Part 1

Technical presentations and discussions

Preamble

These sections present the papers, field study presentations and relevant discussions which took place during the workshop according to the workshop agenda (Appendix 1).

More details include:

1. Thematic papers prepared by professional experts on natural hazards to provide an objective analysis of the roles coastal forests and trees play in protecting lives, resources and infrastructure from coastal erosion, cyclones, tsunamis and wind and salt spray respectively. A coastal area planning paper on incorporating forests and trees into disaster management strategies and a synthesis paper on the current scientific knowledge on the issue were also commissioned.
2. The abstracts of case study presentations (referred to as “field study presentations”), which helped to highlight the use of forests and trees for coastal protection in various countries of Southeast Asia, and the need for better implementation of protection projects.
3. A summary of the key points and observations emphasized in the workshop discussions relative to each hazard.

The power point presentations, full field study presentations (case studies) and other related documents are available in the CD of these proceedings.

CHAPTER 1
PROTECTION FROM TSUNAMIS

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

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Abstract

Artificial structures can be constructed to protect coastal areas from natural hazards, such as storm surges and tsunamis. However, they can cause environmental problems and are expensive. Recently, mangroves and other types of coastal forests and vegetation have increasingly been reconsidered as possible alternatives to be used instead of, or in conjunction with, artificial structures. Mangrove forests are vegetated inter-tidal wetlands that provide goods and environmental services, including protection against wave impact and erosion. The dynamics of tidal flow and wind waves moving through vegetation, including mangroves, are well understood. Tsunamis, on the other hand, are transient waves with much longer wavelengths, such that tidal research cannot be readily applied. Yet, quantitative evaluations of mangroves and other coastal forests as protection against a tsunami's potentially catastrophic impact are limited. This paper describes the effectiveness of forests in mitigating tsunami waves through hydraulic resistance (drag and impact force) owing to bottom roughness and vegetation. Numerical models to simulate the effectiveness of mangroves in reducing tsunami incursion are presented.

1 Tsunamis in the Indian Ocean

Tsunamis are generated by geophysical phenomena such as earthquakes, volcanoes, submarine landslides, and meteorite impacts. Historically, worldwide tsunami events (from 1790 to 1990) were mostly generated by earthquakes (90.3 percent), volcanoes (6.4 percent) and landslides (3.3 percent) (F. Imamura, *pers. comm.* 2005). According to the Integrated Tsunami Data Base, at least 1 963 tsunamis have been noted from 1628 to 2005 (ITDB/WRL, 2005). In the Indian Ocean region, including the eastern part of Indonesia, the Philippines, and Taiwan Province of China, there were at least 282 tsunami events from 1600 to 2005 (Figure 1.1); most were located in the subduction zone of the Indonesian and Philippine archipelagoes. Only one event occurred in the Arabian Sea in November 1945 (earthquake magnitude Ms = 8.3 and tsunami intensity of 3.0). Several events have been also reported in the Bay of Bengal, as well as the Andaman and Nicobar Islands.

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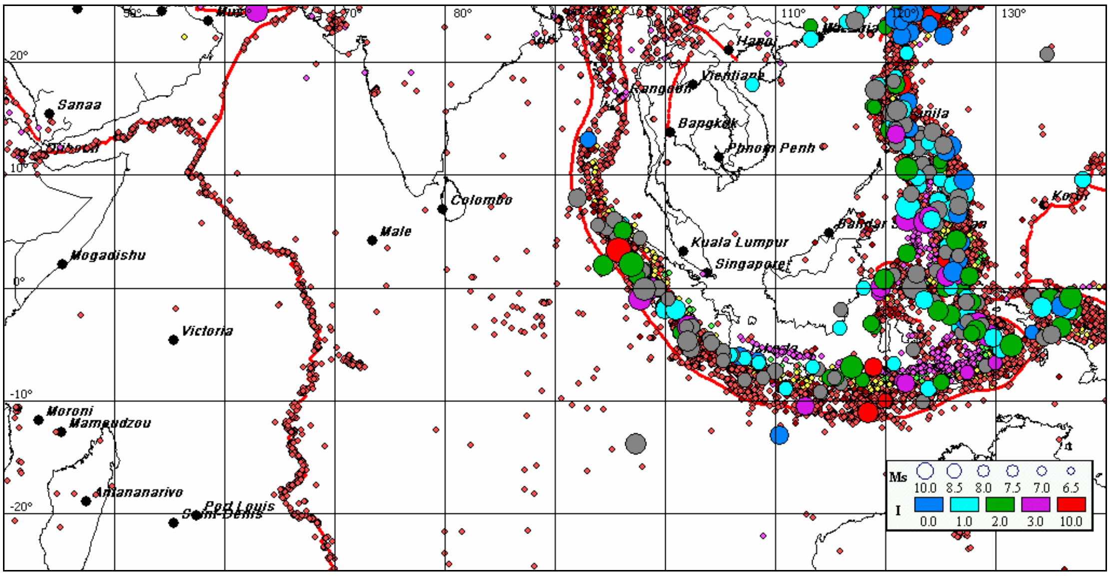


Figure 1.1 Tectonic settings, locations of earthquakes (small squares) and tsunamis (coloured circles) in the Indian Ocean region (ITDB/WRL 2005)

Reviewing Figure 1.2, it is clear that the region centering on the Indonesian and Philippine archipelagoes, have has faced many damaging tsunamis throughout history. In this figure, tsunamis of greater strength and height are indicated by the colour of the circle (Soloviev–Imamura tsunami intensity scale), while the magnitude of the earthquake that produced the tsunami is depicted by the size of the circle. The reason for the frequent tsunamis becomes apparent after noticing the great number of earthquakes along the tectonic plate boundaries in the Indian Ocean, making the region very susceptible to tsunamis.

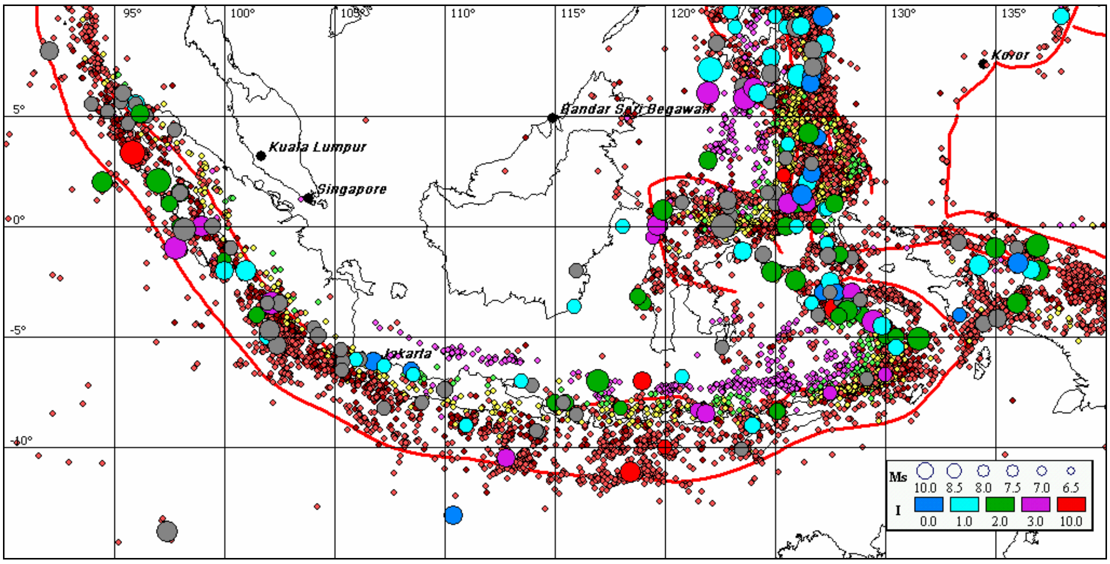


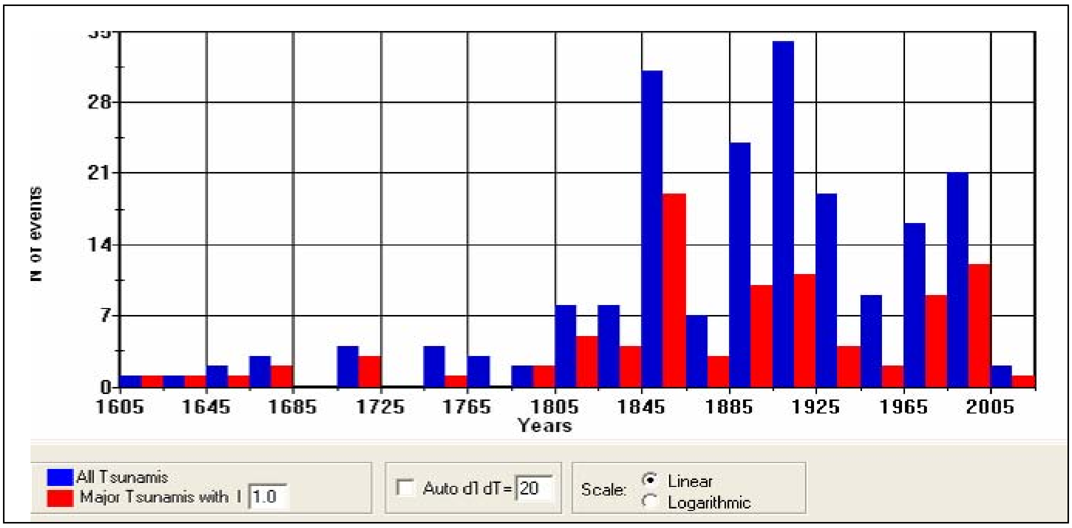
Figure 1.2 Tectonic settings, locations of earthquakes (small squares) and tsunamis (coloured circles) in Indonesian and Philippine archipelagoes and surrounding areas (ITDB/WRL, 2005)

Here, significant straining and fracturing of crustal rocks is occurring as the major tectonic plates, and several minor plates, converge. Several volcanic eruptions and earthquakes have originated along these boundaries, which are considered to be the most seismically active regions in the world. Some of the seismic activities have been accompanied by tsunamis, causing great damage and enormous number of fatalities. Historically, from 1600 to 2005, tsunamis have resulted in approximately 361 905 casualties in Indonesia and the Philippines (ITDB/WRL, 2005; Latief *et al.*, 2000). Two major events resulted in considerable loss of life: (1) the catastrophic disaster caused by the 1883 Krakatau volcano tsunami killed approximately 36 000 people; and and (2) the 2004 Sumatran tsunami killed approximately 283 000 people. Recent tsunamis in this area are listed in Table 1.1.

Table 1.1 Recent tsunamis in the Indian Ocean

Year	Locality	Country	Fatalities
1992	Flores, Nusa Tenggara Timur	Indonesia	1 950
1994	Banyuwangi, East Java	Indonesia	238
1994	Mindoro	Philippines	78
1996	Toli-Toli, Central Sulawesi	Indonesia	6
1996	Biak, Irian Jaya	Indonesia	110
1998	Taliabu, Maluku	Indonesia	18
1998	Aitape, PNG	Papua New Guinea	3 000
2000	Banggai, Central Sulawesi	Indonesia	4
2004	Indian Ocean Tsunami	Indian Ocean countries	283 000
2005	Nias, North Sumatra	Indonesia	*unknown*
2006	Pangandaran, West Java	Indonesia	600

Although many tsunamis have struck in the Indian Ocean and associated seas, the nature of tsunamis and their relationship with seismotectonic zones still needs further investigation. Figure 1.3 shows some preliminary statistics for tsunamis in the Indonesian and Philippine archipelagoes and their vicinities. It can be seen that in the 20-year periods, high frequencies occurred between 1845 and 1865 (30 events), 1885 and 1905 (33 events), 1905 and 1925 (16 events), and 1985 and 2005 (21 events). Though this gives events for the whole region, greater detail of the return period for tsunami- producing earthquakes for specific faults is required. For example, Latief *et al.* (2000) found that the average occurrence interval is about 10 to 15 years in West Indonesia and 10 to 12 years in East Indonesia,.



Major Tsunamis with I 1.0

☐ Auto dI dT= 20

Scale: ● Linear ○ Logarithmic

Figure 1.3 Number of events by 20-year period in Indonesian and Philippine archipelagoes and their vicinities; blue indicates all tsunami events and red major tsunami events with intensity exceeding 1 in the period of 20 years (ITDB/WRL, 2005)

Regarding tsunami heights and their distribution along coastlines, substantial work has been done tabulating data from historical and recent tsunamis;, however. Figure 1.4 illustrates this data. The highest tsunami on record occurred in 1674 at Oma in the Banda Sea, Indonesia. By all accounts, it reached almost 80 metermetres in height and killed 2 970 people. The second highest was the

1883 Krakatau tsunami, which was 36 metermetres high and killed 36 417 people. The most recent tsunami of massive proportions was the 2004 Indian Ocean tsunami, and had a maximum run-up height of approximately 30 metermetres at Loknga, Sumatra. It killed at least 283 000 people in the Indian Ocean rim.

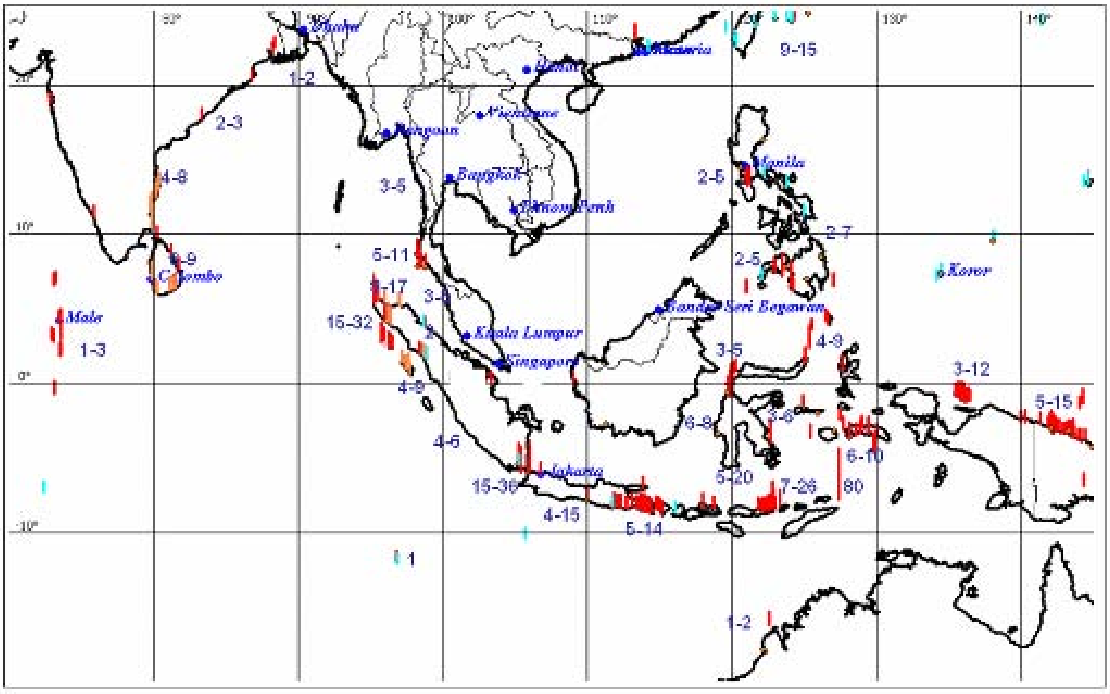
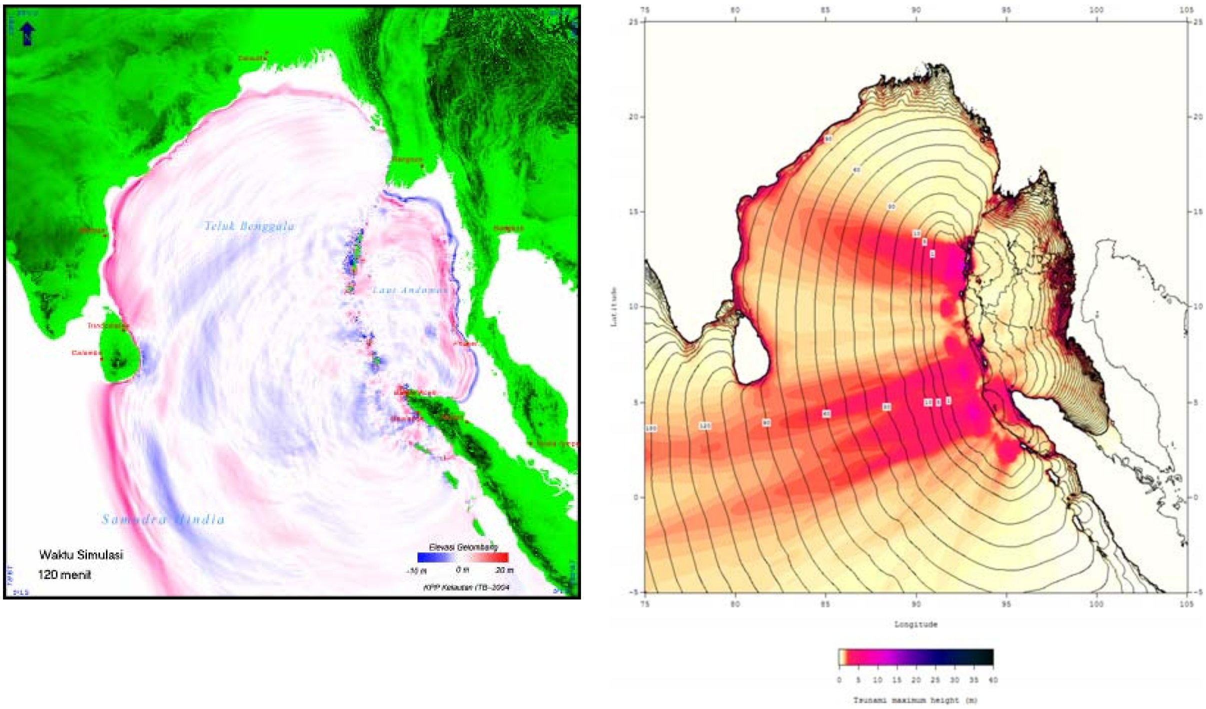


Figure 1.4 Tsunami heights along Indian Ocean coastlines

Most tsunamis in this region are generated by nearby earthquakes. Consequently, arrival times vary from only several to tens of minutes. In such cases, the number killed by tsunami waves can be huge, as seen in Aceh, which is close to the epicenter of 2004 Indian Ocean tsunami. For other countries further away from the epicenter, arrival times varied from one or two and up to ten hours. For instance, Sri Lanka, India and Thailand were struck by the 2004 tsunami about 2 and to 2.5 hours after the earthquake (see Figure 1.5). Latief *et al.* (2006) have shown that numerical simulations can predict arrival times quite well.



a Tsunami pattern after 120 minutes propagated

b Energy distribution and travel time contour

Figure 1.5 Tsunami simulations for the 2004 Sumatran event and its energy distribution and travel time (Latief *et al.*, 2006)

One fault line of particular concern to Indonesia lies at the not so distant subduction zone where the Indian and Australian plates are sliding beneath the Southeast Asian plate. Many large earthquakes have occurred in this zone and some of them generated nearfield tsunamis, such as the 1797 and 1833 Sumatran tsunamis (magnitude Mw = 8.0–9.0) (Sieh *et al.*, 2004) and the 2004 (Mw >9.0) and 2005 (Mw = 8.6) Sumatran tsunamis (Geist *et al.*, 2006). These frequent events indicate that another major earthquake and tsunami are likely. Natawijaya (2002) reported that the earthquake cycle related to the 1833 Sumatran tsunami was around 200 years; meaning that another earthquake of this magnitude could strike the area within the next few decades. Such an earthquake has the potential to generate an ocean-wide teletsunami across the entire Indian Ocean. Close to the rupture zone, it could be very dangerous for the Indonesian cities of Padang and Bengkulu, which have populations exceeding 760 000 and 380 000, respectively.

2 The role of coastal forests in diminishing tsunami impact

2.1 Mangroves and other coastal forests

Mangrove forests grow in coastal areas and estuaries, mostly in muddy alluvial soil that is submerged by seawater at least once a day. The tree species belong to various families such as *Avicenniaceae*, *Rhizophoraceae*, *Euphorbiacea*, and *Combretaceae*. A typical zonation pattern in Sumatra is shown in Figure 1.6;, while Plate 1.1 depicts some actual mangrove tree areas.

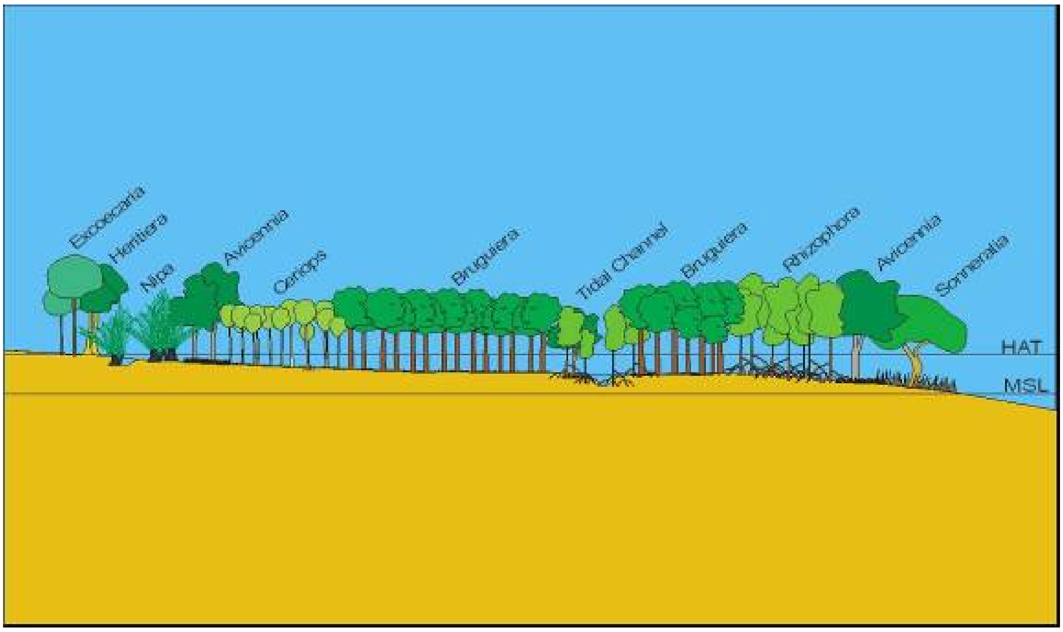


Figure 1.6 A typical zonation pattern for mangroves in Sumatra (after Whitten *et al.*, 2000)

Plate 1.1 Mangrove forest sites

Other types of (non-mangrove) forests and trees are generally found on sandy beaches or atolls. Species typically found in the Indian Ocean include *Terminalia catappa, Casuarina equisetifolia, Pandanus spp*. and *Cocos nucifera* (see Plate 1.2). *Hibiscus tiliaceus* is commonly used commonly in Japan for green belts to protect housing against tsunamis (Hiraishi and Harada, 2003).

Plate 1.2 Coastal forest sites

2.2 Hydraulic forces and wave interaction with vegetation

The reduction of waves and current velocity on passing through mangroves, and other vegetation has been studied thoroughly by many authors. These studies, however, focus on wind-generated waves and tidal inflows. Although they provide important information relevant to the mitigating effect of coastal forests on tsunamis, their results cannot be be directly applied, as tsunamis are transient waves with much longer wavelengths, and as such that the impact is much greater when they strike coastal areas.

Some of the earliest work on vegetation interactions is was carried out by Petryk and Bosmajian (1975). They introduced a method of hydraulic force balance to estimate the Manning coefficient that measures roughness (see Section 3.1). It is a difficult number to estimate, but a necessary input in the calculation of frictional drag forces created by vegetation and bottom roughness. It was found that the drag force of vegetation was the main force impeding flow. Shia-gai and Maruyama (1988) developed a method to estimate the Manning coefficient of a tree by measuring the total mass of a tree. Wolanski *et al.* (1980), Wolanski *et al.* (1992) and Kanazawa and Mazda (1994) studied the tidal flow field on mangroves and simulated the field in a mangrove swamp and creek using the Manning coefficient in their computer models. It was suggested that the coefficient was in the order of 0.20–0.40 in the swamp and 0.02–0.04 in the creek. Mazda *et al.* (1995) conducted a numerical simulation and suggested that the water flow in a creek depended strongly on the drag force. Mazda *et al.* (1997b) found that the drag force in a mangrove swamp fluctuated between mangrove species, vegetation densities and tidal conditions. Mazda *et al.* (1997a) studied mangrove forest as a coastal protection measure from wind-generated waves and found that the effectiveness of mangroves to reduce waves depends on the mangrove age, which correlates with vegetation density.

Regarding tsunami behaviour on land with large obstacles (limited to simple rectangular types with a one-dimensional anomaly), Goto and Shuto (1983) numerically simulated the dissipation of energy in tsunamis and the effect on tsunami inundation. Although large obstacles could reduce tsunami height, the current velocity between obstacles increased. Shuto (1987) compileding damage data from field surveys and witnesses and, estimated the effectiveness of coastal pine forests in Japan against tsunamis. It was established that the capacity of forest to diminish tsunami impact was related to forest width, number of trees and tree diameter.

2.3 Effectiveness of forests to protect against tsunami

Shuto (1987) outlined different ways in which coastal forests may reduce tsunami impact and asserted that a forest is effective for several reasons: 1) it stops driftwood and other flotsam; 2) it reduces water flow velocity and inundation depth; 3) it provides a life-saving snare for people swept off land by a tsunami run-down; and 4) it amasses wind-blown sand and create dunes, which serve as a natural barriers against tsunamis. However, it is important to note that, in the case of a large tsunami, narrow belts of trees or forests may be ineffective in providing protection, and in some cases may even create more damage because of uprooted trees flowing inland. In relation to the 2004 Indian Ocean tsunami, anecdotal feedback and scientific studies indicated that mangroves had saved lives and resources.

Plate 1.3 illustrates that houses behind the beach forest at Serambu Beach, West Nias, were saved from the 3–4 metermetre high waves of the 2004 Sumatra tsunami, while houses behind widely-spaced coconut trees were destroyed. Plate 1.4 shows how coastal forest (40 metermetres in width) reduced tsunami height at Cikalong, West Java. Satellite imagery shown in Plate 1.5 indicates the tsunami impact on houses at Pangandaran Beach, West Java. The area without trees was completely destroyed, while the area with some vegetation was only slightly damaged by the 4–5 metermetre high tsunami. These images support the view that forests may provide protection, while Plates 1.6 and 1.7 illustrate the risk of uprooted trees destroying houses.

Courtesy of Danny Hilman Natawijaya

Plate 1.3 Damaged houses struck by a 3–4-m-high tsunami; some of the houses behind the coastal forest were saved (Sirambu, West Nias)

Plate 1.4 Coastal forest (approximately 50 m wide) diminished a 6-m-high tsunami to 1.6 m in Cikalong, West Java

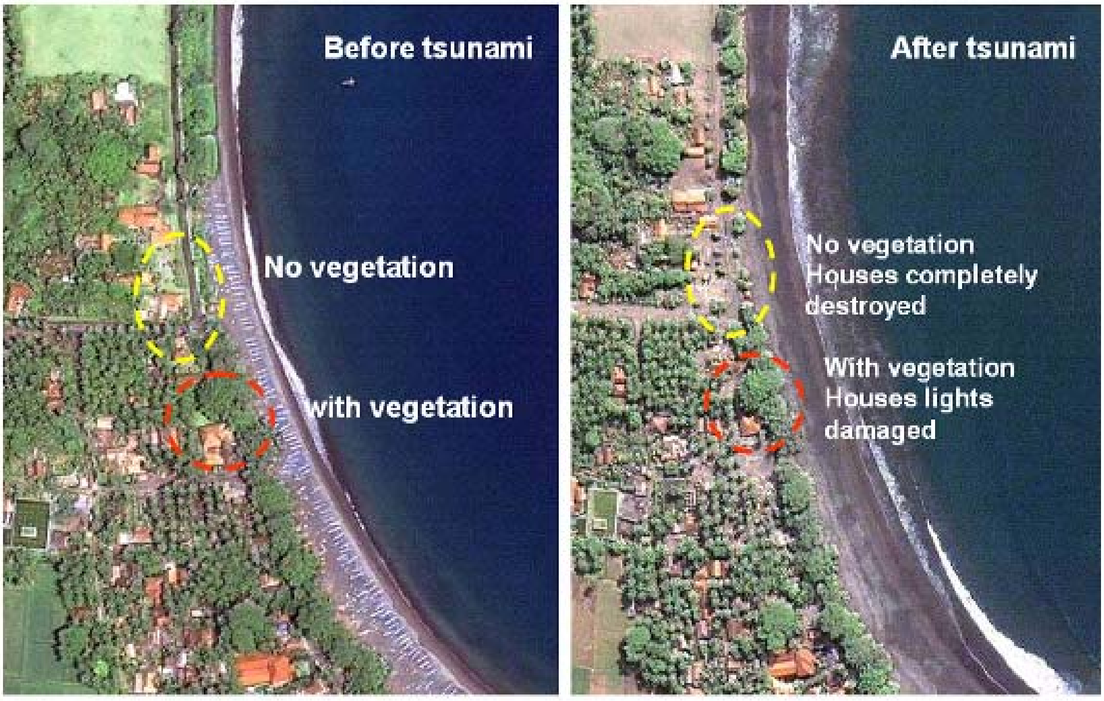


Plate 1.5 Ikonos imagery before and after the 2006 West Java tsunami shows how vegetation reduced tsunami impact at Pangandaran Beach (source: CRPS www.crips.nus.edu.sg)