Research Journal of Applied Sciences, Engineering and Technology 5(18): 4483-4488, 2013
ISSN: 2040-7459; e-ISSN: 2040-7467
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Submitted: August 15, 2012 Accepted: September 17, 2012 Published: May 05, 2013

Effectiveness of Mangrove Forests in Surface Wave Attenuation: A Review

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Abstract: For once, mangrove forests were surprisingly resistant to the forceful impacts of the Indian Ocean Tsunami of December 2004 which swept away entire villages and caused the deaths of approximately 200,000 people. It was reported that human death and loss of property were significantly reduced in areas of dense mangrove forests in southeastern India. As the importance of mangrove is gaining attention lately, numerous countries have started to replant mangroves for coastal protection. This study discusses the extensive researches that have been conducted to study the role of mangrove forests in wave energy dissipation. These include field measurements, numerical studies and laboratory experiments. The findings illustrate that mangrove species, density, forest width, forest structure, age, water depth and incident wave height are among the factors affecting the performance of mangroves in attenuating waves. Dense forest, larger forest width, bigger trunk diameter and higher wave height resulted in relatively more wave energy dissipation by mangroves.

Keywords: Field observation, laboratory experiment, mangrove, numerical studies, surface wave attenuation

INTRODUCTION

The 2004 Indian Ocean Tsunami has caused economic and ecological impact in thirteen Asian and African countries (Kathiresan and Rajendran, 2005). The western coast of Thailand (Tanaka *et al*., 2007) and approximately two-thirds of Sri Lanka (Wijetunge, 2005) were severely destroyed on a scale these countries have never encountered before. Vo-Luong and Massel (2008) reported that in the South-East part of India, the human causalities and economic damage were less severe at the places where dense mangrove forests presented. Most of the mangrove forests experienced minimal damage (Alongi, 2008) and only limited to the seaward focus fringe (Dahdouh-Guebas *et al*., 2005). While in Simeuleu Island in Indonesia where the epicenter of the tsunami was close to the island, however, the death toll on this island was significantly low due to the presence of dense mangroves.

Mangrove forests are capable of reducing the severity of tsunami wave and attenuating the disastrous amount of wave energy associated with it (Mazda *et al*., 1997a, 1997b; Kathiresan and Rajendran, 2005; Dahdouh-Guebas *et al*., 2005). The above-ground portion of wetland plants can directly dampen waves through their structural presence and indirectly dampen wave impacts by stabilizing and building up sediment (Gedan *et al*., 2011). Models of tsunami hydrodynamics indicate that the wave heights and current velocities are reduced when waves propagating through mangrove forests compared to bare land (Hiraishi and Harada, 2003; Teo *et al*., 2009). Because of their great importance, increasing number of researches have been undertaken to study the behavior of wave propagation through mangrove forests. The mangrove species, density, forest structure, forest width, age, tree size, water depth and incident wave height are among the factors influencing the performance of mangrove forests in wave energy dissipation. However, quantitative effect of each factor is still not fully understood. Investigations on wave dissipation in mangroves were more intensified after the 2004 Indian Ocean Tsunami. Although numerous field, laboratory and numerical studies have been carried out, most of the studies only concentrated on a particular mangrove species or wave condition. This study presents an overall review on the previous researches done and also describes the various factors influencing the performance of mangrove forests in wave attenuation including the mangrove vegetation characteristics and hydraulic conditions.

PREVIOUS RESEARCHES

Field observations: Bao (2011) conducted a study at two coastal mangrove forests in Vietnam which consisted of replanting mangroves and naturally regenerating mangroves. The results showed that the wave height decayed exponentially with the distance from mangrove front. A forest structure index expressed as a function of tree height, density and

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canopy closure was derived to determine the required mangrove band width for coastal protection. A field study by Yanagisawa *et al*. (2009) at Pakarang Cape, Thailand revealed that the survival rate of mangroves increased with increasing stem diameter. They found that 72% of Rhizophora trees with stem diameters of 25 cm to 30 cm survived the tsunami impact, whereas only 19% with stem diameters of 15 cm to 20 cm survived. Vo-Luong and Massel (2008) reported that the effect of wave breaking played a more important role on wave attenuation in sparse forest, as observed in Can Gio Mangrove Biosphere Reserve, Vietnam. Quartel *et al*. (2007) conducted field observation in Red River Delta, Vietnam which consisted of 88.9% Kandelia candel, 7.4% of Sonneratia spp. and 3.7% of Avicennia marina. They found that the wave height reduction by mangroves was 5 to 7.5 times larger than by sandy bed only. Mazda *et al*. (2006) reported that Sonneratia spp. gave higher reduction rate which was 0.006 m-1 compared to 0.002 m-1 in the Kandelia candel forest. The effect of the drag force on Kandelia candel by the wave was weak compared to those of Brugueira spp. and Rhizophora spp. because Kandelia candel has no pneumatophores (Mazda *et al*., 1997a). It was also noticeable that the rate of wave reduction decreased with increasing water depth. Massel *et al*. (1999) also added that as the water level increased, wave energy was transmitted further into the forest, thus causing less attenuation of wave energy. This can be explained by the rapid drop of the ratio of the projected area of obstructions to the total cross-sectional area of flow with increasing water level.

A study was conducted by Mazda *et al*. (1997a) in Tong King delta, Vietnam which is a mangrove re-forestation area comprised of Kandelia candel of different ages. At site where mangrove trees were sufficiently tall, the rate of wave reduction per 100 m was as large as 20%. They further predicted that for 6 years-old trees, wave height can be reduced from 1.0 m to 0.05 m across a 1.5 km mangrove forest width while it will only be reduced to 0.75 m in area without mangroves. Another field study carried out by Mazda *et al*. (1997b) in a pristine mangrove forest in Coral Creek, Australia and Iriomote Island, Japan. They found that the hydrodynamics in mangrove swamps changed in a wide range with vegetated mangrove species, vegetation density and tidal condition.

Tanaka *et al*. (2007) in their field survey in Sri Lanka and Andaman coast of Thailand reported that Rhizophora apiculata and Rhizophora mucronata were especially effective in providing protection from tsunami damage due to their complex aerial root structure. Field survey at Parangipettai, India has lead (Kathiresan and Rajendran, 2005) to support that Rhizophora species are more suitable species to mitigate the effect of tsunami than Avicennia species. However, it should be noticed that Rhizophora species generally occurs seaward while Avicennia species exists landward in India which is significantly different from mangrove zonation in Southeast Asia where it is vice-versa.

Laboratory experiments: Reimann *et al*. (2009) tested models of Rhizophora spp. and Casuarina spp. in a wave flume and found that the models with tandem arrangement gave lower wave reduction in comparison to the models with staggered arrangements. Tuyen and Hung (2009) claimed that for same incoming wave heights, the shallower the water the more wave energy will be dissipated. They also suggested that a mangrove forest with the recommended length of about 2 times the wave length in storm condition and above (at least 200 m) can provide 80% wave height reduction approximately. Augustin *et al*. (2009) studied the effect of plant rigidity on wave attenuation and found that both the rigid and flexible vegetation elements yielded the same friction factors in the laboratory experiments. Furthermore, there was less wave damping for near-emergent vegetation condition compared to emergent condition. Both Reimann *et al*. (2009) and Augustin *et al*. (2009) considered the vegetation as cylindrical elements in the experiments. Harada *et al*. (2002) also conducted a hydraulic experiment but to study the tsunami reduction effect using mangroves, coastal forests, wave dissipating block, rock breakwater and houses. Their experiment revealed that mangroves were as effective as concrete seawall structures for the reduction of tsunami effect on property damage behind the forest.

Numerical studies: Suzuki *et al*. (2011) studied the wave dissipation over a vegetation field by implementing the Mendez and Losada (2004) formulation in SWAN (Simulating Waves Nearshore) model. Similar to Vo-Luong and Massel (2008), the varying water depths, wave-trunk interaction and wave breaking conditions were taken into consideration in the numerical model. The main difference was in their attempt to include the vertical layer schematization in case of layered vegetation such as mangroves. This inclusion enabled the vegetation in a given region to be varied so as to reflect real density variations in the field. There are also similarities between Mendez and Losada (2004) formulation and forest structure index derived by Bao (2011) based on field work which accounted for the vegetation characteristics such as density, tree height and diameter.

Vo-Luong and Massel (2008) investigated about the wave-induced velocities at varying water depths and found that the vertical profiles of horizontal and vertical velocities attenuated very quickly with distance from mangrove front and were negligible be-hind the mangroves. Yanagisawa *et al*. (2009) simulated the 2004 Indian Ocean Tsunami and reported that a

mangrove forest of Rhizophora spp. with a density of 0.2 trees/m² and stem diameter of 15 cm in a 400 m wide area can reduce the tsunami wave height by 30%. On the other hand, Hiraishi and Harada (2003) simulated the tsunami reduction effect of coastal trees with higher density of 0.3 trees/m² and reported that it would require a reduced forest width of 100 m to give wave height reduction of more than 50%.

Hadi *et al*. (2003) analyzed two types of mangrove forests, namely Rhizophora and Ceriops forests and found that Rhizophora forest attenuated wave energy most effectively. They also suggested that the resulting rate of wave energy attenuation depended strongly on the density of mangrove forest and on the diameter of mangrove roots and trunks. Their analytical study was based on the model developed by Massel *et al*. (1999). However, Massel *et al*. (1999) did not consider the wave breaking in the model. The theoretical prediction model by Massel *et al*. (1999) served as a rough estimate for attenuation of wind induced waves propagating through mangrove forests due to some limitation of the model.

FACTORS INFLUENCING PERFORMANCE OF MANGROVE

Mangrove vegetation characteristics: A mangrove forest varies from site to site, in terms of its species composition, density, forest width, age distribution, tree sizes and root configuration. Combination of each different vegetation characteristics presents a varying level of resistance to incoming waves, thus affecting the attenuating capability of a mangrove forest is very much dependent on its vegetation characteristics.

- **Species:** The species composition of the mangrove forest is correlated with the its capacity to reduce wave energy (Alongi, 2008; Dahdouh-Guebas *et al*., 2005; Mazda *et al*., 1997a, 1997b; Tanaka *et al*., 2007; Koch *et al*., 2009). Tanaka *et al*. (2007) simulated vegetation drag forces and found that, of mangroves (Rhizophora spp. and Avicennia spp.) and other coastal trees (Pandanus odoratissimus, Casuarina equisetifolia, Cocos nucifera and Anacardium accidentale), Rhizophora mangroves and Pandanus odoratissimus were most effective in slowing down water flow and reducing wave heights. This is further supported by Mazda *et al*. (1997b) that Rhizophora spp. created greater friction to waves. Sanit *et al*. (1992) and Jayatissa *et al*. (2002) explained that Rhizophora apiculata-type trees have complex aerial root structures that contributed to higher drag coefficient. This is parallel with the findings by Tanaka *et al*. (2007) that Rhizophora apiculata and Rhizophora mucronata were especially effective in providing protection from tsunami damage, based on their field observation in Sri Lanka and Andaman coast of Thailand. Therefore a complex of various species would be desirable as different species have different types and sizes of leaves, trunks and roots, hence resulting in different levels of resistance (Tanaka *et al*., 2007). The forest width required is also closely related to the type of mangrove species. According to Alongi (2008), 100 m of Sonneratia forest can reduce wave energy up to 50%. On the other hand, Othman (1994) reported that 50 m of Avicennia forest is sufficient to reduce waves from 1 m to 0.3 m in Sungai Besar, Malaysia, corresponding to 70% wave height reduction.
- **Density:** Dense mangrove forest attenuates waves more effectively than low density forest (Alongi, 2008; Mazda *et al*., 1997a, b; Massel *et al*., 1999). Several studies have related density to the age, size of trees, mangrove species and forest width. The dense mangrove forest presents a much larger drag force to incoming waves as compared to a bare mudflat (Bao, 2011). The greater the friction the wave encounters, the greater the energy that will be dispersed (Lacambra *et al*., 2008). Mangrove density and complex structure were considered to be important by some authors based on site measurement (Mazda *et al*., 1997b), direct observation (Othman, 1994; Danielsen *et al*., 2005) and mathematical developed models (Massel *et al*., 1999; Hiraishi and Harada, 2003). Vo-Luong and Massel (2008) in their numerical model, found that the effect of wave breaking played a more important role on wave attenuation in less dense mangrove forest while the effect of wave-trunk interactions dominated in the case of denser mangrove forest. For the high density forest, the wave height reduction rate was higher. Hadi *et al*. (2003) in their numerical studies also found that the rate of wave energy dissipation was higher for the case of denser mangrove forests.
- **Band width:** Lacambra *et al*. (2008) stated that the optimum mangrove forest width ranges from 100 m up to 1500 m, depending on the mangrove species, stem density and characteristics of the

area. Some Asian countries have outlined the minimum required width for mangrove forests. According to Lacambra *et al*. (2008), a mangrove belt between 500 m and 1000 m width has been set as a buffer zone in Vietnam along the Mekong delta coastline. In Philippines the buffer zone is 20 m and can reach up to 50 m in the storm prone areas. In Malaysia, the 1950s regulation specified 200 m mangrove buffer zone before any structures protecting agricultural land (Othman, 1994).

Field experiment was conducted by Massel *et al*. (1999) at Coral Creek in Australia. Normalized energy was calculated and the results showed a decrease in wave energy transmission with distance into the forest. On the other hand, Bao (2011) analyzed wave attenuation in coastal mangrove forests in Vietnam and established a relationship between the required mangrove forest band width and the forest structure index. When the mangrove forest is tall and dense, a narrower forest band width is required for coastal protection.

- **Forest structure:** The magnitude of the energy dissipated depends on the mangrove structures such as the stem configurations, roots and branches diameters as well as submerged part of the vegetation (Alongi, 2008; Massel *et al*., 1999; Quartel *et al*., 2007). Vegetation leaves and stems slow water velocity, reduce turbulence and increase deposition of sediments (Redfield, 1972; Christiansen *et al*., 2000; Bao, 2011). The wave dissipation rates are also contributed by stem stiffness (Bouma *et al*., 2005; Peralta *et al*., 2008) and the presence of pneumatophores (Mazda *et al*., 2006). From their field work in Vietnam, Mazda *et al*. (2006) found that thick mangrove leaves were capable of dissipating huge amount of wave energy during storms and typhoons. Other field experiment by Quartel *et al*. (2007) also revealed that the wave-driven, wind-driven and tidal currents reduced due to the dense network of trunks, branches and aboveground roots of the mangroves and this could be seen as an increased bed roughness.
- **Age:** Latief and Hadi (2006) related the age of mangrove, indirectly the size of trees to the mangrove capacity in wave energy dissipation. Age of a mangrove tree implies the size of the tree, the trunk and root diameter as well as stem density (Lacambra *et al*., 2008). The older and bigger the trees, the higher their resistances to the wave damage (Othman, 1994; Mazda *et al*., 1997a; Massel *et al*., 1999; Hadi *et al*., 2003; Danielsen *et al*., 2005; Alongi, 2008). Mazda *et al*. (1997a) conducted a field observation in a mangrove reforestation area (dominated by Kandelia candel) in the Tong King delta, Vietnam and reported that the wave reduction rate was influenced by the mangrove vegetation's age. In area with 0.5 year-old mangrove, the rate of wave reduction was small because the vegetation was still young and sparse, thus the wave energy loss was caused by bottom friction only. In area where mangrove trees were 5-6 years old, the wave reduction rate was larger, suggesting the better developed mangrove plants imposed higher drag force, therefore resulted in greater wave reduction rate. The wave reduction rate in area with 2-3 years old mangrove lied between mangrove of age 0.5 year and 5-6 years old.
- **Height:** According to Mazda *et al*. (2006), bottom friction caused by roots and pneumatophores are important at shallow water depth. However, leaves start to play role in attenuating waves at higher water depth. Lacambra *et al*. (2008) reported that taller trees seem to suffer greater damage from wind, but they also seem to be more resistant to wave energy. Mazda *et al*. (1997a) further added that the wave reduction was higher with an increase in mangrove vegetation height and density.

Hydraulic conditions: Besides the vegetation characteristics, the hydraulic conditions also have their influence on wave attenuation. Among the main factors that affect wave energy dissipation include the water depth and incident wave height.

- **Water depth:** The maximum wave height in shallow water is proportional to the depth of water between the bed surface and sea level (Gedan *et al*., 2011). Based on a field experiment, Quartel *et al*. (2007) reported that the resistance due to the un-vegetated sandy bed lowered with increasing water depth, resulted in a lower wave height reduction. While in the presence of mangrove forest, the resistance coefficient increased with increasing water depth, resulted in a higher wave height reduction. This is due to the larger submerged part of mangrove branches and leaves which obstruct the water flow (Quartel *et al*., 2007).

  There is also a correlation between the mangrove species and water depth. Mazda *et al*. (1997a) demonstrate that in a mangrove forest dominated by Kandelia candel where the trees were sufficiently tall, the wave reduction rate per 100 m was as much as 20%. The wave reduction was large even the water depth increased due to the high density of vegetation distributed throughout the whole water depth. To relate water depth with other mangrove species, another field observation was conducted by Mazda *et al*. (2006) at the Vinh Quang coast (dominated by Sonneratia spp.) in

northern Vietnam. They suggested that at shallow water depth, since the shape of pneumatophores of Sonneratia spp. tapered off upward, the effect of drag force by these roots on the wave reduction decreased with increasing water depth. This resulted in a subsequent decrease in the wave height reduction rate.

- **Incident wave height:** At higher water depth, the wave reduction rate in mangrove area is relatively much dependent on the incident wave height. Mazda *et al*. (2006) reported that the wave reduction rate was independent of the incident wave height in the area without mangrove. In the mangrove forest dominated by Sonneratia spp., the wave reduction rate depended in a linear trend with incident wave height when the water level reached the height of the leaves (Mazda *et al*., 2006). This suggests that the wave reduction was caused by the thickly grown leaves. However, this effect is not significant if the waves do not reach the height of the leaves.

CONCLUSION

Mangrove forests are capable of dissipating wave energy, thus they play an important role in coastal protection. This review study articulated how the wave attenuation capacity of a mangrove forest influenced by various factors including mangrove species, density, forest width, size of tree, water depth and incident wave height. At mangrove site, the wave height decays exponentially with distance from mangrove front. The significant function of mangroves in reducing wave heights and thus serve as natural protection buffer for coastal areas warrants the needs for their preservation and maintenance for a more sustainable future.

ACKNOWLEDGMENT

The authors would like to thank the University Technology PETRONAS for providing the facility and funding to conduct this research.

REFERENCES

Alongi, D.M., 2008. Mangrove forests: Resilience, protection from tsunamis and responses to global climate change. Estuar. Coastal Shelf S., 76: 1-13.

Augustin, L.N., J.L. Irish and P. Lynett, 2009. Laboratory and numerical studies of wave damping by emergent and near-emergent wetland vegetation. Coast. Eng., 56: 332-340.

Bao, T.Q., 2011. Effect of mangrove forest structures on wave attenuation in coastal Vietnam. Oceanologia, 53(3): 807-818.

Bouma, T.J., M.B. De Vries, G. Peralta, I.C. Tanczos, J. Van de Koppel and P.M.J. Herman, 2005. Trade-offs related to ecosystem engineering: A case study on stiffness of emerging macrophytes. Ecology, 86: 2187-2199.

Christiansen, T., P.L. Wiberg and T.G. Milligan, 2000. Flow and sediment transport on a tidal salt marsh surface. Estuar. Coastal Shelf S., 50: 315-331.

Dahdouh-Guebas, F., L.P. Jayatissa, D.D. Nitto, J.O. Bosire, D.L. Seen and N. Koedam, 2005. How effective were man-groves as a defense against the recent tsunami? Curr. Biol., 15: 443-447.

Danielsen, F., M.K. Sorensen, M.F. Olwig, V. Selvam, F. Parish, N.D. Burgess, T. Hiraishi, V.M. Karunagaran, M.S. Rasmussen, L.B. Hansen, A. Quarto and N. Suryadipu-Tra, 2005. The Asian tsunami: A protective role for coastal vegetation. Science, 310: 643.

Gedan, K.B., M.L. Kirwan, E. Wolanski, E.B. Barbier and B.R. Silliman, 2011. The present and future role of coastal wetland vegetation in protecting shorelines: Answering re-cent challenges to the paradigm. Climatic Change, 106: 7-29.

Hadi, S., H. Latief and Muliddin, 2003. Analysis of surface wave attenuation in mangrove forests. Proc. ITB Eng. Science, 35(2): 89-108.

Harada, K., F. Imamura and T. Hiraishi, 2002. Experimental study on the effect in reducing tsunami by the coastal permeable structures. Proceedings of the 12th International Offshore and Polar Engineering Conference. Kita-Kyushu, Japan, May 26-31.

Hiraishi, T. and K. Harada, 2003. Greenbelt tsunami prevention in south-pacific region. Report of the Port and Airport Research Institute, 42: 1-23.

Jayatissa, L.P., F. Dahdouh-Guebas and N. Koedam, 2002. A review of the floral composition and distribution of mangroves in Sri Lanka. Bot. J. Linn. Soc., 138: 29-43.

Kathiresan, K. and N. Rajendran, 2005. Coastal mangrove forests mitigated tsunami. Estuar. Coastal Shelf S., 65: 601-606.

Koch, E.W., E.B. Barbier, B.R. Silliman, D.J. Reed, G.M.E. Perillo, S.D. Hacker, E.F. Granek, J.H. Primavera, N. Muthiga, S. Polasky, B.S. Halpern, C.J. Kennedy, C.V. Kappel and E. Wolanski, 2009. Non-linearity in ecosystem services: Temporal and spatial variability in coastal protection. Front Ecol. Environ., 7: 29-37.

Lacambra, C., T. Spencer and I. Moeller, 2008. Tropical coastal ecosystem as coastal defences. Report on the Role of Environmental Management and Eco-Engineering in Disaster Risk Reduction and Climate Change Adaptation. Cambridge Coastal Research Unit, Department of Geography, University of Cambridge, United Kingdom.

Latief, H. and S. Hadi, 2006. The Role of Forests and Trees in Protecting Coastal Areas Against Tsunamis. Regional Technical Workshop Coastal Protection in the Aftermath of the Indian Ocean Tsunami: What Role for Forests and Trees? August 28-31, Khao Lak, Thailand.

Massel, S.R., K. Furukawa and R.M. Brinkman, 1999. Surface wave propagation in mangrove forests. Fluid Dyn. Res., 24: 219-249.

Mazda, Y., M. Magi, M. Kogo and P.N. Hong, 1997a. Man-grove as a coastal protection from waves in the Tong King delta, Vietnam. Mangroves Salt Marshes, 1: 127-135.

Mazda, Y., E. Wolanski, B. King, A. Sase, D. Ohtsuka and M. Magi, 1997b. Drag force due to vegetation in mangrove swamps. Mangroves Salt Marshes, 1: 193-199.

Mazda, Y., M. Magi, Y. Ikeda, T. Kurokawa and T. Asano, 2006. Wave reduction in a mangrove forest dominated by Sonneratia sp. Wetlands Ecol. Manag., 14: 365-378.

Mendez, F.M. and I.J. Losada, 2004. An empirical model to estimate the propagation of random breaking and non-breaking waves over vegetation fields. Coast. Eng., 51: 103-118.

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

Peralta, G., L.A. Van Duren, E.P. Morris and T.J. Bouma, 2008. Consequences of shoot density and stiffness for ecosystem engineering by benthic macrophytes in flow dominated areas: A hydrodynamic flume study. Mar. Ecol. Prog. Ser., 368: 103-115.

Quartel, S., A. Kroon, P.G.E.F. Augustinus, P.V. Santen and N.H. Tri, 2007. Wave attenuation in coastal mangroves in the Red River delta, Vietnam. J. Asian Earth Sci., 29(4): 576-584.

Redfield, A.C., 1972. Development of a New England salt marsh. Ecol. Monogr., 42: 201-237.

Reimann, S., S. Husrin, A. Strusińska and H. Oumeraci, 2009. Damping tsunami and storm waves by coastal forests-parameterisation and hydraulic model tests. FZK-Kolloquium 'Potenziale für die Maritime Wirtschaft', Han-nover.

Sanit, A., S.M. Gordon, H. Sonjai and P. Somchai, 1992. Plants in Mangroves. Bangkok, pp: 120.

Suzuki, T., M. Zijlema, B. Burger, M.C. Meijer and S. Narayan, 2011. Wave dissipation by vegetation with layer schematization in Swan. Coastal Eng., 59: 64-71.

Tanaka, N., Y. Sasaki, M.I.M. Mowjood, K.B.S.N. Jinadasa and S. Homchuen, 2007. Coastal vegetation structures and their functions in tsunami protection: Experience of the re-cent Indian Ocean tsunami. Landscape Ecol. Eng., 3: 33-45.

Teo, F.Y., R.A. Falconer and B. Lin, 2009. Modelling effects of mangroves on tsunamis. Water Manage., 162: 3-12.

Tuyen, N.B. and H.V. Hung, 2009. An experimental study on wave reduction efficiency of mangrove forests. Proceeding of the 5th International Conference on Asian Pacific Coasts (APAC2009). Nanyang Technological University (NTU), Oct. 13-16, Singapore, 4: 336-343.

Vo-Luong, H.P. and S.R. Massel, 2008. Energy dissipation in non-uniform mangrove forests of arbitrary depth. J. Mar. Syst., 74: 603-622.

Wijetunge, J., 2005. Future directions for post-tsunami coastal zone management in Sri Lanka. Proc. IAHR 31ST, 2: 961-962.

Yanagisawa, H., S. Koshimura, K. Goto, T. Miyagi, F. Imamu-ra, A. Ruangrassamee and C. Tanavud, 2009. The reduction effects of mangrove forest on a tsunami based on field surveys at Pakarang Cape, Thailand and numerical analysis. Estuar. Coastal Shelf S., 81: 27-37.