Viewpoint

Tsunamis

Myth of green belts

In the wake of the 2004 Indian Ocean tsunami has come some dangerous myth making about green belts and buffer zones as protective barriers

One of the most pervasive myths following the 26 December 2004 Indian Ocean tsunami is that healthy ecosystems, such as coastal forests and coral reefs, reduced the damage to coastal communities.

Partly on the basis of this myth, governments throughout the region are enthusiastically embracing the planting of mangrove forests as a natural defence against future tsunamis. Vast sums of money are at stake; for example, IUCN-The World Conservation Union is promoting "Mangroves for the Future", a Euro38-mn (US$48.5-mn) programme that aims to build natural barriers of mangroves in 12 countries in Asia and Africa. If saving lives in future tsunamis is the real purpose of these schemes, then every euro may be wasted.

In this article, I briefly review the evidence for the effectiveness of green belts, and conclude that there is, in fact, no good empirical, theoretical or analytical support for the hypothesis that coastal forests provide meaningful protection from tsunamis.

The concept of buffer zones is equally flawed: to be effective, they would need to be many kilometres wide, much wider than those currently proposed, and almost impossible to institute without prohibitively high social and economic costs.

Governments in the region should enact legislation and provide financial assistance to allow people to return to their land and resume their livelihoods. Future loss of life can best be prevented by an effective early-warning system, community education and disaster planning. Future loss of property is unavoidable and preferable to the large social and economic costs of current reconstruction policies.

The idea that healthy coastal ecosystems can provide meaningful protection against tsunamis is a beautiful idea that deserves to be true, but beauty isn't always truth. The horror of the tsunami and a long history of disappointment in the conservation movement as coastal forest degradation accelerated over the last few decades combined to create a strong psychological desire for good news. Even Bill Clinton was seduced by the myth. The suspension of critical faculties is perhaps acceptable among conservationists, whose role as environment advocates is perhaps appropriate, but a lack of rigour among professional scientists is unacceptable.

The crux of the issue for me as an ecologist is that bad science is being used to justify worse policy, with the potential for major social injustice. Hopefully, it is not too late to reverse this injustice before my profession becomes complicit in one of the great land grabs in post-colonial history. Furthermore, the prominence of the mangrove myth must divert resources from potentially more effective measures, and, consequently, those who promote the myth may contribute to unnecessary loss of life in a future tsunami.

Media attention

Released amid large fanfare within weeks of the Indian Ocean tsunami, the United Nations Environment Programme (UNEP) Rapid Assessment Report set the agenda for a plethora of similar reports and international media articles, most of which simply repeated the contents and anecdotes of the UNEP and earlier reports. The uncritical repetition of these studies has only helped to perpetuate the myth by obscuring its provenance.

The UNEP report, *After the Tsunami*, is largely a series of eyewitness reports, with some quantitative estimates of damage that are often inaccurate, at least in Aceh, Indonesia, a region I first visited in 1984 and whose reefs I have been studying since 2000.

For example, the report quotes the central planning agency of Indonesia for estimates of 30 per cent damage to 97,250 ha of reefs in Aceh. Subsequent surveys of the region by myself and my colleagues revealed that the damage to reefs, while occasionally spectacular, was trivial, particularly when compared to pre-existing damage from destructive fishing. More pertinent to the argument here are the conclusions of the report on the mitigating effect of mangroves, based on selective observations from an earlier Wetlands International report. For example, the UNEP report states, "Anecdotal evidence and satellite photography before and after the tsunami event seem to corroborate claims that coral reefs, mangrove forests and other coastal vegetation, provided protection from the impacts of the tsunami". Contrast this with the following statements from the original 2005 Wetlands International report: "...the evidence so far [i.e. after the tsunami] seen from satellite images is that in high-energy situations such as Aceh province, Sumatra, complete loss of mangroves occurred, indicating that in extreme events, very little mitigation may be possible..." and "..in the coastal area of Banda Aceh ... mangroves were carried ...by the waves...two to three kilometres inland; this included mangroves that were in relatively good condition in the area of Ulee Lhee".

The fanfare with which this report was greeted is in stark contrast to the reception given to later UNEP and IUCN-commissioned reports, which were much more ambivalent about the mitigation myth, or, indeed, presented empirical data that contradicted the conclusions of the initial report.

Within four to six months of the event, a small number of articles emerged in the scientific literature that seemed to confirm the mangrove myth, and these, plus the UNEP report, continue to be cited in support of it. Papers and reports that criticize or question these studies are routinely ignored. Below, I outline serious problems with these studies.

Property losses

The first study from Tamil Nadu in India reported that human deaths and property losses were lower in coastal hamlets fronted by coastal forests (Kathiresan, K. and N. Rajendran. 2005. "Coastal Mangrove Forests Mitigated Tsunami". *Estuarine, Coastal and Shelf Science* 65:601-606). However, when my colleagues and I re-analyzed the data, we

discovered that the relationship between coastal forest and tsunami damage was false. In fact, the most important characteristics of villages where damage was lower were height above sea level and the distance of the village from the coast.

Once these two factors were taken into account, the effect of the forest fronting the village was negligible. A second study from the same area, led by scientists from Denmark, used satellite data to conclude that coastal vegetation had reduced damage from the tsunami (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. Suryadiputra. 2005. "The Asian Tsunami: A Protective Role for Coastal Vegetation". *Science* 310:643). However, this study was flawed because these authors did not use statistically independent observations in their analysis. For example, the authors pointed out that three northern villages incurred minimal damage because they were situated behind dense vegetation.

However, no area elsewhere incurred damage this far inland, even when vegetation was absent. The final study from Sri Lanka also concluded that mangroves offered protection; however, once again, despite claiming to use a semi-quantitative approach, the study did not compare the observed pattern of damage against patterns expected by chance: the basis of a robust statistical approach (Dahdouh-Guebas, F., L. P. Jayatissa, D. Di Nitto, J. O. Bosire, D. Lo Seen and N. Koedam. 2005. "How Effective Were Mangroves as a Defence against the Recent Tsunami?" *Current Biology* 15:R443-R447.) In fact, when my colleagues and I analyzed the data, we found no association between tsunami damage and either forest degradation or pre-tsunami forest condition. In other words, the pattern of damage was no different from that expected by chance, and, therefore, cannot be linked to pre-tsunami forest condition. My colleagues and I have written to the editors on each occasion, and, at every journal, our comments have been rejected. Journal editors and peer reviewers must, at some point, take responsibility for what is published. It will be a permanent stain on our profession if this issue is not treated with the rigour it deserves.

Mitigation hypothesis

In a trip to Aceh in March 2005, my colleagues and I were able to collect our own data to test the mitigation hypothesis. We used a combination of variables collected from the reefs and coast of Aceh, Indonesia, including per cent cover of coastal vegetation, to test whether these variables influenced inundation distance. The majority of the variation in inundation distance was explained by the

slope of the coastal terrain. Inundation was independent of reef quality or cover of coastal vegetation prior to the tsunami.

In other words, the tsunami stopped only when it reached the relevant inland contour: where the wave was 10 m high at the coast, it reached the 10 m contour, whether this was 200 m from the coast, or 2 km.

Our results are strongly supported by a later UNEP/IUCN report (Chatenoux, B. and P. Peduzzi. 2006. *Analysis of the Role of Bathymetry and Other Environmental Parameters in the Impacts from the 2004 Indian Ocean Tsunami*. UNEP/DEWA/GRID-Europe, Switzerland: http://www.grid.unep.ch/product/publication/download/environment_impacts_tsunami.pdf), which found that inundation distance was best explained by distance from the earthquake epicentre, that is, wave height at the coast, and, furthermore, that coastal vegetation had no significant effect on inundation distance.

In addition to these empirical studies, one analytical model, combined with experimental simulations, has suggested that dense forests may absorb up to 90 per cent of the energy of a tsunami wave (Hiraishi, T., and K. Harada. 2003. "Greenbelt Tsunami Prevention in the South-Pacific Region". *Report of the Port and Airport Research Institute* 42).

Without strong mathematical training, it is difficult to dissect this analytical approach. However, a model is only as good as the next empirical test, and none of the data from the Indian Ocean tsunami come remotely close to supporting this optimistic prediction.

While mangroves are very effective at dissipating the energy of storm waves, tsunamis are a very different beast, and, a failure to appreciate this is one of many reasons the myth has gained such status. In wind waves, most energy is contained near the ocean surface, and wave-induced water motion decays rapidly with depth.

In contrast, in a tsunami, water is in motion throughout the entire water column. The other major difference is that tsunamis have a wavelength of kilometres, compared to that of a few metres for wind waves. The wavelength of the tsunami when it hit the Acehnese coast has been estimated at 12 km. In places, the ocean kept rolling in for nearly an hour.

Incredibly, theoretical attempts to predict inundation distance from tsunamis are almost non-existent. The only attempt I know of that incorporates features of the terrestrial environment, such as the type of vegetation, is an equation developed for the insurance industry to predict potential damage to coastal settlements from asteroid-impact-generated tsunamis (Bretschneider, C. L., and P. G. Wybro. 1977. "Tsunami Inundation Prediction". Pgs 1006-1024 in C. L. Bretschneider, (Ed.) *Proceedings of the 15th Coastal Engineering Conference*. American Society of Civil Engineers, New York). This equation estimates the inundation distance as a function of tsunami wave height at the coast and the roughness coefficient of local terrestrial terrain. However, the predictions of the equation have yet to be tested empirically. This work has further been criticized because there is no explanation as to how the equation was derived and nor it does not take account of wave period.

In my correspondence with the authors of these studies, many other arguments have been presented to justify the mangrove myth. Some authors appeal to common sense or the laws of thermodynamics. This appeal is logically flawed and hardly scientific. Mangroves will absorb some of the energy in a thermo-nuclear explosion, but will they save lives because of this? This comparison may sound extreme; however, it has been estimated that the energy released by the earthquake was equivalent to 23,000 Hiroshima bombs, nearly four for every kilometre of coastline hit by the tsunami. Others have appealed to the precautionary principle. This is, in effect, an admission of error.

Strange distortion

One scientist has argued that because there may be a risk to life in future tsunamis if mangroves are not rehabilitated, the normal standards of statistical proof should not apply to his research. This is a very strange distortion of the precautionary principle. Which advice is more likely to put people at risk?

Suggesting people are safe behind mangrove barriers, or suggesting they run for the hills?

Others have taken a very Machiavellian view, and while they concede that their analyses are less than perfect, they believe this unimportant as long as mangroves are rehabilitated: a classic case of the end justifying the means. This constitutes a failure to appreciate the potential of their science to affect the lives of the people involved, for example, those evicted or prevented from returning to the buffer zones.

The upshot of this brief review of the scientific literature is that there is no credible theoretical, analytical or empirical evidence to support the idea that coastal vegetation can mitigate the effect of tsunamis on coastal communities. Indeed, the only rigorous statistical analyses of empirical data to date refute the mangrove myth.

In Aceh, the initial reconstruction plan released by Indonesia's central planning agency recommended establishing a 2-km buffer zone along the length of the west coast of Aceh, a policy that would have involved relocating over 500,000 people, nearly 50 per cent of the surviving population. While this initial plan has sensibly been abandoned, the current Master Plan still includes green belts and buffer zones. As of March 2006, no green belts or buffer zones have been established; however, the reconstruction is only beginning, and there is no guarantee they will not appear at a later date.

Will these buffer zones be effective? A simple examination of how far inland the Indian Ocean tsunami penetrated in the various regions suggests this is highly unlikely. The inundation distance in each location was largely determined by the size of the tsunami at the coast and the topography of the coastal zone. In Aceh, the region closest to the epicentre of the pre-tsunami earthquake, the wave height was between 5-12 m. Inundation distances were regularly over 2 km in low-lying areas on the west coast, and up to 6 km near the regional capital, Banda Aceh, generally reaching between the 10 m and 20 m contour.

Inundation distances

Clearly, even a 2-km buffer zone would not have prevented major damage. In Sri Lanka, the wave height was estimated at between 2-8 m, with inundation distances of up to 2 km on the west coast, which, being in the lee of the main tsunami waves, were smaller than on the east coast, for which I can find no data. The proposed buffer zones of between 100-200 m are clearly inadequate. In India, where the maximum wave height was less than 5 m, the tsunami, nonetheless, penetrated up to

2.5 km. Consequently, a buffer zone here of 500 m will not prevent major damage in a future tsunami of similar, or larger, size.

Historically, inundation distances have been much larger: for example, the tsunami following the eruption of Krakatoa penetrated 8 km inland through primary rainforest. A tsunami dated to within 1,000 years before the present on the west coast of Australia reached 30 km inland. Clearly, if saving either life or property is the goal, these buffer zones are totally inadequate.

However, I do not mean to suggest they should be made larger. The concept is impractical, unjust and unworkable. The social, economic and emotional costs of relocating large numbers of people from their traditional homes and livelihoods must also be considered, and, while often difficult to quantify, will almost certainly outweigh the economic cost of rebuilding following rare catastrophic events. Furthermore, the enforcement of these buffer zones without the consent of the displaced people violates numerous international conventions. Another myth of prominence is that the tsunami travelled very fast over land, when, in fact, in Aceh, many people outran the wave, despite getting almost no warning. An effective early-warning system and adequate planning would have saved tens of thousands, if not hundreds of thousands, of lives.

I am concerned that promoting green belts and buffer zones as protective barriers, particularly *in preference* to tsunami early-warning systems, may lead to substantial loss of life in a future event. The available evidence suggests these barriers will be ineffective and, therefore, may encourage a false sense of security. Furthermore, these schemes must direct time and money away from more effective but technologically, logistically and politically challenging measures such as well co-ordinated early-warning systems, community education and emergency planning. Incredibly, over 18 months after the Indian Ocean tsunami, the Indonesian government has yet to deploy an early-warning system south of Sumatra, which the subsequent tsunami of 17 July 2006 has now made clear was a tragic oversight. Furthermore, the tremors from the tsunami were felt in the area affected, and the tsunami was preceded by a wave draw-down, a sure sign that the tsunami was imminent, yet people did not know to run. Government officials were given timely warnings of the likelihood of the tsunami from the Pacific Early Warning Centre in Hawaii, yet they failed to act. Clearly, education efforts in Indonesia have been inadequate.

Coastal vegetation, such as mangroves, can provide coastal communities with many valuable goods and services, and the protection of these ecosystems is, in general, an endeavour I wholeheartedly support; however, if the aim is to protect coastal communities from future tsunamis, the money would much better be spent elsewhere. Furthermore, the proposed buffer zones will not work, and it is time to let those displaced people return to their homes, if they wish, and support them to do so.

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