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海岸林学会誌 (*Journal of the Japanese Society of Coastal Forest*) 7 (3) : 1 – 5 , 2009

Endurance of the *Casuarina* coastal forest in southern Sri Lanka against the Indian Ocean tsunami

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Abstract: In Hambantota, southern Sri Lanka, we implemented a survey of the damage-mitigating effect and the endurance of the *Casuarina* coastal forest against the Indian Ocean tsunami that occurred in December 2004. The tsunami struck by passing over the *Casuarina* forest on the front dune (height of 5.5m above sea level), but it was unable to pass over the next dune (height of 5m); therefore, private houses on the inland side of that dune were not damaged. In contrast, in the shallow trough produced by excavation of part of the dune, the tsunami passed over the front dune (height of 3.5m) and through the *Casuarina* forest; it destroyed private houses 250m from the shoreline. Although the *Casuarina* trees growing on the high dune were not damaged, 57% of the *Casuarina* trees that were directly hit by the tsunami on the trough withered after it passed. However, few tree trunks were broken during the tsunami, so it was suggested that the *Casuarina* forests had been able to withstand the physical impact of the tsunami.

1 Introduction

On December 26, 2004, a large tsunami resulting from a huge earthquake (M9.0) whose epicenter was on the coast of Sumatra Island struck a wide range of the coast of the Indian Ocean, and many countries suffered extensive damage. Indonesia and Thailand, which were near the epicenter, suffered major damage, as did Sri Lanka and India, which were more than 1400 km from the epicenter.

In Japan, earlier studies indicated that coastal forests reduced damage from tsunamis (Ishikawa, 1992). Studies of the tsunami in the Indian Ocean reconfirmed the damage-mitigating effects of coastal forests (e.g., Dahdouh-Guebas *et al.*, 2005; Danielsen *et al.*, 2005; Sakamoto *et al.*, 2008; Yanagisawa *et al.*, in press).

For the present study, we conducted surveys mainly in the coastal area of southern Sri Lanka, which suffered serious damage from the December 2004 tsunami, to verify the damage-mitigating function of coastal forests. The main coastal forests in this area consist of coconut palm plantations, *Casuarina* forests for protecting against sea wind, Mangrove forests on lagoons and rivers, arid zone forests in the southeast area, dry thorny scrublands resulting from disturbance, and home garden woodlands of houses and hotels (Hayashida *et al.*, 2007).

The *Casuarina* species planted in the southern part of Sri Lanka is *Casuarina equisetifolia*. In this region, *Casuarina* forests grow on slightly high coastal dunes. While the *Casuarina* forest was expected to have a higher damage-mitigating effect than that of other coastal forests in Sri Lanka, in one area houses were seriously damaged by the tsunami, despite the presence of a *Casuarina* forest. In that area, a shallow trough had been produced by excavation of part of the dune and was positioned lower than the surrounding dunes.

For this study, we selected two *Casuarina* forests, one on the trough produced by excavation of the dune and the other on a dune where topography had not been changed. After measuring the topography, we interviewed the residents, in an effort to analyze the situation prior to the arrival of the tsunami and the actual state of the damaged houses in inland areas. To determine the importance of topography in mitigating tsunami damage, we compared the two forests. We then examined the endurance of *Casuarina* forests against the tsunami by investigating the damage to these forests.

2 Study area

The study area was the peripheral area of a salt-processing plant located 2 km west of central Hambantota, where a low dune separates the Karagam Levaya lagoon (length 1.5 km and maximum width 3 km) from the ocean (Fig. 1). This area consists of sands with a width of 50 m from the shoreline and a dune with a height of 4 to 8 m and a width of 100 m; the area behind it is a lagoon or low ground (width of up to 500 m). A national road runs behind the dune (100 to 300 m from the shoreline).

In this area, the *Casuarina* forest has a width of 100 to 150 m from the top of the front dune on the shore. This *Casuarina* forest was planted in 1986; thereafter, no care (e.g., thinning and trimming) had been applied to it. The results of a 2005 survey of this *Casuarina* forest indicated that the density of trees was 1,343/ha, the average diameter at breast height was 12.5 cm, the average tree height was 11.4 m, and the average under-branch height was 1.9 m. Because of the low under-branch height, the interior of the forest was dark. Therefore, little vegetation grew on the forest floor, with only sparse growth of *Opuntia dillenii*, an alien plant.

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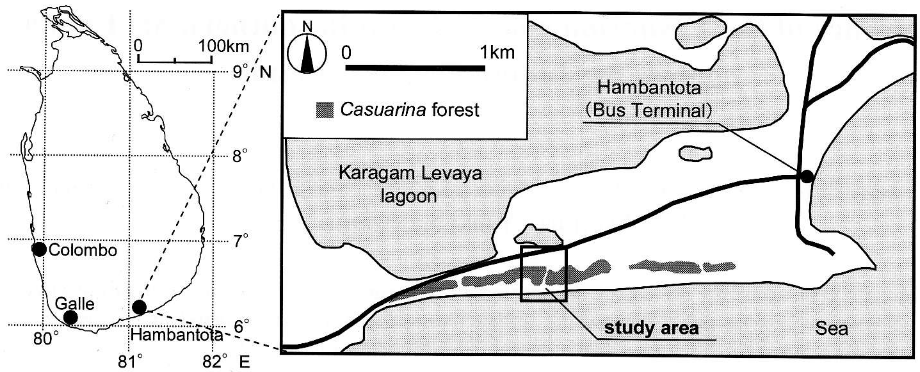

Figure 1. Location of the study area.

Near the salt-processing plant, a shallow trough was produced by excavation of part of the dune, with a width of 30 m and a length of 250 m (Photo 1). This trough was excavated to drain water to the sea when a flood occurred in an inland lagoon in 1970; in 1986, *Casuarina* trees were planted in the area, including this trough.

Among the southern coastal areas, the Hambantota area with *Casuarina* forests suffered the most extensive damage from the tsunami. According to the results of a survey implemented immediately after the tsunami, the tsunami was 7 to 11 m high (Shibayama et al., 2006).

3 Methods

3.1 Measurement of topography

To determine the topography of the trough produced by excavation of the dune as well as the adjacent dune 100m west of it, we performed level measurement and compass measurement along a line drawn from the shoreline to the national road (Fig. 2) (Line 1, Line 2). A TruPulse 200 (Laser Technology, Inc., Centennial CO) was used for level measurement, and a TruPulse 200 and compass glass (Shakujii Keiki Seisakusho, Tokyo) were used for compass measurement. Measurements were performed in December 2007.

Photo 1. Inlet of the trough of the front dune as viewed from the sea side.

3.2 Interviews regarding damages

Several residents were interviewed at the site in December 2006 and December 2007 regarding movement of surface soil and damage to houses, household goods, and human bodies, as well as information about trees (e.g., outflow and inflow of trees, species of damaged trees). Interviews were conducted via a local interpreter who translated the interviewer's questions (Japanese → Sinhalese) and the subjects' answers (Sinhalese → Japanese); additionally, direct inspections of the site with the subjects present were conducted.

3.3 Survey of the actual state of the *Casuarina* forest on the trough

A line was drawn along the lowest part at the center of the trough in the section 160 m from the front dune at the inlet of the trough (Photo 1) to the point where the *Casuarina*

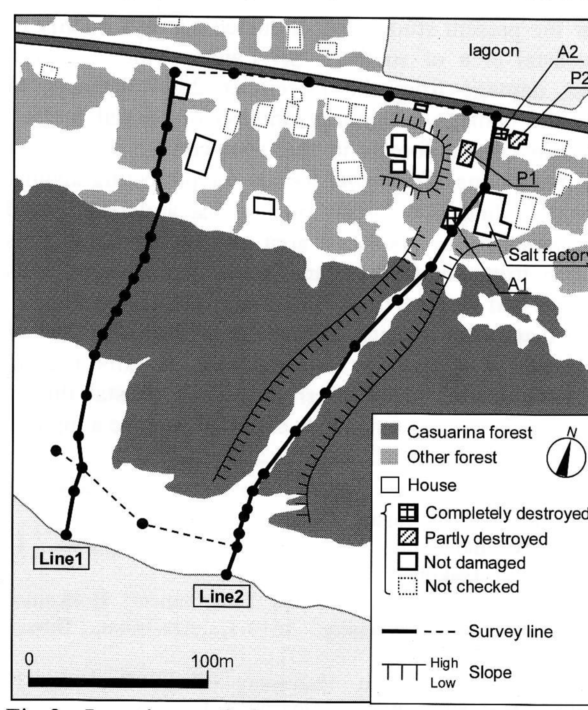

Fig.2. Locations of the two measurement lines and damaged houses. A map was prepared based on the actual state at the time of the survey.

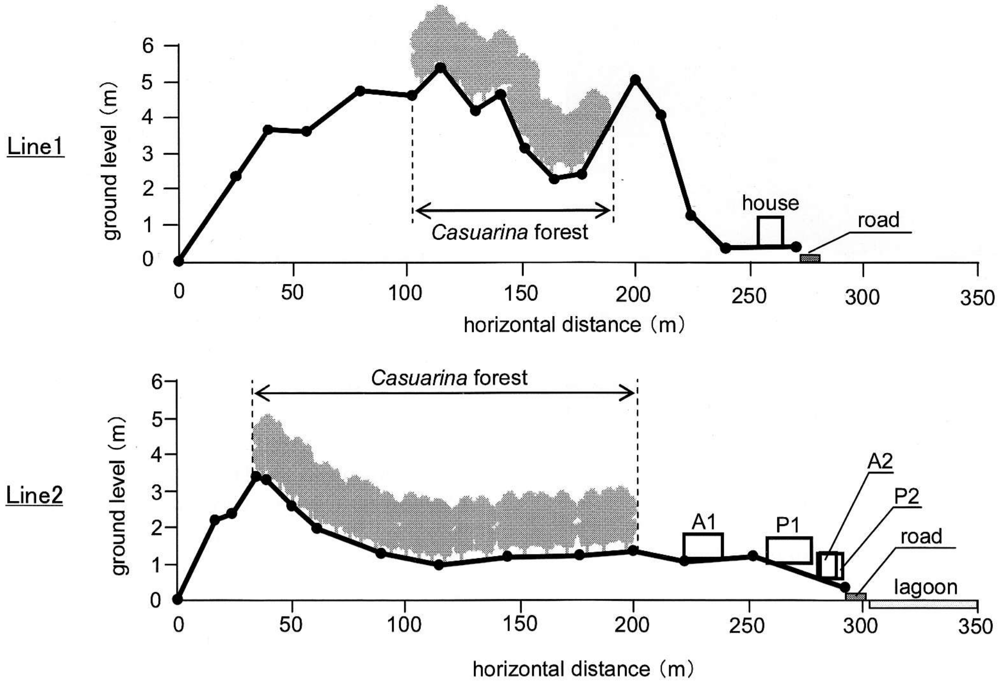

Figure 3. Longitudinal section from the shoreline to the national road along each measurement line, one on the dune and the other on the trough

forest ended. Measurements were made to determine the positions and basal diameters of *Casuarina* trees that were growing in the areas within 10 m on both sides of this line.

We determined whether each *Casuarina* tree was alive or not and recorded whether or not the surviving trees were damaged. For the trees left as stock, we determined whether or not they had been produced by felling through observation of signs.

4 Results

4.1 Topography of the dune and excavated trough

Figure 3 depicts the longitudinal section from the shoreline to the national road of each dune (Line 1) and trough (Line 2). In this figure, Line 1 reaches the top of the front dune; it had a height of 5.5 m at a distance of 110 m from the shoreline, and then the height decreased to 2.5 m at a distance of 50 m from the top of the dune. From that point, the second dune began; after reaching the peak at a height of 5.1 m, the height decreased to 0.5 m at a distance of 240 m from the shoreline.

No vegetation existed in the area up to a distance of 50 m from the shoreline; then, herbs and grasses (e.g., *Ipomoea pes-caprae* and *Spinifex littoreus*) were growing sparsely up to the top of the front dune. The *Casuarina* forest lay in the section with a length of 90 m from the top of the front dune to the top of the second dune.

Along the trough (Line 2), the height peaked at 3.5 m at a distance of 40 m from the shoreline and then decreased gradually up to the national road. *Casuarina* trees had been planted in the section from this peak to a distance of 200 m.

4.2 Situation when the tsunami struck and actual damage to houses

The manager of the salt-processing plant had witnessed the tsunami that passed through the trough. During an interview, he testified that the tsunami was 2.5 m high. Two houses had been located on the extension line from the trough; the one (A1) on the sea side was totally destroyed, whereas the one (P1) on the inland side was only partially damaged (Fig. 2). Three residents in these houses were thrown into the inland lagoon, but all were rescued. Of the two houses along the national road near the plant, one (A2) was totally destroyed and the other (P2) was partially damaged.

A woman living in the house on the west side of the trough had also witnessed the tsunami. According to her testimony during an interview, the tsunami came only once and no wave passed over the dune. However, this house was damaged from partial flooding, due to the wave that came across the trough.

With the exception of the trough, no place was found where houses were damaged by the tsunami passing over the dune. However, a resident confirmed evidence that the tsunami got over the first dune and reached a point nearly 150 m from the shoreline (Line 1 in Fig. 2). Furthermore, testimony indicated signs of tsunami intrusion into the trough by passing from the inlet of the trough and passing over the front dune to the east of it.

4.3 Damage to the *Casuarina* forest

In an interview, the manager of the salt-processing plant reported that he heard the breaking sounds of trees when the tsunami passed through the trough, although few *Casuarina* tree trunks were actually broken by the tsunami.


Photo 2. *Casuarina* trees felled after withering.

However, he also testified that many of *Casuarina* trees in the trough withered one week after the tsunami, and were then felled for use as fuel (Photo 2).

Forty-one (43%) of the 95 trees recognized in the belt transect as established on the trough were found alive, and 54 (57%) were found dead. Of those found alive, 10 were partially broken or cut, 5 had partially died, 7 had trunk damage, and 25 were sound with no damage at all. Most of the dead trees (96%) had been felled; only two were left standing, and they were withered. The trunks of nine trees, including those denuded and alive, were found to be inclining to the inland side.

With the exception of the trough, no place on the peripheral dunes had withering *Casuarina* trees. No withered trees were found in the *Casuarina* forest growing on the front dune, where the tsunami had intruded along Line 1. Tsunami damage to *Casuarina* trees was observed in only the trough.

Forty-three percent of trees on the entire trough were found alive. However, calculation revealed a lower ratio on the sea side (34%) than on the inland side (52%).

5 Discussions

5.1 Damage-mitigating effect of *Casuarina* forests against tsunami

In the Hambantota district, which suffered serious damage from the tsunami, the tsunami did not damage any area after passing through *Casuarina* forests, except in the trough around the salt-processing plant. Therefore, local residents and those who were engaged in forestry assumed that *Casuarina* forests had a disaster-preventing effect against the tsunami. However, all of the *Casuarina* forests were growing on well-developed dunes (with a height of 4 to 8 m above sea level and a width of 50 to 200 m). Therefore, the extent of the *Casuarina* forests' damage-mitigating effect remains unknown.

Because a large difference in the degree of damage was observed between the residential quarter behind the *Casuarina* forest on the trough and that behind the *Casuarina* forest on the dune, the results of this study confirmed the importance of topography as a factor in the degree of damage by a tsunami.

It can also be considered that the tsunami that passed through the *Casuarina* forest on the trough was more destructive because its flow was concentrated into the trough. However, serious consideration must be given to the fact that even though *Casuarina* trees with a 10 cm diameter at breast height had been planted continuously for a width of 160 m at a density of 1,500 trees/ha, houses were totally destroyed by the tsunami that passed through that coastal forest.

5.2 Endurance of *Casuarina* trees against the tsunami

Of the *Casuarina* trees that were growing on the trough where the tsunami passed, fewer than half were left alive. Multiple residents testified that few trees were broken by the tsunami, but many withered after the passage of the tsunami. Signs of cuts by an ax indicated that the remaining trees had been felled.

According to the Hambantota Forest Department Office, *Casuarina* forests were planted for disaster prevention; therefore, felling, including trimming, is strictly prohibited. However, since the collection of withering trees is not prohibited, the residents' testimony that withering *Casuarina* trees were felled is credible.

Why *Casuarina* trees withered after the tsunami is not known. The *Casuarina* trees on the front dune (Line 1 in Fig. 2) did not wither, and the withering rate was higher among the trees on the sea side of the trough than among those on the inland side with a lower ground level. Thus, it is suggested that the cause of withering was not simply salt damage but multiple factors (e.g., damage to the root as a result of the tsunami's impact).

No break or outflow of trunks occurred in the *Casuarina* forest, despite the fact that the strong tsunami destroyed houses behind the forest. Therefore, it can be estimated that the *Casuarina* forest had high endurance against the physical force of the tsunami.

Although we were unable to verify directly the effect of *Casuarina* forests in mitigating the damage from the tsunami, this study confirmed that the *Casuarina* forest had a strong ability to withstand the tsunami' s impact. Trunks of trees that had been broken or knocked down by the tsunami would have caused secondary damage. Therefore, it can be said that the strong endurance of the *Casuarina* forest against the tsunami contributed indirectly to the mitigation of tsunami damage.

Acknowledgements: Sincere thanks go to the Forest Department of the Government of Sri Lanka, which provided valuable information, and the Embassy of Japan in Sri Lanka, which provided much advice on field surveys. This research was conducted using the Grant-in-Aid for Scientific Research No. 18255007.

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〔Received September 10, 2008　Accepted December 20, 2008〕