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The collision mitigation function of coconut palm trees against marine debris transported by tsunami

－A case study of Tangalla on the southern Sri Lanka coast －

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Abstracts: The Indian Ocean tsunami of 2004 reconfirmed that coastal forests could mitigate tsunami damage. A small coastal coconut grove was studied as an example of trees that mitigated tsunami damage at Tangalla, on the southern coast of Sri Lanka. We investigated what kinds of features of a coconut grove would be able to mitigate tsunami damage. We obtained basic information about the tsunami from interviews with the residents of the house. We made cross-leveling from the shoreline to the house, surveyed the location and measured the diameter and height of each coconut tree, identified scars caused by the tsunami and measured the height of the scars. It was the seaward trees that blocked the inland movement of boats in this case, and the coconut trees that had clear traces were located on the outer edges of the grove rather than near the seashore. It is thought that it is hard for a tsunami to topple or eradicate coconut trees unless the wave height reaches the height of the fronds, except when the ground is scoured or eroded. Namely it shows that while a coconut grove might do little to weaken the force of tsunami compared with other species because its lack of branches, a coconut grove can block the movement of large-sized flotsam like boats. Coconut trees can be effective by arranging them, even in a single row, at the front zone to block flotsam, but it is essential that they be located where the ground is not scoured or eroded.

1 Introduction

The Indian Ocean tsunami of 2004 was a serious disaster, with the number of dead or missing persons exceeding 300,000. In Japan, the occurrence of a major earthquake in the Tokai, Nankai and/or southeast maritime region are expected in the near future and various measures have been carried out for mitigating possible damage. The Indian Ocean tsunami disaster can give us useful information for improving these measures. One is how to get the most out of coastal trees. It has been known from past tsunamis in Japan that coastal forests can mitigate tsunami damage, and some specific functions have been identified and investigated (Ishikawa, 1992). The Indian Ocean tsunami reconfirmed that coastal forests could mitigate tsunami damage (for example, Danielsen *et al*., 2006), and the functions of coastal forests for mitigating damage from tsunamis has consequently been reevaluated.

In August and December 2006, and December 2007, we investigated some examples in which coastal forests mitigated tsunami damage in the southern part of Sri Lanka. In this series of investigations, a small coastal coconut (*Cocos nucifera*) grove with a standing tree number of less than 20 was studied as an example of trees that mitigated tsunami damage at Tangalla (Photo 1). Coconut trees have not been considered as a measure

Photo 1: The coconut grove examined in the investigation (a: the view from the shore, b: the view from the house).

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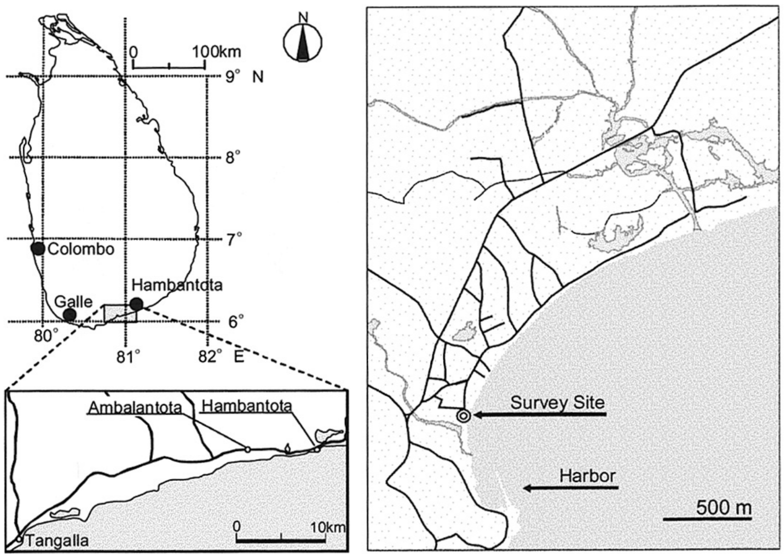

Figure 1: Study site

against tsunamis because they have no branches and tsunamis may be able to pass between trunks with little resistance (for example Sasaki, 2007). However, the residents of the house by this coconut grove recognized its value because it stopped the boats that were being carried by the tsunami from the harbor located south of the grove. Thus, we investigated what kinds of features of a coconut grove would be able to mitigate tsunami damage.

2 Survey site and method

2.1 Description of the survey site

The field survey was carried out at Tangalla, on the southern coast of Sri Lanka (Figure 1), where high-water marks of 1.6～3.8 m were recorded (Shibayame et al., 2005). The residents of a house located 30 m from the shore (that is, the boundary between the backshore and the foreshore; 2.2 m above sea level) had a high regard for the coconut grove, which was located between the shore and the house and was composed of 16 coconut trees. The height of the foundation of the house was 2.3～2.6 m above the sea level and was approximately the same as the shore (Figure 2).

The elevation above sea level was corrected for the tide level at the time of the tsunami. The model WXTide328 [7] was used to find the tide level correction using the tide level at Galle Anchorage (80° 13.0' E, 6° 2.0' N).

2.2 Investigation

We obtained basic information about the tsunami from interviews with the owner of the house (male, 76 years old), his daughter and her husband, and a neighbor (male). We made cross-leveling from the shoreline to the house, surveyed the location and measured the diameter and height of each coconut tree, identified scars caused by the tsunami and measured the height of the scars.

Coconut trees have a unique form, with large, long leaves called fronds spreading radially from the top of the trunk. We measured the tree height from the ground to the top of the trunk, not including the fronds. We distinguished between scars caused by the tsunami and scars caused by other factors based on the verbal evidence of the residents.

3 Results of the interviews

3.1 Overview of the tsunami

An overview of the tsunami and the damage caused by it was obtained based on the interview as follows. Three tsunami events occurred at the site. The first tsunami came at around 9:20 a.m. and was followed by the second tsunami two or three minutes later. The third one was not observed because the residents had escaped to higher ground after the second event.

Although the first tsunami reached the house, and the door was open, it was prevented from entering the house by the 25cm-high doorsill. Since the residents of the house had experienced sea water reaching the gate wall on the seaward side of the house (refer to Photo 2a) during especially high wave activity, they thought at first that it was merely abnormal wave activity, even when the first tsunami came.

The second tsunami was large. Although the owner of the house rushed to shut the seaward door to prevent the wave from reaching his daughter who was watching it come, he was too late. He was swept out of the house from the landward door to the outer wall of a detached building in the back (17.8 m from the seaward door).

Although the man in the neighboring house was outside was carried 80 m inland by the tsunami, he was able to narrowly escape by holding onto a tree there.

The owner of the house contacted diarrhea later because, he thought, he swallowed tsunami water while he was drifting.

They estimated that the height of the second tsunami was 230 cm above the entrance (equivalent to

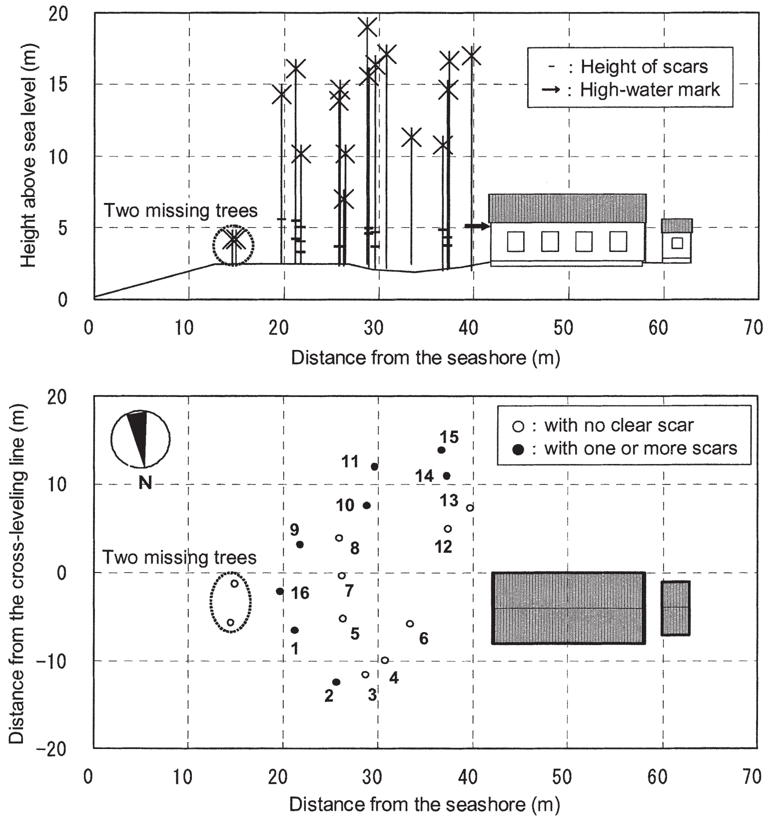

Figure 2 Layout of coconut trees and height of scars and high-water mark

Photo 2: The entrance hall of this house was obliterated by the tsunami (a: before tsunami; b: after tsunami).

Photo 3: The tsunami reached the ceiling beam.

4.9 m above the sea level) and reached the beam (208 cm above the floor, Photo 3) that was attached to the ceiling.

3.2 Influence of the tsunami

The tsunami destroyed the attached seaward portion of the house, and its gate walls (Photo 2). Some furniture in the house had disappeared, and some was pushed against the landward wall of the house. The residents do not know whether the furniture that had disappeared was all washed away by the tsunami or was stolen during their absence. Although sand, mud, garbage, coconut fronds, etc., were deposited in the house, there were no trunks or roots of coconut trees.

Only two or three low coconut trees, whose nuts were reachable by hand, were washed away while the higher ones were remained. The residents said that the low coconut trees had disappeared without a trace, and sand deposited by tsunami had filled the holes where the trees had been.

3.3 Blockage of boats by coconut trees

Depending on the account, from five to seven 40-foot class boats were blocked by the outer (seaward) coconut trees, or by other boats that had been blocked by the trees (Photo 4). There were also accounts of the inner (landward) side of the coconut trees acting to block the boats, too.

4 Condition of the coconut grove

4.1 Description of the coconut grove

Sixteen live coconut trees remained between the house and the seashore when we investigated in December 2006 (Photo 2). The tree height was 4.6-16.5 m (average: 11.7 m) and the diameter at breast height was 23.3-40.5 cm (average: 31.6 cm). The distance from a coconut tree to its closest neighboring tree ranged from 2.6 to 4.9 m (average: 3.9 m) (Table 1). Compared with the relationship between tree height of coconut trees and their distances which Tanaka *et al.* (2006) investigated, the coconut trees in this investigation were considered to be very close together for their heights. The eradicated low coconut trees had been planted seaward of these remaining ones.

When the tsunami height in the coconut grove was assumed to be the same as the value at the front of the house (4.9 m above the sea level), the ratio of tsunami submerged height to surviving coconut trees ranged from 0.16-0.58 (average of 0.26).

4.2 Traces of flotsam collision

We detected clear traces that indicated flotsam had collided with trunks of 8 of the 16 coconut trees (Photo 5). Those trees that have a clear trace or traces were

Photo 4: Boats were blocked by the coconut trees.

Photo 5: Trace of flotsam impact on a coconut trunk.

Table 1: Overview of surviving coconut trees.

Tree No.	Tree Height (m)	Diameter of Breast Height (cm)	Distance to nearest neighboring tree (m)	Height of Scar(s) (cm)	Direction of Scar (deg)	Inundation depth ratio
1	13.7	34.8	4.7	175～295 (5 sacrs)	57	0.19
2	11.5	23.3	3.1	130	134	0.24
3	16.5	28.1	2.6	—	—	0.16
4	14.9	30.7	2.6	—	—	0.19
5	7.6	29.6	4.8	—	—	0.34
6	8.9	32.1	4.9	—	—	0.30
7	4.6	33.8	4.3	—	—	0.58
8	12.2	35.1	4.2	—	—	0.21
9	7.7	29.4	4.2	75, 155, 255	70	0.34
10	13.3	40.5	4.4	230, 260	114	0.21
11	14.2	32.3	4.4	140, 240	135	0.20
12	14.5	29.1	3.4	—	—	0.20
13	15.0	29.6	3.4	—	—	0.20
14	12.5	28.2	3.0	215, 155	89	0.24
15	8.8	30.5	3.0	280	328	0.35
16	11.9	38.0	4.7	310	148	0.22
Ave.	11.7	31.6	3.9		—	0.26
Max.	16.5	40.5	4.9	75	—	0.58
Min.	4.6	23.3	2.6	310	—	0.16

located on the outer edge of the grove.

Except for one tree, the directions of the traces were seaward, from 57-148 degrees. The exception was the No.15 tree, on which a clear trace was detected on the trunk of the inland side at 328 degrees. According to the interview, this was not caused by a boat but by a tank that had been carried from the harbor located south of the site (Photo 6). One possibility is as follows: the tank passed between the No.15 and No.11 trees, hit the No.14 tree, and bounded back to collide with the No.15 tree from the inland side.

Some trees had only one trace each and others had more. The maximum number of traces was 5, which were found on the No.1 tree. The height of traces ranged from 0.8-3.1 m above the ground (3.0-5.3 m above the sea level). The traces at 5.3 and 5.2 m above the sea level on two of the seaward trees exceeded the 4.9 m tsunami height at the seaward wall of the house. The traces were 4.5 m on the trunks comparatively near the house and 4.6 m in the middle part of the grove. The traces were higher on the trees located closer to the sea, but it is difficult to say such a tendency is remarkable considering possible measurement error, etc.

5 Discussion

5.1 Function of flotsam blocking

It was the seaward trees that blocked the inland movement of boats in this case. Although there were accounts that the inside trees had also blocked boats, no clear evidence was found on the trunks. Therefore, even if inside trees had blocked flotsam, it is presumed that the impact of the flotsam on the inside trees was weaker than that which the seaward trees received. Thus, even if it is a single row, a coconut grove has the potential to mitigate the damage caused by flotsam.

In addition, the coconut trees that had clear traces were located on the outer edges of the grove rather than near the seashore. The reason may be that the flotsam from the harbor came at an angle with respect to the shoreline of other than 90 degrees. That is, in the case of the coconut grove of a single row, an arrangement which encloses the object(s) that must be protected from a tsunami is more effective than an arrangement that is parallel to the coastline.

5.2 Tolerance of coconut trees to tsunami

Coconut trees have to withstand the impact of a tsunami to demonstrate a tsunami damage mitigation function. Since coconut trees do not develop branches, if a tsunami does not reach the height of the leaves (fronds), coconut trees receive little tsunami wave force compared with other species. For this reason, although the trees do little to abate the force of a tsunami, they also receive little of its destructive force. That is, it is thought that it is hard for a tsunami to topple or eradicate coconut trees unless the wave height reaches the height of the fronds, except when the ground is scoured or eroded.

Tanaka and Sasaki (2007) investigated the

Photo 6: A tank carried by the tsunami (center left).

relationship between the height of coconut trees and inundated depth after the 2006 Java tsunami in Indonesia, and found that coconut trees were susceptible to be pulled down by the tsunami when the tsunami height exceeded 70 % of the tree height. The results of the present study support their results, because only low trees that were overtopped by the tsunami were eradicated and the tsunami did not reach 60 % of the height of the lowest surviving tree, which was 4.6 m.

Tanaka and Sasaki (2007) showed that *Pandanus odoratissimus* is susceptible to toppling when the tsunami height exceeds 80 % of the tree height and that is a higher ratio of wave height than what coconut trees can bear; however, substantial toppling resistance of coconut trees is much larger than that of *Pandanus odoratissimus* because coconut trees are much taller than *Pandanus odoratissimus*.

From the findings described above, the tolerance of coconut trees to a tsunami is sufficiently high to manifest their flotsam protection function.

In addition, the coconut trees that were eradicated by the tsunami were located on the forefront edge of the back beach where topsoil was easily eroded and the 16 remaining coconut trees were located 5 m inland from the lost trees.

5.3 Evaluation of coconut trees

A tree and shrub belt has been proposed to weaken the force of a tsunami (Ishikawa, 1992). The proposed belt consists of a front zone of shrubs, a middle zone of a dwarf tree coppice, and a high tree zone behind them. High trees are not included in the front zone in that proposal, presumably because the height of trees by the side of the sea is low in the coastal forests of Japan. However, coconut trees are not included in the front zone even in the tree arrangement model of the tsunami protection coastal forest that was proposed by Sasaki (2007) based on the survey of the damage caused by the Indian Ocean tsunami of 2004.

On the other hand, our study showed that coconut trees planted near the seashore can be evaluated for their ability to mitigate tsunami damage. Namely it shows that while a coconut grove might do little to weaken the force of tsunami compared with other species because its lack of branches, a coconut grove can block the movement of large-sized flotsam like boats. This function would be useful not only to block the flotsam itself, but also to facilitate the restoration efforts after the damage. In that sense, coconut groves that are located between the seashore and an object targeted for protection can be held in high regard.

5.4 Practical use of coconut trees

Coconut palms are extremely useful trees that naturally grow near the seashore and are often planted in residential areas (Hayashida et al., 2007). From the findings described above, we may conclude that it is possible to use coconut trees for mitigating tsunami damage, as follows. Coconut trees can be effective by arranging them, even in a single row, at the front zone to block flotsam, but it is essential that they be located where the ground is not scoured or eroded. In addition, when trees are required to provide resistance to a tsunami, it is not necessary to replace coconut trees with another species, but it is desirable to plant one or more other species in the understory of the coconut trees.

The case study that we investigated shows that coconut trees which are growing near the seashore can help to block flotsam. Tanaka and Sasaki (2007) findings on the threshold conditions of tsunami-induced toppling of coconut trees was based on the results of their investigation of coconut trees whose inundation depth was less than 7 m. Therefore, an investigation of cases of inundation depth of 7 m or more and associated theoretical analysis are required to gain a more accurate understanding of the ability of coconut trees to withstand tsunamis.

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