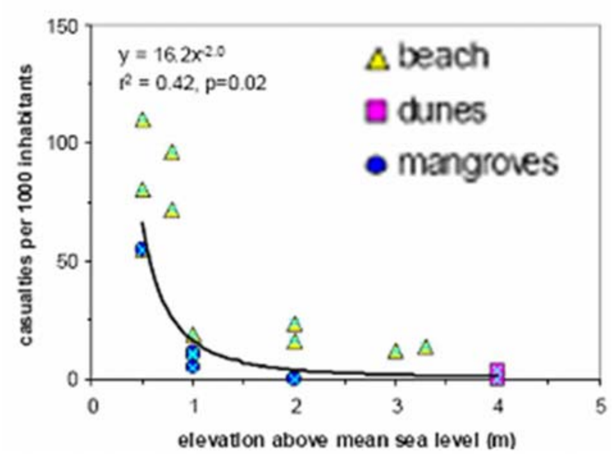

Figure 6.8 For the 2004 Indian Ocean tsunami, plot of mortality (lives lost/1 000, right) in 18 hamlets on the coast of Tamil Nadu against distance from the shore (km) and elevation above mean sea level (m), respectively. The symbols depict different coastal types (Δ = beach; □ = dune; O = mangroves). The curve is fitted to the pooled data set of 18 hamlets. Data from Vermaat and Thampanya (2006)

Trees are thus effective as long as they are not uprooted or snapped, in which case they form debris that may destroy human lives and property. The survival of the trees depends on the size of the trees, their density and the size of the tsunami. The calculations (Appendix B) suggest that a three-metre tsunami is thus able to uproot an isolated three-metre mangrove tree. However, if the trees grow close together, then, as a result of interlocking of roots from adjoining trees, densely vegetated trees of a height greater than six metres may be able to withstand a six-metre tsunami wave. There is some evidence of this from observations of the Indian Ocean tsunami. Mangroves cannot survive a larger tsunami. Thus, mangroves probably cannot protect the coast against a tsunami greater than six metres. All of these results agree qualitatively with observations of the impact on mangroves of the Indian Ocean tsunami (Plate 6.1A–D; Latief and Hadi, this volume).

Mangroves can thus save human lives in a small to moderate tsunami (Figure 6.8). However, if the wave exceeds the threshold level, catastrophic failure of the mangrove ecosystem occurs, whereby snapped or uprooted trees are carried by the currents as debris to destroy other trees in its path and harm people and property. From models, this threshold can be determined by the size and the density of the mangrove vegetation, the root and soil structure, and the size of the tsunami.

Non-mangrove trees such as *Casuarina* and palm trees also exerted a similar impact on absorbing tsunami wave energy. However, the tsunami threshold level was smaller, about two to three metres even for fully grown trees, where trees snapped or were uprooted (Figure 6.9e,f; http://river.ceri.go.jp/rpt/asiantsunami/en/survey.html). Thus, plantations of these trees offer protection against only small tsunamis.

5.3 Erosion from shallow water wind waves and boat wakes

Mangroves are not efficient at absorbing small water waves from boat wakes and shallow-water wind waves at low tide when the wave erodes the soil below the root level. Once the erosion starts, it swiftly progresses, sometimes taking only a few weeks until the undercut trees fall down in the water (Plate 6.1G).

6 Protection of the coast against wind and salt spray

In the same way that the water current through a mangrove forest is decreased by vegetation that exerts a drag force on the water, the vegetation also exerts a drag force on the air flow through the canopy. The wind through a tree canopy (Figure 6.9a) is decreased throughout the height of the tree, particularly at the height of the leaves. This shelters the area downstream through a wake effect to a distance rarely greater than five times the height of the tree (Figure 6.9b), as dictated by classical fluid dynamics.

Because the flow around vegetation is three-dimensional, this sheltering distance can be significantly increased if the trees are grown in a wide shelterbelt (one or two rows of trees whose canopies touch each other) and forest belts (multiple rows). A wide shelterbelt forms a long turbulent wake in its lee (Figure 6.9c). Then the sheltering distance can be as much as 20 times the height of the trees if the wind blows perpendicular to the shelterbelt. The sheltering distance is only twice the height of the trees if the wind blows parallel to the shelterbelt (Takle *et al.*, this volume).

This sheltering effect diminishes in a typhoon if the tree is wholly or partially defoliated (Figure 6.9d–e), and disappears if the tree is overturned (Figure 6.9f). Large trees are overturned more readily than small trees (Figure 6.9f) because they are exposed to stronger winds as a result of the wind shear near the ground (Figure 6.9a). Experience with cyclones in Australia and hurricanes in the United States shows that total defoliation of fully developed mature mangrove trees happens only during super cyclones, and is typically restricted to a strip less than 50-metres wide (M. Williams, personal communication).

The foliage of some non-mangrove trees such as *Casuarina* is less hardy and the tree can be defoliated by severe, but non-cyclonic, winds. Often these trees are also much more readily snapped or overturned by the wind; thus, they constitute an unreliable wind bioshield during a typhoon.

Trees also offer significant protection against salt spray, i.e. fine salt particles carried in suspension in the air (Takle *et al.*, this volume). Just as water flow through mangrove forests creates less turbulent wakes behind trees where the suspended mud is deposited, the air flow downwind of trees creates less turbulent zones where the suspended salt particles are deposited (Figure 6.9b). This effect extends downwind of a windbreak to a distance equal to about ten times the height of the tree.

Thus, a wide shelterbelt projects a wide turbulent wake that is very efficient at capturing salt particles in suspension (Figure 6.9c). This process traps the salt spray near the coast, facilitating its return to the sea and preventing the salt from polluting inland soils.

7 Discussions

7.1 Services to the coastal community

Mangroves provide important services to the human population by providing ingredients for traditional medicine, housing prawns and fish, and supplying wood and fodder (Badola and Hussain, 2005; Blaber, 1997; Prasetya, this volume; Preuss, this volume; Manson *et al.*, 2005). In addition, mangroves provide two hydrodynamic services of importance to the coastal population that are described hereunder.

<u>Maintaining navigable channels:</u> Mangrove creeks are self-scouring (Wolanski, 1992; Wolanski *et al.*, 2001). During spring tides there is a marked tidal asymmetry of the currents in the channel or estuary that drain the mangroves, the peak ebb tidal currents at the mouth of the creek being measurably larger than the peak flood tidal currents. If the mangrove area decreases from mangrove clearing, the creek silts up. Examples of this abound in areas where developers, such as prawn farmers, have reclaimed mangrove land. In the case of Klong Ngao Estuary in Thailand, where half of the mangrove land was reclaimed, the tidal creek silted within five to ten years so that it now dries up completely at low tide. In its natural state it was navigable even at low tide (Wattayakorn *et al.*, 1990). Thus, mangrove vegetation is essential to maintain navigable channels.

<u>Trapping of fine sediment:</u> Muddy waters enter the mangroves at rising tide, deposit some of the suspended sediment in quiet zones near slack high tide in the mangroves, and return to the estuary with less sediment. The difference between the mud that enters and leaves is sediment trapping. Field studies (Victor *et al.*, 2004, 2006) have shown that a mangrove that covers 3.8 percent of the river drainage area traps 40 percent of the riverine mud inflow; the rest contributes to estuarine

siltation (20 percent) and is exported to coastal waters (40 percent). This relationship is independent of land use in the catchment, holding true for developed and undeveloped catchments.

Mangroves fringing muddy open waters are also effective in trapping large amounts of mud from coastal waters – up to 1 000 tonnes/km^2/year (Wolanski *et al.*, 1998).

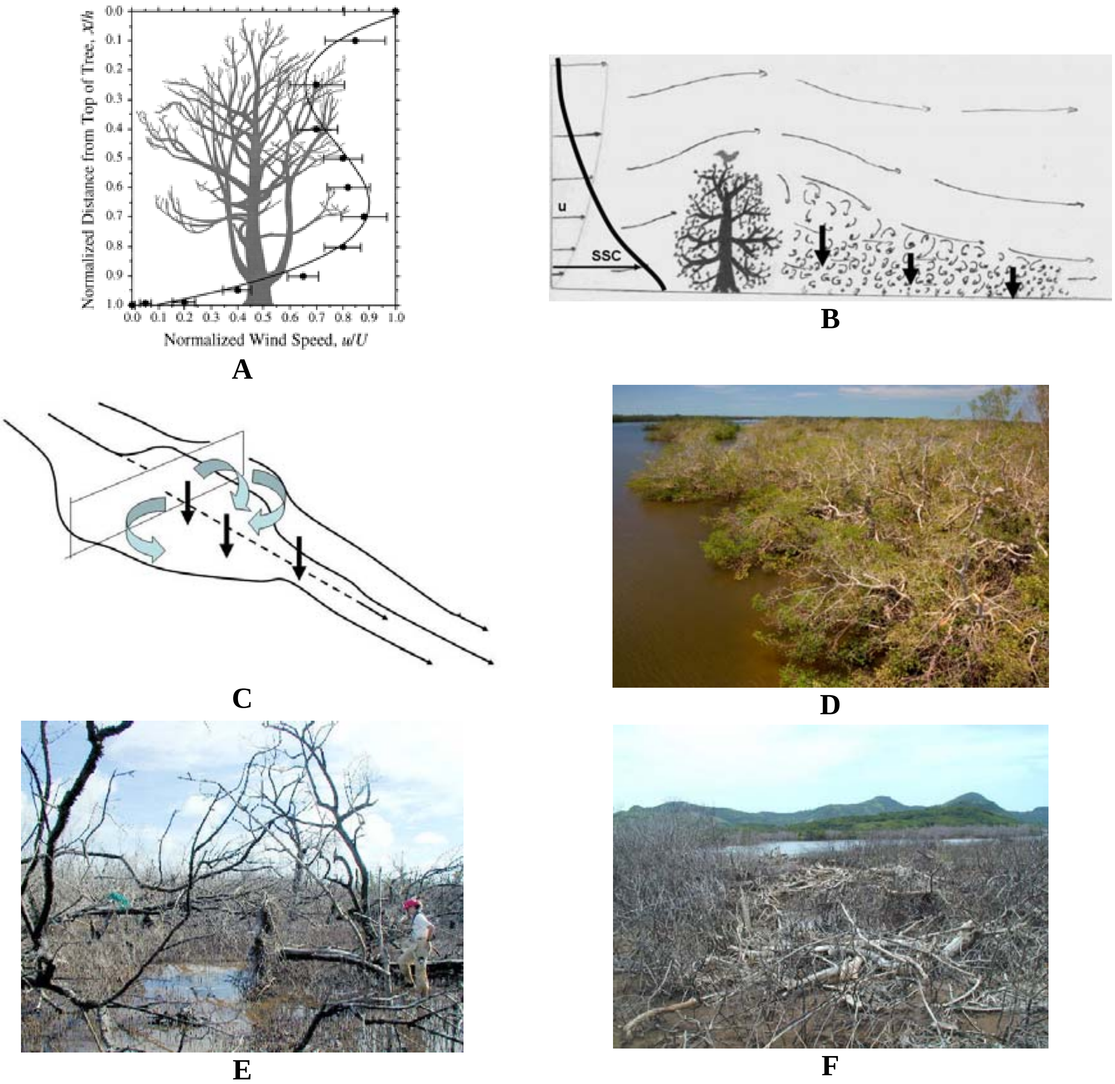

Figure 6.9 A: Vertical profile of windspeed u through a 13.1-m-high wild cherry tree, 0.4 m in diameter at 0.5 m from ground level, growing in an open site. The velocity is normalized by the maximum windspeed u measured at the top of the canopy. The silhouette of the tree shows all branches for which d >5 mm (from Niklas *et al.* [2000]). B: Sketch of the air flow around, over and through: (a) a single tree; and (b) a shelterbelt — the wind accelerates over and around the vegetation and a turbulent wake forms behind the tree. SSC = suspended salt concentration; down arrows = deposition of salt particles in the wake. C: A wide shelterbelt forms a long turbulent wake in its lee. D–F: Mangroves in Florida: (D) partially defoliated; (E), totally defoliated by a hurricane; and (F) overturned by the hurricane. (Note: Large trees are overturned more readily than small trees.) Source: USGS Florida

7.2 The relevance of bioshields against natural hazards

Mangroves help to protect the coast from wave erosion by wind-driven waves and typhoon waves. Coastal forests and mangroves can save human lives and property in a tsunami by transforming a shock wave into a flood, at least up to threshold level. They also shelter the hinterland from salt spray and wind damage up to threshold level.

All these findings have been observed in the field; they are science-based because they result from well-known principles of fluid and soil mechanics, structural engineering and ecology. Thus, the benefits of mangroves and coastal forests for protection against natural hazards and enhancing the quality of life of human populations are numerous.

7.3 Creating bioshields

Creating bioshields is a highly soft technology that involves tree plantations on land, as well as restoring former mangrove areas and even planting mangroves at sea.

7.3.1 Restoring mangroves in sheltered areas

Recreating mangroves from abandoned shrimp ponds is the easiest option and has the additional benefit of fostering commercial activities. For instance, fish and crab ponds in mangrove-fringed tidal creeks can be successful. However, planting mangroves in shallow shrimp ponds, as attempted in Viet Nam, has largely failed (B. Clough, personal communication).

Soil preparation is needed because former mangrove soils turn acidic when used as shrimp ponds. Planting seedlings in reclaimed shrimp ponds fails if the natural drainage pattern is not properly restored; otherwise, the seedlings rot and die in stagnant water (Plate 6.2a).


A **B**


C **D**

Plate 6.2 A: Mangrove plantation in a reclaimed shrimp pond near Surat Thani, Thailand. About half of the mangrove seedlings died where the water was ponded. B: Planting mangrove seedlings in Eritrea where mangroves did not formerly exist (http://www.ramsar.org/wwd/3/wwd2003_rpt_eritrea1.htm). C: Planting mangroves along the north coast of the Inner Gulf of Thailand has been unsuccessful due to accelerated wave erosion; hard structures are necessary to protect the coast against wave erosion. D: Protection of mangrove seedlings using the Riley encased method (Riley and Kent, 1999; http://mangrove.org/video/rem.html) is suitable for sheltered estuaries where ocean swell is absent and the only waves are shallow wind waves and boat wakes

7.3.2 Creating mangrove forests along estuaries and at sea

Mangroves are highly susceptible to below-root level erosion from boat wakes and shallow water wind waves near low tide. This limits the areas where mangroves can be planted.

Mangrove forests can even be created at sea by planting seedlings over an intertidal area above mean sea level, provided that the shallow coastal water strip is very wide (typically a 2–3-kilometre-wide area above mean sea level). This was done successfully over a muddy substrate in Viet Nam (Mazda *et al.*, 1997, 2006). It was done with moderate success over a muddy sand substrate in Eritrea (Plate 6.2b) and in Thailand's Chumphon Bay (Brown and Limpsaichol, 2000). It has failed somewhat along the north coast of the Inner Gulf of Thailand due to persistent wave erosion; the shallow coastal water strip is too narrow and this allows frequent wave attacks along the coast (Plate 6.2c). Planting mangroves at sea fails in areas where large waves occur, even if only occasionally, because in this case mangroves are planted in areas where they would not occur naturally. For successful mangrove planting, the maximum wave height appears to be one metre according to the experiences in Viet Nam, Thailand and Eritrea.

In estuaries and channels where boat wakes and small wind waves occur, successful attempts have been made, but at great cost, to protect the young trees until they can survive the waves. Techniques include: (1) allowing the seedlings to grow much longer in a nursery until they become small trees that can better resist waves; (2) planting the seedlings in hollows within solid structures such as tyres or a concrete structure; (3) planting the seedlings in transparent PVC tubes (Plate 6.2d); and (4) protecting the seedlings behind temporary structures such as bamboo walls.

7.3.3 Sacrificial bioshields

A belt of forest might be sacrificed to give protection against extreme natural hazards; it should be managed accordingly. The seaward edge of the forest (mangrove or non-mangrove) is the sacrificial zone (Takle *et al.,* this volume). It takes the brunt of the damage due to "flagging" by wind, high salt impaction and occasionally suffers total defoliation (in typhoons) and destruction of the trees by typhoons or tsunamis, as well as from coastal erosion events that can occur even when the coast is generally prograding seaward in the long term. Management has to accept that this zone is unsteady and unstable and precludes human settlement; also, it should allow for natural regeneration, replanting of destroyed trees and possibly construction of artificial fences to better protect the first line of trees from lethal salt and wind damage in high impact zones.

7.3.4 The width of bioshields

In terms of protection against typhoon winds, mangroves constitute excellent wind bioshields and a zone of 100 metres may be sufficient against a typhoon (Dutton, 1986). Empirical evidence (for example, Cyclone Winifred in Queensland in 1986) (Dutton, 1986) suggests that coastal forests need to be much wider (up to one or two kilometres?) to measurably protect the hinterland from cyclone winds; however, the science is unavailable to better quantify this theory.

In terms of protection against coastal erosion from typhoon waves, field evidence suggests that when the coastal waters are shallow, a coastal belt of 500 to 1 000 metres of adult mangroves seems to be necessary to protect small coastal dykes that halt further coastal erosion. Thus, the protection is twofold: it consists of mangroves absorbing the brunt of the wave energy and a small coastal dyke absorbing the rest (Figure 6.2). This will fail if the coastal waters are deep because the waves are large and will uproot the mangroves. Nature is a good guide to where this technique can be used. If there are no mangroves growing in such areas, this is probably because the coast is naturally eroding; thus, attempts to plant mangroves at sea will fail in the long term (Hanley, 2006). In arid areas of Eritrea, the lack of natural mangroves is due to extreme temperatures that affect the seedlings.

In terms of protection against tsunamis, the science remains qualitative rather than quantitative; as a rule of thumb, field data suggest that a belt of at least 500 metres of adult, densely forested, mangroves will measurably save human lives from a tsunami not exceeding four metres in height. A width of 2 000 metres will reduce the tsunami to a small wave of less than one metre. In all probability, mangroves will not be helpful against a larger tsunami. As pointed out by Latief and Ladi (this volume), the size of the tsunami wave cannot be predicted because it varies spatially as a result of tectonics and interacts with the local bathymetry. Thus, the decision to create a bioshield is based on a calculated risk, i.e. knowing that the bioshield will be ineffective for extremely large tsunamis, at which times other measures (such as advance warning systems, evacuation plans and shelters) are necessary.

8 Limitations and constraints

8.1 Diagnostic tools

For a sheltered estuary (Figure 6.10a), a muddy or degraded coast can be restored and better protected by the use of mangroves. The sediment capture rate of the mangroves depends on the riverine sediment inflow and can be calculated. This enables one to calculate how fast land can be reclaimed for agriculture. The data required are oceanography, mud dynamics and riverine sediment inflow, and mangrove forestry in order to select the appropriate species of trees, the eventual use of a mangrove nursery and the forestry exploitation rate.

For protection against erosion on an open coast (Figure 6.10b), historical data can be used to determine if a coast is eroding or prograding in the long term. However, the past is not an indication of the future if a large structure has been built, or is planned, because this may reverse the coast from prograding to eroding. If the coast is eroding, planting mangroves at sea is likely to fail. If the coast is prograding, planting mangroves over intertidal areas above mean sea level in coastal waters may succeed in protecting the coast if combined with a hard structure such as a small levee or dyke, as practised in the Gulf of Tonkin. If the intertidal area is too short to reduce the wave height to below one metre, a bioshield may be successful if combined with an offshore structure as well as a hard structure on the coast.

For protection against typhoons and their associated river floods, winds and storm surges (Figure 6.10c), bioshields have minimal impact on peak flood levels, but have a large impact on reducing waves, currents and wind. If the drainage pattern is well-planned, they can significantly reduce the flooding duration. A bioshield of two kilometres may be needed, together with a sacrificial bioshield, possibly accompanied by a sand dune nearest the coast. Data required include hydrology (river floods), oceanography and meteorology, to determine the width of the sacrificial bioshield based on acceptable loss of economic returns. The drainage patterns must be carefully designed so as to allow the water to readily return to sea. In the case of a super cyclone, bioshields will not help measurably and other measures need to be planned to save human lives, including storm surge barriers, an evacuation strategy and shelters.

For protection against tsunamis (Figure 6.10d) the first defence has to be an early warning system combined with an evacuation strategy, shelters, community awareness and engineering structures to reduce damage to infrastructure and loss of life. The level to which a bioshield can protect against a small tsunami (< 5–6 metres) varies locally according to the bathymetry (areas near headlands are most at risk), the angle of attack and the distribution of the bioshield. A mangrove forest may block the tsunami wave — and protect people and property as close as 500 metres from the beach — while at the same time it can redirect the wave towards an estuary where the damage may be amplified. The wave can be largely attenuated within 2.5 kilometres. A large tsunami (> 6 m) may be unstoppable by a bioshield.

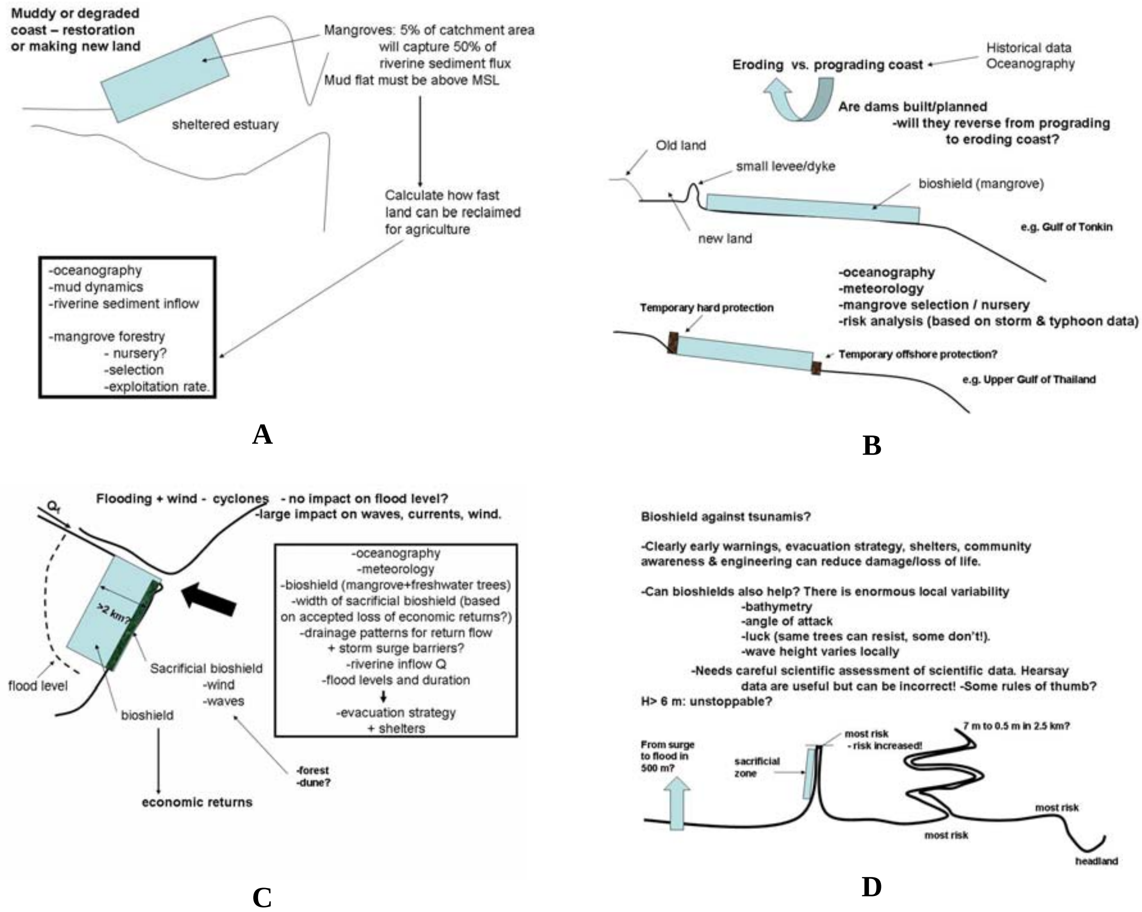

Figure 6.10 Diagnostic tools for the use of bioshields in: (A) a sheltered estuary (B) protection against erosion of an open coast (C) protection of a coast from a typhoon (D) protection against a tsunami

9. Conclusion and discussion

To protect the human population living near the coast from excess sedimentation and erosion, a governance system needs to be established to regulate human activities in the whole river catchment as the fundamental planning unit; the aim is to decrease soil erosion and to stop mud flows, largely by the use of vegetation, especially on steep slopes and on the river banks, as well as to maintain sediment fluxes when rivers are dammed so as to prevent human-induced coastal erosion.

The cost of bioshields is high, but it is balanced by the ecological and socio-economic services that they provide. This cost is much lower than that of a hard structure that fully protects the coast. However, when hard structures fail, the cost can be catastrophic because of the accumulation of human assets in its shadow.

As a rule of thumb, a mangrove area covering about five percent of the catchment area can halve the impact on coastal sedimentation, seagrass and corals. It can considerably lessen the impact of increased riverine sediment on fisheries (see Table 6.1) owing to poor land use in the river catchment. Thus, mangroves protect fisheries by sheltering the seagrass and coral reefs from excess sedimentation.

The efficacy of bioshields for protection against natural hazards as well as to provide socio-economic and ecological services has been proven. In practice, the level of applicability depends on the local climate, hydrology, drainage pattern, meteorology, oceanography, soil type, wave, storm pattern and socio-economic drivers. Climate change may complicate the situation. There is no unique recipe. Applicability to various sites thus depends more on the willingness and the capacity of individual countries to adopt mangroves and coastal forests as bioshields, on a case-by-case basis. The level of adoption will depend on socio-economic imperatives (Preuss, 2006). Where the coast has been totally urbanized by planned developments or slums, this solution is then in practice impossible to implement. In other cases the practical use of coastal forests and mangroves is feasible to protect people and property and enhance their livelihoods and quality of life. The protection that bioshields offer is far from total; it also involves risks because the usefulness of bioshields has limits in extreme events. The bioshield solution is advantageous because it is often practical and inexpensive in comparison with pure engineering solutions (such as the Dutch solution of building dykes along the coast), requires relatively low technology and it protects and enhances the environmental services provided by estuaries and coastal waters on which populations often depend for their livelihoods. It is thus a matter of living within accepted risks.

The level of risk will vary from site to site apropos the bathymetry and topography of the coastal areas, geology, meteorology and oceanography. Judging from typhoon statistics alone, no two sites are alike in Asia, suggesting that the relevance and use of bioshields will also vary spatially (Takle *et al.,* this volume).

The science of bioshields is well-established; however, the technology of bioshields is still developing. It is a mixture of many socio-economic and ecological considerations that include the following (see details in Saenger, 2002; Prasetya, this volume; Hanley, 2006; Preuss, this volume):

- Site selection based on existing land use and infrastructure, as well as the intensity and frequency of natural hazards, largely avoiding naturally eroding areas and selecting species based on rainfall, wind tolerance and salt spray for coastal forests and suitable sheltered coastal sites with suitable rainfall and appropriate tidal inundation for mangroves.
- Selection of species for mangrove and coastal forests that have the correct ecological requirements for the physical characteristics at the site.
- Selection of available species from the wild (some mangrove species may have become locally extinct, e.g. in Aceh — see Hanley, 2006) or from nurseries.
- Soil preparation.
- Restoring tidal flows in shrimp ponds.
- Planned economic utility (e.g. providing societal benefits such as fisheries and coastal protection in the case of mangroves, or direct benefits such as wood, fibre and fodder for mangroves and coastal forests).
- Community aspirations.
- Community involvement.
- Plantation techniques and planting pattern.
- A maintenance programme for the seedlings and the plantation.

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Appendix A

The vector of the horizontal force F is the sum of the inertial F_i and drag F_d forces (Figure 6A1; Milne-Thompson, 1960):

$$F = F_i + F_d \quad \text{(A1)}$$

where

$$F_i = C_m \rho_w V a \quad \text{(A2)}$$

$$F_d = 0.5 \rho_w C_d (D Z) |u| u \quad \text{(A3)}$$

where C_m (≈ 1.5 for fully turbulent flows) and C_d (≈ 0.45) are the inertia and drag coefficients, u is the water velocity, V is the displaced volume of the body, ρ_w is the density of water, a is the acceleration, D the diameter of the vegetation assumed cylindrical, Z is the depth to which the vegetation is submerged. It is readily possible to extend the theory for a tapered stem where D diminishes with elevation (Niklas, 2000).

For an unbroken wave of period T,

$$u = U \cos(kx - \omega t) \quad \text{(A4)}$$

$$a = 2 \pi U \cos(kx - \omega t)/T \quad \text{(A5)}$$

where

$$U = \pi H \cosh k(z+h) / T \sinh(kh) \quad \text{(A6)}$$

where h is the water depth, H the wave height, k is the wave number defined from the dispersion relation

$$\omega^2 = g k \tanh(kh) \quad \text{(A7)}$$

where g is the acceleration due to gravity.

For tidal inundation and wind or typhoon waves, the vegetation is only partially submerged; therefore Z = h.

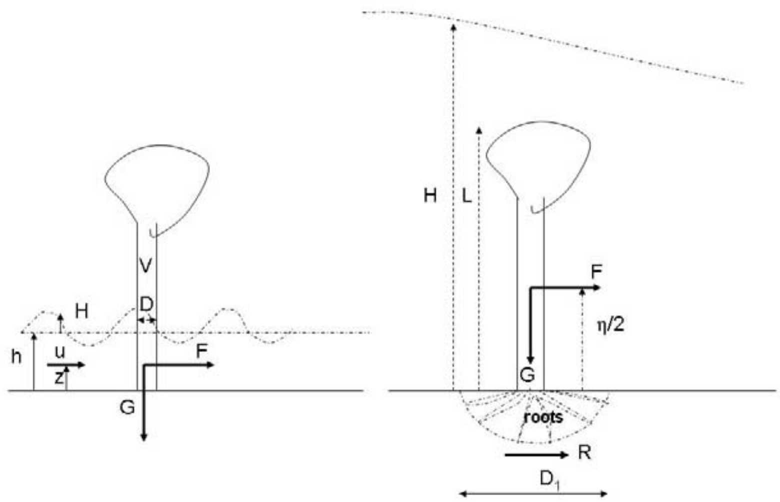

Figure 6A1 Idealized wind and typhoon waves (left) and a tsunami wave (right) through trees showing terms used in the text

Appendix B

The tsunami propagating in a mangrove is initially a broken wave. The horizontal velocity u is (Hedges and Kirkgoz, 1981)

$$u = 0.5\ (g\ H)^{1/2} \qquad \text{(A8)}$$

Trunk breaking occurs if the horizontal breaking strength σ_s ($\approx 185 \pm 35$ MN/m^2) of the tree at the base is exceeded by inertial and drag forces (Niklas, 2000),

$$4\ (F_i + F_d)\ /\ 3 \geq \pi\ (D/2)^2\ \sigma_s \qquad \text{(A9)}$$

For typical values of σ_s of healthy trees, this mode of trunk breaking is unlikely. Breaking instead seems to result from the overturning moment of forces F_i and F_i that act at an elevation η (η = H/2 or L/2, whichever is the smallest, where L is the height of the vegetation). The overturning moment lifts the upstream edge of the basal area and forces down the downstream edge, creating tension at the upstream edge and compression at the downstream edge. Trunk breaking occurs if tension exceeds the breaking strength in tension σ_t of the tree,

$$-G/\ 2\ \pi\ (D/2)^2 + \eta\ (F_i + F_d)\ D/2\ /\ 0.25\ \pi\ (D/2)^4 \geq \sigma_s\ ` \qquad \text{(A10)}$$

or the breaking strength in compression σ_c of the tree,

$$G/\ 2\ \pi\ (D/2)^2 + \eta\ (F_i + F_d)\ D/2\ /\ 0.25\ \pi\ (D/2)^4 \geq \sigma_c \qquad \text{(A11)}$$

where G is the weight of the tree. The calculations suggest that, for typical material shear strength of timber, for a 3-metre tsunami wave in the mangroves, 3-metre tall trees will snap and for a 6-metre tsunami wave, 8-metre tall trees will snap.

Trees overturn with their roots if the overturning moment exceeds the soil-resisting moment (Peck *et al.*, 1973; Bowles, 1988),

$$(F_i + F_d)\ \eta/2 > \pi\ R\ (D_1/2)^2 \qquad \text{(A12)}$$

where (Figure 6A1) R is the force of resistance of the soil to shearing at the interface between the root matrix and the soil and D_1 (D_1 ~4 D) is the width of the root system, and

$$R = c + P \tan\theta \qquad \text{(A13)}$$

where c is the cohesion (c ~ 75 kg m^{-2} for compacted clay, c = 0 for pure sand), P is the normal stress, and θ is the angle of internal friction (θ ~ 40^o for sand, θ ~ 0 for clay).

Key points and observations emphasized in the discussions

During the past 20 years, population pressure on coastal zones has nearly doubled — they house approximately 60 percent of the world's population. In Asia, several coastal localities are under threat from natural hazards, which can be divided into two main areas:

1. Hazards from land. Some examples are soil erosion caused by river deposition of silt from steep areas which occur in flat river valleys and can result in higher flood levels, or by large dams which can trap coarse sediments that normally sustain sediment wedges in coastal estuaries, and may lead to exacerbated coastal erosion.

2. Hazards from the sea, for example storms/typhoons, tsunami, coastal erosion or prograding (accretion) and salt spray (worst in arid areas where annual precipitation is less than one metre.

Mitigation measures have been discussed in Chapters 1 to 5; however, the synthesis presentation and relative discussions have highlighted that:

1. Human mortality from a tsunami is higher in coastal areas where people live along exposed beaches as opposed to areas protected by mangroves.
2. Coastal forests can provide some protection against a tsunami, in addition to all the other kinds of services and benefits such as food, wood and medicinal benefits for local communities, enhancing estuarine fisheries, trapping land-borne sediments and protecting reefs, providing self-scoured deep navigable channels, etc.
3. Mangrove trees may offer a higher protection than *Casuarina* or coconut trees.
4. It is important to note that mangroves, as well as other kinds of coastal forests, cannot stop big waves (for example, waves of three to six metres in height can snap mangrove trees three to eight metres in height respectively).
5. Indicative widths of mangrove bioshields could be:
   - typhoon: 100–300 metres
   - typhoon waves: 500–1 000 metres
   - storm surge: 200 metres
   - tsunami: 500–2 000 metres

In conclusion:

1. Coastal bioshields can provide some kind of protection, but cannot provide complete protection and should include an accepted "sacrificial zone" (i.e. the first lines of trees which could be damaged by the hazard).

2. As a consequence of this, natural hazard-prone localities should have well-developed and effective warning systems and evacuation plans, which should work in conjunction with the mitigation measures in order to save lives during the impact of natural hazards.

3. In the case of plantations, tree species should be chosen with care and based on the type and severity of hazards.

4. Mitigation solutions should involve entire watershed areas, not just coastal zones.

5. Where possible, relevant infrastructures (e.g. hospitals, schools, roads) in tsunami-prone areas should be located on high ground.

CHAPTER 7
FORESTRY INITIATIVES FOR COASTAL PROTECTION

Six presentations on current initiatives on coastal forest management for forest protection were discussed by government representatives (Forestry Department of Sri Lanka and the Forest Research Institute of Malaysia) and by officers of national and international organizations (UN/ISDR, Wetlands International, IUCN and SAARC).

Brief descriptions of the aforesaid presentations are given below; the full power-point presentation is available on the CD of this proceedings.

UN International Strategy for Disaster Reduction (UN/ISDR): Mr Akshat Chaturvedi, Programme Officer of UN/ISDR, reported on the organization's strategy for disaster risk reduction and environmental management; he also provided a summary of its mission and its main objectives as well as some of the current activities and outputs.

Green Coast project: Mr Vikmuthi Weeratunga, Biodiversity Coordinator of the World Conservation Union, provided relevant information on the "Green Coast for Nature and People after the Tsunami" project, an international partnership of four international nature conservation and environmental organizations (IUCN, Both Ends, WWF and Wetlands International), supported by Novib/Oxfam and the Netherlands. The project aims at rehabilitating local livelihoods through sustainable restoration and management of coastal ecosystems affected by the 2004 Indian Ocean tsunami. The project will be implemented in India, Indonesia, Thailand, Malaysia and Sri Lanka.

Mangroves for the Future initiative: Mr Vikmuthi Weeratunga, IUCN's Biodiversity Coordinator, presented a brief introduction of the Mangroves for the Future (MFF) initiative. This multi-agency initiative has the main goal of conserving and restoring mangroves and other coastal ecosystems as key assets which support human well-being and security in the Indian Ocean region. In April 2006, the initiative was endorsed by UN representatives from all the tsunami-affected countries. The initiative will be implemented in six countries: India, Indonesia, the Seychelles, Sri Lanka, Thailand and the Maldives.

Forestry Programme for Early Rehabilitation of Tsunami-Affected Areas in Sri Lanka: Mr Ananda Wijesooriya, Senior Deputy Conservator of Forests of the Forest Department (Sri Lanka) provided information on the state of the art of the Sri Lankan component of the programme, which is implemented in six districts of the southern and eastern provinces of the country. The project supports the restoration of local people's livelihoods and contributes to improving their protection from future hazards.

Tsunami events in Peninsular Malaysia — intensified research and development to establish vegetation for coastal protection: Dr Shamsudin (Forest Research Institute of Malaysia [FRIM]) reported on recent research activities conducted by FRIM in trying to establish improved planting techniques to enhance the survival of planted seedlings in the aftermath of the 2004 Indian Ocean tsunami. Although the effectiveness of mangroves in protecting lives and properties depends very much on the distance from the epicentre of a tsunami, the presence of mangroves in northern parts of Peninsular Malaysia proved to be effective in reducing tsunami impacts.

As part of its post-tsunami programmes, the government initiated a special task force to re-examine the condition of mangroves along coastal areas, especially those that are identified as vulnerable to future tsunamis. Most of the coastal areas in the east and west coast of Peninsular Malaysia are subject to different degrees of erosion.

Areas that are exposed to severe erosion are unstable in supporting mangrove vegetation and some form of hard structure, for example, geo-tubes, is necessary to alleviate strong wave action. The placement of geo-tubes approximately 100 to 150 metres seaward provides a sufficient area of mudflats to be rehabilitated with mangroves. However, planting of mangroves within these areas poses many challenges because the substrate is very soft and liquid and cannot support seedlings.

The concept of planting in these areas is different from normal planting practices in productive mangrove, where the muddy substrate is more stable for supporting seedlings and very often the planting strips are sheltered and surrounded by mature mangroves trees. FRIM was given the task of conducting research in trying to rehabilitate such areas with different species of mangroves. If successful, 100 to 150 metres of mudflats will act as a buffer that offers additional protection to coastal areas besides the placement of geo-tubes.

Upcoming activities of the SAARC Coastal Zone Management Centre related to coastal protection: Mr Mohamed Ali, Director of the South Asian Association for Regional Cooperation (SAARC) Coastal Zone Management Centre, reported on the background for the establishment of the centre (on 25 June 2005), on its structure, terms of reference, priority areas in the region and the activity programme for 2006.

Part 2
Diagnostic tool

Introduction

Four working group sessions were held in parallel to develop "diagnostic tools" to assist in identification of situations under which forests and trees would be suitable to protect coastal areas against: (i) tsunamis; (ii) cyclones; (iii) coastal erosion; and (iv) wind and salt spray. Groups were asked to assume the roles of experts called upon to develop a tool to assist coastal planners in deciding where trees could be planted to protect a coastline from one of the other natural hazards. The steps suggested to construct the tool were as follows:

1. Identify the various criteria/conditions that can influence whether or not it makes sense to use trees in coastal protection.
2. Roughly sequence these on the basis of importance and the level of information likely to be available.
3. Put the criteria/conditions into dichotomous format.
4. Test the criteria/conditions for a specific set of circumstances (e.g. an urban area, a rural coastline, a bay, a headland or a specific location[s] known to group members) and adjust the tool accordingly.

Suggestions were made for possible initial criteria/conditions as follows:

- Is the coastline affected by the natural hazard?
- Is existing coastal protection present?
- Are there populations or assets present that should be protected?

Criteria/conditions appearing further into the diagnostic tool were suggested as follows:

- Is space available to establish trees?
- Is funding available to establish trees?
- Are other forms of coastal protection more appropriate?

The point was made that in most cases, the appropriateness of trees or forests for coastal protection may depend on several factors that must be weighed against one another. Further quantification, analyses or assessments could also be required and, in such cases, it was suggested that relevant comments be recorded. In cases where specific information on the capacity of trees/forests to protect against a specific hazard was unknown, it was suggested that required information be noted.

Tsunami working group results

The tsunami working group began with the same objectives as the other groups, but in spite of the concerted efforts all members, the meeting ended in deadlock with little movement towards the objectives owing to fundamental disagreement over the validity of the question. Several opposing points of view were fielded by different sections and individuals. In summary:

- Physicists and engineers were ready to entertain the question given there is no reason to deny the notion that obstacles such as trees could modify the motion of tsunami waves and potentially provide protection for people and assets.
- Pragmatists were unwilling to concede that planting mangroves and other coastal forests could be proposed as a serious solution to alleviate damage from tsunamis — trees take years to grow, occupy valuable space and the return period for tsunamis may be 200 years in much of the Indian Ocean.
- Sceptics did not think that the scientific evidence for tree and forest protection against tsunamis was strong enough to support planting for this reason.
- Field-based practitioners with funding to plant trees in coastal areas who, because their mandate removed several of the aforementioned obstacles, reasoned that if trees could provide even a limited degree of protection, then so much the better.
- Those believing that trees are good in all areas and at all times, and therefore, that it is inherently "good" to plant whenever and wherever possible.

Other points included:

Limitations on using trees and forests as coastal protection measures against tsunamis:

- Coastal green belts cannot provide complete protection.
- Tsunamis rarely strike areas where *mangrove* forests occur.
- Land would have to be available and people would have to be prepared to live behind the forest for green belts to be proposed as a protective measure.
- Trees and forests are not relevant where the shore is steeply sloping.
- Trees and forests are less relevant where local bathymetry provides protection or where other means of protection are present.
- Exposed high risk areas are often the most attractive for development and in such cases trees and forests are not appropriate to provide protection.
- Governance structures and institutions are frequently unable to enforce regulations governing construction in green belts.

Interactions between trees/forests and tsunamis:

- Although trees can significantly slow a tsunami, flooding can still occur.
- Although a porous barrier can reduce the height of a tsunami, the speed of flow may increase in nearby areas.
- Trees and forest are likely to reduce the penetration of water inland as the period of tsunami waves is in the same order as the time it takes a wave to travel across a few hundred metres of land.
- Gaps and channels through vegetation can increase the intensity of a tsunami as a result of funnelling of waves and intensification of backwash. The frequent presence of habitations along such channels may amplify catastrophic effects (river gates may provide protection).
- Larger tsunamis are overwhelming and trees and forests would not provide protection in these cases. For smaller tsunamis, a wide belt of vegetation may provide protection; width estimates vary between 20 and 100 metres.
- Tsunamis can break trees, turning them into projectiles, although the possibility of broken trees acting as projectiles should not be relevant given that evacuation from danger areas should be the priority.
- Broken trees and branches can become lodged in vegetation and provide greater resistance against passage of water.

- Trees with strong roots and trunks are likely to provide the most effective resistance to tsunamis; undergrowth also slows the advance of water.
- Reef maintenance, dune protection and protection and establishment of other protective structures should be considered in addition to possible establishment/protection of trees and forests.

The wealth of information and viewpoints makes summary problematic. Overall, the consensus during the workshop was that trees and forests *can* provide protection against tsunamis. The main questions, therefore, revolve around the quantity and quality of forest necessary to provide protection against a tsunami under a set of local conditions, and whether the result can be implemented under the prevailing socio-economic conditions. To make the diagnostic tool operational, and notwithstanding questions of feasibility, it would be necessary to bring together detailed information quantifying the physical parameters that define the effectiveness of trees and forests in protecting against tsunamis. This basic information could then be applied at the local level prior to implementation of analyses to assess environmental, social and economic costs and benefits of trees and forests in comparison with other forms of coastal protection.

Cyclone working group results

The diagnostic tool developed by the cyclone group is given below. The key decisions relate to the size of the expected storm surge. If the surge is expected to be above five metres, other measures should be taken as trees and forests will have little impact on influxes of water of this magnitude. There is a further important point: Where coasts are eroding, trees will not secure the coastline in the long term and engineered measures are required. This point also relates more generally to the other coastal hazards. Other key points relating to the potential protection provided by trees and forests against cyclones were:

- Trees should only be considered as appropriate protection against the effects of cyclones for low intensity storms.
- During cyclones, water (i.e. from the related heavy rains) kills in order of magnitude more people than wind does.
- If the coastal bathymetry is predominantly shallow, the storm surge is greater.
- Barrier islands, although affording protection against tsunamis, do not attenuate cyclone-related surges.
- Although a band of around ten kilometres of mangroves is required for protection against cyclones, they *can* provide protection, as in the case of the Sunderbarns. However, forests with less breadth are useful in reducing the strength of storm waves.
- Penetration of floodwater cannot be stopped by trees and flood levels may remain for a day or more.
- Storm waves related to cyclone winds can be attenuated by trees.
- Cyclones and tsunamis do not usually affect the same areas.

A major misapprehension concerning the effects of cyclones is that wind is the main threat to life. As stated earlier, water kills many more people than wind and this has important repercussions on the protective functions of trees and forests. Because flood levels are likely to remain for a day or more, porous structures such as forests will not prevent the influx of water. They will, however, attenuate wind-driven waves. Given these observations, it is clear that a broad breadth of tree cover would be necessary to provide protection from cyclones. It is commonly held, for example, that the Sunderbarns in Bangladesh afford cyclone protection and recent data from Orissa, India indicate that a 0.5-kilometre band of mangroves can protect lives with a statistical confidence level of 95 percent, whereas a 1.5-kilometre strip can protect lives with a confidence level of 99 percent (Saudamini Das, unpublished data). More data are likely to emerge to further inform on this issue, but with the large areas of land required for tree planting, apropos protection of people and assets, it would be more likely that the above arguments would be used in calls for conservation rather than the establishment of forests exclusively as protective measures against cyclones.

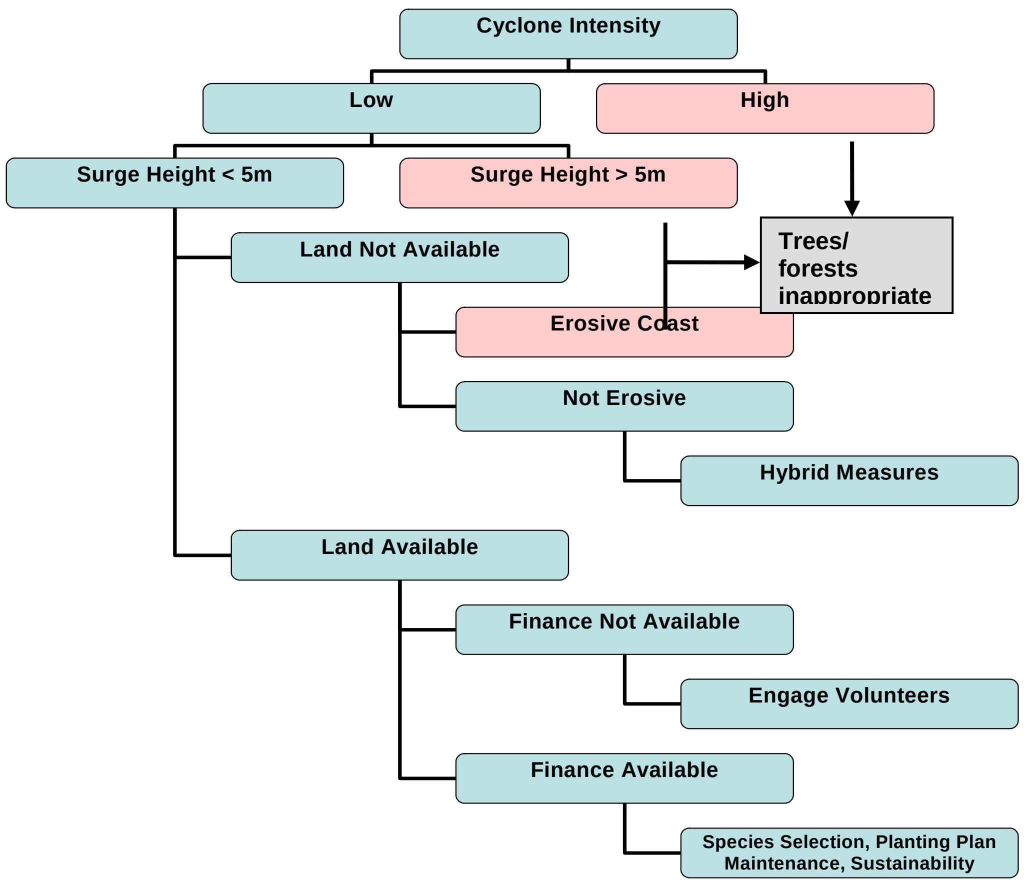

Exhibit 1 Cyclone diagnostic tool

Wind and salt spray working group results

The diagnostic tool developed for wind and salt spray followed a similar approach to that adopted by the cyclone group. Information required for the tool relating specifically to wind and salt spray included the nature of the local winds, whereby coastal shelterbelts would only be appropriate where onshore winds occurred. It was also noted that deep-rooted trees should be used to enable water uptake and to provide adequate support in sandy soils; moreover, they should also be sturdy and salt-resistant. Further information could be included in the tool to specify the degree to which salt spray and wind effects could be alleviated by using shelterbelts and also the area over which benefits would be experienced. It should be noted in this context that salt may be suspended throughout the boundary layer and transported inland. Larger crystals of salt are likely to fall out of the air mass under less turbulent conditions, but smaller particles may be carried far inland. Therefore, the effects of coastal shelterbelts may be fairly localized and tree planting would probably be best for protecting specific valuable structures or assets. For additional information see Takle *et al.* (this volume).

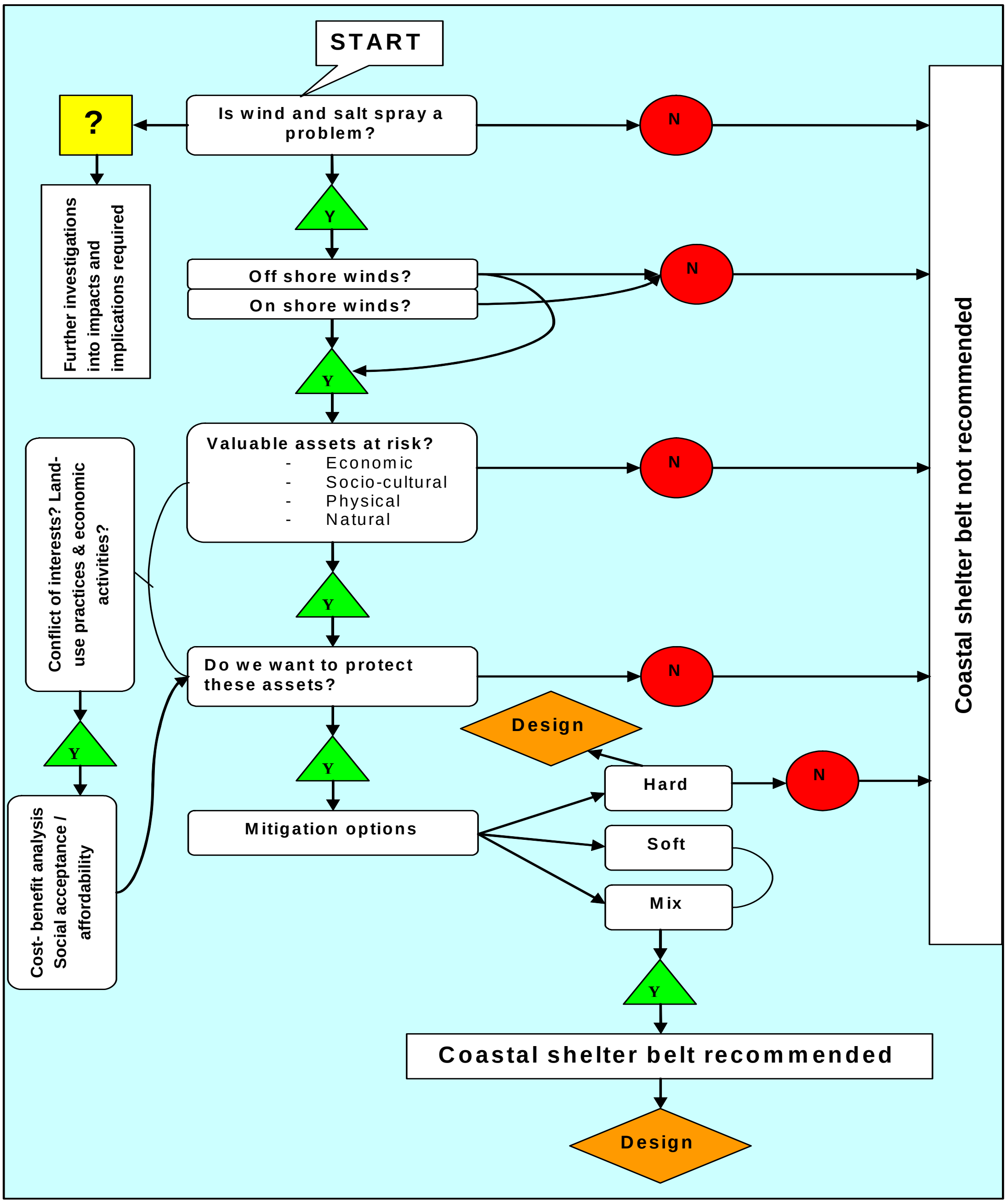

Exhibit 2 Wind and salt spray diagnostic tool

Coastal erosion working group results

The coastal erosion group developed a tool based on a coastal protection strategy including possible short- and long-term measures in combination with prioritization of areas according to the severity of erosion. The group agreed that economic, environmental, social and cultural values are likely to be subjects of protection from coastal erosion, and that national governments should determine priorities, depending on their specific situations.

In the short term, it was proposed that engineering solutions should be targeted at critical areas, according to prioritization of all areas. In the long term, guidelines, shoreline management plans within Integrated Coastal Zone Management (ICZM) initiatives and coastal laws should be developed to support short-term measures and overall aims. The following levels were categorized to facilitate prioritization:

- **Critical** — erosion is serious and is immediately threatening: (i) property and human activity of high economic value; and (ii) sensitive irreplaceable ecological systems.
- **Significant** — erosion serious, entities same as above will be threatened in five years or more if nothing is done (the situation will become critical).
- **Acceptable** — erosion affecting areas with no economic, ecological or heritage value.

According to this prioritization, critical and significant erosion areas are protected first to prevent loss of land, natural resources and heritage, to avoid displacement of population and to maintain/improve tourism value.

Once consensus is reached on the areas in which protection is needed, processes are initiated to consult local residents and stakeholders, collect and analyse data and develop an understanding of erosion and key coastal processes in the area. Following this process, available options, including hard engineering, soft engineering, reforestation and combined measures are considered for a period according to the urgency of the situation, with critical situations requiring more immediate action. Points considered include:

- The effectiveness of each option in overcoming/reducing the threat.
- Socio-economic and environmental impacts of each option (hard engineering structures generally cause more serious environmental impact than soft solutions).
- Engineering parameters (hydraulics/hydrodynamics, geotechnical matters, construction materials/techniques).
- Time needed for construction.
- Funds available.

In summary, it was noted that reforestation is not appropriate for all areas and the following criteria are mandatory:

- Sufficient time frame.
- Local participation.
- Available space.

Following this assessment, an identification of minimal data requirements for reforestation is carried out and reviews are undertaken by experts at critical decision-making stages throughout the process. A note was made that the tool focuses on continental coastlines and mangroves, and that small islands require different approaches and considerations as the environmental conditions and guiding principles are different.

Little information was included in the diagnostic tool on the circumstances under which trees could be suitable for arresting or reversing coastal erosion. In relation to this, it should be noted that trees may not decelerate the pace of erosion at all on naturally eroding coastlines, and therefore, local circumstances should be reviewed before decisions are made.

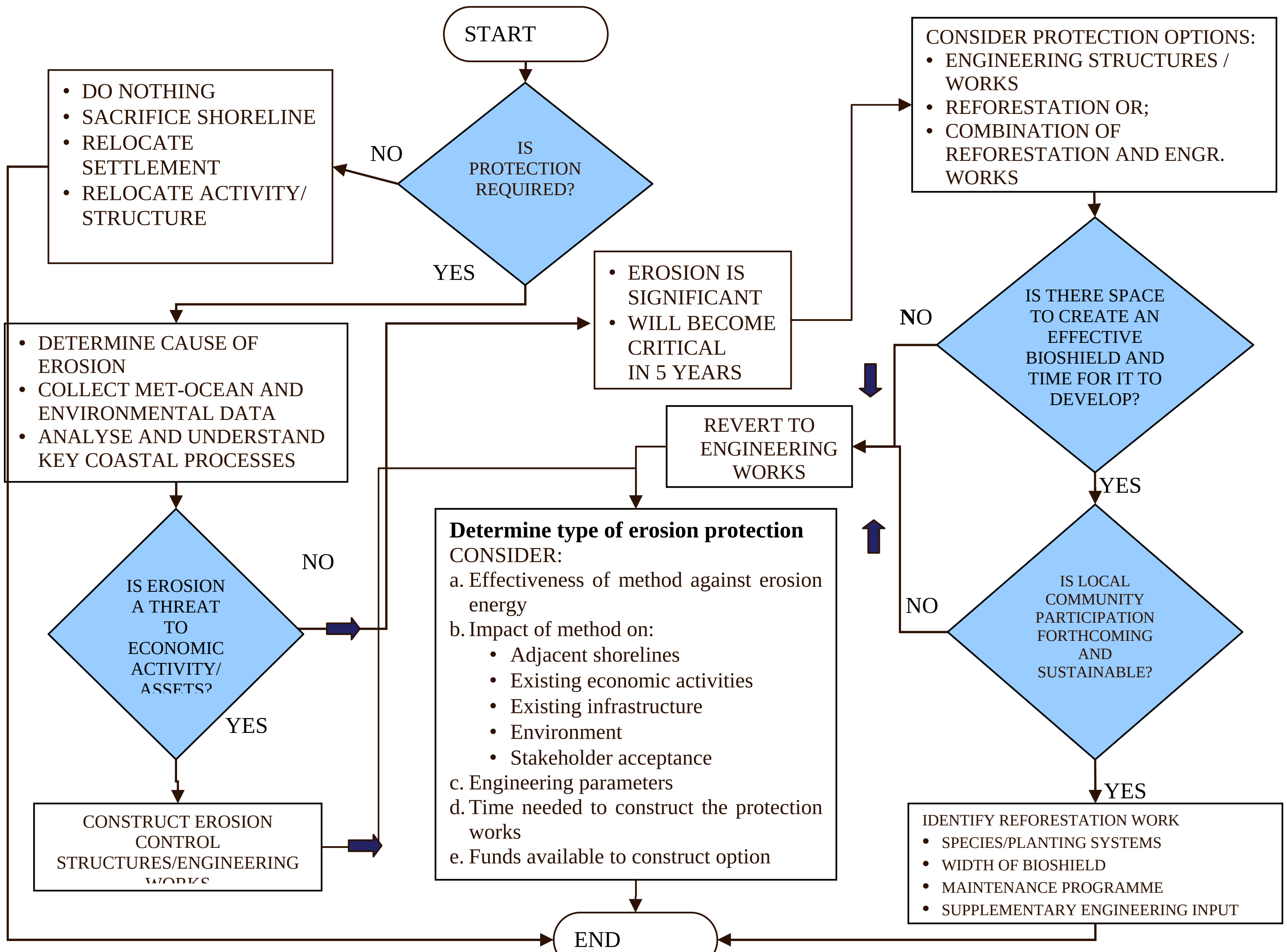

Exhibit 3 Coastal erosion diagnostic tool

Working group conclusions and further refinements

A number of elements contained in each diagnostic tool were generic and could be used for a variety of coastal hazards with minor adjustments made to accommodate technical information. The following questions were central:

1. What is the coastal hazard?
2. Are valuable assets at risk?
3. Are trees effective in protecting against the type and intensity of hazard expected?
4. Is the coast undergoing erosion?
5. Is land available in terms of area and possible lost opportunity costs?
6. Are finances available to establish trees?
7. Are different types of protection more environmentally or socially preferable?
8. Do trees or forests offer comparative advantages over other types of structure in terms of protective capacity, cost, environmental benefits or social benefits?

To further develop and operationalize these diagnostic tools, a greater level of technical detail is required to quantitatively define the relationships underlying points 2 and 8 above. This information has proved to be unavailable in forms readily accessible to foresters and policy-makers, but discussions during the workshop indicated that there is further information available to quantify the degree to which trees can protect against a coastal hazard under given sets of coastal conditions. A number of the technical experts present at the workshop supported follow-up work to unearth, consolidate and make public such information, and by doing so, resolve some of the controversy over the protective capacity of trees and forests — especially in relation to tsunamis.

Part 3
Conclusions and recommendations

Conclusions

1. Coastal forests and trees can, under certain conditions, act as bioshields to protect lives and valuable assets against coastal hazards, including: tsunamis, cyclones, wind and salt spray and coastal erosion.
2. The degree of protection offered by coastal bioshields depends on a number of variables, including: (i) the characteristics of the hazard itself (e.g. type, force, frequency); (ii) the features of the site (e.g. bathymetry, coastal geomorphology); and (iii) the characteristics of the bioshield (e.g. type of forest/tree, width, height and density of the forest).
3. Care must be taken to avoid making generalizations about the protective role of forests and trees based on evidence from one or a few areas; the many factors that influence the protective role of the forests/trees must be understood and taken into consideration before lessons can be learned and applied elsewhere.
4. Coastal forests and trees are not able to provide effective protection against all hazards (e.g. extremely large tsunami waves, flooding from cyclones and certain types of coastal erosion); provisions for other forms of protection and (in extreme events) for evacuation must be relied upon. Care must be taken not to create a false sense of protection against coastal hazards.
5. The importance of incorporating coastal protection as an integral part of coastal area planning and management is recognized.
6. The options for protection include: soft and hard solutions and a hybrid of the two. If none of these is appropriate and viable, it may be necessary to zone coastal land use to prevent (further) settlement and construction of valuable assets in the vulnerable zone.
7. It is important to match the species with the site in order to avoid high mortality and low performance of the planted trees. Some forest types and tree species cannot survive or thrive in areas exposed to specific coastal hazards; therefore, they are not candidates for protective measures.
8. Development of bioshields is not possible in all situations owing to, *inter alia*, biological limitations, space constraints, incompatibility with priority land uses and prohibitive costs.
9. The level of knowledge and understanding of the functions of forests and trees in coastal protection is still insufficient and there is a lack of multidisciplinary research and cooperation in this field. Specific areas needing further attention include research in non-mangrove coastal forests and collection of data and development of models on interaction between the physical and ecological parameters.
10. There is a need to recognize that many years are required to establish and grow bioshields to a size and density that could offer protection against coastal hazards.
11. Considerable research and field initiatives related to forests and coastal protection have been carried out over the past several years; they provide a useful foundation for further work to improve understanding of the protective role that forests can offer.

Recommendations

Assessment and design of bioshields

1. The following analysis sequence is recommended to assess the potential for protection:
   a) Identify the areas that are subject to coastal hazard(s) and the characteristics of the hazard(s).
   b) Identify and prioritize the assets that need protection.
   c) Identify the options for protection (hard, soft and hybrid measures).
   d) Consider the costs and benefits of the protective measure(s).

When a conclusion has been reached that forests and trees should be used for protection, the bioshield should be designed using best practice.

2. The following broad approaches are recommended:
   a) Protecting and managing existing coastal forests that provide protection to people and valuable assets against coastal hazards in order to maximize their protective role.
   b) Rehabilitate existing degraded forests whose protective function has been impaired.
   c) Plant new forests and trees in sites where they have the potential to provide protection.

3. The design of protective measures using trees and forests must take into consideration not only physical and biological features, but also the economic, social and cultural factors of the site.
4. Local people should be involved in the design and development of the bioshield so that they have a stake in protecting and maintaining it over the long term.
5. The multiple functions of coastal forests and trees (i.e. economic/livelihood protection, wildlife habitat, aesthetics) need to be recognized and prioritized in establishing and managing coastal forests to enhance protection. It should be recognized that these functions and objectives may be compatible and mutually supportive, or they may be mutually exclusive.

Institutional and policy support and outreach

6. National governments should review existing coastal forest management policies and regulations to assess their practicality, e.g. regarding set-back (no construction) zones and protected forests.
7. National and local governments should develop/revise policies on coastal forest management and, as appropriate, ICZM policies, regulations and guidelines so that they adequately reflect the role of coastal forests/vegetation in enhancing coastal protection and improving livelihoods.
8. National/local governments should develop national/local coordination bodies for coastal area management and establish realistic integrated and participatory coastal management plans, incorporating bioshield development and management, as appropriate.
9. All sectors involved in the management of coastal forests and related natural resources should be involved in the development of disaster management policies and plans and be included in national disaster management committees (where they exist) to ensure that the role of forests and trees is adequately addressed.
10. National disaster management committees should identify the link between disaster management and environmental management with special emphasis on the role of coastal forests and trees.

11. Additional research and multidisciplinary cooperation is needed to improve scientific knowledge and understanding of the protective functions of forests and trees against coastal hazards.
12. Efforts should be made to translate scientific knowledge into practical guidelines and technical information for use by coastal forest managers and other relevant coastal land managers.
13. Capacity in coastal forest management for protection should be strengthened through education, training and extension.
14. Efforts should be made to raise awareness of the importance of forests and trees, apropos coastal protection among disaster management decision-makers, natural resource managers, NGOs, the private sector, local communities and the general public (e.g. through demonstration sites, published materials and mass media such as videos, comic books and "pocket books").

National, regional and international cooperation

15. National agencies, the private sector and international donors should provide financial support for research, capacity strengthening and field implementation related to forest management for enhanced coastal protection.
16. FAO should support enhanced regional cooperation, including through workshops, working groups and technical networks.
17. A regional database should be developed on best practices, suitable species and other relevant information for improved management of coastal forests for enhanced protection.
18. FAO should collect and publish information on local and indigenous knowledge, attitudes and practices related to the use of forests and trees for coastal protection.
19. Support should be provided to initiatives (e.g. Mangroves for the Future, Green Coast and Asian Greenbelt) that provide a framework for national actions and regional cooperation to address the issue of coastal rehabilitation for protective purposes.

Appendixes

Appendix 1 Workshop agenda

Pre-workshop: Sunday 27 August

15:00 – 18:00	Registration of participants	*Reception desk, Business centre*

Monday 28 August

08:00 – 09:00	Registration of participants	*Reception desk, Business centre*
09:00 – 09:15	Welcome address *Mr He Changchui* *FAO Assistant Director-General and Regional Representative for Asia and the Pacific*	*Plenary*
09:15 – 09:30	Introduction to the workshop and speakers *Ms Susan Braatz* *FAO; Programme Coordinator, Forestry Programme for Early Rehabilitation in Asian Tsunami Affected Countries* Adoption of the agenda	*Plenary*
	Protection from tsunamis	
09:30 – 10:00	Thematic paper: The role of forests and trees in protecting coastal areas against tsunamis (20 min presentation, 10 min Q&A) *Dr Hamzah Latief* *Department of Oceanography, Faculty of Geosciences and Mineral Technology, Institute of Technology, Bandung, Indonesia*	*Plenary*
10:00 – 10:30	COFFEE BREAK	
10:30 – 10:45	Field study presentation: The coastal vegetation role in protecting the Thailand coast against the 26 December 2004 tsunami *Ms Absornsuda Siripong* *Marine Science Department, Faculty of Science, Chulalongkorn University, Thailand*	*Plenary*

Protection from tsunamis, cont.

10:45 – 11:00	Field study presentation: Outcomes of the project "In-depth assessment of mangroves and other coastal forests affected by the tsunami in Southern Thailand" *Dr Chongrak Wachrinrat* *Kasetsart University, Thailand*	*Plenary*
11:00 – 11:15	Field study presentation: Understanding tsunami impacts from reef islands' perspective: experience from the Maldives *Dr Mohamed Ali* *Ministry of Environment, Energy and Water, Maldives* *Director, SAARC Coastal Zone Management Centre*	*Plenary*
11:15 – 12:00	Open discussion of forests/trees' roles in protection from tsunamis based on the above four presentations and participants' experience	*Plenary*
12:00 – 13:15	LUNCH BREAK	

Protection from cyclones

13:15 – 13:45	Thematic paper: The role of coastal forests and trees in protecting against cyclones (20 min presentation, 10 min Q&A) *Dr Hermann Fritz* *School of Civil and Environmental Engineering, Georgia Institute of Technology, USA*	*Plenary*
13:45 – 14:00	Field study presentation: Cyclone disaster mitigation in Bangladesh *Prof M. Alimullah Miyan* *South Asian Disaster Management Center ,* *International University of Business Agriculture and Technology Bangladesh*	*Plenary*
14:00 – 14:15	Field study presentation: Evaluation of storm protection function: A case study of mangrove forest in Orissa, India and the 1999 super cyclone *Ms Saudamini Das* *Institute of Economic Growth, University of Delhi Enclave, Delhi, India*	*Plenary*
14:15 – 15:00	Open discussion of forests/trees' role in protection from cyclones based on the above three presentations and participants' experience	*Plenary*
15:00 – 15:30	COFFEE BREAK	

	Protection from wind and salt spray	
15:30 – 16:00	Thematic paper: The role of coastal forests and trees in protecting against wind and salt spray (20 min presentation, 10 min Q&A) *Prof Eugene Takle* *Department of Geological and Atmospheric Science* *College of Liberal Arts and Sciences, Iowa University, USA*	*Plenary*
	Protection from wind and salt spray, cont.	
16:00 – 16:30	Field study presentation: Use of coastal shelterbelts along the east coast of India *Dr Narasimhan Duvuru* *Department of Botany, Madras Christian College, India* Field study presentation: The important role of trees in combating coastal erosion, wind and salt spray — a New Zealand case study *Mr Peter Berg.* *NZ Forestry Limited. New Zealand* *Presented by Mr Jeremy Broadhead, FAO*	*Plenary*
16:30 – 17:00	Open discussion of forests/trees' role in protection from wind and salt spray based on the two presentations and participants' experience	*Plenary*
18:30 – 20:00	WELCOME RECEPTION	*Kuk- Kak*

<u>Tuesday 29 August</u>

	Protection from coastal erosion	
08:00 – 08:30	Thematic paper: The role of coastal forests and trees in protecting against coastal erosion. (20 min presentation, 10 min Q&A) *Mr Gegar Prasetya* *Agency for the Assessment and Application of Technology, Indonesia*	*Plenary*
08:30 – 08:45	Field study presentation: Status of coastal erosion in Viet Nam and proposed measures for protection *Dr Ngo Ngoc Cat* *Centre for Training, Consultancy and Technology Transfer* *Viet Nam Academy of Science and Technology*	*Plenary*
O8:45 – 9:30	Open discussion of forests/trees' role in protection from coastal erosion based on the two presentations and participants' experience	*Plenary*
09:30 – 10:00	COFFEE BREAK	

	Coastal area planning and management	
10:00 – 10:20	Thematic paper: Coastal area planning and management with a focus on disaster management and the protective role of coastal forests and trees *Ms Jane Preuss* *Planwest Partners, USA*	*Plenary*
10:20 – 10:45	Open discussion of coastal area planning and disaster management.	*Plenary*
10:45 – 11:00	Field study presentation: Mangrove planting for coastline protection — to plant or not to plant? *Mr Tan Kim Hooi* *Centre for Coastal & Marine Environment, Maritime Institute of Malaysia*	*Plenary*
11:00 – 11:30	Open discussion of mangrove planting for coastline protection	*Plenary*
	Synthesis	
11:30 – 11:50	Thematic paper: Synthesis of the protective functions of coastal forests and trees against natural hazards *Dr Eric Wolanski* *Australian Institute of Marine Science*	*Plenary*
11:50 – 12:30	Open discussion of the synthesis and overall findings regarding the protective functions of coastal forests/trees against natural hazards	*Plenary*
12:30 – 13:30	LUNCH BREAK	
13:30 – 14:00	Introduction to the diagnostic tool	*Plenary*
14:00 – 15:30	Diagnostic tool working groups	*Break-out rooms*
15:30 – 16:00	COFFEE BREAK	
16:00 – 17:00	Diagnostic tool working groups, continued	*Break-out rooms*

<u>Wednesday 30 August</u>

08:30 – 10:00	Presentation and discussion of the results of the diagnostic tool working groups	*Plenary*
10:00 – 10:15	Introduction to the recommendations of working groups	*Plenary*
10:15 – 10:45	COFFEE BREAK	
10:45 – 11:45	Recommendations of working groups	*Break-out rooms*
11:45– 12:00	Introduction to the field trip *Mr Sa-Ngob Panichart* *Forest Official, Department of Marine and Coastal Resources* *Mangrove Research and Development Station, Phuket*	*Plenary*

12:30 – 17:00	Packed lunch and field trip *Post-tsunami forest rehabilitation:* *Coastal shelterbelts at Laem Krang Yai, Pakarang Cape and mangrove replanting at Ban Nam Khem, Phang Nga*	

<u>Thursday 31 August</u>

08:00 – 09:00	Presentation of "consolidated" diagnostic tool results	*Plenary*
09:00 – 10:30	Recommendations of working groups, continued	*Break-out rooms*
10:30 – 11:00	COFFEE BREAK	
11:00 – 11:45	Presentation and discussion of the recommendations of working groups' results	*Plenary*
11:45 – 12:30	Presentations: Forestry initiatives for coastal protection	
	UN/International Strategy for Disaster Reduction, including coastal protection *Mr Akshat Chaturvedi, UN/ISDR Regional Programme for Asia and the Pacific*	*Plenary*
	Wetlands International: Green Coast project & *IUCN: Mangroves for the Future initiative* *Mr Vikmuthi Weeratunga, IUCN, Sri Lanka Office*	*Plenary*
	Forestry programme for early rehabilitation of tsunami-affected areas in Sri Lanka *Mr Ananda Wijesooriya, Forest Department, Sri Lanka*	*Plenary*
	Tsunami events in Peninsular Malaysia: Intensified research and development to establish vegetation for coastal protection *Dr Shamsudin, Forest Research Institute of Malaysia*	*Plenary*
	Presentation/discussion of other organizations' related initiatives *Dr Mohamed Ali, upcoming activities of SAARC Coastal Zone Management Centre related to coastal protection*	
12:30 – 13:30	LUNCH BREAK	
13:30 – 14:15	Presentation and discussion of the consolidated list of recommendations	*Plenary*
14:15 – 15:30	Adoption of the results and recommendations and closing of the workshop	*Plenary*

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The FAO Regional Office for Asia and the Pacific held a four-day regional technical workshop on the protective functions of forests from 28 to 31 August 2006. The activity was undertaken thanks to the generous contribution of the Government of Finland through the FAO-supported project OSRO/GLO/502/FIN "Forestry Programme for Early Rehabilitation in Asian Tsunami Affected Countries.

The meeting brought together experts on the role of coastal trees and forests in protecting against cyclones, tsunamis, salt spray and coastal erosion. The workshop aimed to provide scientifically based information of use to coastal planners and managers developing disaster mitigation measures and to forestry agencies implementing coastal reforestation and forest rehabilitation programmes.