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Review article

Damage Caused by the 26th December, 2004 Tsunami on the Coastal Forests in Southern Thailand: A Review

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ABSTRACT

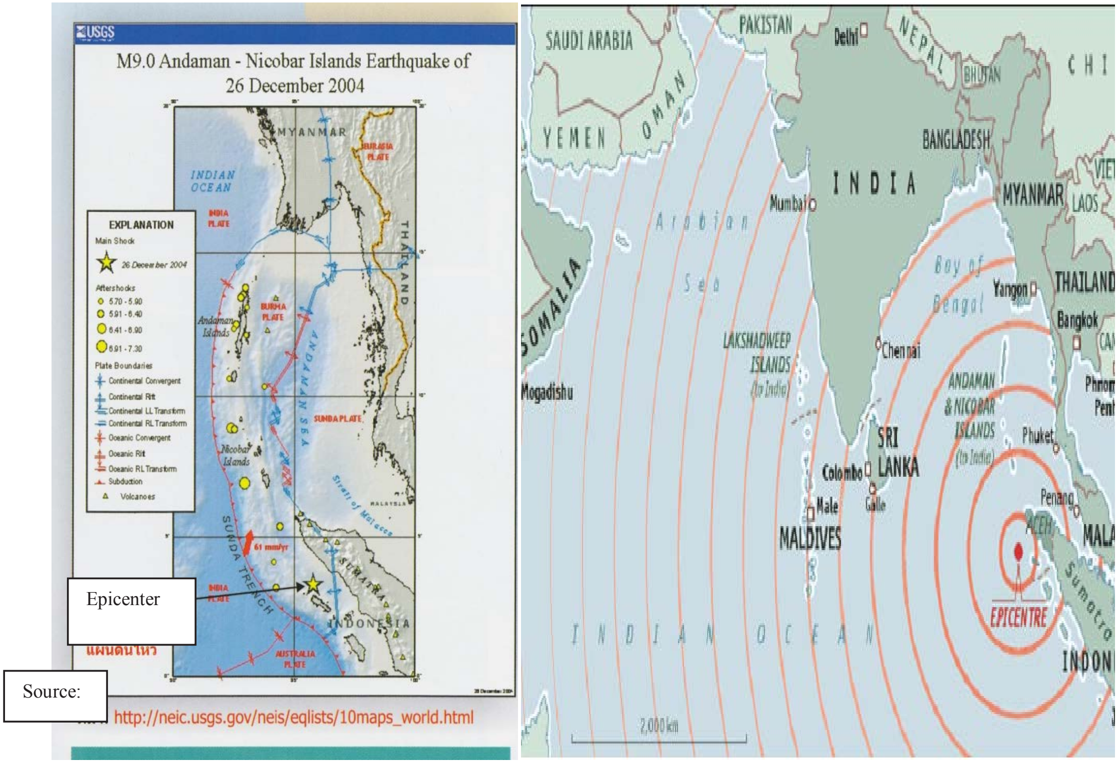
The disastrous tsunami of 26th December, 2004, caused a considerable damage in six provinces of Thailand. Not only were the coastal forest resources, existing along the Andaman coast affected, a huge loss of human life and property was also recorded. Factors affecting the intensity of the tsunami disaster could be the coastal shape, geomorphology, landscape, topography, human settlement, and forest communities along the coast. There were two forest community types (mangrove and beach forests) along the coast that were affected by the disaster. The magnitude of forest damage was thoroughly examined and reviewed using various available documents appearing during a ten year period after the occurrence of disaster. The activities related to the forestry sector in Thailand and in other countries, that experienced the same level of damage, were also investigated, to gain a deeper insight into the post-tsunami rehabilitation of the affected forests, especially in countries having long experience and advanced knowledge about such disasters. In addition, the severity, damage, rehabilitation, and mitigation measures related to coastal forest hazards and risk management are also summarized. The vulnerable coastal forest resource in such countries are also summarized to realize the vital role that these coastal forests play in this context.

Keywords: Andaman coastal forests, beach forest, coastal characteristics, mangrove forest, tsunami.

INTRODUCTION

The catastrophic tsunami event of 26th December, 2004 was generated by an earthquake with its epicenter in the western Sumatra region. With a magnitude of 9.3 on Richter scale, it was one of the most severe disasters ever recorded after the Alaska earthquake and was the ninth deadliest event in modern history (New World Encyclopedia, recent accessed on 23 September, 2013). In the academic circles, this event is called the

Great-Sumatra-Andaman Earthquake. It was termed as the Asian Tsunami in the Asian countries and international media and was named the Boxing Day Tsunami by some media in Australia, Canada, New Zealand, and UK. The tremors lasted for as long as 550 to 600 seconds or 8.3 to 10 minutes, as recorded by the USGS seismographs (2005). The tremors in western Sumatra Island triggered a huge wave along the Andaman sea coast . It subsequently caused a tremendous loss, not only to the human life, but also to the coastal natural resources in the 6 provinces situated along the western coast of southern Thailand. Although the epicenter of earthquake was determined to be in Sumatra, Indonesia, the subsequent tsunami wave spread over the Indian Ocean and traversed approximately 1,260 km to hit the Andaman Islands and the coastal areas of the Indian Ocean after a few minutes (Fig.1). FAO (2005a), referring to the report of OCHA, stated that the affected areas included 17 countries situated along the coast of Indian Ocean, Andaman Sea coast, East Africa, and parts of the Australian coast (Fig.2). Subsequently, GISTDA (2005) published several pre- and post- tsunami satellite images and ground photographs of the surrounding affected coastal areas of Thailand, including the property damaged by this catastrophic event along the Andaman coast . The loss of human life and destruction of property, in Thailand alone, was reported by several sources, e. g., DDPM (2005), FAO (2005b) and DMCR (2008). The confirmed exact number human lives lost in the 6 provinces, particularly along the Andaman coast of Thailand, was 5,395 dead, 2,817 missing, 8,457 injured, and 7,000 displaced (USGS, 2005). The coastal forest communities affected by tsunami were also subsequently reported by some investigators and by national and international media. This disaster also came as a shock to overseas tourists who had gathered along the sightseeing spots around the affected areas. Relief measures to reduce the loss of human life and to rescue the victims who survived were immediate and supported by several domestic and international organizations. The rehabilitation of coastal forest resources was undertaken shortly afterward in some affected areas by the authorities of Thai government, such as Department of Marine and Coastal Resources (DMCR), Department of National Park, and Wildlife and Plant Resources Conservation (DNP). Many Thai scientists working in the field of marine and coastal resources independently launched their own field investigations in the affected areas, post-tsunami.



(A) (B)

Figure 1 Epicenter of the Sumatra earthquake on 26th December, 2004 (A) and tsunami propagation (B). Modified from GISTDA (2005).

(A)

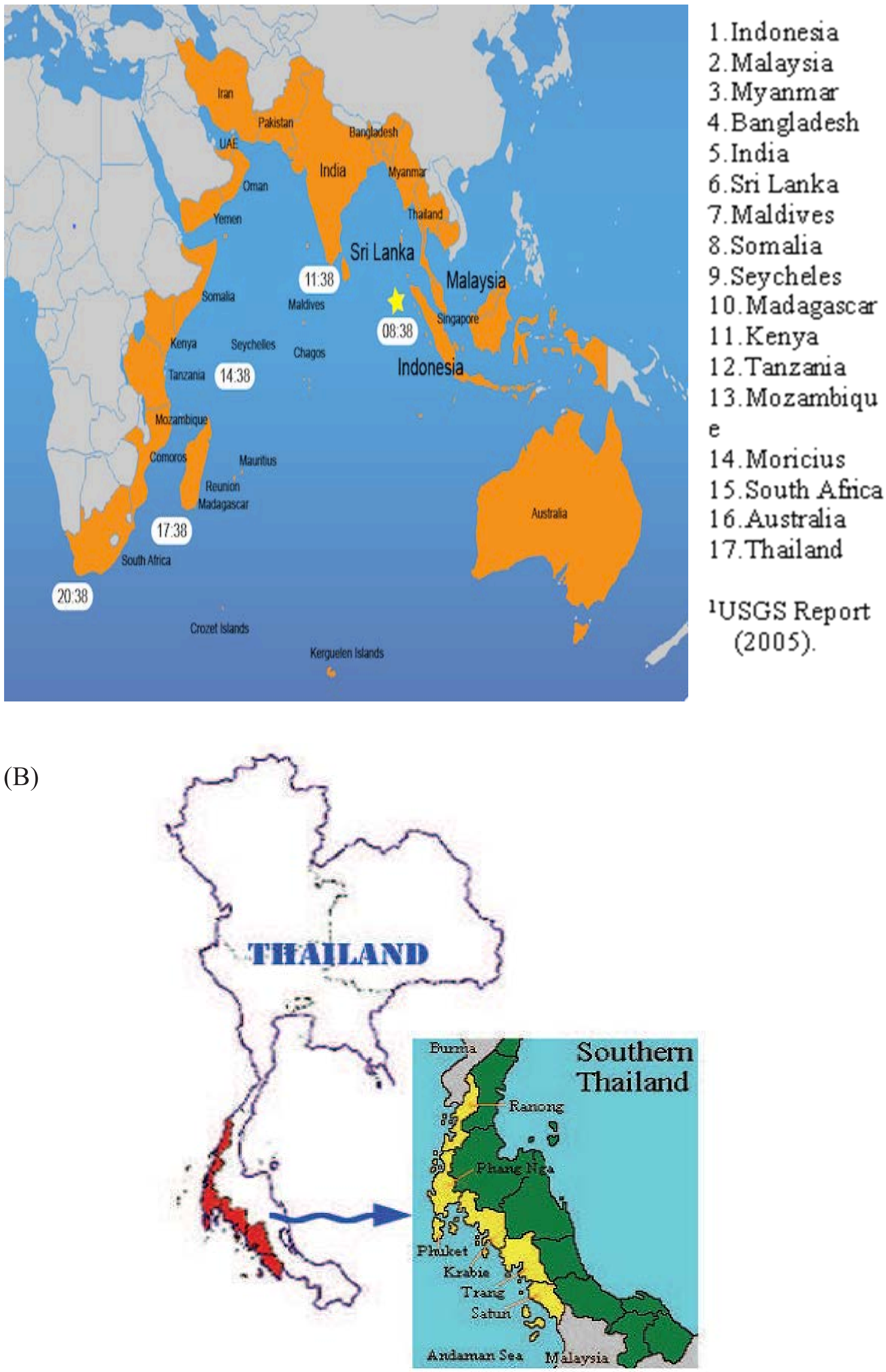


Figure 2 (A) The 17countries that were affectedby the 26th December 2004 tsunami and (B) the 6 coastal provinces along the Andaman coast of Thailand.

The FAO regional office for Asia and Pacific, located in Bangkok (FAO /RAPA), supported by OCHA and UNEP, also launched an investigation to assess the tsunami affected mangrove and other coastal forests (FAO, 2005a). In this project, two field investigation groups were assembled, comprising of forestry and economic staff, mandated to carry out a detailed scientific and economic field study on the impacts and loss due to this catastrophic event. Geographic information system (GIS) instruments were procured and donated to DMCR and GIS specialists were also employed by FAO/RAPA for training and transferring the techniques to DMCR's Mangrove forest field management staff to strengthen their skill set in rehabilitation planning and formulating management strategies. Preliminary field observations in the 6 affected provinces were initially carried out by the author, after which an in-depth investigation was carried out by the two selected field surveying groups.

Forest communities along the coastline play an essential role in the stabilization of the surrounding environment and contribute towards the livelihood of the local inhabitants. At the same time, they act as a refuge for both aquatic and terrestrial wildlife and other organisms. During such an unpredictable event, the role of a coastal forests in safeguarding humans living along the coastline cannot be denied. Generally, coastal forest communities serve as sources of various kinds of forest products, provide sites for recreational grounds, promotion of education, revenue generation through tourism, and stabilizing the coastal ecosystem. Cochard (2011) pointed out that the services provided by an ecosystem comprising of coastal forest communities needed a more elaborate scientific studies related to their roles in protection against tsunami disaster as well as in risk management and mitigation of natural hazards. Offices and organizations dealing with coastal forest resources should be educated about the risk management and the various protection measures.

Coastal forest communities can be divided into two main types: mangrove and beach forests. Other plant communities, such as swamp forest, sea grass, algae, sea weed, coral reef, karst vegetation, and nipa palm, and several kinds of man-made plantations such as coconut, pararubber, oil palm, cashew trees, fruit crops, herbs, and home-yard garden plants, are also significant. Parts of these forests have also been designated as inland and marine national parks. In the wake of tsunami, the rehabilitation of damaged coastal forests was carried out by DMCR, RFD, DNP, and KU, according to their annual management and implementation plans, supported by the government. The direct role of DMCR is to maintain and manage all costal marine and terrestrial resources while RFD manages the protected and reserved forest areas. DNP manages and maintains the protected areas, both in the inland and marine national parks, wildlife, and conservation of plant genetic resources. On the academic side, RCMCR under KU, located in the Ranong province, also plays an essential role in research and rehabilitation. Private sector companies, as well as local government organizations, also took part as the rehabilitation partners.

The present review paper is aimed at summarizing some aspects and efforts relating to the dangers posed by the tsunami, the forest damage and rehabilitation strategies implemented for remediating and mitigating future damage to coastal forest resources. The study will be related to the 26th December 2004 tsunami, and reports will be critically drawn from various published sources, both which have appeared in document form domestically and internationally in manuals and journals. This paper is mainly concerned with the damage caused by the tsunami and the related factors causing severe damage, with particular focus on the 6 southern provinces of Thailand, situated along the Andaman coast. Another paper will deal with the rehabilitation of post-tsunami affected areas along the Andaman coast in southern Thailand. The ultimate aim of this review is to provide an up-to-date information about the integrated coastal resource development and management planning in the disaster affected areas and in other similar coastal forest resources of Thailand.

Characteristics of the coastal forest resources

As has already been stated above, the coastal forest resources in Thailand are generally composed of two major forest communities: mangrove and beach forests, and other minor communities such as swamps, karsts, and aquatic plants, that were not significantly affected by the event. The characteristics of the two major coastal forest communities affected by tsunami, will be dealt with in this review paper.

1. Mangrove forest is a forest community that appears in the coastal areas of the gulf of Thailand on the east and the Andaman coast on the west. This forest community type generally flourishes in the muddy flats, along the channel bank and in some lowlying areas where soft muddy sediment soil deposits are found. Such soil deposit are high in organic matter, highly acidic, and have anaerobic conditions. Such areas are located along the interface of tidal marine waves and fresh water from an upland river that mix together as brackish water. Perennial plants with supporting roots surrounding the main trunk or stilt (prop) root systems are commonly found in such forests. The major tree species belong to the genera of *Rhizophora, Avicennia, Brugiera, Ceriops, Xylocarpus,* and *Soneratia*. The pattern of plant distribution in the growing zone or inland zonational habitat is generally dependent on the hardness of the substrate along the offshore and inland distances. The nomenclature or the other name of such a forest type is a littoral forest. Mangrove forest acts as a habitat for spawning, hatching, and breeding for a variety of marine life. Moreover, it is a source of

wood used in construction, charcoal making, and fishing gear. Besides all these roles, it acts as a buffer and stabilizer of the coastal environment. Its ecological roles are the sources of high primary productivity, efficient nutrient cycling, regulating the exceptionally large carbon sequestration, filtering, and trapping various kinds of pollutants.

2. Beach forest is a forest community that appears in patches in a shallow and flat coast, where sand deposits are prominent. The dominant tree species belong to the genera of *Casuarina, Callophyllum, Hibiscus, Pongamia,* and *Terminalia* with some perennial plants, such as *Pandanus* and various grasses, growing in the understory . *Melaleuca* tree stands growing either as a relatively pure stand or as a mixture with some other broadleaved tree species can also be found in patches. Since this forest type is always distributed along the coastline, which connects the sea and the inland forest and other man-made orchards, it is a hotspot for tourists and other recreational activities. Moreover, it serves as a natural shield against strong winds, storms, and filters the salt sprayed in the coastal areas. Besides, it is a source of wood and shoreline stabilization.

The most up-to-date estimates of the area of the existing mangrove forests in Thailand is shown in Table 1, while the damaged area is indicated in Table 2.

A substantial area covered by beach forest is not available; however, they are always found in patches. Presently, the beach forest serve to attract tourists and are used for recreational purposes, as well as for protection of the coastal topography. In the recent years after the tsunami, the beach forests have also been recognized as being one of the many effective buffer zones protecting the coast and the life and property of the inhabitants living along the coastline.

Table 1 The area covered by the mangrove forest along the Andaman coast in southern Thailand compared to other regions, based on the data compiled by Bechteler *et al*. (2006).

Region	Area (ha)
Eastern region	27,981
Central region	294
Eastern coast and its peninsula	20,366
Western coast and its peninsula	147,788
Total country	196,429

Table 2 Damage to the mangrove forest by tsunami wave as compiled by Kashio (2005).

Location of damage	Damaged area (rai)
1. Unit 16 (Takuapa, Phang nga)	
- Ban Bang Nai Si	50
- Ban Tung Noi	50
2. Unit 17 (Nang Yon, Kuraburi, Phang nga)	
- Ban Tung Nangkam, Kuraburi	350
- Ban Khoa Ra, Kao Pra Thong	150
3. Unit 18 (Bangwan, Takuapa, Phang nga	
- Ban Ao We, Kuraburi	300
- Ban Pak Jok, Kuraburi	200
- Ban Tung Dab, Kuraburi	50
4. Unit 19 (Lam ken, Phang nga)	
- Ban Nog Na, Takuapa	150
- Ban Tab Lamu, TaaDindang, Tai Muang	600
5. Unit 36 (Ta Pae, Satul)	
- Tarutao National park	10
Total	1,910 (=305.6 ha)

Source: Department of Marine and Coastal Resources, 14 January 2005.

Remark: 6.25 rai =1 ha. The above damage figures represent 0.2 % of the total mangrove area cover in the Andaman coast of southern Thailand.

Characteristics of the Andaman coast

The physical characteristics of a coast are an important factor that can determine the severity of a wave hit and the subsequent damage caused by it. The Andaman coastal area lies on the western coast of peninsular Thailand. The topographic, geomorphologic, climatic, and landscape conditions of the Andaman coast are the main components of the coast. The area stretches for about 1,260 km from a latitude of 5° N to 11° N, where the six administrative provinces, Ranong, Phang nga, Phuket, Krabi, Trang and Satul, are located.

The coast runs lopsided facing the Andaman Sea, where the area features mountainous rocky crest and narrow coastal plains, rocky coastlines, archipelagos, scattered islands, and islets, as well as seamounts and reefs. The sea is a means of living, foremost, with a rich variety of marine resources. Fisheries and trade got people, from near and far away from the shores, involved in exchanges like seafaring, as done by the merchants of the Coromandel coast in the present-day India, and of realms on the island of Sumatra. Several pockets of sandy beaches are found along the coast. The offshore of the Andaman Sea is composed of a number of islands, with the largest one being the Phuket province and the rest include the protected areas and marine national parks.

The area is one of the most populated areas of southern Thailand. Historically, the western coast of Thailand used to be an area of tin mining when Thailand depended exporting its natural resources for foreign exchange, during the early phase of the country's development. During that time, a number of job opportunities were available to absorb the labor supply and other related businesses. Later on, during the last decade, when the tin ore deposits have diminished, the mining has become less productive and limited its usefulness. The utilization of other natural resources, such as mangrove forests for charcoal production, shrimp culture, rubber plantations, and the development of infrastructure to build a tourism industry, has become popular. Such activities have led to a large population settling, both temporarily and permanently, in the six provinces along the Andaman coast. This inflow of population has led to a rapid increase in number of overseas tourists and labor from other regions of the country and from the neighboring countries .

Lessons learnt from the natural disaster: the tsunami

A tsunami is a wave train, or series of waves, generated in a body of water by an impulsive disturbance that displaces the sea water vertically. Earthquakes, landslides, volcanic eruptions, explosions, and even the impact of meteorites can generate tsunamis. In particular, relatively shallow earthquakes (triggered within a depth of less than 30 km) beneath the seas can generate tsunamis. Needless to say, tsunamis can savagely attack coastlines. Tsunamis are vastly different from the typical (wind-generated) waves, which can be observed on coastal beaches. Technically they are characterized as shallow-water waves, but with a long period and wave length. Wind-generated waves have a period of about 10 seconds and a wavelength of 150 m. A tsunami, on the other hand, can have a wavelength exceeding 100 km and a period of the order of an hour.

A shallow-water wave has a notable ratio between the water depth and its wave length. Shallow-water waves move at a speed that is equal to the square root of the product of the acceleration of gravity (9.8 ms^{-2}) and the water depth. This implies that if a typical water depth in the ocean is about 4,000 m, a tsunami travels at over 700 $kmhr^{-1}$. Because the rate at which a wave loses its energy is inversely related to its wave length, tsunamis not only propagate at high speeds, they can also travel great, transoceanic distances with a limited energy loss. Thus, even after they have travelled vast distances, tsunamis reach distant coastlines with almost the same power as they had when they left the earthquake epicenter.

As a tsunami leaves the deep waters of an open ocean and travels into the shallower waters near the coast, it slows down. This is because a tsunami travels at a speed that is directly related to the water depth. However the tsunami's energy flux, which is dependent on both its wave speed and height, remains nearly constant. Consequently, as the tsunami's speed reduces as it travels into shallower water, its height grows. Because of this shoaling effect, a tsunami, almost imperceptible at sea (being only 30 cm above the surface), may grow to be several meters or more in height near the coast. When it finally reaches the coast, a tsunami may appear as a rapidly rising or falling tide. As a tsunami approaches the shore, it begins to slow down but grows in height. Just like other water waves, tsunamis begin to lose energy as they proceed towards the shore, with a part of the wave energy reflected offshore, while the shoreward-propagating wave energy is dissipated through bottom friction and turbulence. Despite these losses, tsunamis still reach the coast with tremendous amounts of energy. Tsunamis may reach a maximum vertical height onshore above sea level, often called a run up height, of 10, 20, or even 30 meters. Because tsunamis have very long wavelengths, they hit the shore more like a long lasting flood wave rather than the wave breaking a surfer usually experience.

Impacts of tsunami wave on the coastal forest resources

In Thailand, the tsunami wave, of 26th December, 2004, hit the Andaman coast (954 kms in length) between 9.40 and 10.30 A.M. local time. The first wave passed almost unnoticed, four to ten kilometers offshore. A second series of waves, up to 10 meters high, however, had a severe impact on the six coastal provinces along the Andaman Sea. The level of devastation in the six provinces varied significantly depending on a number of natural parameters including bathymetry, slope, elevation, and the presence of natural barriers, as well as human induced factors, such as coastal land-use and development. The province which was most severely affected was Phang nga, in particular the Khao Lak district. Phuket and Krabi provinces were also moderately impacted. In Ranong, Trang, and Satul provinces, many islands situated offshore recorded severe damage, but the impacts recorded on the mainland were comparatively moderate (UNEP, 2005).

Scientific investigations on the impacts of the Indian Ocean tsunami

Immediately after the tsunami wave hit the coastal areas of the various countries situated along the coast of the Indian ocean, the scientific community started to investigate the impacts of this unprecedented event. The most well known scientists from the Disaster Prevention Research Institute in Kyoto university, Japan were the first mission group to reach the damaged sites of southern Thailand (Kawata *et al.,* 2004). They were followed by the Saitama University's coastal engineering group (Sasaki *et al.*, 2005) and scientists from New Zealand led by Bell and his associates (Bell *et al*., 2005). Local survey teams, comprising of a number of institutions, carried out detailed surveys on various aspects of the impact. Their reports covered a wide range of damages incurred, mitigation countermeasures, and suggestions related to rehabilitation plans. Thereafter, there were several seminars, workshops, and scientific meetings. Numerous papers were published, related to the post-tsunami impacts and rehabilitation methods.

This part of current review paper emphasizes on the two major coastal forests affected by the tsunami wave. The progress on rehabilitation activities, particularly along the Andaman coast of southern Thailand, will be dealt with in another paper of this series.

Types of damage, causes, and subsequent effects on the mangrove and beach forests

1. Types of damage to the forest communities

Besides the considerable loss of human life, infrastructure, private assets and damage to the buildings, the coastal forests along the Andaman coast were affected in different ways, depending on various factors. The group of scientists from Kyoto university (Kawata *et al.*, 2004) reported on investigations performed in three locations: Khao Lak in Phang nga province, Phuket island, and Phi Phi island in Krabi. Although their study focused on the intensity of the wave in terms of measured variables. These were properties of the tsunami wave (number of waves, the largest wave, depression or elevation of the leading wave, etc.), height of the tsunami wave (run up height and inundation depth), inundated area, damage to the constructed infrastructure, velocity and hydraulic power, and energy dissipation capability of the vegetation. However, they also reported on the role of vegetation in protecting the residential areas from direct impact of the wave. In other words, most of the power was dissipated by the vegetation barrier, leading to lesser damage from the wave and a shallower inundation depth.

The investigation done by the coastal engineering group from Saitama university (Sasaki *et al*., 2005), also reported on the damages to the coastal areas in southern Thailand by the tsunami wave, covering a distance of about 250 km along Andaman coast, from Phuket to Ranong. In order to explain the natural protection provided by the vegetation against the tsunami, the representative vegetation was classified according to the stand structure of the trees. The representative trees were classified into five categories based on their stem diameter (d), tree height, branch structure, tree density , and the forest width in the direction of the tsunami, were also investigated. From the survey, mangrove, especially the *Rhizophora apiculata* forest, was effective in protecting against the tsunami damage, with its complex root system as was *Anacardium occidentale,* with its thick low branches. On the contrary, the reduction in wave velocity provided by *Casuarina equisetifolia* was relatively lesser and was only effective when their diameter d was greater than 0.5m with a large stem spacing (7-30m).

The engineering group from New Zealand (Bell *et al*., 2005), after investigating the physical damage of the infrastructure and other utilities, reported that New Zealand may have never experienced a tsunami event of such magnitude as the 26th December 2004 event. Their Thai study indicated to some common vulnerabilities in the coastal communities exposed to such tsunami hazards which include extensive development close to beaches, on sand spits, and in the narrow coastal corridors, lack of higher grounds for refuge in many of these areas, foreshores modified for coastal development by cutting trees, lowering the dunes to enhance ocean views and hardened coastal defense structures, which could exacerbate wave run-up. Observations in Thailand suggested that "greenbelts" such as dunes, mangroves, and dense coastal trees can significantly reduce the force of impact when the depths of tsunami waters does not exceed a few meters.

Meanwhile the mission officer was sent by FAO/RAPA, to evaluate the coastal forest resource damage caused by the tsunami in southern Thailand (Kashio, 2005), just after the field staff of DMCR, Thailand had performed a preliminary assessment. The report (Kashio, 2005) collected data from all the areas of affected mangrove forest and a list of damaged sites was prepared and a number of photographs were taken. The mission also indicated that the mangrove forest acted as a buffer, protecting the communities, including houses and land, from the force of the tsunami. On the basis of rapid observations and photographic analysis as well as on site assessment, Kashio (2005) concluded that mangrove and other coastal forests may have played a significant role in protecting the beaches, land, houses, animals, and trees from being destroyed by the tsunami. However, no scientific studies have been carried out to determine how a stand's protective function varies with its characteristics, such as location, size, and shape, species composition, tree height, and density, soil type, etc., and also the management techniques practiced. He also recommended to focus on several points that can be studied further in more in-depth, scientific ways. Nevertheless, it is worthwhile to emphasize that the Thai forest scientists lack adequate knowledge, very limited experience, and lack of proper tools to measure several characteristic factors that determine the resistance of tree species to counter the strength of a tsunami wave. Therefore, the type of trees investigated provide very little information in designing an effective tree belt (e.g., shelterbelt, greenbelt, bioshields) for protection and mitigation purposes to counteract the current tsunami hazard.

Kasetsart University's Marine and Coastal Research Center (KU-MCRC), which is located on the Ranong coast, was also severely damaged. Not only were the facility buildings, infrastructure, plant, and marine invertebrate specimens destroyed, but the surrounding mangrove and beach forest communities were also badly affected. These included some species of wildlife which were affected mostly due to the habitat being rendered unsafe after the wave attack (Marod, 2006), including the alteration of some soil properties (Wachrinrat, 2007). Field assessment and research work was performed to investigate the mangrove and beach forest conditions and recovery in the aftermath. Several short and long-term observation plots were set up in the Center in the Suksamran district located in Ranong province, along the Andaman coastal area (Marod, 2006). However, there has been no further progress report published since then.

Subsequent outcomes of scientific investigation were published and circulated through seminars, workshops, and symposia, in which scientific papers were presented and compiled into a document form since then until 2012. These studies were published by FAO, UNEP, ISME, etc; in collaboration with some local and international institutions.

Damage to the forest communities was not only limited to the tree and plant species, but effects were also seen on the immediate environment responsible for their development and survival. Soil and plant components of each affected forest were needed to be examined closely. The damage type in the two forest communities was categorized as no effect, uprooted, standing dead, leaning or declination, and branch and/or stem broken (Figs. 3 and 4). The reports indicated that trees of small to medium size in both the forest types were largely damaged as a result of uprooting due to the tsunami wave, particularly in the coastal areas of Ranong (Marod, 2006; Wachrinrat, 2007). Large size trees strongly resisted the wave, with the mangrove tree species supported firmly by their stilt root system and large sized beach forest trees through their root systems with plank buttress and a canopy high enough to withstand a direct hit from the wave. Similar results were reported by Fujioka *et al*. (2008) after observing the plots in Ranong for three months and monitoring for three years post-tsunami .

Later on 2009, Yanagisawa *et al*. (2009), using an integrated approach which included analysis of satellite imagery, field measurements, and numerical modeling, reported on the effects of the tsunami on mangrove forests in Thailand. They investigated the damage to the mangroves caused by the

2004 Indian Ocean tsunami in Pakarang Cape in Phang nga Province, Thailand. Comparing pre- and post-tsunami satellite images of the study area, they found that approximately 70% of the mangrove forest was destroyed by the tsunami. Based on the field observations, the survival rate of mangrove forests increased with increasing stem diameter. Specifically, it was found that 72% of *Rhizophora* trees, with a stem diameter of 25–30 cm, survived the tsunami, whereas only 19% of trees with a stem diameter of 15–20 cm, survived. They simulated the tsunami using a nonlinear shallow-water wave theory to reproduce the inundation caused by the tsunami and investigated the bending moment acting on the mangrove trees. The results of the numerical modeling showed that the areas inundated by the tsunami, along the mangrove creeks, with its velocity reaching 5.0 ms^{-1}. Based on the field measurements and numerical results, they proposed a fragility function for mangroves, which is a relationship between the probability of damage and the bending stress caused by the maximum bending moment. They refined the numerical model to include the damage probability of mangrove forests, using the obtained fragility function, to investigate the effectiveness of mangrove forests in reducing the force of the tsunami . From simple numerical conditions related to the mangrove forest, ground level, and incident wave, the model indicated that a mangrove forest, comprising of *Rhizophora* sp., with a density of 0.2 trees.m^{-2} and a stem diameter of 15 cm, spread over an area of 400 m, can reduce the tsunami inundation depth by 30% when the incident wave is assumed to have a 3.0 m inundation depth and wave period of 30 min at the shoreline. However, 50% of the mangrove forest was destroyed by a tsunami of 4.5 m inundation depth and most of the mangrove forest was destroyed by a tsunami with an inundation depth greater than 6 m. The forest's ability to resist the damage caused by the tsunami decreased when the inundation depth exceeded 3 m with the forest not being able to withstand an inundation depth exceeding 6 m.

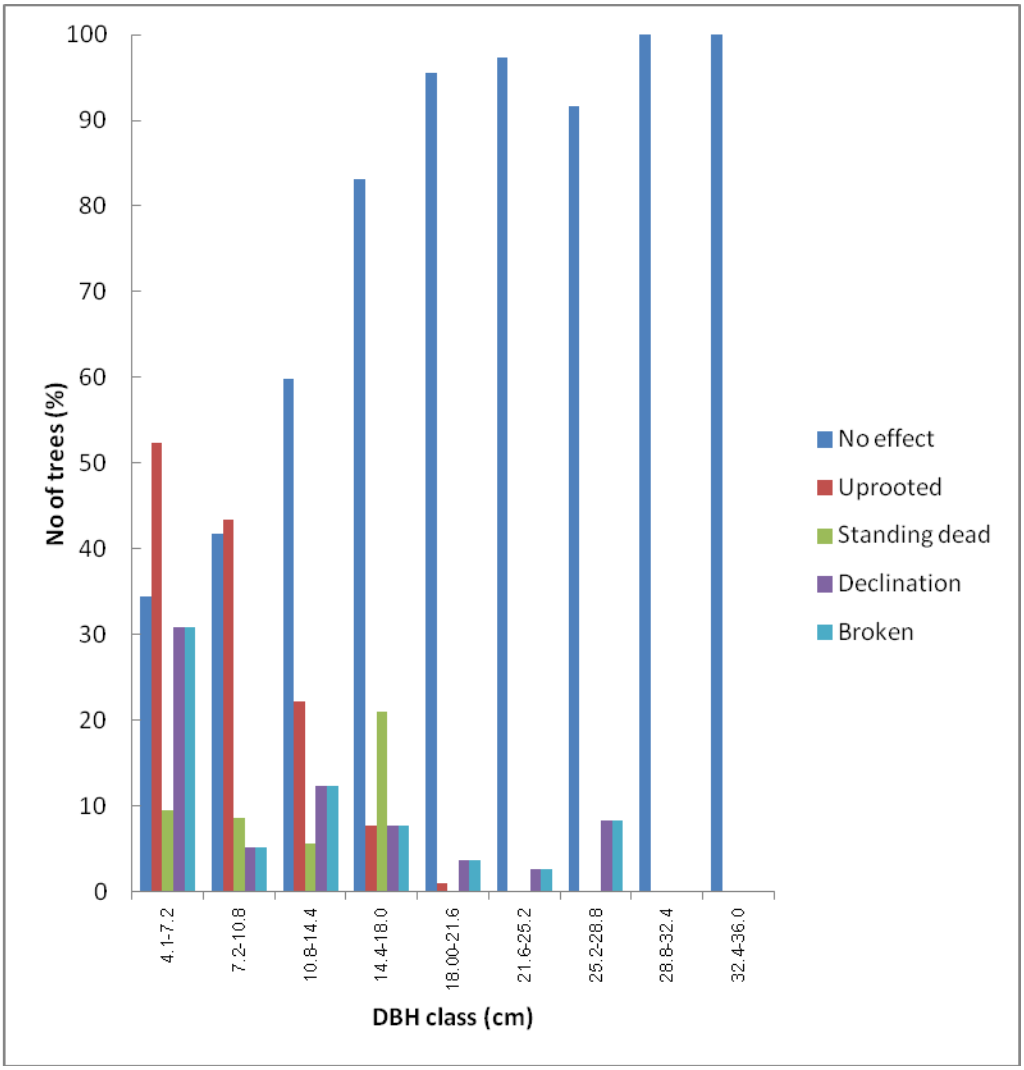


Figure 3 Types of damage observed in the mangrove forest in Ranong coastal area after being hit by the tsunami wave. Modified from the data reported by Marod (2006) and Wachrinrat (2007).

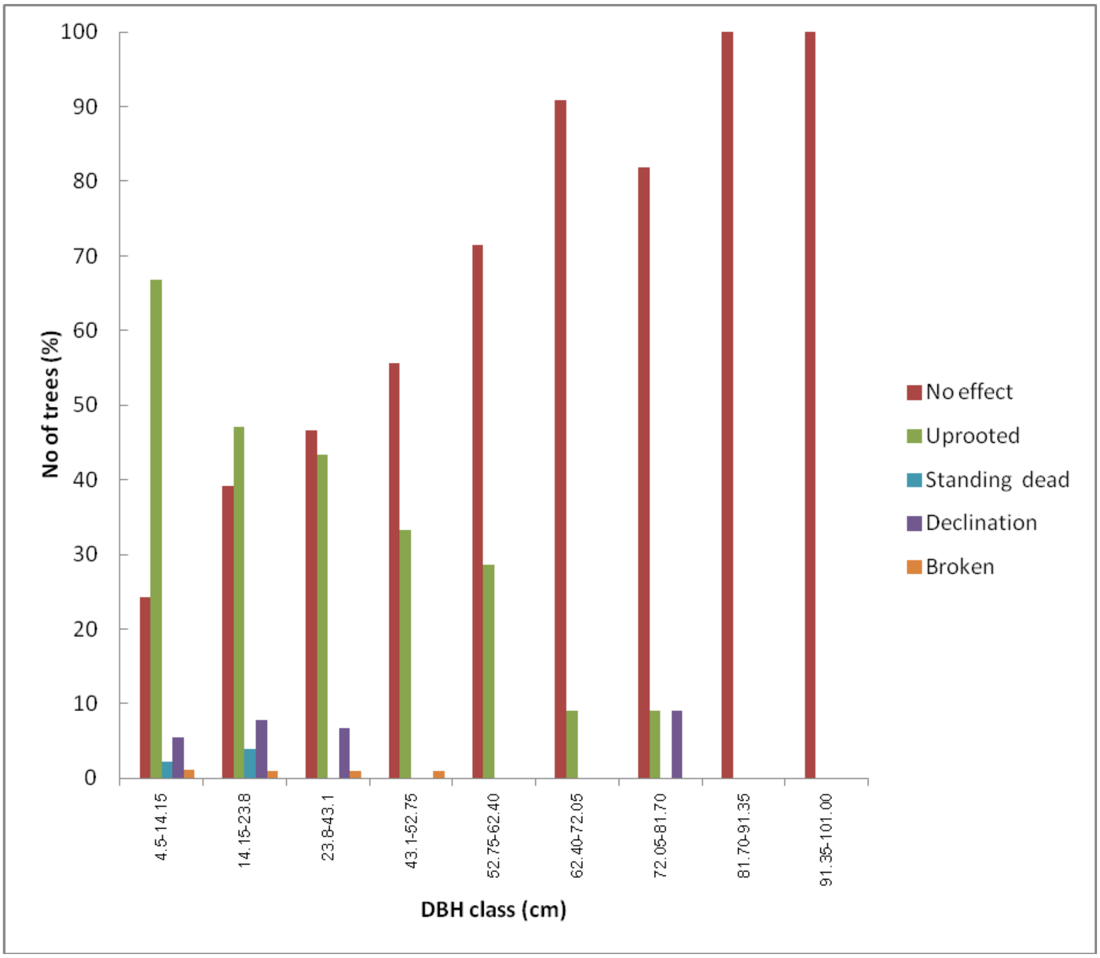


Figure 4 Types of damage to the beach forest in Ranong coastal area after being hit by the tsunami wave. Modified from the data reported by Marod (2006) and Wachrinrat (2007).

2. Damage to soil

Soil properties were investigated to address the change in soil as a result of tsunami wave. It was observed that the soil incurred physical damages in the form of soil erosion, deposition, and changes in soil particle composition due to the strength of the tsunami wave and marine water inundation in the affected areas. Several qualitative studies indicated substantially changes (e.g., Kawata *et al*., 2004; Sasaki *et al*., 2005; Bell *et al.,* 2005). Besides, changes in soil salinity, color, pH, and accumulation of organic matter were also reported elsewhere (e.g., Thanawood *et al*., 2006; Wachrinrat, 2007; Fujioka *et al*., 2008; Doydee *et al*., 2010; Srisutam and Wagner, 2010;Wagner and Srisutam, 2011). The significant changes in the composition of soil particles, in the affected mangrove forest of Ranong, were the deposition of sand particles on the deep soil mud flat of mangrove areas (Doydee *et al*., 2010) even after 3 years had elapsed since the event. Soil color was also reported to change from ordinary black through the soil profile, to brown or bright color after the event, resulting from sand deposition. Grain size distribution of the sand deposited in the sandy beach forest also indicated a more coarse grain structure transported upward into the beach during the run up of the tsunami wave (Fujioka *et al*., 2008).

Soil salinity changed as a result of marine saline water and affected the existing inland forest vegetation, causing numerous patches of standing dead trees. The EC (electrical conductivity) showed an abrupt increase in the soil profile from the surface down to about 50 cm depth in both the forest types (Thanawood *et al.*, 2006; Wachrinrat, 2007). These changes in soil properties obviously influenced the natural regeneration of the existing forest vegetation, since the seedlings are very sensitive to damage by soil salinity, as well as by the thick deposition of sandy particles on the muddy soil layer, particularly in the mangrove forest.

3. Damage to the forest vegetation structure

Foreign researchers carried out detailed studies on the vegetation structure along the coast after the wave hit. Their study focused on the capability of the trees to resist the wave, taking into account the study performed in the coastal forests in Sri Lanka and Thailand as sample cases (Tanaka *et al*., 2007a). They analyzed the effect of a vegetation structure on the drag forces[2], by using the observed characteristics of tree species to resist the wave forces using fluid dynamics. The drag coefficient ($C_{d\text{-}all}$), including the structure of vertical stands (Fig.5) and the vegetation thickness (cumulative trunk diameter of vegetation in the direction of the tsunami) per unit area (dN_u, where d: reference diameter of trees, N_u: number of trees per unit area), varied greatly with different species. Based on the field survey and data analysis, *Rhizophora apiculata* and *Rhizophora mucronata* (hereafter *R. apiculata*-type), various kind of mangroves, and *Pandanus odoratissimus*, a representative tree that grows on beach sand, were found to be especially effective in reducing the force of tsunami damage, due to their complex aerial root structure. Two layers of vegetation in the vertical direction with *P. odoratissimus* and *Casuarina equisetifolia,* and a horizontal vegetation structure comprising of trees with small and large diameter, were also important in increasing the drag and trapping floating objects, broken branches, houses, and people. The vertical structure also made for an effective soft landing for people washed up by the tsunami or for escaping the tsunami waves, although its dN_u was not large compared to the *R. apiculata*-type and *P. odoratissimus*. In addition, the creeks inside mangroves and the gaps inside *C. equisetifolia* vegetation were assumed to be effective in reducing the impacts of the tsunami waves. They also suggested that this information should be considered when planning for future coastal landscape, rehabilitation, and coastal resource management.

4. Roles of the coastal forests related to hazards of the disaster

The role of mangrove forests in saving human life during the tsunami hazard was confirmed by several studies, e.g., Kathiresan and Rajendran (2005), although there was a counter argument to this report (Kerr, *et al*., 2006), but a substantial evidence provided in a former paper (Dahdouh-Guebas *et al*., 2005) was widely accepted. Their conclusion from the analyses was similar to a recent publication about the 'Asian Tsunami: a protective role for coastal vegetation' that appeared in the Science journal (Danielsen *et al*., 2005). This work was, in fact, undertaken in an area nearby to the study site of Kathiresan and Rajendran, (2005) and based on the satellite images, it was also noted that the areas with coastal tree vegetation (mangroves and *Casuarina* plantations) incurred relatively less damage compared to areas void of vegetation. Further, there was ample evidence in favor of the coastal vegetation in mitigating the effects of tsunami. Tree vegetation reduced the wave amplitude and energy, as proved by measurements of wave forces and fluid dynamics modeling (Massel *et al*., 1999). Analytical models showed that 30 trees in an area of 100 m^2, in a 100-m-wide belt, might reduce the maximum flow pressure of a tsunami by more than 90% (Hiraishi and Harada, 2003). Later, Vermaat and Thampanya (2006) similarly concluded that the mortality and property losses were less in areas covered by mangrove. Sakamoto *et al.* (2009) investigated the characteristics of mangrove forest, which helped in reducing the damage caused by tsunami, and determined whether or not the mangrove trees that were uprooted or broken by the tsunami and swept inland had caused extensive damage. Their conclusion was that mangroves played an important role in reducing the force of tsunamis and should be maintained as barriers against tsunamis, even in instances where the mangroves were not facing the open sea, particularly in areas where the original coastal vegetation has been lost due to anthropogenic pressure. The roles of coastal forest in reducing the ill-effects of tsunami were compiled by FAO (2007a).

Although beach forests in Thailand widely grow naturally along the Andaman coast, detailed studies about the affect of tsunami on the beach forests have been few and far between. Recent development of tourism facilities around the Scenic sites along the coast has led to a reduction in the extent of the most beautiful and naturally abundant beach forest. A few detailed studies on the beach forests in Thailand have been published, notably by Hayasaka and Fujiwara (2005) on the relationship between species composition and environmental factors, including human activities, such as beach cleaning, mowing, and trampling, in southern Thailand's maritime strand forests and sand dunes. The study was conducted just six months prior to the Indian Ocean earthquake which generated the tsunami and hit the Andaman coastal area, including the research sites in Phuket. Another report by Sasaki *et al*. (2005) was on the phytosociological studies of coastal dune vegetation in Narathiwat, which is an area located opposite to the Andaman coastal area .

Nine months later, the same group carried out research on the same area (Hayasaka *et al*., 2009) to investigate the recovery of the beach forest after the tsunami wave. Their studies provided very useful information on the structural composition and change in the beach forest conditions from pre- to post-tsunami. Although the perennial plants were not adequately established after the wave impact, the area was full of annuals, especially grasses and asteraceous plants, rather than by perennials. In contrast, the occurrence frequency of species, with clonal growth by stolons, decreased significantly. Factors determining the differences in species habitat were the soil hardness (penetration resistance of sandy soil), per cent silt content, soil water content, and beach management. Differences in habitat among the beach herbaceous species, originally found in non-sandy areas, that had expanded towards the coast after the disaster, were governed by sand accretion or erosion caused by the tsunami. Many herbaceous communities found on sandy beaches changed into *Dactyloctenium aegyptium* communities, originally constituted by non-sandy beach *D. aegyptium* with *Cenchrus echinatus,* as a result of the tsunami. Although the forest floor of most maritime forests was invaded originally by non-sandy beach *Tridax procumbens, Eleusine indica* or *D. aegyptium,* after the tsunami, did not result in a change in the vegetation.. This was because the species' loss was restricted to the understory. In time, these forests will recover to their previous community composition (Hayasaka *et al*., 2009).

Casuarina is the major tree species often found in the beach forests. In spite of its usefulness in the past for wood in Thailand, the popularity of *Casuarina* plantation was in fact, not only along the coastal area but also on land where trees from natural forest were scarce. This kind of plantation was very popular in the past few decades. *Casuarina* trees play a protective role along the coast as a windbreaker around the farming area, besides being planted as the roadside amenity tree or in small recreational areas. It was well known as a shelterbelt beneficial for either economical and/or coastal environmental stabilization. However, the Thai forestry sector had neglected this plantation ever since other tree species plantations become popular country wide, e.g., *Eucalyptus* spp. However, shelterbelts of *Casuarina* trees have always been recognized for their important benefits in coastal areas.

Relief measures

There was no substantial evidence indicating a reduction in the damage caused by tsunami wave through planting *Casuarina* in Thailand, compared to other countries that have had the similar experiences or even for the protection of land and coastal areas, for instance on the Nagapattinam coast of India (Ganesan, 2005). Shelterbelt plantations have been established as a coastal protection measure in almost all tsunami affected areas in the northern part of Japan since 1933 (Edward *et al*., 2006). Under normal circumstances, most of the sand moved by storms accumulates offshore, and moves back to the beach via wave transport. On the beach, *Casuarina* roots retain sand. Stabilizing the shifting sand dunes is based on the principle of reducing the threshold velocity of the wind by a tree-belt. Sand dune stabilization with plant species is a more permanent measure compared to mechanical mulching and chemical fixation techniques (FAO, 1989). *Casuarina* plantations, covering an area of 7,549 ha, are serving as a coastal shelterbelt in Tamil Nadu in India, acting as a first line of defense against frequent cyclonic storms and heavy winds (Institute for Ocean Management, 2007). The coastal shelterbelts act as a bioshield in the great lakes of the American Midwest, providing protection to households during storms and allow circulation of cool breez during summers (Wu *et al*., 2007). Often, sand bars form in front of sea shores, and shelterbelts prevent bare strips on the sand bars caused by wind erosion. Without a vegetation cover, sand dunes move in the direction of wind, putting the city households, agricultural crops and roads at imminent risk. To prevent encroachment of beach by tidal waves, the sand dunes must be stabilized. Shelterbelts were planted to stabilize the Ainsdale sand dunes in UK and to turn the wasteland into a more productive estate (Simpson and Gee, 2004). The development of coastal dunes on the western coast of Hainan Island in China was done using forest shelterbelts (Sen *et al*., 2007). *Casuarina* grew rapidly on the Florida coastal dunes , providing dense shade and litter accumulation. A chemical produced by *Casuarinas* inhibits the growth of native plants (IFAS Extension, 2007). The coastal belt is considered as a priority area for re-vegetation under the greening program of Kuwait, due to its proximity to the main urban and recreational areas, which enhances the conservation and visual value of this zone (Al Bakri, 1994). A 6.67 million ha and 15,000 km major coastal shelterbelt in China has brought 6.17 million ha of farmland under effective protection and reduced the extent of water and soil erosion by 50% (China Internet Information Center, 2002). Coastal shelterbelts in Kochi and Miyazaki prefectures in Japan were developed several centuries ago for protecting agriculture lands from salt sprayed by strong winds (Edward *et al*., 2006). Tree shelterbelts act as a wind barrier, which can reduce wind erosion of the soil, increasing crop yield by up to 25% (Environment Bay of Plenty, 2007). A shelterbelt established on the west coast of New Zealand produces at least a commercial crop of logs and firewood (Berg, 2006). Torbay Council (2007) in New Zealand, under its Regional Planning Guidance for the South West in 2001, noted the importance of coastal landscape planted as groups of trees or shelterbelts for tourism. As reported by Vervest (2007), besides providing protection from natural disasters, multiple species shelterbelt contribute to local biomass supply.

The effects of tsunami wave on coastal forest resources have been mostly investigated by the local plant and some marine scientists, particularly on the area affected, type of plant or tree damage, and sometimes include the chances of natural recovery or regeneration. Very few studies have been undertaken related to the causes and the subsequent effects of such severe real disasters, which have rarely occured in Thailand in the past, except those in areas hit by frequent high and strong wave erosion. The reasons along with the causes and effects are not investigated scientifically. Most of the efforts focus on rehabilitating the coastal areas by planting trees, mainly for vanity, without any long term success or failure of the project. This is probably because Thailand lacks adequate knowledge about disaster prevention and events are always neglected, especially when there are very few scientists, environmentalists, and coastal engineers to integrate the causes and effects of various kind of waves and search for effective ways to remediate and mitigate the impacts. The most advanced countries on Tsunami science, apart from working on other disaster prevention and mitigation policies in Asia are Japan, Sri Lanka, India, and Indonesia. In Thailand, this type of academic field should be urgently promoted as the coastal areas are always vulnerable to such kinds of unprecedented disaster events.

CONCLUSION

The Indian ocean tsunami of 26th December, 2004 caused severe damage to a relatively large area of mangrove and beach forests in the six provinces along the southern Andaman coast of Thailand. There were several investigations focusing on the severity and losses incurred carried out by many national and international scientists. All evidence pointed to the coastal forest communities reducing the damage by diminishing the strength of wave and thus protecting human life, property, and the residential area surrounding and situated behind the forests. The two coastal forests themselves also showed damages to different degrees, depending on the location, topography, tree size, and so on. This paper reviewed the characteristics of tsunami disaster, the characteristics coastal area and forest community and the impacts of tsunami attack. Investigations performed by scientists and investigators from many offices and institutions, both overseas and domestic, were examined based on the available and accessible documents. In addition to the damage to the coastal forests, the soil properties underneath the two forest types were also affected. To remediate and rehabilitate the damaged forest sites, trees in the post-tsunami mangrove and beach forest areas in southern Thailand were planted by the central governmental offices assigned to the local areas or by the concerning private and local government sectors in the affected sites. However, the trees in these sectors were planted in patterns without taking into consideration the future protection of these forests, if a similar or other disaster event occurs in the future. There are several disasters known to occur along both the coasts of peninsular Thailand and on eastern coast, the existing mangrove and beach forests may be susceptible to such unpredictable disasters. Planting trees by considering their protection, and mitigation and amelioration, pre-and post- disaster and for the purpose of lessening the impacts, should be planned in every vulnerable coastal forest site. This should also include the important roles trees play in saving natural resources and the surrounding areas, while giving top priority to protection of human life.

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