Total area losses amount to 0.91 square kilometres/year for the Gulf coast and 0.25 square kilometres/year for the western coast. Most of the eroded areas increase with larger areas of shrimp farms, less mangrove forest area, and when dams reduce riverine inputs and coastal land subsidence transpires. In areas where erosion has prevailed, the presence of mangroves has reduced erosion rates. Mangroves dominating coastal locations exhibit less erosion than areas with non-vegetated land or former mangrove areas.

Such examples indicate that there is a strong relation between major coastal erosion problems throughout the region and degradation of the protective function of coastal systems such as coastal forest and trees – particularly mangrove forest. Artificial and natural agents that induce mangrove loss and make coastal areas more susceptible to coastal erosion include anthropogenic factors such as excessive logging, direct land reclamation for agriculture, aquaculture, salt ponds, urban development and settlement, and to a lesser extent fires, storms, hurricanes, tidal waves and erosion cycles owing to changing sea levels (Kovacs, 2000). More scientific investigation and quantification of the physical processes and dynamic interaction of the system is needed to understand how and under what circumstances mangrove forests and other coastal vegetation effectively protect the shoreline from erosion. A number of efforts have focused on field observations, laboratory and numerical model experiments and theoretical analysis (Wolanski 1992; Mazda *et al.*, 1997; Massel *et al.*, 1999).

Plate 4.1 Different types of coastal protection structures in Tanjong Benoa and Sanur Bali for protecting the valuable tourism base. Clockwise: Satellite images of the offshore breakwater and artificial headland, groynes and beach nourishment (Google maps); headland and beach nourishment with coconuts; loc cit *waru* trees; revetment protection using limestone in combination with *waru trees* (note the dangerous placing of the boats)

2.2 The causes of coastal erosion

Coastal erosion and accretion are complex processes that need to be investigated from the angles of sediment motion under wind, wave and tidal current action; beach dynamics within a sediment/littoral cell; and human activities along the coast, within river catchments and watersheds and offshore, both at spatial and temporal scales. In terms of temporal scales, the issue of sea-level rise is complex and produces a range of environmental problems. As the sea level rises, the water depth increases and the wave base becomes deeper; waves reaching the coast have more energy and therefore can erode and transport greater quantities of sediment. Thus, the coast starts to adjust to the new sea level to maintain a dynamic equilibrium. Figure 4.2 lists the processes of coastal erosion and accretion, as well as natural factors and human activities.

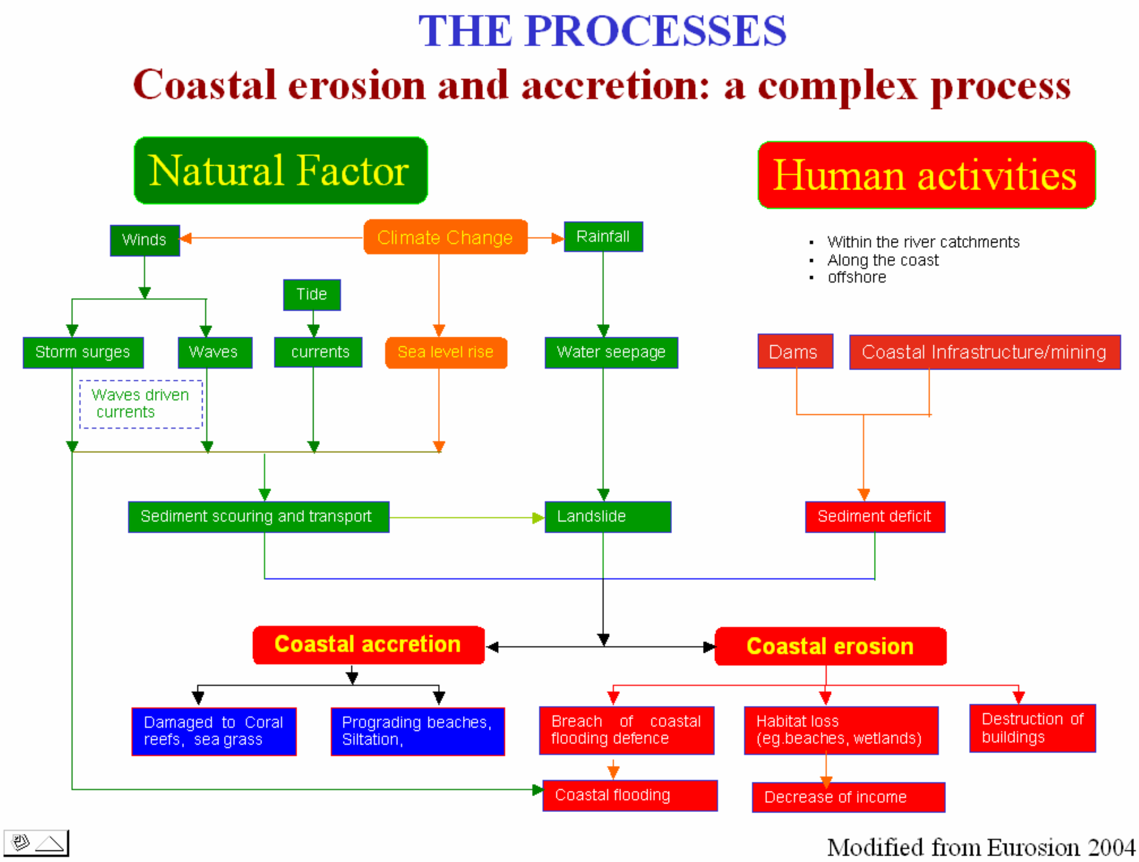

Figure 4.2 The complex processes of coastal erosion and accretion

The key physical parameters that need to be understood to identify coastal erosion as a problem in the coastal zone are:

- Coastal geomorphology: Coastline type and sensitivity to coastal processes.
- Wind: The main force in wave generation; under the right environmental conditions, wind may transfer sediment from the beach environment landward on all open coastlines.
- Waves: They are the most important forces for sediment erosion and transport to the coastal zone. They introduce energy to the coast and also a series of currents that move sediment along the shore (longshore drift) and normal to the shore (cross-shore transport). It is important to understand the movement of wave forms as well as water particles and their interaction with seabed material; also how the waves determine whether the coasts are erosive or accretional.
- Tides: They are influential in beach morphodynamics. They modulate wave action, controlling energy arriving on the coast and drive groundwater fluctuation and tidal currents.

The interaction of groundwater with tides in the coastal forest environment is crucial in understanding why coastal forest clearance causes intensive coastal erosion in particular environments.

- Vegetation: Important for improving slope stability, consolidating sediments and providing some shoreline protection.

Equally significant human activities that must be considered over the range of spatial and time scales are:

- Activities along the coast: Building houses via land reclamation or within sand dune areas and port/harbour development has a long-term impact on shoreline change; protective seawalls lead to erosion at the end of the structures, generate beach scouring at the toe of seawall and shorten the beach face. This can occur in the short term (less than five years) or the long term (more than five years). Other structures such as groynes and jetties typically cause erosion down-drift of the structure within a short period of time (between five and ten years). Removal of dune vegetation and mangroves will expose low energy shorelines to increased energy and reduced sediment stability, causing erosion within five to ten years
- Activities within river catchments/watersheds: Dam construction and river diversion cause reduction of sediment supply to the coast that contributes to coastal erosion. The effects of dam and river diversion in terms of coastal erosion are not straightforward, but there are mid- to long-term impacts (20 to 100 years) with spatial scales approximately from one to 100 kilometres.
- Onshore and offshore activities: Sand and coral mining and dredging may affect coastal processes in various ways such as contributing to sediment deficit in the coastal system and modifying water depth that leads to altered wave refraction and longshore drift. The impact of these activities will be obvious within a short period of time (one to ten years).

Understanding the key processes of coastal dynamics and how the coasts function both in spatial and temporal time scales (short and long term), as well as human activities along the coast, within the river watershed and offshore is essential for managing coastal erosion because it may occur without reason. A quantitative understanding of changes in spatial and short- and long-term time scales is indispensable for the establishment of rational policies to regulate development in the coastal zone (NRC, 1990). Table 4.1 summarizes possible natural factors and human activities that affect shoreline change over a range of time scales, leading to coastal erosion.

Table 4.1 Possible natural factors and human activities that affect shoreline change

Factor	Effects	Time scale									
		sec's	hours	days	months	years	10 years	50 years	100 years	1000 years	10.000 years
Natural Factors											
Short wave period	Erosion										
Waves of small stepnees	Accretion										
Large wave height	Erosion										
Storm surge	Erosion										
Alongshore currents	Accretion, no change or erosion										
Rip currents	Erosion										
Underflow	Erosion										
Overwash	Erosion										
Wind	Erosion										
Sediment supply (source and sink)	Accretion or Erosion										
Inlet presence	Net erosion; hig instability										
Sea level rise	Erosion										
Land subsidence (tectonic)	Accretion or Erosion										
Human activities											
Dredging	Erosion or Accretion										
Coastal defence	Erosion or Accretion										
Vegetation clearing	Erosion										
Harbour development	Erosion or accretion										
River damming	Erosion										
Land reclamation	Erosion										

3 The coastal type and protective function of the coastal system

Coastlines comprise the natural boundary zone between the land and the ocean. Their natural features depend on the type of rocks exposed along the coastline, the action of natural processes and the work of vegetation and animals. The intensity of natural processes formed their origin — either as erosional or depositional features. The geological composition of a coastal region determines the stability of the soil, as well as the degree of rocky materials and their breakdown and removal.

3.1 Coastal types

3.1.1 Cliff coast

Cliff coast can be classified as "hard" coast as it was formed from resistant materials such as sedimentary or volcanic rocks. This type of coast typically has a short shore platform that is usually exposed during low tide. Natural erosion is attributable to slope instability, weathering and wave action and leads to regression of the shoreline. As illustrated in Figure 4.3, extreme wave conditions such as storm waves and tsunamis will have a less erosive effect on this type of coast; traces of tsunami wave height can be found on cliffs as a trim line where trees or shrubs on the cliff had been erased.

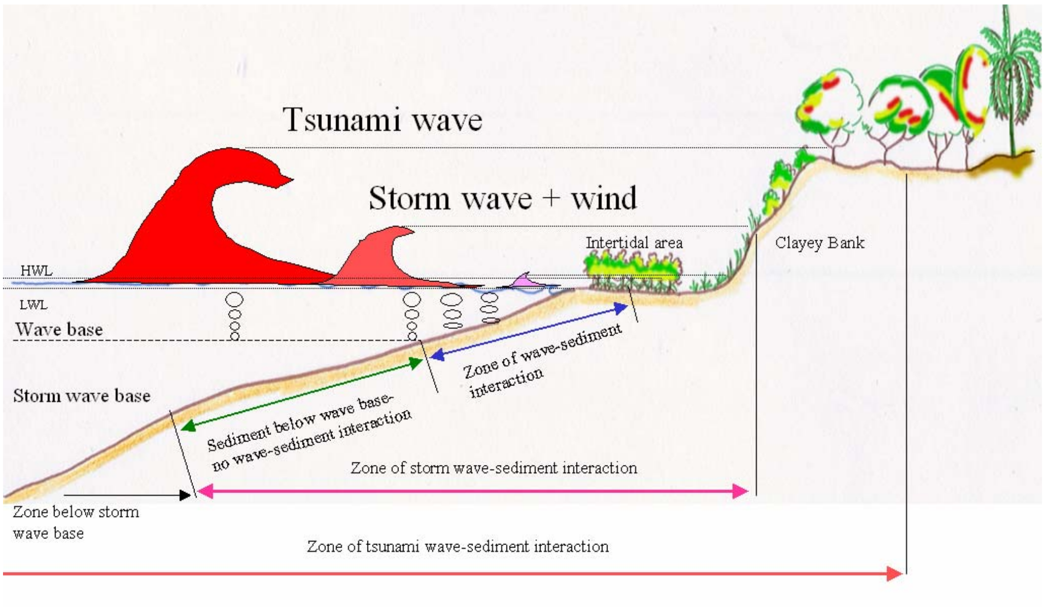

Figure 4.3 Cliff coast (modified from ARC [2000] and French [2001])

3.1.2 Clayey bank coast

This type of coast can be classified as a "semi-hard" coast, consisting of cohesive soils; it is common on estuarine coastlines and often has nearly vertical banks ranging from one to five metres in height. The rate of erosion is relatively high compared to the hard coast because it is composed of weaker and less resistant material. Erosion is mostly due to coastal processes, weathering and loss of vegetation cover (ARC, 2000). For extreme events such storms and tsunami, as illustrated in Figure 4.4, vegetation cover plays a significant role in protecting the coast from flooding and inundation by reducing wave height and energy and decelerating tsunami flow speed; hence, erosive forces and inundation distance are decreased.

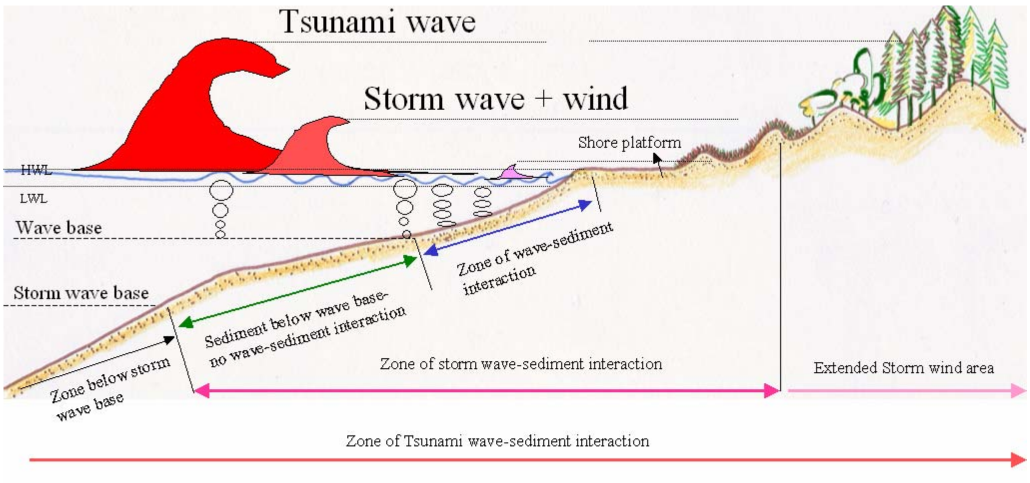

Figure 4.4 Clayey bank type coast (modified from ARC [2000] and French [2001])

3.1.3 Intertidal/muddy coast

This type of coast is characterized by fine-grained sedimentary deposits, predominantly silt and clay that come from rivers; it can be classified as a "soft" coast. It has a broad gentle seaward slope, known as an intertidal mud flat where mangrove forest, saltmarshes, shrubs and other trees are found. Most erosion is generated by river damming that reduces sediment supply, diminishes vegetation cover (usually mangroves and saltmarshes) and exposes vegetation roots by lowering the mud flat (Figure 4.5) that leads to their final collapse. During storms, healthy and dense vegetation/coastal forest and trees can serve as barriers and reduce storm wave height, as well as affording some protection to the area behind them. In the case of a tsunami, coastal forest and trees can decrease wave height and tsunami flow speed to some extent if the forest is dense and wide enough. Both extreme events can cause severe erosion and scouring on the coast and at the river mouth.

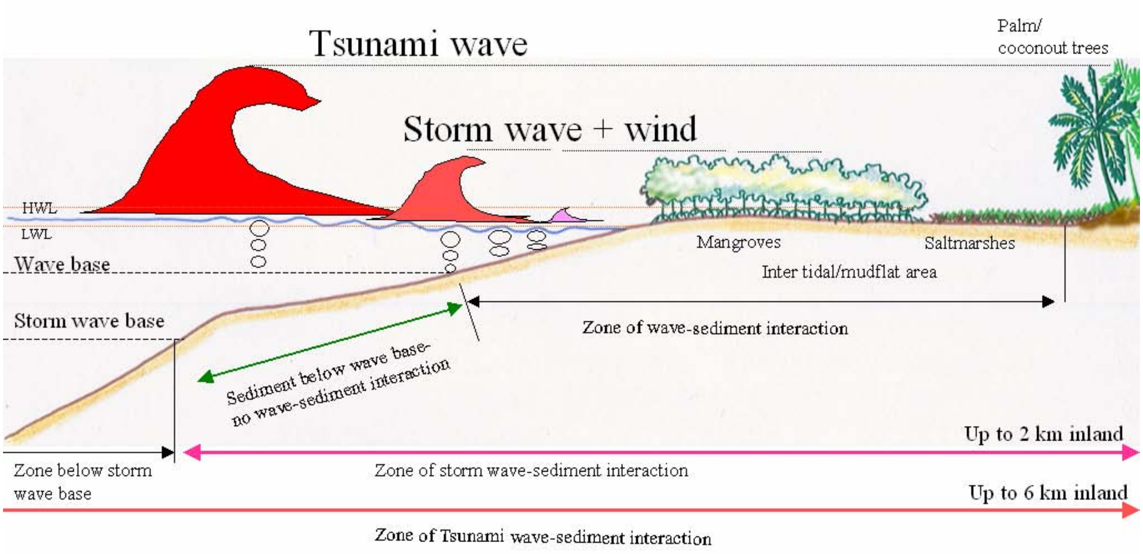

Figure 4.5 Intertidal/muddy coast (modified from ARC [2000] and French [2001])

3.1.4 Sand dune coast

This type of coast consists of unconsolidated material, mainly sand, some pebbles and shells; it can be classified as a soft coast. It has a gentle seaward slope — known as dissipative beaches that have broad fine sand and gradually steep slopes at the backshore/foredunes. Its profile depends on wave form and energy and wind direction; hence, profiles can be adjusted to provide the most efficient means of dissipating incoming wave energy. This type of coast experiences short-term fluctuation or cyclic erosion — accretion and long-term assessment is needed to identify erosion as a problem here. Often accretion and dune rebuilding take much longer than erosional events and the beach has insufficient time to rebuild before the next erosive event occurs. Erosional features are a lowered beach face slope and the absence of a nearshore bar, berm and erosional scarps along the foredune. Generally, erosion is a problem when the sand dunes completely lose their vegetation cover that traps wind-borne sediment during rebuilding, improves slope stability and consolidates the sand. During extreme events such as storms and tsunamis (Figure 4.6), this type of coast can act as a barrier for the area behind the dunes. Sand dunes and their vegetation cover are the best natural protective measures against coastal flooding and tsunami inundation.

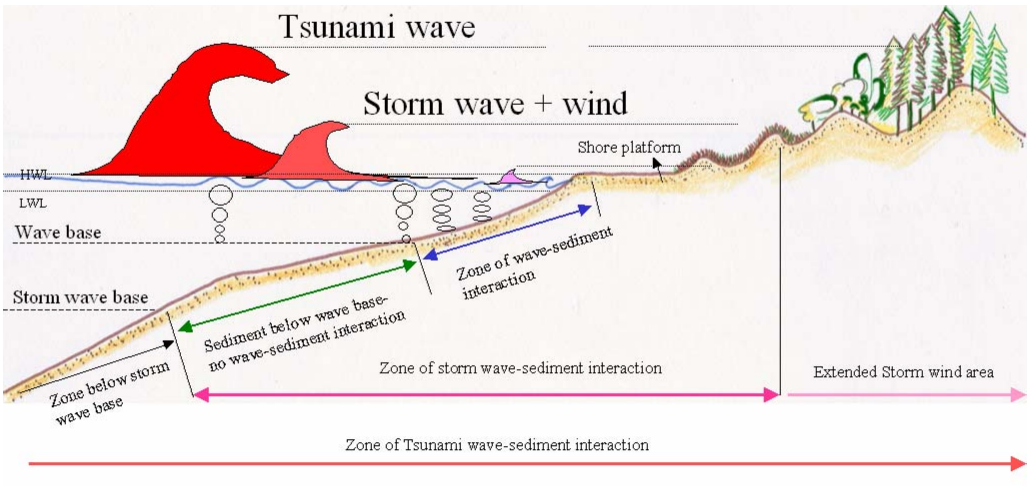

Figure 4.6 Sand dune coast (modified from ARC [2000] and French [2001])

3.1.5 Sandy coast

This type of coast consists of unconsolidated material — mainly sand from rivers and eroded headlands, broken coral branches (coralline sand) and shells from the fringing reefs. It can be classified as a soft coast with reef protection offshore. The beach slope varies from gentle to steep slopes depending on the intensity of natural forces (mainly waves) acting on them. Coconut trees, *waru* (*Hibiscus tiliaceus*), *Casuarina catappa*, pandanus, pine trees and other beach woodland trees are common here. Most erosion is caused by loss of (1) the protective function of the coastal habitat, especially coral reefs (where they are found) that protect the coast from wave action; and (2) coastal trees that protect the coast from strong winds. During extreme events (Figure 4.7), healthy coral reefs and trees protect coasts to some extent by reducing wave height and energy as well as severe coastal erosion.

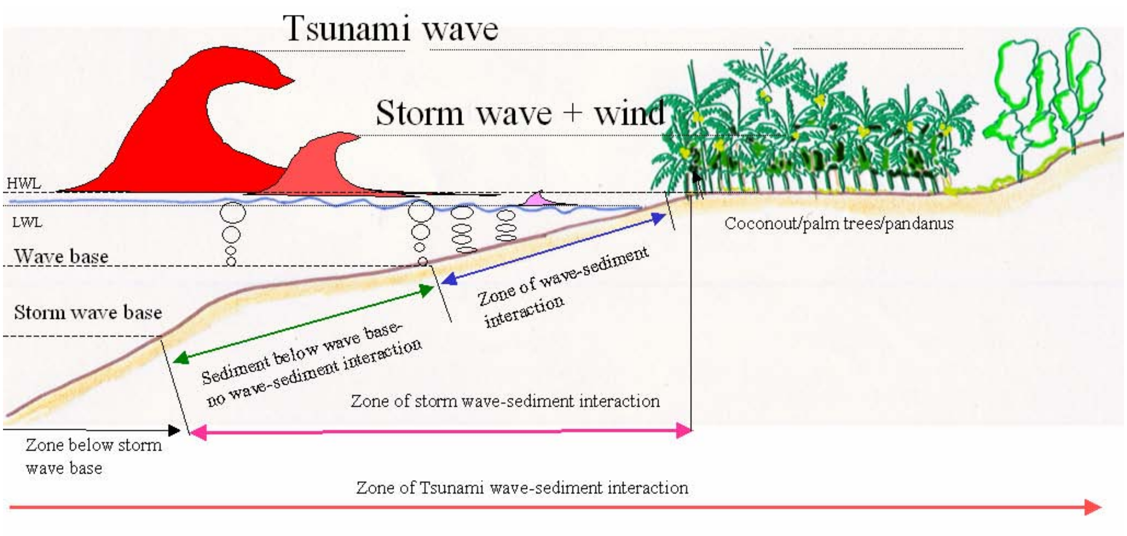

Figure 4.7 Sandy coast (modified from ARC [2000] and French [2001])

3.2 The protective function of coastal systems

Coastal areas with natural protective features can reestablish themselves after natural traumas or long-term changes such as sea-level rise. The protective features of the coastal system vary (Figure 4.8). The role of coral reefs in coastal protection has been studied for some time and recent efforts have focused on the role of coastal vegetation, especially mangrove forest and saltmarshes in this context.

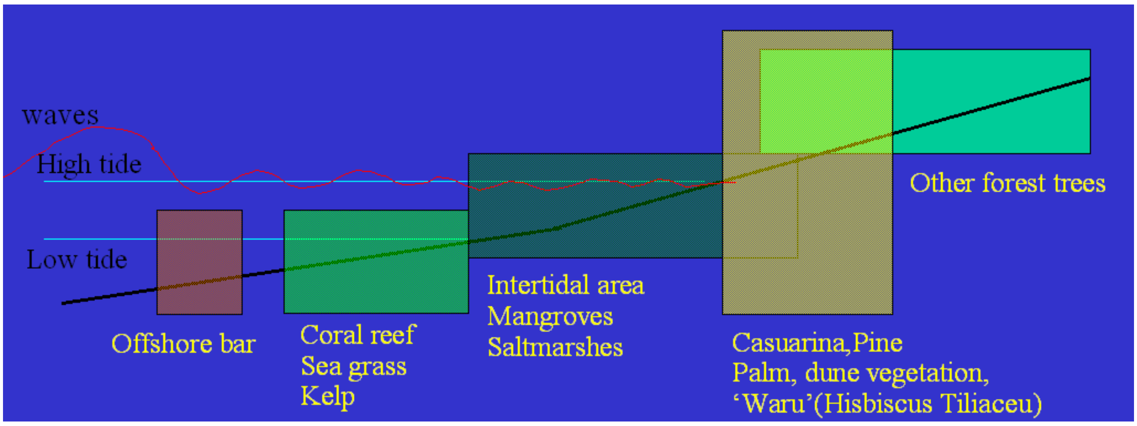

Figure 4.8 The natural protective features of coastal systems

3.3 Scientific findings on the protective functions of coastal forests and trees

Scientific investigations on how coastal vegetation provides a measure of shoreline protection have been conducted (Sale, 1985; Kobayashi *et al.*, 1993; Mazda *et al.*, 1997; Massel *et al.*, 1999; French, 2001; Blasco *et al.*, 1994; Moller *et al.* 1999; Wu *et al.* 2001; Baas 2002; Jarvela 2002; Mendez and Losada 2004; Lee, 2005; Dean and Bender, 2006; Daidu *et al.*, 2006; Moller, 2006; Turker *et al.*, 2006). These field, laboratory and numerical studies show that mangrove forest and other coastal vegetation of certain density can reduce wave height considerably and protect the coast from erosion, as well as effectively prevent coastal sand dune movement during strong winds. Healthy coastal forests such as mangroves and saltmarshes can serve as a coastal defence system where they grow in equilibrium with erosion and accretion processes generated by waves, winds and other natural actions.

3.4 Field studies

The coastal areas around the Bay of Bengal are vulnerable to strong winds, storm surges, tectonic movement, oversedimentation, rapid coastal erosion, fluctuating water and soil salinity and long periods of constant flooding. Based on their scientific investigations in the Bay of Bengal, Blasco *et al.* (1994) reported that the mangrove areas in India and Bangladesh, especially at the mouth of the Ganges (known as the Sunderbans — the largest natural mangrove area of the region found in one block) were able to heal cyclonic wounds and maintain the extent of their total area through natural succession without human interference. Mangroves in these regions have withstood highly adverse environmental conditions such as muddy soils with high salt and water content, destructive tidal effects and strong winds over the flat areas where they have grown in geological terms since the Tertiary (lower Miocene) Period. Via their root systems, mangroves can stabilize the substrate where they occur. According to studies, most erosion is caused by diversion of river flow to coastal areas and mangrove regression due to human activities that convert them for agriculture or aquaculture purposes.

Fan *et al.* (2006) analysed cross-shore variations in the morphodynamic processes of an open coast mudflat in Changjiang Delta, where waves play a dominant role in shaping the tidal-flat profile during typhoons. Each year, roughly seven out of 16 typhoons directly strike China's coast with a 95 percent probability of hitting southwards and the coast of the Chanjiang Delta; they generate waves up to 6.2 metres in height. One-third of the mudflat is colonized by *Spartina alterniflora*, followed by scirpus (*Scirpus mariquete* and *Scirpus triquiter*), and then gradually transits into a less-vegetated pioneer zone behind the bar mudflat. The boundary between the mature marsh and the pioneer marsh is located near the mean neap high water mark and single *Scirpus* stems can survive near the neap lower water elevation. The site-specific erosion rate is related to the local water depth, sediment properties, vegetation and exposure time per semi-diurnal tidal cycle. The area below mean sea level (MSL) at the intertidal mudflat is characterized by dynamic changes in erosion and accretion phases; meanwhile, the higher section is dominated by continuous accretion due to the abundant sediment supply. The area where the *Spartina*-dominated marshes are found has continuous accretion without significant erosion owing to the protection afforded by high and dense vegetation.

Moller *et al.* (1999) studied wave transformation over saltmarshes through field and numerical modelling studies. There is quantitative evidence of the effectiveness of a meso- to macrotidal open coast saltmarsh in attenuating incoming waves over a range of tidal and meteorological conditions. Field measurements indicated that wave energy dissipation rates over the saltmarshes were significantly higher (an average of 82 percent) than over the sand flat (an average of 29 percent); this is due to the saltmarshes having greater surface friction compared to the sand flat. Based on the numerical model, the surface friction factors are of the order ≤ 0.4. The results of this study provide empirical support to maintaining saltmarshes in front of existing coastal defence structures and for creating new saltmarshes as part of coastal set-back/shoreline re-alignment schemes, as well as reduction of design criteria for flood defence embankments that are fronted by saltmarshes.

Mazda *et al.* (1997) observed the physical processes in fringe forest in coastal areas of Thuy Hai and Thuy Truong in Thai Thuy District, Thai Binh Province, Viet Nam, in a delta of the Gulf of Tonkin. This study elaborated the characteristics of water elevation and water flow in these areas and demonstrated wave reduction by mangroves in the tidal flat off the coast of Thuy Hai where *Kandelia candel* has been planted for several years. Based on these field studies, the wave and current characteristics of propagation through the mangrove forest area are as follows:

- Tidal elevation rises faster at the early stage of flood tide and falls more slowly at the later stage of ebb tide owing to the effects of flow resistance by mangrove vegetation and the bottom mud. In comparison with changes in mangrove swamps dominated by *Rhizophora* spp. and *Bruguiera* spp., changes effected by *Kandelia candel* are considerably smaller because *Rhizopora* spp. and *Bruguiera* spp. have intricate and large prop roots or numerous pneumatophores compared to *Kandelia candel*. These facts suggest that the effect of the drag force on *Kandelia candel* on long-period waves, such as tidal waves, is weak compared to those of *Rhizophora* spp. and *Bruguiera* spp.

- The wave height of the swell increases with increasing tidal level, and decreases with increasing proximity to the coast, which suggests wave energy loss caused by bottom friction and resistance to flow by the mangrove vegetation.

- Wave size decreases considerably through denser mangrove areas; therefore, in well-grown and healthy mangrove areas, the effects on wave reduction do not decrease with increasing water depth, which has important practical implications.

- According to the research, the effectiveness of mangroves with *Kandelia candel* of sufficient height (three to four years old) in reducing wave height per 100 metres was as high as 20 percent and increased to 95 percent when the trees were six years old. At this age, one metre wave height on the open coast will be reduced to 0.05 metre at the coast compared to 0.75 metre without mangroves. Vegetation height and density and the width of the area to be planted are important factors in reducing wave height and protecting the coast from erosion. The effect of wave reduction was considerable even when water depth increased due to the high density of vegetation.

Mazda *et al.* (2002) also analysed coastal erosion caused by tidal forces at Loang Hoa, South Viet Nam, which is located in a wide, flat alluvial fan and lies between two major tidal rivers – the Mui Nai River and the Nga Bay River. Based on field and numerical studies, they found that degradation of mangroves along the tidal rivers led to intensification of tidal currents at the mouths of the rivers and erosion on the coast. This study reached the same conclusion as a study carried out by Wu *et al.* (2001) for Merbok Estuary, Malaysia.

Othman (1994) observed that nearly 30 percent of the coastline of Malaysia is undergoing erosion. Many of these areas are coastal mudflats, fringed by mangroves. He found that instead of erosion due to clearing of the mangrove area for development projects, conditions in the west coast of Peninsular Malaysia suggest that mudflats undergo a cycle of accretion and erosion such as found in Sungai Burong, Pulau Pinang, where this cycle is about 20 years. Based on his observations in Sungai Besar Selangor, a 50-metre-wide belt of *Avicennia* is sufficient to reduce waves of one metre to a height less than 0.3 metre. However, these mangroves are also susceptible to erosion generated by the lowering of mudflats in front of the mangroves that leads to waves agitating the mud base below the root system and causing trees to collapse. *Avicennia* is a pioneer species that decelerates currents via its root system, and together with its trunk, attenuates wave height. The closer the trees are to each other, the greater the wave energy will be reduced. A five-year new growth of *Avicennia* can serve as an efficient wave attenuator. In the studied area behind the *Avicennia* zone, *Rhizophora* and *Bruguiera* zones were found, which contribute to reduced wave height and velocity.

3.5 Laboratory model experiments

Among the different coastal protection techniques and procedures, the protective capacity of coastal vegetation has yet to be investigated and analysed in detail (Turker *et al.*, 2006). Knowledge on the interaction between vegetation and incident waves creates a better understanding of ecological and geomorphological processes in coastal waters, with particular respect to coastal defence management by vegetation. Important developments in understanding the effects of vegetation on coastal bed morphology and the interaction between waves, sediment transport and the vegetated area can be achieved through extensive studies in controlled laboratory conditions. The controlled laboratory environment will allow measurement of wave parameters that are not easily measurable in natural conditions. Coops *et al.* (1996) conducted an experimental study in a wave tank to assess the interaction between waves, bank erosion and emergent vegetation. They used two helophyte species, *Phragmites australis* (Cav.) Trin. ex Steudel and *Scirpus lacustris* L., and two types of sediment (sand and silty sand) in a wave tank. Their findings showed that emergent vegetation influenced the erosive impact of waves by both sediment re-inforcement and wave attenuation. A smaller amount of net erosion was measured in the wave-exposed area covered by vegetation than in the area where there was no vegetation. Most of the erosion of the soil occurred due to the uprooting of rhizome parts, and in this case it happened to *Scirpus lacustris* but not to *Phragmites australis*. The greatest wave attenuation was measured in fully developed vegetation of both species.

Struve *et al.* (2003) combined laboratory experiments (in wave flume) and a two-dimensional (2-D) numerical model to investigate additional roughness owing to vegetation as an important factor for influencing water velocities and levels in a mangrove estuary. The effect of varying stem diameter and density was tested and staggered and linear models of tree distribution were also analysed. The smallest dowels used in some experiments were fitted with bent extensions similar to the stilt roots of *Rhizophora*. The results of the study showed that the effect of stilt roots was similar to stems, despite their different shape, and the change in velocity along the flume was related to the surface area of the model trees. A comparison between staggered and linear model tree distribution indicated that hydraulics shading had an effect based on the size and interference of the wave.

Turker *et al.* (2006) examined a changing beach profile under the protection of emergent vegetation (*Phragmites australis* without foliage) through various wave conditions in a laboratory; the most important governing parameters of coastal erosion in term of waves and sand properties under the protection of emergent vegetation were evaluated and defined. The findings showed that emergent vegetation is a relevant element for beach protection that tends to minimize erosion and even leads to zero erosion (Turker *et al.*, 2006). The vegetated area absorbs substantial wave energy due to friction and drag force; the experimental analysis showed that the amount of erosion is directly proportional to wave height and inversely proportional to sediment particles and the density of vegetation.

3.6 Numerical model and analytical studies

Massel *et al.* (1999) used a theoretical approach to predict the attenuation of wind-induced random surface waves in mangrove forest. The geometry of mangrove trunks and their locations were taken into account and the interaction between mangrove trunks and roots was introduced through the modifications of the drag coefficients. Examples of numerical calculations based on observations of wave attenuation through mangrove forest at Townsville, Australia, and Iriomote Island, Japan, showed that the resulting rate of wave energy attenuation depends strongly on the density of the mangrove forest, the diameter of mangrove roots and trunks, and on the spectral characteristic of the incident waves. Computation results for very dense mangrove forest (width unfortunately not defined), indicated that waves attenuate very quickly with distance from the mangrove front, and in the area behind the mangroves they are negligible. With very low density of mangrove forest and the same wave characteristics, wave energy is transmitted relatively easily through the mangrove forest; however, approximately 86 percent of the energy is still dissipated by the mangroves. The field observations (Figure 4.9) show almost the same results on how the mangrove forest can attenuate waves significantly over a relatively short distance. Wave energy is reduced by 75 percent in the wave passage through 250 metres of mangroves.

An interesting result recently revealed by Dean and Bender (2006) in relation to the effects of wave damping by vegetation and bottom friction on the static wave set-up during a severe storm is in line with studies to establish hazard zones associated with 100-year storm events along the shoreline of the United States; it can be used to explain the phenomena investigated by Blasco *et al.* (1994) for the Bay of Bengal area. Based on these studies, using various wave characteristics, the effect of vegetation and bed friction on both internal and bottom energy losses, and associated forces, resulted in a net wave set-down rather than wave set-up, which decreased wave impact on the shoreline behind the vegetated/coastal forest area.

More research is still needed for other coastal forests and trees such as *Pandanus*, *Casuarina* and pine, which do not directly interact with waves during normal conditions, but do so during extreme events such as major storms and tsunamis. Current knowledge is adequate to derive a general guideline on the protective role of the coastal forest in combating coastal erosion. However, it should be borne in mind that the effectiveness of each species in protecting the coast from erosion is very site-specific.

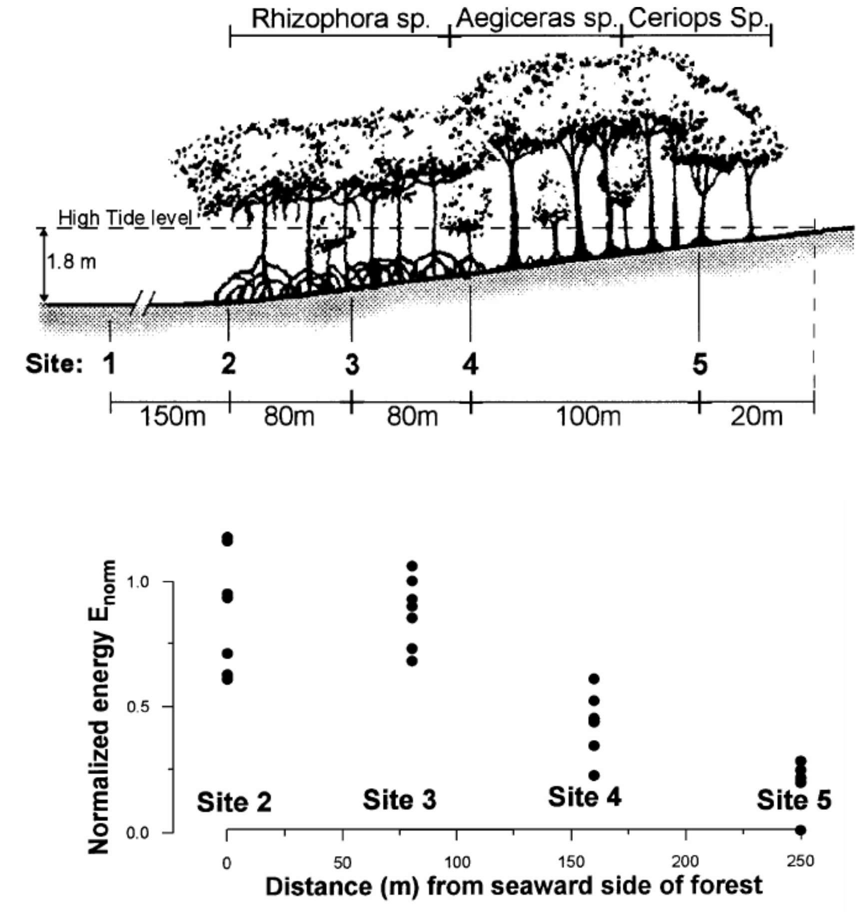

Figure 4.9 Wave attenuation by mangrove forest (*Rhizophora* sp., *Aegiceras* sp., *Ceriops* sp.) at Cocoa Creek, Australia is obvious; measurements at sites 2–5 show the decline in wave energy transmission through the mangrove forest. The incoming wave was measured at site 1 (Massel *et al.*,1999)

4 Managing the coastal erosion problem: Options for coastal protection

Assessing coastal erosion can be done by visual observation and through discussions with inhabitants to ascertain its degree and when it started. Common visual indicators to identify erosion problems are summarized in Table 4.2. However, determining the causes of coastal erosion and which coastal protection options should be used requires a comprehensive study of coastal processes that work on a regional scale (not only on sites) through every season.

Options for combating coastal erosion are traditionally twofold, namely hard structural/engineering options and soft structural/engineering options. These solutions have at least two hydraulic functions to control waves and littoral sediment transport (Kawata, 1989); in applying the solutions, their underlying principles should be well-understood, otherwise they will fail. A combination of hard and soft options has become more popular recently for optimum results because they have weaknesses when used singly. Many schemes have failed and resulted in environmental and socio-economic problems owing to improper design, construction and maintenance, and were often only implemented locally in specific places or at regional or jurisdictional boundaries, rather than at system boundaries that reflect natural processes (Kamphuis, 2002).

Table 4.2 Common visual indicators for identifying erosion problems

All coastlines	Cliff and platform (hard coast)	Clayey banks and muddy coast (semi-hard coast)	Sandy coast (soft coast)
Object (e.g. fence, shed or tree) which falls into the sea	Very steep cliff faces	Tree angle	Stable backdune vegetation in the active zone
Presence of existing coastal erosion management works (particularly poor condition of structures)	Shore platforms	Non-vegetated clayey banks	Damaged vegetation in the active zone (exposed roots)
	Sea caves, notches, stacks	Slumping slopes	Erosion scarps
	Debris at toe of cliff	Dislodged vegetation in the coastal area	Discontinuous vegetation cover on foredunes
	Tree angle at the top of the cliff	Erosion scarps	Irregular foredune crest, blow outs
			Very steep dune formation

4.1 Hard structural/engineering options

Hard structural/engineering options use structures constructed on the beach (seawalls, groynes, breakwaters/artificial headlands) or further offshore (offshore breakwaters). These options influence coastal processes to stop or reduce the rate of coastal erosion.

4.1.1 Groyne

A coastal structure constructed perpendicular to the coastline from the shore into the sea to trap longshore sediment transport or control longshore currents. This type of structure is easy to construct from a variety of materials such as wood, rock or bamboo and is normally used on sandy coasts. It has the following disadvantages:

- Induces local scour at the toes of the structures.
- Causes erosion downdrift; requires regular maintenance.
- Typically more than one structure is required.

4.1.2 Seawall

A seawall is a structure constructed parallel to the coastline that shelters the shore from wave action. This structure has many different designs; it can be used to protect a cliff from wave attack and improve slope stability and it can also dissipate wave energy on sandy coasts. The disadvantages of this structure are:

- It creates wave reflections and promotes sediment transport offshore.
- Scour occurs at the toes of eroded beaches.
- It does not promote beach stability.
- It should be constructed along the whole coastline; if not, erosion will occur on the adjacent coastline.

4.1.3 Offshore breakwater

An offshore breakwater is a structure that parallels the shore (in the nearshore zone) and serves as a wave absorber. It reduces wave energy in its lee and creates a salient or tombolo behind the structure that influences longshore transport of sediment. More recently, most offshore breakwaters have been of the submerged type; they become multipurpose artificial reefs where fish habitats develop and enhance surf breaking for water sport activities. These structures are appropriate for all coastlines. Their disadvantages are:

- They are large structures and relatively difficult to build.
- They need special design.
- The structure is vulnerable to strong wave action.

4.1.4 Artificial headland

This structure is constructed to promote natural beaches because it acts as an artificial headland. It is relatively easy to construct and little maintenance is required. The disadvantages are:

- It is a relatively large structure.
- It can cause erosion downdrift of the protected length of coastline.
- Has poor stability against large waves.

4.2 Soft structural/engineering options

Soft structural/engineering options aim to dissipate wave energy by mirroring natural forces and maintaining the natural topography of the coast. They include beach nourishment/feeding, dune building, revegetation and other non-structural management options.

4.2.1 Beach nourishment

The aim of beach nourishment is to create a wider beach by artificially increasing the quantity of sediment on a beach experiencing sediment loss, improving the amenity and recreational value of the coast and replicating the way that natural beaches dissipate wave energy. Offshore sediment can be sourced and is typically obtained from dredging operations; landward sources are an alternative, but are not as effective as their marine equivalents because the sediment has not been subject to marine sorting.

This method requires regular maintenance with a constant source of sediment and is unlikely to be economical in severe wave climates or where sediment transport is rapid.

It has been used in conjunction with hard structural/engineering options, i.e. offshore breakwaters, headlands and groynes to improve efficiency.

4.2.2 Dune building/reconstruction

Sand dunes are unique among other coastal landforms as they are formed by wind rather than moving waters; they represent a store of sand above the landward limits of normal high tides where their vegetation is not dependent on the inundation of seawater for stability (French, 2001). They provide an ideal coastal defence system; vegetation is vital for the survival of dunes because their root systems bind sediment and facilitate the build-up of dune sediment via wind baffle. During a storm, waves can reach the dune front and draw the sand onto the beach to form a storm beach profile; in normal seasons the wind blows the sand back to the dunes. In dune building or reconstruction, sand fences and mesh matting in combination with vegetation planting have successfully rgenerated dunes via sediment entrapment and vegetation colonization. The vegetation used should be governed by species already present, such as marram, sand couch grass and lyme grass.

4.2.3 Coastal revegetation

Based on studies and scientific results, the presence of vegetation in coastal areas improves slope stability, consolidates sediment and reduces wave energy moving onshore; therefore, it protects the shoreline from erosion. However, its site-specificity means that it may be successful in estuarine conditions (low energy environment), but not on the open coast (high energy environment). In some cases, revegetation fails because environmental conditions do not favour the growth of species at the particular site or there is ignorance as to how to plant properly given the same conditions. It is also possible that anthropogenic influences have completely altered the natural processes in the area. The most obvious indicator of site suitability is the presence of vegetation already growing. This can be extended by other factors such as the slope, elevation, tidal range, salinity, substrate and hydrology (Clark, 1995; French, 2001).

4.2.3.1 Coastal revegetation in muddy coastline environments (tidal zones of estuaries)

In muddy coastal environments or within the tidal zones of estuaries, mangrove forest and other indigenous shrub species are commonly found. Most erosion in these zones is attributable to the removal of the mangroves and other trees. To overcome this problem, replanting is necessary because these trees can regenerate and serve as coastal defence structures.

Planting vegetation species relative to their correct elevation in mudflat environments is important. At low- and subtidal deltas below the high water mark, saltmarsh species are recommended. Saltmarshes are typically zoned according to elevation, the zones being controlled by the frequency and duration of tidal inundation. Within this zone, *Spartina* as a pioneer species is tolerant of more frequent inundation than higher marsh species, and as such, is often used because it can be planted well down the intertidal zone (French, 2001). Other saltmarsh species that can be used are helophyte species such as *Phragmites australis* (Cav.) Trin. ex Steudel and *Scirpus lacustris* L. Within this area, mangroves are also recommended and can be planted easily. If the area already has a serious erosion problem, then special seeding techniques are needed.

A combination of species is suggested to reduce pest damage; however, the choice should be well planned in order to avoid competition. A number of publications provide planting/replanting guidelines, for example Hanley (2006). The mangrove forest should have a minimal width of 300 metres, densities of at least 0.5 metre and be planted in staggered alignment.

4.2.3.2 Coastal revegetation on other coastal types

Sandy coast

Beaches composed of fine sand are usually broad and have a gentle seaward slope representing a low energy environment; beaches with coarse sand, gravel, shells, or broken coral branches have relatively steep slopes representing a high energy environment. Short-term fluctuations on these coasts (if there is no human intervention) do not mean that an erosion problem exists; variations on the beach face are the natural response of the beach to wave form and energy and also strong winds. After extreme conditions, a naturally eroded beach, with features such as a lowered beach face slope, the absence of berms and erosional scarps along the backshore/foredune will return to normal during lower wave energy seasons when waves return sand to the beach and wind transports it landwards to rebuild the upper beach and foredune. Therefore, long-term observations are needed before deciding that the beach is being seriously eroded.

Severe erosion problems on these types of beaches are usually due to human activities such as dam building that decreases the river sediment supply to the coast, vegetation clearance on dunes and in beach woodlands, offshore mining, and building inappropriate coastal structures. In terms of erosion generated by vegetation clearance, revegetation of the area using indigenous vegetation is the only option. Other coastal protection options should be considered in combination with revegetation if the erosion problem is attributable to multiple factors.

Cliff and platform structures

Erosion of cliff and platform structures where there is no beach during high tide is due to complex processes and no single process predominates. These include gradual changes to cliff morphology owing to weathering and wave action at the base of the cliff, and slope instability due to episodic failure of the cliff. Planting shrubs and trees will improve slope stability, for example with *belukar* (dense thickets possibly dominated by isolated trees tangled with lianas); however, other coastal protection options should be considered in combination with revegetation.

4.3 Combinations of options

As mentioned already, combining hard and soft solutions is sometimes necessary to improve the efficiency of the options and provide an environmentally and economically acceptable coastal protection system. Hard solutions are known to:

- cause erosion and unnecessary accretion;
- be expensive and often further aggravate the problem; and
- spoil the aesthetic aspect of the beaches or coastlines they seek to protect, hence decreasing their economic value, especially for tourism purposes.

Meanwhile, many soft solutions can:

- take time to become effective (not overnight or quick-fix solutions), which generates negative public response; and
- be effective solutions only in medium- to long-term perspectives (five to ten years).

A planned retreat where the coast is left to erode can be expensive, unnecessary and sometimes impossible, especially in highly modified environments such as tourism areas and waterfront cities. To optimize the long-term positive impact of soft solutions, many combinations with hard solutions can be selected; combining beach nourishment and artificial headlands/groynes and revegetation and temporary offshore breakwaters/artificial reefs that act as interim hard structures is the most common approach.

4.3.1 Beach nourishment and artificial headlands/groynes

To reduce the frequency of renourishment and downdrift erosion in beach nourishment options, artificial headlands or groynes are often used as they can trap the downdrift movement of sediment.

4.3.2 Revegetation and temporary offshore breakwaters/artificial reefs

In some cases, revegetation in a low energy environment is required because deforestation of the coastal forest has led to direct exposure to wave action. There is also a need to establish offshore breakwaters/artificial reefs as temporary wave protection structures for mangroves and saltmarshes; otherwise, seawalls/revetments for vegetation that grows above the highest water mark such as *waru*, *Casuarina*, pine and palm trees can be built. Once the plants have established themselves, the structures may be removed.

5 Social and environmental implications

Social and environmental problems caused by coastal erosion are relevant and easy to observe. Losses in aquaculture (fish or shrimp ponds) due to erosion diminish fishery productivity and increase the number of unemployed people. Erosion has the same impact on tourism and urban areas where decreasing property values are a major problem. The problem is exacerbated when coastal protection measures have been improperly designed, constructed and maintained, or when they stop locally at specific places such as in front of hotels or properties that can afford to protect their own beaches, but the adjacent coast is left to erode (Plate 4.2). Or they may stop based on ownership (high public vs. private values) or at jurisdictional or administrative boundaries rather than at system boundaries that reflect natural processes. These “solutions” create more problems than answers. Coastal erosion cannot be resolved in a piecemeal fashion; protective measures should be integrated, consider socio-economic conditions and reflect the natural processes that work in the region.

Plate 4.2 Coastal protection efforts to protect a valuable tourism base; meanwhile, the adjacent shore with less economic value has minimal and improper protection. Even revegetation with *waru* to replicate planting at the neighbouring resort failed; the coast was then abandoned and left to erode

Hard and soft options have positive and negative aspects. Most hard options are effective solutions in the short term but create domino effects. They stop local erosion in order to protect the asset, but then contribute to erosion in adjacent areas. In the long term their effectiveness is mostly unsatisfactory. Meanwhile, soft options are effective solutions in medium- to long-term perspectives, but the main issue (French, 2001; Eurosion, 2004) is raising awareness among the public so that they provide effective protection for their homes and businesses; the public perception of security is critical. During the planning process, it is quite common for many people to admit feeling much more secure behind a concrete wall than behind a beach and forest. In this context, a combination of hard and soft structures is advisable.

Public or community involvement in using coastal forest and trees as coastal protection measures is very important during planning, implementation and monitoring; it will raise awareness on these solutions and the concomitant benefits for the ecosystem and all stakeholders. A good example comes from Bangladesh (Clark, 1995). The coastal green belt that had been incorporated with coastal embankments used a variety of trees that afforded not only protection from hazards, but also offered various benefits from the output of the green belt such as fruits, nuts, thatch, coconuts, fuel and poles.

Nature has not only demonstrated how to erode, but also how to protect, and there is probably no protective measure initiated by human beings that has not been originally developed by nature (Bruun, 1972; Bache and MacaSkill, 1981).

6 General guidelines on managing coastal erosion and their options

Understanding the key processes of coastal dynamics and how coasts developed in the past and present, as well as over the short and long term, is very important for managing coastal erosion problems because coastal erosion may occur without cause for concern. This can be very complex and possibly controversial where many conflicts of interests exist within the coastal environment. The main underlying principles for coastal erosion management are as follows (NRC, 1990; ARC, 2000):

- Identify and confirm coastal erosion as a problem.

- Identify, confirm and quantify the cause of the problem and ensure that any management option is well thought out before implementing coastal erosion measures.
- Understand the key processes and characteristics of coastal dynamics and system boundaries that reflect the natural processes of the erosion problem.
- Determine the coastal erosion measure options and implement them using proper design, construction and maintenance with careful evaluation of the effects on adjacent shores.
- Consider the balance of the options’ costs and their associated benefits.

A flowchart of this general guideline is given in Figure 4.10.

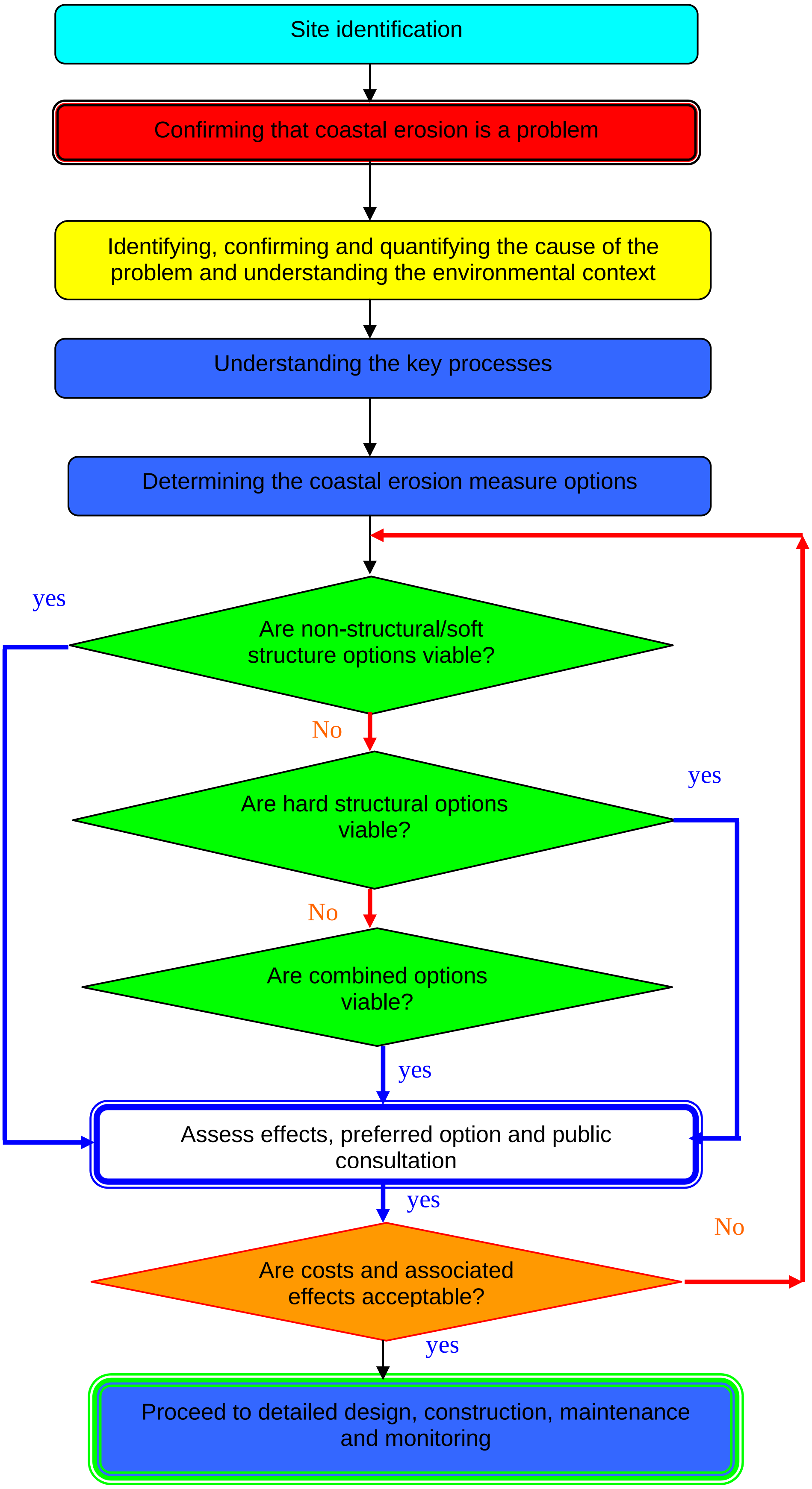

Figure 4.10 Flowchart of the guidelines for managing coastal erosion (modified from ARC, 2000)

Site identification: Simple site identification of coastal erosion can be done visually and through discussion with local inhabitants to give an indication of what is happening on the coast and when it started.

Confirming coastal erosion is a problem: As the coast has transient features, it is natural for it to erode or accrete sediment in response to changing forces; therefore, confirming that coastal erosion is a problem is very fundamental. Generally, coastal erosion is problematic in tourism areas, waterfront cities/residential blocks and aquaculture sites (shrimp ponds). Any legal issues pertinent to coastal management and development should be considered and discussed.

Identifying, confirming and quantifying the cause of the problem: Identifying the cause of the problem requires analysis that should consider any possible sources — both natural and anthropogenic — confirm them, and quantify the scale and intensity of the source and impact in the past, present and possibly in the future. Field observations and data collection of not only physical, but also socio-economic (including historical if available) data of the region are required and crucial at this stage. This will give an idea of what kind of options could be implemented, related to any legal or policy framework on coastal erosion management for the region.

Understanding the key processes: Understanding the key processes of coastal dynamics and how the coasts are functioning in areas where coastal erosion is a problem is essential to determine the system boundary that reflects natural processes. Many mathematical/numerical and physical models of coastal systems have been developed as tools to understand the behaviour of coastal systems. These tools can predict coastline evolution and interaction with the source of the problem and possible options to be implemented in the short and long term. These tools thus contribute to countermeasure planning and design as well as coastal erosion management.

Determining options for addressing coastal erosion: Choosing the optimum option must involve the public or community affected by the erosion. Discuss the available options and provide technical information such as design of the options, materials to be used, construction methods and maintenance and cost–benefit analysis in a wider context to consider the balance of the cost and associated benefits.

6.1 Set up a green belt/buffer zone

The purposes of setting up coastal green belts must not be solely for preventing coastal erosion and mitigating other natural hazards, but also for addressing the socio-economic status of the local communities as well as ecological sustainability.

The purposes of coastal green belts/buffer zones must serve to:

- control and stabilize the shoreline by holding and trapping sediments and consolidate land for areas such as intertidal mudflats with mangrove green belts and sandy coasts with *Casuarina*, pine trees or coconuts and palm trees;
- attenuate the force of devastating storm surges and waves that accompany cyclones and tsunamis;
- provide an amenity and a source of food, materials and income for local communities; and
- benefit biodiversity and create habitat corridors for wildlife that can be used for conservation activities and ecotourism development.

In general, the underlying concepts of setting up green belt/buffer zones (Clark, 1996) are:

- Social forestry: This should not be considered as a source of government or private sector revenue, but to support sustainable livelihood development among the coastal community.

- Ecodevelopment: This is beneficial for conservation activities, educational and recreational opportunities.
- Participatory planning, implementation and monitoring: The indigenous knowledge of local communities should be used in decision-making so they receive benefits directly.

Selection of the vegetation for setting up the green belt/buffer zone should take into account the natural protective function of the coastal system as illustrated in Figure 4.11:

- Start with vegetation at the water's edge and gradually proceed to hydric species inland.
- Select water-edge vegetation that is found locally on each type of coast. In most cases the width of the buffer zone for the intertidal delta ranges between 300 and 500 metres, depending on the slope of the region.
- Select beach vegetation that is found locally on each type of coast. The width of the buffer zone should be a minimum of 100 metres for the flat area, even with sand dunes or coastal embankments.

7 Conclusions

Coastal erosion and accretion are natural processes; however, they may become a problem when exacerbated by human activities or natural disasters. They are widespread in the coastal zone of Asia and other countries in the Indian Ocean owing to a combination of various natural forces, population growth and unmanaged economic development along the coast, within river catchments and offshore. This has led to major efforts to manage the situation and to restore the ability of the coast to accommodate short- and long-term changes induced by human activities, extreme events and sea-level rise. Understanding the key processes of coastal dynamics and how coasts are functioning both in spatial and temporal time scales (short and long term), in juxtaposition with human activities along the coast, within river watersheds and offshore is crucial for managing coastal erosion problems. Three main conclusions can be drawn on the roles that coastal forest and trees can play in combating coastal erosion:

1) There is evidence that they provide some coastal protection and their clearance has increased the vulnerability of coasts to erosion. Based on scientific findings, the presence of vegetation in coastal areas will improve slope stability, consolidate sediment and diminish the amount of wave energy moving onshore, therefore protecting the shoreline from erosion.
2) Increased interest in soft options (in this case the use of coastal forest and trees) for coastal protection is becoming predominant and is in line with advanced knowledge on coastal processes and the natural protective function of the coastal system. This is because hard options are mostly satisfactory in the short term, while soft options are effective in medium to long-term perspectives (five to ten years).
3) A combination of hard and soft solutions is sometimes necessary to improve the efficiency of the options and to provide an environmentally and economically acceptable coastal protection system.

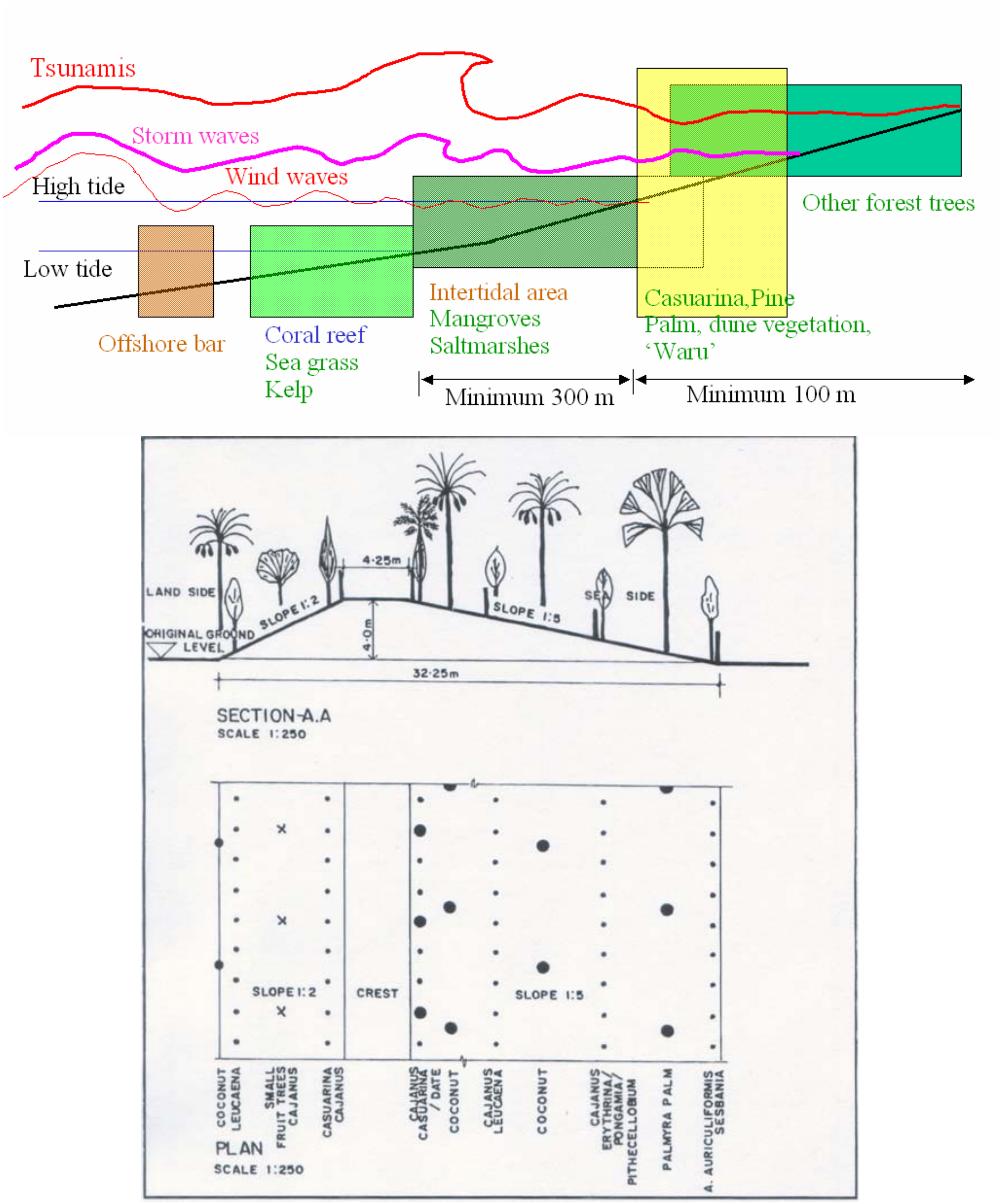

Figure 4.11 The natural protective functions of coastal forest and trees, starting with water-edge vegetation on intertidal deltas, rising to hydric species on higher soils or land. The green belt model below with coastal embankments (in Bangladesh) combines different type of trees, including fruit trees, which benefit local communities (Clark, 1995)

Acknowledgements

The author wishes to thank FAO reviewers for their input during manuscript preparation.

Bibliography

ARC**.** 2000. **Auckland regional council, 2000.** Technical Publication No. 130. Coastal Erosion Management Manual.

Baas, A.C.W**.** 2002. **Chaos, fractals and self-organization in coastal geomorphology: simulating dune landscapes in vegetated environments.** *Geomorphology,* 48: 309–328.

Bache D.H. & I.S. Macaskill. 1981. **Vegetation in coastal and stream-bank protection.** *Landscape Planning,* 8: 363–385.

Bird, E.C.F. & O.S.R. Ongkosongo. 1980. **Environmental changes on the coast of Indonesia.** NRTS-12/UNUP-197. Tokyo Japan, the United Nation University. 55 pp.

Black K.P. 1999. **Submerged structures for coastal protection: A short summary of what they are, why we need them and how they work.** Hamilton, New Zealand, Artificial Reefs Program. Centre of Excellence in Coastal Oceanography and Marine Geology Department of Earh Sciences, University of Waikato and National Institute of Water and Atmospheric Research. 9 pp.

Bilan, D. 1993. **The preliminary vulnerability assessment of the Chinese coastal zone due to sea level rise.** Proceedings of the IPCC eastern hemisphere workshop, Tsukuba, Japan 3–6 August 1993.

Blasco, F., Janodet, E. & M.F. Bellan. 1994.**Natural hazards and mangroves in the Bay of Bengal.** *Journal of Coastal Research,* Special Issue No.12: 277–288.

Bray, J.M., Carter, D.J. & J.M. Hooke. 1995. **Littoral cell definition and budgets for central southern England.** *Journal of Coastal Research,* 11(2): 381–400.

Bruun, P. 1972. **The history and philosophy of coastal protection.** Proc. 13th Coastal Engineering Conf. ASCE.New York. NY (1). pp 33–74.

Cat, N.N., Tien, P.H., Sam, D.D. & N.N. Bien. 2006. **Status of coastal erosion of Viet Nam and proposed measures for protection.** This volume (abstract).

Clark, J.R. 1995. **Coastal zone management handbook.** Lewis. 695 pp.

Chong, J. 2005. **Protective values of mangroves and coral ecosystem: A review of methods and evidence.** IUCN. G.V.

Coops, H., Geilen, N., Verheij, H.J., Boeters & van der Velde. 1996. **Interaction between waves, bank erosion and emergent vegetation: an experimental study in a wave tank.** *Aquatic Botany*, 53: 187–198.

Crowly, G.M. & M.K. Gagan. 1995. **Holocene evolution of coastal wetland in wet-tropical northeastern Australia.** *Holocene,* 5(4): 385–399.

Daidu, F., Guo, Y., Wang, P. & J.Z. Shi. 2006. **Cross-shore variations in morphodynamic processes of an open-coast mudflat in the Changjiang Delta, China: with an emphasis on storm impacts.** *Continental Shelf Research,* 26: 517–538.

Dean, R.G. & C.J**.** Bender. 2006. **Static wave setup with emphasis on damping effects by vegetation and bottom friction.** *Coastal engineering,* 53: 149–156.

Eurosion. 2004. **Living with coastal erosion in Europe: Sediment and space for sustainability. Part IV — a guide to coastal erosion management practives in Europe: lessons learned.** 27 pp.

Fan, D., Guo, Y., Wang, P. & J.Z. Shi. 2006. **Cross-shore variations in morphodynamic processes of an open-coast mudflat in the Chanjiang Delta, China: with an emphasis on storm impacts.** *Continental Shelf Research,*26: 517–538.

FAO**.** 1998. **Integrated coastal area management and agriculture, forestry and fisheries.** FAO document repository, www.fao.org.PART C.

French, P.W. 2001. Coastal defences: processes, problems & solutions. Florence, KY, USA, Routledge. http://site.ebrary.com/

Gopinath, G. & P**.** Seralathan. 2005. Rapid erosion of the coast of Sagar island, West Bengal – India. *Environment Geology,* 48: 1058–1067.

Huq, S., Karim, Z., Asaduzzaman, M. & **F.** Mahtab **(**Eds.) 1999. **Vulnerability and adaptation to climate change in Bangladesh.** Dordrecht, the Netherlands, J. Kluwer Academic Publishers. 147 pp.

Jarvela, J. 2002. **Flow resistance of flexible and stiff vegetation: a flume study with natural plants.** *Journal of Hydrology,* 269*:* 44–54.

Kamphuis, J.W. 2002. **Introduction to coastal engineering and management. Advance series in ocean engineering.** World Scientific. 437 pp.

Komar, P.D. 1998**. Beach processes and sedimentation.** Second edition. Prentice-Hall.

Kobayashi, N., Raichle, A.W. & T. Asano. 1993. **Wave attenuation by vegetation.** *Journal of Waterway, Port, Coastal, and Ocean Engineering,* 119(1): 30–48.

Kawata, Y. 1989. **Methodology of beach erosion control and its application.** *Coastal Engineering in Japan,* 32(1): 113–132.

Kovacs, J.M. 2000. **Perceptions of environmental change in a tropical coastal wetland.** *Land Degradation & Development,* 11: 209–220.

Lee, T.M**.** 2005. **Monitoring the dynamics of coastal vegetation in Southwestern Taiwan.** *Environmental Monitoring and Assessment,* 111: 307–323.

Malini, B.H. & K.N. Rao. 2004. **Coastal erosion and habitat loss along the Godavari delta front – a fallout of dam construction (?).** *Current Science,* 87 (9): 1232–126.

Massel, S.R., Furukawa, K. & R.M**.** Brinkman. 1999. **Surface wave propagation in mangrove forests**. *Fluid Dynamics Research,* 24: 219–249.

Mazda, Y., Magi, M., Nanao, H., Kogo, M., Miyagi, T., Kanazawa, N. & D**.** Kobashi. 2002. **Coastal erosion due to long-term human impact on mangrove forests.** *Wetlands Ecology and Management,* 10: 1–9.

Mazda, Y., Wolanski, E., King, B., Sase, A., Ohtsuka, D. & M. Magi. 1997. **Drag force due to vegetation in mangrove swamps.** *Mangroves and Salt Marshes,* 1: 1993–1999.

Mazda, Y., Magi, M., Kogo, M. & N.P. Hong. 1997. **Mangroves as a coastal protection from waves in the Tong King delta, Viet Nam.** *Mangroves and Salt Marshes,* 1: 127–135.

Mendez, F.J. I.J. & Losada. 2004. **An empirical model to estimate the propagation of random breaking and nonbreaking waves over vegetation fields.** *Coastal Engineering,* 51: 103–118.

Moller, I., Spencer, T., French, J.R., Leggett, D.J. & M. Dixon. 1999. **Wave transformation over salt marshes: A field and numerical modeling study from North Norfolk, England**. *Estuarine, Coastal and Shelf Science,* 49: 411–426.

Moller, I. 2006. **Quantifying saltmarsh vegetation and its effect on wave height dissipation; results from a UK east coast saltmarsh.** *Estuarine, Coastal and Shelf Science,* XX: 1–15.

NRC**.** 1990. **Managing coastal erosion.** Committee on Coastal Erosion Zone Management, Water Science and Technology Board, Marine Board, Commission on Engineering and Technical System, National Research Council. Washington, DC, National Academy Press. 182 pp.

Nurkin, B. 1994. **Degradation of mangroves forest in South Sulawesi, Indonesia.** *Hydrobiologia,* 285: 271–276.

Othman, M.A. 1994. **Value of mangroves in coastal protection.** *Hydrobiologia,* 285: 277–282.

Prasetya, G.S. & K.P. Black. 2003. **Sanur and Kuta Beaches in Bali – case studies for replacing traditional coastal protection with offshore reef**. Proceedings of Artificial Surfing Reef, 2003. Raglan, NZ.

Sale, E.V. 1985. **Forest on sand, the story of Aupouri state of forest.** The New Zealand Forest Service.

Samarayanke, R.A.D.B. 2003. **Review of national fisheries situation in Sri Lanka.** In: G. Silvestre, L. Garces, I. Stobutzki, M. Ahed, R.A. Valmonte-Santos, C. Luna, L. Lachica-Alino, P. Munro, V. Christense & D. Pauly (Eds.) *Assessment, management and future direction of coastal fisheries in Asian countries,* pp. 987–1012. WorldFish Center Conference Proceedings 67. 1120 pp.

Sato, Y. & N. Mimura. 1997. **Environmental problems and current management issues in the coastal zones of south and southeast Asian developing countries.** *Journal of Global Environmental Engineerin*g, 3: 163–181.

Struve, J., Falconer, R.A. & Y. Wu. 2003. **Influence of model mangrove trees on the hydrodynamics in a flume.** *Estuarine, Coastal and Shelf Science,* 58: 163–171.

Swan, S.B.Stc**.** 1974. **The coast erosion hazards southwest Sri Lanka: an introductory survey.** University of New England. 182 pp.

Swan, S.B.Stc. 1984. **The coastal geomorphology of Sri Lanka.** *New England Research in Applied Geography*, No. 40. 125 pp.

Syamsudin, K. & F. Riandini. 2000. **Coastline evolution monitoring at up drift and downdrift of some coastal structure in Indonesia.** Proceedings Institut Tekonologi Bandung on Seminar on Sediment Transport. Supplement 32, No.3. 2000, pp. 45–54.

Tjardana, P. 1995. **Indonesian mangroves forest.** Duta Rimba, Jakarta.

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

Turker, U., Yagci, O. & M.S. Kabdasl. 2006. **Analysis of coastal damage of beach profile under the protection of emergent vegetation.** *Ocean Engineering,* 33: 810–828.

UNEP–WCMC. 2006. **In the front line: shoreline protection and other ecosystem services from mangroves and coral reefs.** Cambridge, UK, UNEP-WCMC. 33 pp.

Van der Weide, J., de Vroeg, H. & F. Sanyang. 2001. **Guidelines for coastal erosion management.** In: E. Ozhan, ed. *Medcoast 01: proceedings of the fifth international conference on Mediterranean coastal environment*. Vol. 3, pp. 1399–1414. Ankara. Turkey.

Wolanski, E. 1992. **Hydrodynamics of mangroves swamp and their coastal waters.** *Hydrobiologia,* 247: 141–161.

Wu, Y., Falconer, R.A. & J. Struve. 2001. **Mathematical modeling of tidal currents in mangroves forests.** *Environmental Modelling & Software,* 16: 19–29.

Xia, D.X., Wang, W.H., Wu, G.Q., Cui, J.R. & **F.L.** Li. 1993. **Coastal erosion in China.** *Acta Geographica Sinica,* 48(5): 468–476 (English abstract).

Field study presentation: Status of coastal erosion in Viet Nam and proposed measures for protection

N.N. Cat, P.H. Tien, D.D. Sam and N.N. Bien, Centre for Training, Consultancy and Technology Transfer, Viet Nam Academy of Science and Technology

The coastal zone of Viet Nam is 3 260 kilometres long, extending through the territories of 24 provinces and cities. Interaction between the land and the sea, between the dynamic forces of rivers and the sea and between natural and human processes occurs in this zone. On average, river mouths are found every 20 kilometres along the Viet Namese coast. Landforms are diverse and natural calamities occur frequently, causing multidirectional impacts on natural and socio-economic conditions. In particular, coastal erosion generates many difficulties for the coastal population.

Some coastal processes (for example, wind, waves and tides) have been identified as key factors vis-à-vis *influencing coastal erosion. Human activities* (inter alia *vegetation clearance, harbour development, land reclamation) may often result in sediment addition or reduction. During a tsunami impact, coastal erosion is caused by the rundown of the water, which will remove a high percentage of sediment and debris from the land. Modification of soil composition after such an event should be taken into account during rehabilitation activities.*

Mitigation measures currently in use are hard structures (for example walls, rip-raps), soft structures (beach nourishment, mangrove plantation) and a combination of the two. The effectiveness of each mitigation measure can only be analysed on a case-by-case basis.

Extreme erosion in Viet Nam depends on several factors that should be further investigated in order to respond in an effective manner. Even though human pressure has been recorded as one of the main causes, to date, the construction of the Dinh Vu Dam seems to have decreased erosion in some regions of the country. Protective measures such as dykes and revetments and the plantation of trees are used to control erosion. The Viet Namese Government is investing in research for effective protective measures.

Key points and observations emphasized in the discussions

The main conclusions of the presentations and discussions were as follows:

1. Longshore erosion may cause worse problems than cross-shore erosion.
2. Economic, environmental, social and cultural values are all subjects of protection from coastal erosion; national governments can determine priorities by taking these factors into account, depending on the specific situation (often areas of high economic value are protected with appropriate measures, while land with low economic value is left unprotected).
3. Coastal forests (and forests in general) provide benefits to local populations (they provide a wide range of wood and non-wood forest products) and to fauna.
4. Trees prevent coastal erosion and stabilize shoreline areas by consolidating sediment and building up land.
5. The establishment of a green belt/buffer zone should always be done using participatory planning in collaboration with local communities.
6. Sufficient time frames, local participation and space availability are key factors for supporting reforestation options.