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Nature's protection against nature's fury: a post tsunami assessment of the importance of mangroves as a natural barrier against the wrath of the sea

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Abstract

In the aftermath of recent tsunami, mangrove ecosystems have drawn a high attention as a potential natural barrier against high-energy events such as tsunami, wind generated waves and storm surges. However there is a paucity of definitive studies to determine whether or not mangroves acted as a buffer against the last tsunami. This is an attempt to fill this void. In addition to assessments on impacts of the recent tsunami on mangroves in Sri Lanka that is one of the most severely affected countries in the Indian Ocean by the recent tsunami, a GIS based survey was carried out to find out whether mangroves have protected the infrastructure on the coastal areas as well as to determine the extent of coastline that would be protected in future against tsunami and other high energy events by protection and restoration of mangroves.

Some of the coastal GN divisions (i.e. the smallest administrative unit in Sri Lanka) that are located in low-lying areas but sheltered by mangroves were totally protected from the tsunami whilst the adjacent GN divisions without mangroves were affected. This fact, in addition to our qualitative assessment and anecdotes by survived mangrove dwellers, clearly verify that mangroves can act as a green dyke against tsunami. Nevertheless the extent of the coastline that could have been protected by potential mangroves was not correlated negatively with the destruction by the tsunami, implying that much of the potential mangrove areas lack good mangrove forests. It is revealed that if all the potential mangrove areas of Sri Lanka are restored, more than 30% of the coastline could be protected against tsunami and other high-energy events.

Introduction

The recent tsunami strike and its consequences have become a commanding motive for authorities in affected countries to revise, improve and implement appropriate policies in disaster management. However, as man cannot control high energy events such as tsunami, wind generated waves and storm surges, the only thing possible is to plan and implement measures for the mitigation of such disasters. Civil defense plans including establishment of regional early warning systems and educating the public on what to do in case of such a disaster could be useful to protect human lives. However, as a permanent solution, this is not sufficient as the immovable properties and coastal erosions would be at the mercy of the killer waves. Therefore, the establishment of physical barriers against tsunami and wind generated waves may be the only solution to minimize damages. The development of natural barriers against such high-energy events is favored over man-made artificial barriers as they are inexpensive and environmentally friendly.

In the aftermath of tsunami, the importance of mangroves as a natural barrier against wrath of the sea has become a popular topic in many critiques suggesting that the protection and restoration of mangroves should be incorporated into the rehabilitation strategies (Clarke, 2005; Pethiyagoda, 2005). Nevertheless most of these critiques are based not on proper assessments of the defense of mangroves against tsunami but on superficial observations and/ or anecdotes (Overdorf and Unmacht, 2005). Therefore the validity of the suggestion can be evaluated only by a definitive study that should firstly answer the following questions: How mangrove ecosystems have fared in the Tsunami? Are all mangrove forests comparable in withstanding the tsunami? Whether and how mangroves have served as a natural protective barrier for lives and properties? Although answers to these questions prove that mangroves are capable to protect lives and properties against tsunami, the importance of the suggestion that is to give priorities for protection and restoration of mangroves in rehabilitation measures, depends on the percentage of country's coastline that can be protected by mangroves. Mangroves can only develop along low energy or protected coasts where sediments are retained and mangrove seedlings can establish. Therefore the study should also to be extended to determine the extent of country's coastline with mangrove habitats. This paper is an attempt to execute requisites and address the problems given above by taking Sri Lanka, one of the most severely affected countries in the Indian Ocean by the recent tsunami, as a paradigm.

Methodology

I. Field observation on the impact of tsunami on mangrove vegetation

The coastal stretch from Kalutara (west coast) to Batticaloa (east coast) that represent all the major climatic zones of the island and areas severely affected by the recent tsunami were selected for post-tsunami observations on mangroves. In

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January 2005, 25 lagoons and estuaries with mangroves in this coastal stretch were visited and following five characteristics were assessed semi-quantitatively with the help of previous field knowledge: (A) the pre-tsunami extent of the front mangrove (the first 500 m fringe, taking into account that this is a conservative width with the ability to provide protection against a tsunami); (B) the 'naturalness' of the mangrove, in terms of the presence or absence of cutting activities and other disturbances (C) tsunami damage to the front mangrove; and (D) tsunami damage to lives and properties behind the mangrove. In addition to our direct observation on above D, data on population and housing units destroyed or affected by tsunami as well as the map showing the distribution of affected *Grama Niladari* (GN) divisions of Sri Lanka were collected from the Department of Census and Statistics, Sri Lanka.

II. Mangrove areas along the coastline

Irrespective to the fact whether or not mangroves are there, intertidal areas of all the lagoons, river mouths and sheltered bays within the first 1 km landward belt from the sea, are considered in this study as **potential mangrove areas** or potential mangrove habitats, considering that mangroves inhabited there at least in the past. Identification of potential mangrove areas was made, using the hydrological network of coastal areas shown in toposheets (1:50000 in scale), which was in a GIS overlaid with a layer of contour lines (see below) of the ground. If a water body, with an inflow of sea water through seepage or via an opening, lies within the first 500 m zone and below the 10 m contour line, its margin or inter tidal area is considered as a potential mangrove habitat. The two lines drawn perpendicular to the coastline, marking margins of the potential mangrove habitat, demarcate a segment of 1 km wide coastal belt as the area that can be protected against tsunami and wind generated waves by potential mangrove areas in the 500 m zone. The coastline segment arrested by the two perpendicular lines with a potential mangrove area between them, is considered as a part of the 'mangrove coastline' of the country. (Hereafter in this paper, **'mangrove coastline'** refers to the total length of such segments for the whole country or in a particular administrative division. Similarly, the rest of the coastline refers **'non-mangrove coastline'**).

III. Vulnerable areas along the coast

Vulnerability of the coastal land area for tsunami and wind generated waves depends primarily on the elevation of the coastal land from the mean sea. Considering the fact that the mean run up height of previous tsunami at the shore is about 10 m (Clarke, 2005), the coastal land area lying under 10 m contour line was considered as the most susceptible area for a tsunami and hereafter referred to as **'vulnerable area'** in this paper. Vulnerable area of the country was extracted from the GIS layer of contour lines (see below) with 10 m intervals which was generated using SRTM - DEM data. However, before this extraction, a manual correction was made by using our knowledge on the area and professional expertise, for errors due to the presence of 'pseudo elevations' eg. buildings in populated areas along the coastline.

Except at places with coastal cliffs rising more than 10m directly from the sea level, the boundary of the polygon of vulnerable area overlap with the coastline of the country. The total length of all these overlapping parts of the coastline is referred as '**vulnerable coastline**' of the country or relevant administrative unit. The rest of the coastline is considered as the '**geographically protected coastline**' of the same entity.

IV. Base maps and satellite data

Some elementary data, which were used in this study, was downloaded from web sites of some agencies and institutes. GIS layers for hydrological network and roads network as well as administrative divisions of the country were downloaded from the website of International Water Management Institute (i.e.www.immidsp.org) that worked in collaboration with the Survey Department of Sri Lanka, to make these data available for the public. The coastline map downloaded from the same source was modified by joining narrow mouths of lagoons and rivers to get only the coastline that may face the direct hit of a tsunami. (Hereafter 'coastline' refers to this modified version). These GIS layers were also used as base maps for geocoding of scanned toposheets for coastal areas.

Contour lines lower than 20 m or 100 feet are not shown on Sri Lanka toposheets. (Although the contour lines at lower levels are given in 1:10,000 maps, which are presently the most detailed, they are available only for few areas, not for the entire country.) Therefore the SRTM - DEM data downloaded from the website of 'Consultative Group for International Agricultural Research' (CGIAR) were used to generate 10 m interval contour lines of the coastal areas. The generated 20 m and 30 m contour lines were checked against the contour lines given in standard toposheets to correct for eventual horizontal or vertical shifts in the SRTM data.

V. Statistical analysis

A statistical analysis was performed to ascertain whether there is a correlation between the mangrove coastline/ vulnerable coastline and tsunami damage to the properties in coastal DS (i.e. Divisional Secretariat) divisions of five districts, Galle, Matara, Hambantota, Ampara and Batticaloa. The number of fully destroyed houses

can be taken as a measure of the destructive force of the tsunami and was used as the dependent variable in statistical analysis. The housing density among DS division varies and therefore the variable density affected data received for dependent variables. Moreover, higher the population density (and hence the housing density), larger the administrative unit. Therefore following equation was used to normalize the data of the two dependent variables nullifying effects of variable density and area, before using them in statistical analysis.

$$(H_n / H_t) A$$

H_n = number of fully destroyed houses in the DS division
H_t = total number of houses occurred before tsunami in the same area
A = vulnerable area of all the affected GN divisions in the DS division

Then Spearman correlation coefficients between either of these normalized dependent variables and mangrove coastline or vulnerable coastline were computed.

Results

In mature mangrove forests dominated by true mangroves, trees at the water edge had taken all the energy and were damaged . Even such damages are minimum in 'fringe forests' (eg. mangrove belt of Panama lagoon and lagoon proper area of Rekawa lagoon) compared to riverine forests (eg. Walawe Ganga). Damages to mangrove forests which remained at a young stage (less than 5 m in height) as a result of continous removal of larger trees, were remarkably high (eg. Akurala and canal area of Rekawa lagoon). Damages to forests dominated by mangrove associates were also higher compared to those dominated by true mangroves (eg. Talalla). However, irrespective of the matuarity or species composition, damaged area in any mangrove forest was not extended beyond the first 200-300 m zone of the forest from the sea front.

The tolerance of individual species also showed remarkable differences. Except some isolated, multi-stemmed trees, there were only a few uprooted adult trees among 20 species of true mangroves in Sri Lanka (Jayatissa *et al.* 2002a). Even the damages to the shoot system of true mangroves were minimum in larger and medium sized trees. *Nypa fruticans* (Mangrove palm) was an exception as their aerial parts (i.e. leaves) had broken, but their rhizomatous stems were protected and hence allowed new young leaves to emerge in less than a month after the tsunami impact (eg. Talalla and Kahandamodara). Species of Rhizophoraceae, particularly *Rhizophora* and *Bruguiera* spp., that are fortified by prop or knee roots, had stood firm against the ocean surge. In general, it was evident that mangrove associates (eg. *Anona glabra, Cerbera manghas, Dolichandrone spathacea, Hibiscus tileaceus*) are more vulnerable than true mangroves. Out of true mangroves, major mangroves (eg. *Avicennia, Nypa, Bruguiera Ceriops, Rhizophora, Sonneratia*) appeared to be more resistant than minor mangroves (eg. *Excoecarea, Xylocarpus, Aegiceras, Heritiera*).

The total coastline computed in this study and its categorization are given in Table 1. Potential mangrove habitats occur along 30.9% of the total coastline and 97% of this 'mangrove coastline' is vulnerable or low elevated (i.e. <10 m from the mean sea level). Vulnerable coastlines in DS divisions are correlated positively with the number of fully destroyed houses (Corr.coef. = + 0.711; $p< 0.01$) whilst the mangrove coastline also correlated positively with the number of fully destroyed houses but at a lesser degree (Corr. coef. = + 0.633; $p <0.01$).

The map of tsunami affected GN divisions of Sri Lanka shows that several GN divisions along the coastline are not affected by tsunami. The overlay of this map with two other GIS layers, one showing vulnerable areas and geographically protected areas and the other showing mangrove and non mangrove areas of 1 km wide coastal belt, revealed that some of the non-affected GN divisions lie not on geographically protected areas but on mangrove protected areas. Figure 1 shows a few examples.

Table 1. Total coastline of Sri Lanka and its breakdown into different categories

	Mangrove coastline (km)	Non-mangrove coastline (km)	Total (km)
Vulnerable coastline (km)	523	1057	1580
Geographically protected coastline (km)	15	143	158
Total (km)	538	1200	**1738**

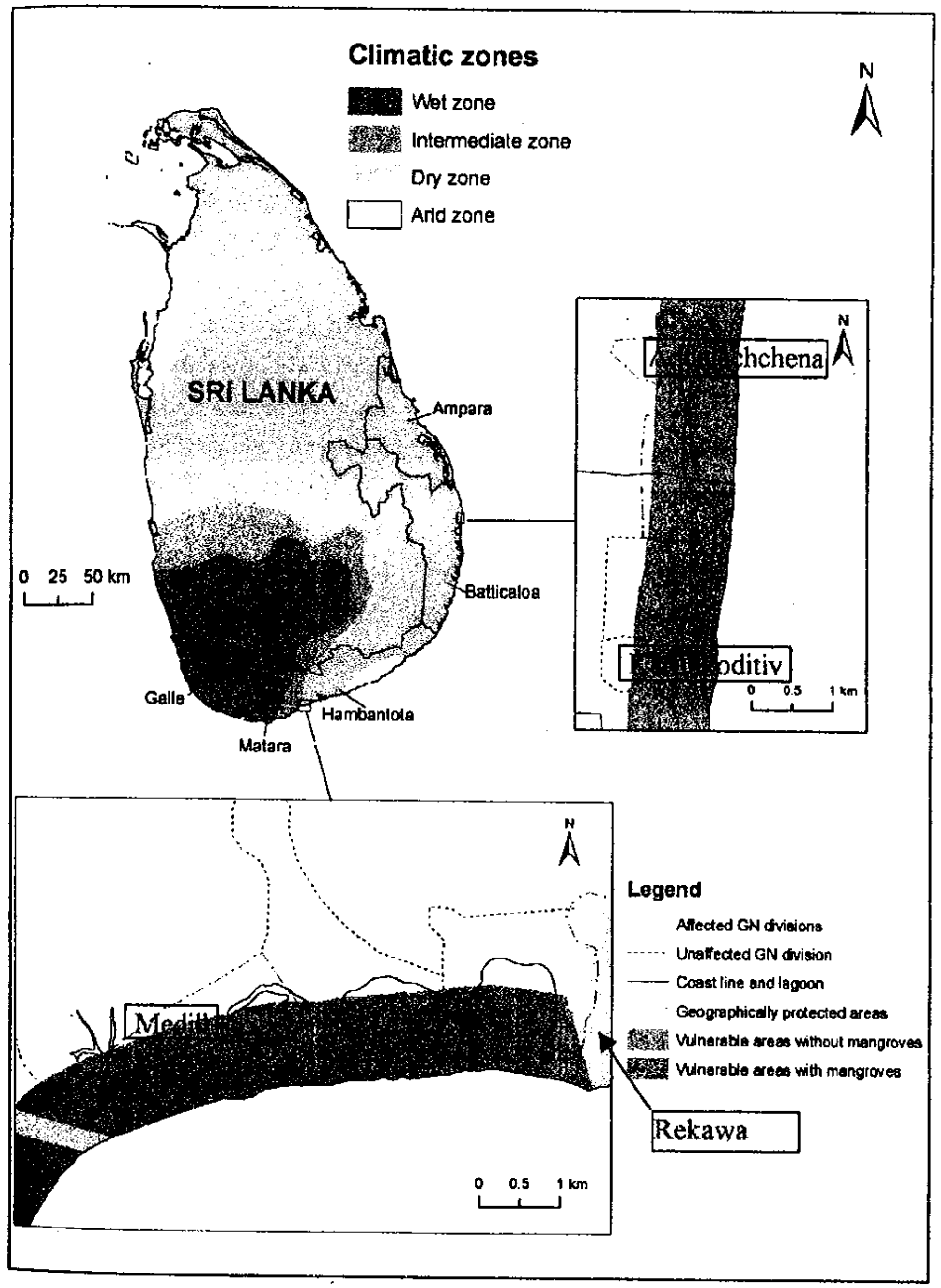

Figure 1. Map of Sri Lanka showing coastline considered in this study and five coastal districts from which secondary data on impact of tsunami were collected. Major climatic zones are given according to Pemadasa (1996). The two insets represent examples for some GN divisions, which were protected against tsunami by mangroves whilst located in low lying areas.

Discussion

According to the values resulted in this study, only 9.0 % of the total coastline of the country is geographically protected against tsunami of which the run up height is about 10 m at the coast. In other words, more than 90% of the coastal area of the country is vulnerable not only to tsunami, but also to wind generated wave struck, coastal erosion by tidal wave actions and loss of land area due to rising sea level by global warming. This damaging situation may further aggravated by the frequency of such catastrophes. As given in Dahdouh–Guebas *et al.* (2005), the Indian Ocean area counted 63 tsunami events between 1750 and 2004 and more than three of wind generated wave struck per year. Most of them had not been highlighted in the history, probably because they could not do much damage to the properties and lives due to the presence of natural barriers active at optimum level. In contrast, an optimistic view came forward after the recent killer tsunami saying that there will not be another tsunami in the same region for a long period. This idea was challenged by the event of another major earth quake (Richter scale >8.5) took place in the sea of the same region just 91 days after the killer tsunami. The coastal erosion by tidal waves is also a major and continuous hazard particularly in the southern and western coasts of Sri Lanka. As all these catastrophes cannot be prevented and in most cases cannot be predicted, the only solution is to address the issue of better preparedness and disaster mitigation.

This study clearly shows that mangrove forests can withstand against tsunami if anthropogenic disturbances on them is low. However, it is a common observation that disturbances such as cutting activities or continuous removal of larger individuals of major mangroves have prevented mangrove forests reaching the maturity and enhanced the introgression of minor mangroves and mangrove associates into the forest. It was noticed that the capability of such mangroves to withstand the recent tsunami was hindered due to disturbance by human activities. Some reports based on qualitative assessments (Clarke, 2005; Overdorf and Unmacht, 2005) and evidence received in this study from survived mangrove dwellers in affected areas, good mangroves have protected lives and properties against the recent tsunami. Such anecdotes were verified in this study, by the fact that low-lying GN divisions located behind some of the good mangroves were not affected by tsunami whilst adjoining GN divisions were badly affected. However statistical analysis performed in this study did not result the expected negative correlation between the mangrove coastline and the destruction by tsunami. Probably it may be due to the fact that most of the potential mangrove areas are free from mangroves as they were destroyed by man before the tsunami. Under such situation, areas protected by potential mangroves may become just low-lying areas vulnerable

to tsunami. It may be the reason for that mangroves coastline showed a positive correlation with the destruction by tsunami as same as vulnerable coastline. But the correlation between the former pair was in lesser degree compared to that of the later pair probably due to influence by presence of little mangroves in potential mangrove areas. Instead of the actual extent of mangrove area, the potential mangrove area was used in analysis of this study as the mangrove cover of Sri Lanka is not known, except for few lagoons. There are archives reporting that, mangrove habitats in Sri Lanka were covered by extensive mangrove forests in the past (Tennent, 1859). It is reasonable to assume that the actual mangrove cover occurred in the past (i.e. before exerting the anthropogenic pressure on mangroves) could be closer to the figure of potential mangrove cover in Sri Lanka. The potential mangrove area can be reasonably estimated based on the mangrove coastline computed in this study and accurate extents of mangroves, which occurred in 1956, already known for some lagoons/ estuaries. As given in Dahdouh–Guebas *et al.* (2002 and 2005) and Jayatissa *et al.* (2002b) the accurate extent of mangroves in five lagoons, Galle, Kahandamodara, Kalametiya, Pambala and Rekawa, is 572 ha. As computed in this study, the sum of mangrove coastline for the same five lagoons is 9.2 km whilst the total length of mangrove coastline of the country is 538 km. Based on these values the extent of potential mangrove cover for the whole country can be estimated as about 33700 ha. The estimated figure given by different authors for the current extent of actual mangroves in Sri Lanka vary from 6000 to 12570 (Pinto, 1986; Amarasinghe, 1996) implying that the actual mangrove cover is less than one third of the maximum potential area of mangroves. It is understandable because there are many reports for that mangroves in the world as well as in Sri Lanka have been destroyed in an alarming rate during the last few decades (Alongi, 2002; Dahdouh-Guebas *et al.*, 2002; De Silva and Balasubramaniam, 1984-85). If the destroyed mangroves are restored, more than 30% of the coastal areas could be protected against tsunami and extreme weather events.

As evidenced in this study, different species of mangroves fared in different ways during the tsunami. As an example, Rhizophoraceae representatives, which are the most vulnerable from an ecological point of view, most valuable and impacted from an ethnobotanical point of view, showed the highest capability of withstanding against tsunami Fortunately the species diversity of true mangroves in Sri Lanka is remarkably high with many species which can stood firm against tsunami; but, about 20% of the true mangrove species in Sri Lanka are now at the margin of extinction (Jayatissa *et al.* 2002a). Therefore the protection of the remaining mangroves should be given the prime importance in any attempt to use them for any purpose.

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