

Short note

## Coastal mangrove forests mitigated tsunami

Kandasamy Kathiresan\*, Narayanasamy Rajendran

*Centre of Advanced Study in Marine Biology, Annamalai University, Parangipettai 608 502, Tamil Nadu, India*

Received 30 March 2005; accepted 24 June 2005

Available online 26 August 2005

### Abstract

A study conducted after the 26th of December 2004 tsunami in 18 coastal hamlets along the south-east coast of India reiterates the importance of coastal mangrove vegetations and location characteristics of human inhabitation to protect lives and wealth from the fury of tsunami. The tsunami caused human death and loss of wealth and these decreased with the area of coastal vegetation, distance and elevation of human inhabitation from the sea. Human inhabitation should be encouraged more than 1 km from the shoreline in elevated places, behind dense mangroves and or other coastal vegetation. Some plant species, suitable to grow in between human inhabitation and the sea for coastal protection, are suggested.

© 2005 Elsevier Ltd. All rights reserved.

*Keywords:* tsunami; mangroves; human inhabitation; coastal vegetation; sand dunes

### 1. Introduction

The tsunami of December 26, 2004 has caused economic and ecological disaster in 13 Asian and African countries. The sea-waves were generated due to a massive undersea earthquake, measured at 9.3 on the Richter scale, the world's largest earthquake after the Alaskan event of 1964, off Sumatra in Indonesia, where two plates of the Earth's crust, the Indian plate and the Burma plate, grind against each other. The Indian plate usually moves northeast at about 6 cm every year. As the Indian plate pulled down on the Burma plate, the two plates slid about 15 m at once! It is estimated that about 1200 km of the Burma plate forced a massive displacement of water in the Indian Ocean (Kamble, 2005). This motion generated waves that spread in all directions, moving as fast as  $800 \text{ km h}^{-1}$ . The monstrous waves killed more than 0.2 million

people, made about 2 million people homeless and resulted in a loss of 6 billion US \$ in 13 countries. It seems, however, that the coastal communities living behind the mangrove forests largely escaped from the fury of the tsunami. In this regard, a case study on the mitigating effect of mangroves on human lives against tsunami is presented here.

### 2. Study area

The study was made in about 25-km coastline at Parangipettai, Tamil Nadu, India (Lat.  $11^{\circ}26'–30'N$ ; Long.  $79^{\circ}45'–48'E$ ; Fig. 1) consisting of (1) 18 fishermen's hamlets, (2) an estuarine complex made of two estuaries namely the Vellar and the Coleroon, and (3) two mangrove formations (one is naturally formed at Pichavaram with an area of  $11 \text{ km}^2$  and the other one has been artificially developed by the authors' research team since 1992 along the Vellar estuary). The location of hamlets range between 0.1 and 2.5 km away from the shore and are elevated from 0.5 to 4 m from mean sea

\* Corresponding author.

E-mail addresses: [cdl\\_aucasmb@sancharnet.in](mailto:cdl_aucasmb@sancharnet.in), [kathirsum@rediffmail.com](mailto:kathirsum@rediffmail.com) (K. Kathiresan).

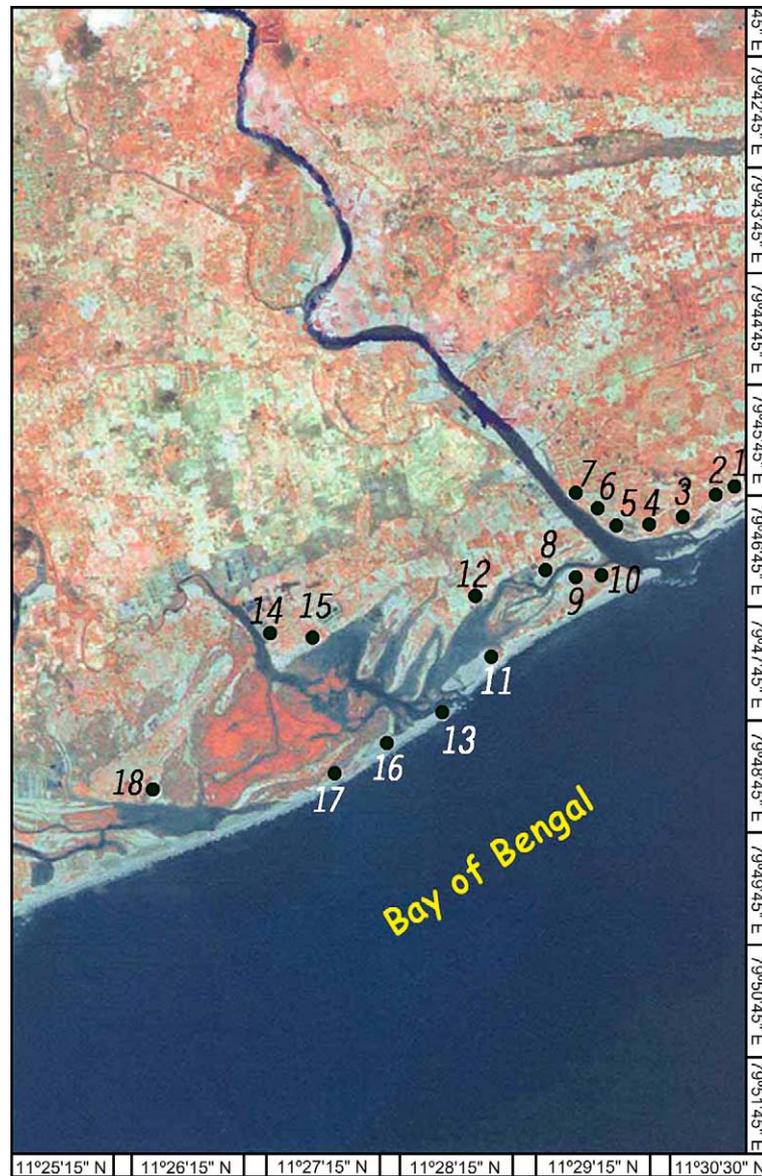


Fig. 1. Map showing the location of fishermens' hamlets existing along the Parangipettai coast, South India.

level. The height of the hamlets varies from 3 to 6 m. Data on vegetation characteristics (type of habitat, dominant plant species, and area of vegetation) in and around the hamlets and the effects of tsunami on loss of human lives and wealth of those hamlets were collected and are given in the Table 1.

### 3. Observations

Loss of human lives ranged from 0 to 110 for every 1000 persons of the study area (Table 1). Of 323 death cases, women were 53%, followed by children (27%) and men (20%). Most of the death toll was due to a thorny plant species *Prosopis spicifera* which caused heavy wounding and damage to the human body,

eventually leading to death. This species, which is frequently abundant in close proximity to the shore, should be removed and it can be allowed to grow densely in barren coastal wastelands, beyond 3 km stretch from the shoreline for its value as firewood.

A heavy loss of human lives was recorded in six hamlets (hamlet No. 17 – 110 deaths, No. 11 – 96, No. 16 – 80, No. 3 – 72, No. 9 – 55 and No. 13 – 55; Table 1). These hamlets are in close proximity to the shoreline at between 0.1 and 0.4 km without any significant vegetation cover, and they also occur in low-lying areas with smooth topography without the presence of sand dunes in between the hamlet and shore. This situation allowed giant sea-waves to rush into the human inhabitation and caused havoc with a total loss of US \$ 3.482 million in the study area.

Table 1  
Impact of tsunami on loss of human lives and wealth in 18 different fishermen hamlets existing along the Parangipettai coast, Tamil Nadu State, India

Fishermen hamlet no.	Human inhabitation		Coastal vegetation		No. of deaths <sup>a</sup>					Per-capita loss of wealth (huts, gears & crafts (US \$))
	Distance from sea (km)	Elevation from mean sea level (m)	Nature of habitat	Area (ha)	Male	Female	Child	Total	No./1000 individuals	
1	0.3	2.0	Sandy shore with mid shore dunes	0.5	2	4	1	7	16	511
2	0.3	3.0	Sandy shore with mid shore dunes	0.9	2	20	3	25	12	244
3	0.4	0.8	Low-lying sandy shore with embryonic dunes	0.1	23	57	13	93	72	333
4	0.4	2.0	Sandy with mid shore dunes	0.3	8	24	11	43	24	267
5	0.7	1.0	Sandy shore with hind dunes	0.4	9	17	2	28	19	244
6	0.7	3.3	Sandy shore with mid shore dunes	0.15	4	7	1	12	14	444
7	2.0	2.0	Muddy shore with dense mangroves	10	No death (0)				0	18
8	1.0	4.0	Elevated sandy shore with hind dunes	11.3	No death (0)				0	378
9	0.2	0.5	Low-lying sandy shore with embryonic dune	0.52	1	3	5	9	55	1000
10	0.4	4.0	Elevated steep sandy shore with mid shore dunes	15	1	1	0	2	4	289
11	0.1	0.8	Low-lying sandy shore	0.2	8	21	26	55	96	956
12	1.0	1.0	Mud-sandy shore with shrubby mangroves	2.0	2	2	1	5	11	222
13	0.1	0.5	Low-lying sandy shore	0.8	1	6	4	11	55	489
14	2.5	2	Muddy shore with dense mangroves	10	No death (0)				0	44
15	2.5	1	Muddy shore with dense mangroves	2	2	2	1	5	10	44
16	0.15	0.5	Low-lying sandy shore	0.28	0	1	3	4	80	267
17	0.15	0.5	Low-lying sandy shore	0.08	2	5	12	19	110	178
18	2.0	1.0	Muddy shore with dense mangroves	10	1	1	3	5	5	9

<sup>a</sup> Data collected from taluk office, Chidambaram and Dept. of Fisheries, Govt. of Tamil Nadu.

The per-capita loss of wealth in different hamlets ranged from US \$ 9 to US \$ 1000 exhibiting a trend, similar to human death with a significant positive correlation (0.46  $P < 0.05$ ; Fig. 2a) (Table 1). Even though the human death toll was high, the per-capita loss was, however, low in three hamlets (No. 3, 16 and 17). A reverse situation was observed in a hamlet (No. 8) where the human loss was nil, but the per-capita loss was high (US \$ 378). These variations can be attributed

to the differences in the values of huts, craft and gear damaged by the tsunami.

There was no loss of lives in three hamlets (No. 7, 8 and 14). The human death toll was low in four hamlets (No. 10 – 4 deaths, No. 18 – 5 deaths, No. 15 – 10 deaths and No. 12 – 11 deaths). All these hamlets (except No. 8 and 10) are situated behind the mangrove forests, located at a distance ranging from 1 to 2.5 km away from the shoreline and are also in elevated places

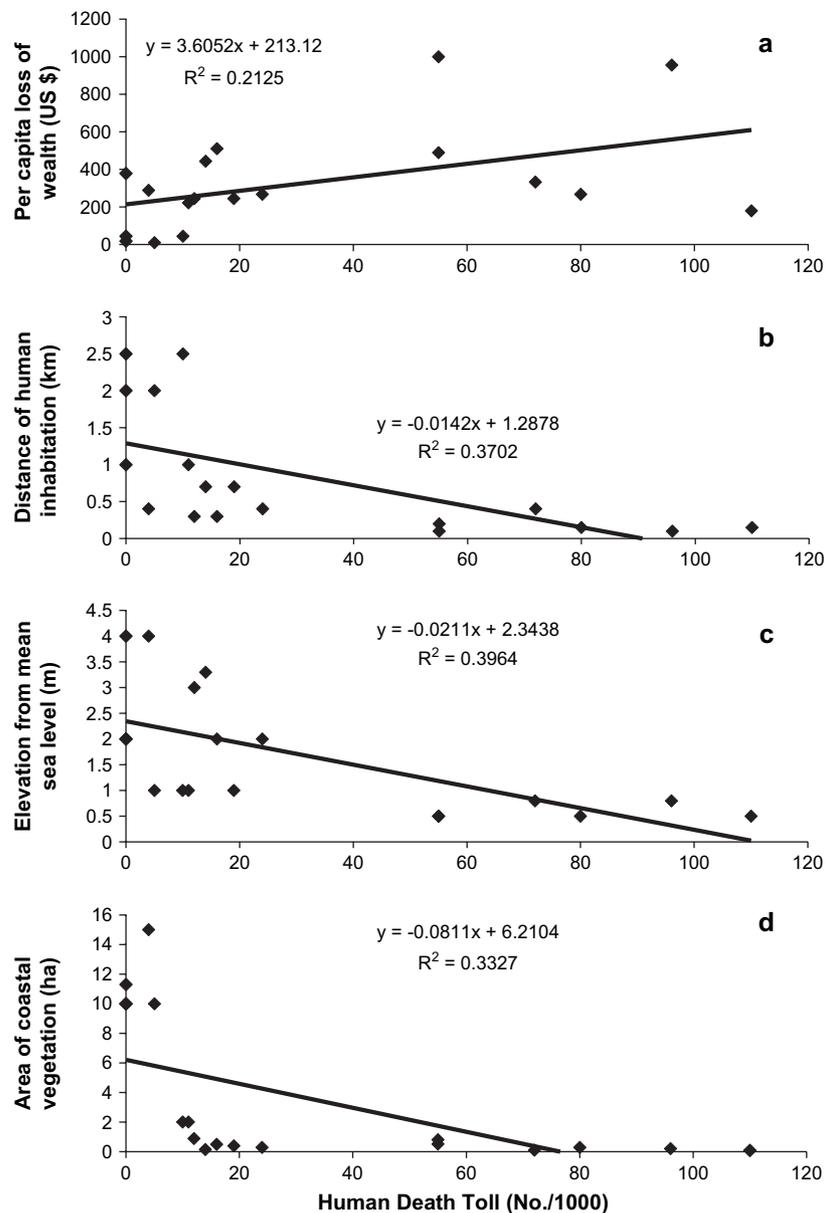


Fig. 2. Human death toll after tsunamis of 26th December 2004, in relation to (a) per-capita wealth loss, (b) distance (c) elevation of human inhabitation and (d) area of coastal mangrove vegetation.

with steep topography and with the presence of sand dunes in between the hamlets and shoreline. This situation reduced the speed of the tsunami waves minimising human death to the minimum. The hamlets No. 8 and 10 are located in close proximity of less than 1 km distance from the sea, but they did not lose many human lives, because they are situated in elevated shore areas, protected with a dense vegetation of casuarina, palmyra and coconut trees in the sand dunes.

There is a significant negative correlation between the human death toll and the distance of human inhabitation from sea ( $r = -0.61$ ,  $P < 0.01$ ; Fig. 2b), the elevation from mean sea level ( $r = -0.63$ ,  $P < 0.01$ ; Fig. 2c) and the area of mangrove and other coastal vegetation ( $r = -0.58$ ,  $P < 0.01$ ; Fig. 2d).

Mangroves have also been observed to mitigate the recent tsunami effects in other places. In Indonesia, the epicenter of the tsunami was closer to Simeuleu Island; however, the death toll on this island was significantly low because of presence of very good mangroves there. This country has planned to revive its coastal defenses, earmarking some 600,000 ha of mangroves across the country, which had lost 30% of its mangrove forest cover over the past several decades. The dense growth of mangroves in thousands of kilometers of Sundarbans saved West Bengal (India) and Bangladesh from the killer impact of tsunami. In Thailand, the island chain of Surin off the west coast escaped heavy destruction because the ring of coral reefs and mangroves that surround the island helped to break the lethal power of the tsunami. In the

south-east part of India, there were only few human casualties and there was less economic damage in places where dense mangrove forests are present; hence, the Governments of Tamil Nadu and Kerala in India plan to protect the coastline with forests, spending respectively about 45 and 9 million US \$. The mangroves of Bhitarkanika in Orissa, India (which serves as the breeding ground for the Olive Ridley turtles) have greatly reduced the impact of the 'super cyclone' with a wind speed of 310 km/h that had struck in October 1999, whereas in the areas without mangroves, over 10,000 people were killed, and millions became homeless. In and around the Yale National Park, Sri Lanka, where the waves were very strong and there were no physical barriers present such as sand dunes, the mangroves and scrub jungle, bore the full fury of the tsunami. Other tourist places in Asia have to learn the lessons from Myanmar and Maldives which suffered less from the tsunami; one of the reasons being that the tourism industry had so far not spread to the virgin mangroves and coral reefs surrounding the coastline.

#### 4. Discussion

The role of mangroves in reducing the sea-waves has been scientifically proved. For instance, a six-year-old mangrove forests of 1.5 km width will reduce 1 m high waves at the open sea and 0.05 m at the coast (Mazda et al., 1997). This is only a short period wave attenuation and this cannot be directly extrapolated to tsunami which has long wave period (Massel, 1999). This

reduction of waves depends on the water depth, the wave period, the wave height, the species of mangrove trees, the density of mangrove forest and diameter of mangrove roots and trunks (Mazda et al., 1997).

Harada et al. (2002) conducted a hydraulic experiment to study the tsunami reduction effect of the coastal permeable structures using different models – mangroves, coastal forest, wave dissipating block, rock breakwater and houses. This work revealed that mangroves are effective as concrete seawall structures for reduction of tsunami effect on house damage behind the forest. The forest, however, located behind the human inhabitation, could not prevent human death which ranged from 55 to 110 in five hamlets (No. 9, 11, 13, 16, 17; Table 1).

The wave attenuation is because of the fact that the mangrove forests function as sinks for the suspended sediments (Woodroffe, 1992; Wolanski et al., 1992; Wolanski, 1995; Furukawa et al., 1997). In numerous cases, annual sedimentation rate, ranging between 1 and 8 mm, has been reported in mangrove areas with expansion of land (Bird and Barson, 1977). The density of mangrove species and their complexity and flexibility of aerial root systems do determine the sedimentation process and the wave reduction process (Kathiresan, 2003). In general, *Rhizophora* species, which occur seaward, are more suitable species to mitigate the effect of tsunami, than *Avicennia* species that exist generally landward. This is due to the fact that the aerial stilt roots of the former are more tolerant than pneumatophores of the latter to long periods of submergence by flood water (Kathiresan and Bingham, 2001).

Table 2

Plant species and their suitable habitats suggested for plantation for possible coastal protection against tsunami. Based on the personal observations and Desai and Untawale (2002)

No.	Name of plant species	Site of plantation
1	<i>Rhizophora apiculata</i> , <i>Rhizophora mucronata</i> , <i>Sonneratia alba</i> , <i>Kandelia candel</i> , <i>Avicennia marina</i> , <i>Avicennia officinalis</i>	Mangroves: intertidal, estuarine and backwater areas; silty clay soil. <i>Rhizophora</i> spp., <i>Sonneratia alba</i> and <i>Kandelia candel</i> be planted along the waterfront and <i>Avicennia</i> behind them on landward side
2	<i>Ipomoea pes-caprae</i> , <i>Spinifex littoreus</i> , <i>Cyperus arenarius</i> , <i>Canavalia maritima</i> , <i>Launaea sarmentosa</i> , <i>Panicum turgidum</i> , <i>Eusine flagellifera</i> , <i>Eragrostis</i> spp. <i>Saccharum</i> spp. <i>Halopyrum mucronatum</i> , <i>Borreria articularis</i> , <i>Asparagus dumosus</i> , <i>Enicostema hyssopifolium</i>	On embryonic dune, nearest towards the sea, just above the high tide level with steeper face inland; soil is find to coarse sand and the organic material is extremely low with very little macronutrients Sand to loamy sand with calcium carbonate (Max. 92%) and organic matter (up to 20%)
3	<i>Spermacoce stricta</i> , <i>Leucas aspera</i> , <i>Vitex negundo</i> , <i>Clerodendrum inerme</i> , <i>Calotropis gigantea</i> , <i>Calotropis procera</i> , <i>Capparis decidua</i> , <i>Tamarix troupii</i> , <i>Sericostoma pauciflorum</i> , <i>Crotalaria burhia</i> , <i>Aerusa tomentosa</i> , <i>Rhynchosia minima</i> , <i>Leptadenis spartium</i> , <i>Zizyphus rotunefolia</i> , <i>Calligonum polygonooides</i>	On mid shore dune, which is more or less stable, suitable for shrubby plants Sand to loamy sand with calcium carbonate (Max. 35%) and organic matter (up to 3%)
4	<i>Clerodendrum inerme</i> , <i>Anacardium occidentale</i> , <i>Pandanus tectorius</i> , <i>Casuarina equisetifolia</i> , <i>Cocos nucifera</i> , <i>Eucalyptus</i> sp. <i>Acacia auriculiformis</i> , <i>Acacia tortolis</i> , <i>Acacia senegal</i> , <i>Acacia jacquemontii</i> , <i>Delonix elata</i> , <i>Aloe</i> sp., <i>Cassia auriculata</i> , <i>Capparis aphylla</i> , <i>Salvadora oleoides</i> , <i>Tecoma undulata</i> , <i>Tamarix articulata</i> , <i>Prosopis spicifera</i> , <i>Prosopis juliflora</i> , <i>Balanites roxburghii</i>	Hind shore dune, suitable for tree species with long root system

The tsunami destroyed coastal forests and damaged agriculture lands. The affected parts of the forests were mostly seedlings, less dense forests, narrow strips of forests and the aerial roots that are clogged with silt deposits. In India, tsunami-hit Nagapattinam in Tamil Nadu suffers the damage of 6073 ha of agricultural land along with paddy and groundnut crops, due to intrusion of seawater inland which is attributed to absence of mangroves and other coastal vegetations. The mangroves prevent the entry of seawater inland and thus protect the underground water systems, which form a source of drinking water supply to coastal populations. Very often, sharp changes have been noticed in salt concentrations of groundwater at the interface between salt flats and mangroves. This suggests that the mangrove systems can modify the salinity of the groundwater by lowering it drastically (Ridd and Sam, 1996).

It is suggested from the present observations that the fishermen's hamlets should not be permitted within 1 km from the shoreline and that they should be encouraged to live behind dense mangrove or other coastal vegetation in elevated places. A proper planning and policy is necessary for the location of hamlets along the sea-coasts, where a vast majority of global human population (about 60% of the world's population) is getting concentrated (Adeel and King, 2002). It is also suggested to grow plant species suited to the soil substrates (Table 2): mangroves in the muddy substrates in the sheltered shorelines; and, coconut, palm, casuarina and sand-binding vegetation in the sandy substrates in close proximity to the shoreline. The sandy shore vegetation would hold good as wind-breakers but it may not provide adequate protection against huge tidal waves. After tsunami, most of the coastal vegetation has been affected in the study area with shedding of leaves or browning of canopies, but mangroves tolerated the tsunamic waves without showing any apparent damage. Thus mangroves are evidently the most suitable species to mitigate the effects of mighty tidal waves.

With continuing degradation and destruction of mangroves, there is an urgent need to conserve and restore the mangroves as defense against tidal waves, wherever muddy substrates are available and tidal flushing are regular. Human inhabitations should be permitted only behind mangrove forests but not in front of the forest. The habitat between human inhabitations

and sea should be planted with suitable plant species to protect the coastal lives against natural calamities.

### Acknowledgements

The authors are thankful to the authorities of Annamalai University for providing facilities.

### References

- Adeel, Z., King, C., 2002. Conserving Our Coastal Environment – A Summary of UNU's Research on Sustainable Management of the Coastal Hydrosphere in the Asia Pacific Region. United Nations University, Tokyo, Japan, 30 pp.
- Bird, E.C.F., Barson, M.M., 1977. Measurement of physiographic changes on mangrove-fringed estuaries coastlines. *Marine Research of Indonesia* 18, 73–80.
- Desai, K.N., Untawale, A.G., 2002. Sand Dune Vegetation of Goa: Conservation and Management. Botanical Society of Goa, India, 101 pp.
- Furukawa, K., Wolanski, E., Mueller, H., 1997. Currents and sediment transport in mangrove forests. *Estuarine, Coastal and Shelf Science* 44, 301–310.
- Harada, K., Imamura, F., Hiraishi, T., 2002. Experimental study on the effect in reducing tsunami by the coastal permeable structures. Final Proceedings of the International Offshore and Polar Engineering Conference USA, pp. 652–658.
- Kamble, V.B., 2005. Tsunami lesson. *Dreams* 2047 (6), 25 and 39.
- Kathiresan, K., 2003. How do mangrove forests induce sedimentation? *Revista de Biologia Tropical* 51, 355–360.
- Kathiresan, K., Bingham, B.L., 2001. Biology of mangroves and mangrove ecosystems. *Advances in Marine Biology* 40, 81–251.
- Massel, S.R., 1999. Tides and Waves in Mangrove Forests: In Fluid Mechanics for Marine Ecologists. Springer-Verlag, pp. 418–425.
- Mazda, Y., Magi, M., Kogo, M., Hong, P.N., 1997. Mangrove on coastal protection from waves in the Tong King Delta, Vietnam. *Mangroves and Salt Marshes* 1, 127–135.
- Ridd, P.V., Sam, R., 1996. Profiling groundwater salt concentrations in mangrove swamps and tropical salt flats. *Estuarine, Coastal and Shelf Science* 43, 627–635.
- Wolanski, E., 1995. Transport of sediment in mangrove swamps. *Hydrobiologia* 295, 31–42.
- Wolanski, E., Mazda, Y., Ridd, P., 1992. Mangrove hydrodynamics. In: Robertson, A.I., Alongi, D.M. (Eds.), *Coastal and Estuarine Studies: Tropical Mangrove Ecosystem*. American Geophysical Union, Washington DC, USA, pp. 43–62.
- Woodroffe, C., 1992. Mangrove sediments and geomorphology. In: Robertson, A.I., Alongi, D.M. (Eds.), *Coastal and Estuarine Studies: Tropical Mangrove Ecosystem*. American Geophysical Union, Washington DC, USA, pp. 7–41.