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Do bio-shields affect tsunami inundation?

R. S. Bhalla

Foundation for Ecological Research, Advocacy and Learning, No. 27, 2nd Cross, Appavou Nagar, Vazhakulam, Puducherry 605 012, India

Conversion of coastal sand dunes to plantations has intensified dramatically after the tsunami of December 2004, driven largely by the belief that bio-shields mitigated tsunami inundation. This assumption was tested using field-based mapping and remote sensing. A regression between the Normalized Difference Vegetation Index and inundation distance was non-significant, questioning the premise for large-scale bio-shield plantations, mostly *Casuarina equisetifolia*, an exotic timber with unquantified ecological impacts. These plantations may obliterate the natural sand dune ecosystems along the Coromandel coast, which are an important natural defence and provide a range of ecological goods and services.

e-mail: bhalla@feralindia.org

Keywords: Bio-shields, coastal sand dunes, remote sensing, tsunami.

VEGETATIVE shelter belts or bio-shields received a great degree of attention in India after the tsunami of 26 December 2004, where they were credited with mitigating tsunami inundation. Particular attention was given to mangroves[1] and more recently, *Casuarina*[2–6]. The total area proposed[7–9] to be covered by the Tamil Nadu Forest Department alone was 4000 ha of *Casuarina* and 1400 ha of mangroves during the period 2005–07. *Casuarina* was the preferred species due to its easy availability, low cost and high survival rate. Initial publications supported these plantations, with Dahdouh-Guebas *et al.*[10] and Kathiresan and Rajendran[11] suggesting that vegetative shelter belts, particularly mangroves were effective defences against the tsunami.

However, Kerr *et al.*[12] re-analysed their data and showed that vegetative area explained less than 1% of the variation in human mortality. Chatenoux and Peduzzi[13] showed that among geomorphic configurations, a long and shallow proximal slope caused greater wave run-up. This has been demonstrated by others as well[13–17]. Thus shallow coasts such as Nagapattinam are more vulnerable than deep shelves such as those around Puducherry. Among biological configurations measured by Chatenoux and Peduzzi[13], areas behind sea grass seemed less heavily affected by the tsunami. They also found that mangroves appeared to have no effect on inundation.

Much of the confusion about role of vegetation as tsunami defence lies in the relationship between bathymetry, near-shore elevation, distance from coast and presence of biological 'protection' such as mangroves[13]. Evidence from the Nicobar Islands[18] questions the premise that vegetation can absorb the enormous energy dissipated by a tsunami, albeit the fact that some obstacle would be better than none.

The inundation caused by tsunami run-up was measured using a baseline corresponding to a coastline digitized from high resolution QuickBird satellite image comprising red and blue bands at 2.44 m, hybridized with a panchromatic band at 0.6 m. Images of 31 December 2004 were downloaded from the Pacific Disaster Centre site (http://www.pdc.org). River mouths and backwaters were digitized such that the coastline looped into them to ensure that the analysis took into account inundation observed along backwaters.

Inundation points were identified with local residents and their coordinates recorded using a Garmin-76 GPS

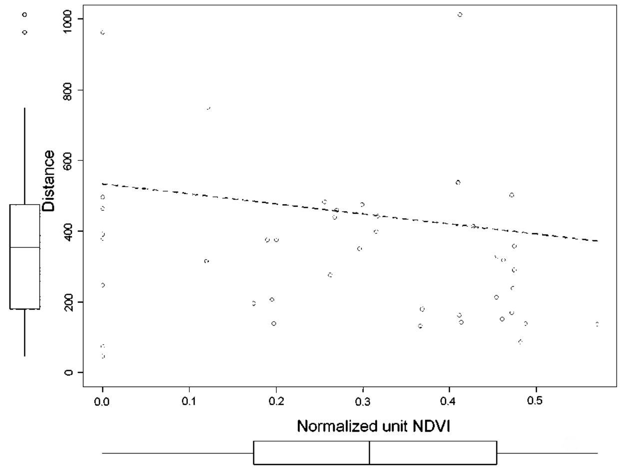

Figure 1. Relationship between inundation and vegetation.

unit. Perpendicular distances were calculated from these points to the coastline. The Normalized Difference Vegetation Index (NDVI) along the pixels falling beneath this perpendicular was summed and divided by its length to arrive at a unit NDVI. The NDVI is based on the equation NDVI = (Near infrared – red)/(near infrared + red), which estimates the amount of chlorophyll present in a given pixel on a scale from 0 to 1, and is a good indicator of green biomass.

Statistical analysis[19] was carried out using *R*, and remote sensing and GIS using GRASS[20]. Perpendicular distance was regressed vs unit NDVI for 46 of 69 such points falling along the Coromandel coast between Kalapet, Puducherry and Vedaraniyam in Nagapattinam. Twenty-three points were rejected for lack of satellite data. The unit NDVI values were normalized prior to running the regression using a $Y' = Y^{0.25}$ transform. Results showed a non-significant relationship between tsunami inundation distance and unit NDVI values; adjusted R-squared = –0.009, $P = 0.45$. The power of the test, i.e. the probability of rejecting a false null hypothesis[21,22] was done to test the non-significance of the relationship. This yielded 0.99 with $n = 44$, $f = 0.56$ and significance level = 0.05 (Figure 1). Thus unit NDVI or vegetation did not have a significant impact on the inundation distance. The study did not differentiate between types of vegetation and cannot conclude whether certain vegetation types were better defences than others.

Sand dunes appear to provide the most immediate form of coastal protection. However, a few agencies involved in restoration along the Coromandel coast have considered beach and dune conservation. On the contrary, extensive dune plantations have been undertaken and the construction of permanent settlements, sea walls and groynes is leading to the disappearance of beaches, Puducherry being a case in point. Definition of the vulnerability line for coasts also needs to take both the bathymetry and the ephemeral nature of the dunes into account. Non-availability of data on near-shore bathymetry remains a major lacuna in this respect.

Figure 2. The Bommayapalayam Dune. ***a***, Satellite shot of inundation along vegetation (yellow) and the dune (blue). ***b***, Looking North, near the blue transect shown in (***a***). Imagery not to scale.

Evidence of sand dunes as a defence against tsunami inundation is persuasive (Figure 2 *a* and *b*). Dunes act as windbreaks, protect against storm surges and tsunami inundation[23,24]. Many coastal settlements built behind or on coastal dune formations were protected from the tsunami. Unfortunately, dunes are not considered a worthy ecosystem, sometimes condemned even by ecological restoration projects[24,25]. However, they are integral to the livelihood of artisanal fishing communities. Coastal dunes are also responsible for groundwater recharge[26]. They are a habitat for ghost crabs (*Ocypode* sp.), and a nesting habitat for sea turtles, chiefly Olive Ridleys (*Lepidochelys olivacea*). The tourism industry has a stake in the protection of sandy beaches. Clearly there is a need to re-look at interventions that modify or are likely to alter the existence of this habitat.

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Dendroclimatic potential of millennium-long ring-width chronology of *Pinus gerardiana* from Himachal Pradesh, India

Jayendra Singh[1,2,*] and Ram R. Yadav[1]

[1]Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226 007, India
[2]Present address: Institute for Botany and Landscape Ecology, University Greifswald, Greifswald, Germany

We have developed a 1087-yr (AD 919–2005; so far the longest) chronology of *Pinus gerardiana* (chilgoza pine) from Kinnaur, Himachal Pradesh using 15,083 annual ring-width measurements from 35 increment cores. The tree growth–climate relationship using response-function analyses indicated that precipitation, except for the months of January, February and October, has a direct relationship with growth. However, this relationship was significant for previous year's October and current year's February, March, May and June. Mean monthly temperature showed largely negative relationship with growth, except for June and August–October. The longevity and climate sensitivity of this species shows its potential in developing millennium-long climatic reconstructions needed for understanding the long-term climate variability in the Himalayan region.

Keywords: Climate variability, dendroclimatic potential, *Pinus gerardiana*, ring-width chronology.

PROXY climate records from high-latitude regions[1,2] and climate models[3] have shown that the level of warming during the past few decades has been unprecedented in the context of the past two millennia. With global warming there is a growing notion that the frequency and/or severity in weather extremes in recent decades is increasing. The unusual heat wave in April 1999 in northwest and central India[4] in the context of the observed data of the 20th century, might provide proof of the impact of global warming in the country. Any potential increase in intensity or frequency of such extremes would have serious implications as agriculture, contributing about 50% of the national economy, is highly sensitive to weather and climate. However, one should be cautious about attributing the effect to any such individual event or making assumptions about the likelihood of future events from observed data, unless such events are placed in longer palaeoperspective.

Tree-ring records from the Himalayan region with annual and seasonal resolution have proven potential to extend instrumental climate records back to several centuries[5,6]. However, tree species covering the Little Ice Age and

*For correspondence. (e-mail: jayendra1673@yahoo.co.uk)