The Asian Tsunami: A Protective Role for Coastal Vegetation

Finn Danielsen,[1]* Mikael K. Sørensen,[2] Mette F. Olwig,[2] Vaithilingam Selvam,[3] Faizal Parish,[4] Neil D. Burgess,[5,6] Tetsuya Hiraishi,[7] Vagarappa M. Karunagaran,[3] Michael S. Rasmussen,[2] Lars B. Hansen,[2] Alfredo Quarto,[8] Nyoman Suryadiputra[9]

The scale of the 26 December 2004 Indian Ocean tsunami was almost unprecedented. In areas with the maximum tsunami intensity, little could have prevented catastrophic coastal destruction. Further away, however, areas with coastal tree vegetation were markedly less damaged than areas without. Mangrove forests are the most important coastal tree vegetation in the area and are one of the world's most threatened tropical ecosystems (*1*).

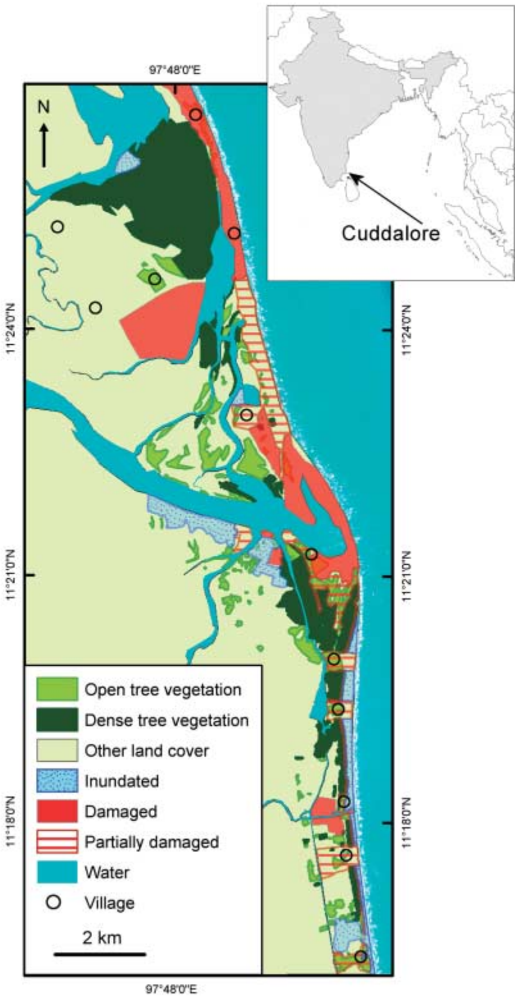

Fig. 1. Pre-tsunami tree vegetation cover and post-tsunami damages in Cuddalore District, Tamil Nadu, India.

Measurement of wave forces and modelling of fluid dynamics suggest that tree vegetation may shield coastlines from tsunami damage by reducing wave amplitude and energy (*2*). Analytical models show that 30 trees per 100 m^2 in a 100-m wide belt may reduce the maximum tsunami flow pressure by more than 90% (*3*). Empirical and field-based evidence is limited, however.

Cuddalore District in Tamil Nadu, India, provides a unique experimental setting to test the benefits of coastal tree vegetation in reducing coastal destruction by tsunamis (*4*). Cuddalore has a relatively straight shoreline, a fairly uniform beach profile, and a homogenous continental slope. Moreover, the shoreline comprises vegetated as well as non-vegetated areas and was documented by cloudfree pre- and post-tsunami satellite images.

The force of the tsunami impact in Cuddalore is illustrated by the central part of our study area (Fig. 1). At the river mouth, the tsunami completely destroyed parts of a village (fig. S1) and removed a sand spit that formerly blocked the river. However, areas with mangroves (Fig. 1, dark green polygon) and tree shelterbelts were significantly less damaged than other areas (supporting online text). Damage to villages also varied markedly. In the north, stands of mangroves had five associated villages, two on the coast and three behind the mangrove. The villages on the coast were completely destroyed, whereas those behind the mangrove suffered no destruction even though the waves damaged areas unshielded by vegetation north and south of these villages. In the south, the shore is lined with *Casuarina* plantations (Fig. 1). Five villages are located within these plantations and all experienced only partial damage. The plantations were undamaged except for rows of 5 to 10 trees nearest to the shore, which were uprooted (fig. S2).

Our results suggest that mangroves and *Casuarina* plantations attenuated tsunami-induced waves and protected shorelines against damage. Human activities reduced the area of mangroves by 26% in the five countries most affected by the tsunami, from 5.7 to 4.2 million ha, between 1980 and 2000 (*5*). Conserving or replanting coastal mangroves and greenbelts should buffer communities from future tsunami events. Mangroves also enhance fisheries (*6*) and forestry production. These benefits are not found in artificial coastal protection structures. Coastal tree vegetation can be established for investments of U.S.$150 to U.S.$2000 per ha (*7*). Mangroves, however, are suitable for planting only on coastal mudflats and lagoons, which cover ~25% of the continental coastline of the Bay of Bengal (*8*). Elsewhere, the conservation of dune ecosystems or green belts of other tree species, such as *Casuarina*, could fulfil the same protective role.

References and Notes

1. I. Valiela, J. L. Bowen, J. K. York, *Bioscience* **51**, 807 (2001).
2. S. R. Massel, K. Furukawa, R. M. Brinkman, *Fluid Dyn. Res.* **24**, 219 (1999).
3. T. Hiraishi, K. Harada, *Greenbelt Tsunami Prevention in South-Pacific Region*, available at http://eqtap.edm.bosai.go.jp/useful_outputs/report/hiraishi/data/papers/greenbelt.pdf (2003).
4. Materials and methods are available as supporting material on *Science* Online.
5. Food and Agriculture Organization (FAO), *State of the World's Forests* (FAO, Rome, 2003).
6. P. J. Mumby *et al.*, *Nature* **427**, 533 (2004).
7. F. Parish, *Assessment of Cost of Mangrove Replanting in Tsunami-Impacted Regions* (Global Environment Centre, Selangor, Malaysia, 2005).
8. V. J. Chapman, Ed., *Wet Coastal Ecosystems*, vol. 1 of *Ecosystems of the World* (Elsevier, Amsterdam, 1977), p. 3.
9. We thank T. Y. Chee, D. Lee, T. Nuyim, I. Renshaw, E. Topp-Jørgensen, and E. Wikramanayake for assistance. Supported by the Solstice Foundation.

Supporting Online Material
www.sciencemag.org/cgi/content/full/310/5748/643/DC1
Materials and Methods
SOM Text
Figs. S1 and S2
Table S1
References and Notes

10 January 2005; accepted 20 September 2005
10.1126/science.1118387

[1]NORDECO, Skindergade 23, Copenhagen DK-1159, Denmark. [2]Geographic Resource Analysis and Science, University of Copenhagen, Øster Voldgade 10, Copenhagen, Denmark. [3]M. S. Swaminathan Research Foundation, 3rd Cross Street, Taramani, Chennai 600 113, India. [4]Global Environment Centre, 2nd Floor, Wisma Hing, 78, Jalan SS2/72, 47300 Petaling Jaya, Selangor, Malaysia. [5]Conservation Biology Group, Department of Zoology, University of Cambridge, Cambridge, UK. [6]World Wildlife Fund USA, 1250 24th Street NW, Washington, DC 20037–1193, USA. [7]Port and Airport Research Institute, Nagase 3-1-1, Yokosuka, Japan. [8]Mangrove Action Project, Post Office Box 1854, Port Angeles, WA 98362–0279, USA. [9]Wetlands International Indonesia, Post Office Box 254/BOO, Bogor 16002, Indonesia.

*To whom correspondence should be addressed. E-mail: fd@nordeco.dk