Mangrove bio-shield in tsunami protection

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Thanks to Dr. Krishnamurthy
University of Madras,
Kyoto University,
Middle East Technical University,
World Bank Institute and
UN-ISDR
Only tall tree forest situated between land and sea in tropical & subtropical coast. Among the world’s most productive vegetation communities include:

- Tidal forest
- Oceanic rain forest
- Coastal wood land
- Root of the sea
Marvel of nature
Ecological wonder
Scenic splendor

Arching roots
breathing roots
salt-vomiting leaves
mud-dancing fishes
breath-taking beauty

I LOVE MANGROVES!
Mangroves protect the coast against waves, currents & storms and from coastal erosion.

Mangroves are live sea walls, more effective than concrete wall structures.
Super cyclone in Orissa on east coast of India
October 1999
310 km/h speed
Killed 10,000 people
made 7.5 million homeless

Only one area not affected:
Bhitharkanika with dense mangroves
not even a single tree uprooted in the area, but many old avenue trees uprooted

Cyclonic storms hit Indian coast @ 2.1 per year
• 1970 typhoon in Bangladesh
  0.3 million human died
  due to 1000s ha replaced with paddy fields

• 1983 cyclone in the Kachchh, Gujarat, India
  heavy human loss

• 1991 flood disaster in Bangladesh
  due to 300 sq km mangrove area replaced with shrimp farming and rice cultivation
Mangroves play central role in biogeochemical cycles of coastal environment

Sites of accumulation of sediment, contaminants, carbon & nutrients
Mangroves protect other marine ecosystems (seaweeds, coral & sea grass)
High rate of primary productivity (24 t/ha/yr)

Sink for atmospheric CO$_2$ (0.055 g C/cm$^2$ soil)

Biomass is greater than any other aquatic systems

Significantly contribute to oceanic carbon

(25 billion kg of carbon to ocean per year in northern Brazil)
Mangroves are sources of wood, poles, firewood, charcoal, fodder, medicines, honey
Mangroves serve as nursery, feeding and breeding grounds for birds, fish, crabs, prawns, shell fish, reptiles, mammals.

Provide livelihood to local human population.
Impact of mangroves on fisher’s income???

Two years data
Peoples’ income

Luxuriant mangroves (Pichavaram) & sparse mangroves (Ariyankuppam)

68-fold higher shellfish income
2.4-fold finfish income
Mangrove forests being worshipped in India

Sundarbans “Banabibi” temple
A mangrove species (*Excoecaria agallocha*) being worshipped as temple tree in Chidambaram
Sites for recreation & education

Economic value of mangroves is US$ 10,000 /ha/yr
greater than that of coral reefs, continental shelves and opens sea
GLOBALLY MANGROVES CONTINUE TO DISAPPEAR

50% since 1900 (Alongi 2002)

35% in past 2-decades (Valiela et al., 2001)

Rate of loss is 1 - 2% per year
this is greater than the loss of tropical rainforests and coral reefs
Techniques for propagation of mangroves:

- Air – layering
- Tissue culture
- Cuttings
Grafting in between seedlings and adult stem.

Grafts detached from mother plant and grown in earthen pots.
Mangrove Nursery techniques developed
Students planting
Ariyankuppam estuary,
Pondicherry
8 years after
Vellar estuary, just opposite to my Centre
15 years after

Fish resources increased
Prawns by 115 times
Crabs by 3 times
Fish by 2 times in 5 years
Participation of women in mangrove planting on 10, 11 Dec. 2004
After World War, if there was another tragedy in human history, it was the tsunami of December 26, 2004.
Killed 12,405 people in India
Destroyed 0.24 million houses
Affected 2.8 million people in 1089 villages
Damaged 83,800 boats
Destroyed 39,035 ha of cropped area
Killed 31,755 livestock
Monetary loss of 1,15,450 million rupees
Tsunami just opposite to my laboratory

Concrete Boat Jetty

Concrete structures broken into pieces, but not mangroves
Our mangroves saved about 1,000 people living behind.
Trained women thanked with gratitude for the mangroves saved their lives
To prove the tsunami-mitigating effect of mangroves & other coastal vegetation

18 coastal villages existing 25 km stretch along South India

Two mangrove formations:

- Natural mangroves (Pichavaram)
- Artificially raised mangroves (Vellar estuary)
Coastal village:
  • Distance from sea
  • Elevation from MSL

Coastal vegetation:
  • Area
  • Density

No. of human death:
  • Male, Female, Child, Total
  • No. /1000 people

Per-capita wealth loss (huts, gear & grafts)
### Impact of tsunami and loss of human lives and wealth in 18 different fishermen hamlets

<table>
<thead>
<tr>
<th>Fishermen Hamlet No.</th>
<th>Human inhabitation</th>
<th>Coastal vegetation</th>
<th>No. of Deaths*</th>
<th>Per capita Loss of Wealth (huts, gears &amp; crafts (US$))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Distance from sea (Km)</td>
<td>Elevation from mean sea level (m)</td>
<td>Nature of Habitat</td>
<td>Area (ha)</td>
</tr>
<tr>
<td>1</td>
<td>0.3</td>
<td>2.0</td>
<td>Sandy shore with mid shore dunes</td>
<td>0.5</td>
</tr>
<tr>
<td>2</td>
<td>0.3</td>
<td>3.0</td>
<td>Sandy shore with mid shore dunes</td>
<td>0.9</td>
</tr>
<tr>
<td>3</td>
<td>0.4</td>
<td>0.8</td>
<td>Low-lying sandy shore with embryonic dunes</td>
<td>0.1</td>
</tr>
<tr>
<td>4</td>
<td>0.4</td>
<td>2.0</td>
<td>Sandy with mid shore dunes</td>
<td>0.3</td>
</tr>
<tr>
<td>5</td>
<td>0.7</td>
<td>1.0</td>
<td>Sandy shore with hind dunes</td>
<td>0.4</td>
</tr>
<tr>
<td>6</td>
<td>0.7</td>
<td>3.3</td>
<td>Sandy shore with mid shore dunes</td>
<td>0.15</td>
</tr>
<tr>
<td>7</td>
<td>2.0</td>
<td>2.0</td>
<td>Muddy shore with dense mangroves</td>
<td>10</td>
</tr>
<tr>
<td>8</td>
<td>1.0</td>
<td>4.0</td>
<td>Elevated sandy shore with hind dunes</td>
<td>11.3</td>
</tr>
<tr>
<td>9</td>
<td>0.2</td>
<td>0.5</td>
<td>Low lying sandy shore with embryonic dune</td>
<td>0.52</td>
</tr>
<tr>
<td>10</td>
<td>0.4</td>
<td>4.0</td>
<td>Elevated steep sandy shore with mid shore dunes</td>
<td>15</td>
</tr>
<tr>
<td>11</td>
<td>0.1</td>
<td>0.8</td>
<td>Low lying sandy shore</td>
<td>0.2</td>
</tr>
<tr>
<td>12</td>
<td>1.0</td>
<td>1.0</td>
<td>Mud-sandy shore with shrubby mangroves</td>
<td>2.0</td>
</tr>
<tr>
<td>13</td>
<td>0.1</td>
<td>0.5</td>
<td>Low lying sandy shore</td>
<td>0.8</td>
</tr>
<tr>
<td>14</td>
<td>2.5</td>
<td>2</td>
<td>Muddy shore with dense mangroves</td>
<td>10</td>
</tr>
<tr>
<td>15</td>
<td>2.5</td>
<td>1</td>
<td>Muddy shore with dense mangroves</td>
<td>2</td>
</tr>
<tr>
<td>16</td>
<td>0.15</td>
<td>0.5</td>
<td>Low lying sandy shore</td>
<td>0.28</td>
</tr>
<tr>
<td>17</td>
<td>0.15</td>
<td>0.5</td>
<td>Low lying sandy shore</td>
<td>0.08</td>
</tr>
<tr>
<td>18</td>
<td>2.0</td>
<td>1.0</td>
<td>Muddy shore with dense mangroves</td>
<td>10</td>
</tr>
</tbody>
</table>
Human death and property loss were less behind mangroves & sand dune vegetations

(Estuarine Coastal Shelf Science 65: P.601)

Perhaps the first research paper on this aspect)
Criticized (Kerr et al., 2006; France, Australia, Indonesia)

1. Statistical regression is not the best tool
2. Statistical variation is not significant

The statistical analysis is correct and the variation is significant.

confirmed after re-analysing our original data (Vermaat and Thampanya 2006; Netherlands & Thailand)
Human death was most strongly reduced with increasing elevation of human inhabitation.
Property loss was more strongly reduced with distance from the shore.
Remote sensing data in the same area by comparing the presence & absence of protective coastal vegetation (Danielsen et al., 2005, Olwig et al., 2007; Denmark, USA, Japan, Malaysia, Sri Lanka, Indonesia, India).

Criticized by Belgium scientists (Dahdoubh-Guebas & Koedam, 2006)

Besides coastal vegetation, variation in house construction & in mangrove settings (margin and estuarine forests) are important to be considered for tsunami mitigation effects.
The image of the mosque as the only building left standing in Banda Aceh after the tsunami suggests that the architecture of buildings or the materials that are used for their construction are factors in withstanding the tsunami wave (Adger, 2005).
As Length of woody vegetation increases, the extent of damage along the transects reduces.

100 m vegetation reduces damage to < 800 m
500 m vegetation reduces damage to < 500 m
1 km vegetation reduces damage greatly

(Olwig et al., 2007)
Satellite imagery before and after the 2006 West Java tsunami (www.crips.nus.edu.sg)
Mangroves in Sundarbans saved West Bengal in India and Bangladesh from tsunami.

Myanmar & Maldives suffered very less from tsunami due to the virgin mangroves and corals surrounding the coastline.
In Thailand, mangroves and coral reefs protected the Island of Surin from tsunami.

In Sri Lanka:

<table>
<thead>
<tr>
<th>Coastal village</th>
<th>Status of mangroves</th>
<th>Human death</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kapuhenwala</td>
<td>200 ha of dense mangroves and scrub forests</td>
<td>2</td>
</tr>
<tr>
<td>Wanduruppa</td>
<td>Cut down mangroves</td>
<td>6,000</td>
</tr>
</tbody>
</table>

IUCN, 2005
Mangroves provide no protection against Very large tsunami

<table>
<thead>
<tr>
<th>Year of tsunami</th>
<th>Location</th>
<th>Tsunami wave height (m)</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>1883</td>
<td>Krakatoa, Indonesia</td>
<td>12</td>
<td>Wave penetrated 8 km inland through forest</td>
</tr>
<tr>
<td>2004</td>
<td>Banda Aceh, Indonesia</td>
<td>10</td>
<td>No coastal protection</td>
</tr>
<tr>
<td>2004</td>
<td>Nicobar Islands</td>
<td>7</td>
<td>51-100% of mangrove area damaged (3,900 ha damaged &amp; 855 ha lost)</td>
</tr>
<tr>
<td>2004</td>
<td>South Andaman Islands</td>
<td>4.5</td>
<td>30-80% of mangrove area damaged <em>Avicennia marina</em> &amp; <em>Sonneratia alba</em> not affected, but <em>Rhizophora</em> spp. affected due to continuous submergence of water (3,900 ha damaged &amp; 855 ha lost)</td>
</tr>
<tr>
<td>2004</td>
<td>Middle and North Andaman Islands</td>
<td>1.5</td>
<td>No significant damage to mangroves due to elevation of area</td>
</tr>
</tbody>
</table>
Mangroves in Tamil Nadu mitigated tsunami

Reason:
Low wave height (2.8 m)
Sheltered mangroves (estuarine and creek types)

Mangroves in Andaman & Nicobar damaged by tsunami

Reason:
High wave height (7m)
Fringing & over-wash type of mangroves
Submergence of habitat for a long time
Types of mangrove forests (Lugo and Snedaker, 1974)

Types less resistant to natural hazards
1. **Overwash** (small islands)
2. **Fringing** (borders of shorelines; sensitive to erosion)
3. **Scrub** (dwarf on flat coastal margins)

Types resistant to natural hazards
4. **Riverine** (luxuriant)
5. **Basin** (interior side of swamps)
6. **Hammock** (elevated basin)
Protective role of coastal vegetation

1. Giant wave characteristics
2. Vegetation characteristics
Vegetation characteristics

- Tree density
- Tree height
- Mangrove species composition
- Diameter of mangrove roots & trunks
- Elevation of habitat
- Degrading and luxuriant status of habitats

Wave characteristics:
- Wave period
- Wave height
- Depth of water

Diagram:
- W = stand width
- R = canopy diameter
- λ = wavelength
- b = distance between trees
To what extent do mangrove systems can mitigate tsunami damage?

Physical process of tsunami

- Wave attack
- Towing flow

Resistance force

Drag force

Vegetation characteristics
By virtue of complex root systems, the mangroves prevent giant wave action.
Avicennia species with dense aerial roots
Knee roots in *Bruguiera* and *Ceriops*
Snake-like Plank Roots in *Excoecaria*
Do mangroves reduce waves?

(Mazda et al., 1997)
WITHOUT MANGROVES

1.0 m

0.75 m

1.5 km

\( \tau \)
Do mangroves reduce velocity of water currents?
Tree vegetation reduces wave amplitude and energy, as proved on measurement of wave forces and modeling of fluid dynamics

(Massel, 1999)

30 trees per 100 m² in a 100-m wide belt reduce the maximum tsunami flow pressure by > 90%, if the wave height is <4 m

(Hiraishi & Harda, 2003).
In our study area, the tsunami wave height was only 2.8 m. Tree canopy height was about 3-5 m, and vegetation density was 25 trees/100 m² area.

The mangrove vegetation can offer coastal protection against tsunami when the height of mangrove forest is higher than that of tsunami wave height.
When is the next catastrophic tsunami in Bay of Bengal?

- within 30 years (Borrero, 2006)
- within 200 years with 8.8 magnitude earthquake (Roach, 2007)
Scientists have discovered an asteroid, called **2002 NT7**, that may possibly strike Earth on February 1, 2019. It's thought to be large enough to destroy a continent on impact.

**Scale of NEOs**

- **2002 NT7**
  - 164 ft: will burn up in atmosphere
  - 0.62 miles: can cause tremendous local scale damage
  - 1.24 miles: equivalent of one million megaton explosion
  - 9.32 miles: (100 million megatons - wiped out the dinosaurs 65 million years ago)

Source: NASA, NEO Information Center
A growing threat is climate change

- Temperature rise
  (3-6°C by 2100)
- Heat waves & cyclones
  (10% intense for 2°C)
- Sea level rise
  (18-59 cm by 2100)
Global Warming Projections

- CCSR/NIES
- CCCma
- CSIRO
- Hadley Centre
- GFDL
- MPIM
- NCAR PCM
- NCAR CSM

Temperature Anomaly (°C)

1900 1950 2000 2050 2100
Cyclone & Flood

Increase of cyclone intensity by 10-20% for a rise in sea temperature of 2 to 4 °C

<table>
<thead>
<tr>
<th>Area</th>
<th>Frequency of cyclone (1891-1970)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total no.</td>
</tr>
<tr>
<td>Bay of Bengal</td>
<td>366</td>
</tr>
<tr>
<td>Arabian Sea</td>
<td>98</td>
</tr>
</tbody>
</table>
Sea level rise

In Sundarbans of India, two islands (Suparibhanga & Lohacharra) disappeared that evacuated 10,000 people.

12 more islands in the southernmost part of the region are most vulnerable that may evacuate 0.1 million people.

In Gulf of Mannar, two islands (Poovarasanpatti & Vilanguchalli) have already disappeared.
No. of plant species recorded on the coastal sandy shores of India

<table>
<thead>
<tr>
<th>Maritime States</th>
<th>No. of coastal plant species</th>
<th>% of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>West Bengal</td>
<td>153</td>
<td>18.5</td>
</tr>
<tr>
<td>Orissa</td>
<td>48</td>
<td>5.7</td>
</tr>
<tr>
<td>Andhra Pradesh</td>
<td>235</td>
<td>28.3</td>
</tr>
<tr>
<td>Tamil Nadu</td>
<td>328</td>
<td>39.5</td>
</tr>
<tr>
<td>Andaman &amp; Nicobar Islands</td>
<td>97</td>
<td>11.6</td>
</tr>
<tr>
<td>Kerala</td>
<td>91</td>
<td>10.9</td>
</tr>
<tr>
<td>Karnataka</td>
<td>59</td>
<td>7.1</td>
</tr>
<tr>
<td>Maharashtra &amp; Goa</td>
<td>28</td>
<td>3.3</td>
</tr>
<tr>
<td>Gujarat</td>
<td>304</td>
<td>36.6</td>
</tr>
<tr>
<td>Total no species</td>
<td>828</td>
<td>100</td>
</tr>
</tbody>
</table>

Mangroves and sand dune vegetations if properly managed can be of great help to the coastal protection.
Ipomoea pes-caprae
Rooted Cuttings of *Ipomoea* for propagation
Spinifex littoralis
Rooted cuttings of *Spinifex* sp. for propagation
No guidelines for coastal bio-shield at both national and international levels considering physical, biological, economic, social and cultural factors.
## Coastal bioshield model

<table>
<thead>
<tr>
<th>Zone</th>
<th>Distance (Km) from high tide line</th>
<th>Type of plant species</th>
<th>species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seaward (Ecological zone)</td>
<td>0.25-1.00</td>
<td>Sand binders, herb</td>
<td>Nil</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Ipomoea pes-caprae, spinifex littoralis,</td>
</tr>
<tr>
<td>Middle (Low economic zone)</td>
<td>1.00-2.00</td>
<td>Shrub and small trees</td>
<td>Firewood, fodder</td>
</tr>
<tr>
<td>Landward (High economic zone)</td>
<td>&gt;2</td>
<td>Trees</td>
<td>Fruit bearing and timber trees</td>
</tr>
</tbody>
</table>
Broad approaches

- Protecting and managing the existing coastal forests
- Rehabilitation of existing degraded forests
- Planting new forests in sites vulnerable to hazards
Local people should be involved in the design and development of the bioshield for protecting and maintaining the shelter-beds over the long term.
To design and develop ‘coastal bioshield’ using mangrove & coastal species

Is it cost effective measure? Yes

Economic values...US$ 0.2 - 0.9 million/ha/year (Wells et al. 2006)

Cost of restoration...US$ 225 – 0.2 million/ha (Lewis, 2005)

Mangrove & coastal systems can be an economic part of coastal infrastructure
Natural disaster

Scientific knowledge and understanding of the protective function of forests and trees against coastal hazards
MANGROVE GREENING - SOLUTION FOR GLOBAL WARMING

MANGROVE RISE - SOLUTION FOR SEA LEVEL RISE

MANGROVE PROSPERITY - SOLUTION FOR NATURAL CALAMITY

Grow coastal trees tall

Protect coast first of all

THANK YOU