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The damage caused by the 2004 Indian Ocean tsunami and the mitigating effects of the mangrove forest against the tsunami

—A case study of Medilla, southern Sri Lanka—

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Abstract: The purpose of this study is to examine the mitigating effects of the mangrove growing on the lagoon shores and near the estuary (not facing the open sea) in Medilla area on the 2004 Indian Ocean tsunami. The research methods consisted of a geodetic survey and interviews about the conditions at the time of the tsunami and the damage caused by it. A comparison of the Mangrove Area and Flat Area in Medilla revealed that the distance from the coast and the height from sea level were the same; however, the direction of the propagation of waves, damage caused to buildings, and degree of the deposition of surface soil differed. Thus, it was confirmed that in the case of a tsunami, mangrove forests can mitigate the intensity of waves and reduce the inflow of earth and sand.

1 Introduction

The Indian Ocean tsunami of 2004 was a serious disaster that resulted in many casualties and cases of missing persons.

As the tsunami caused extensive damage in Sri Lanka, the disaster [13], rehabilitation work [7], and support for this work [2] received a considerable amount of coverage. It is known that coastal forests can mitigate tsunami damage, and the relationship between forests and the tsunami (in case studies of the Indian Ocean tsunami [1] [10] and Solomon Islands tsunami [5][11]) and the mitigating effects of mangroves on the tsunami [12] have been reported. The purpose of this study is to examine the mitigating effects of the mangroves growing on the lagoon shores and near the estuary (not facing the open sea), which is one of the general characteristics of the Medilla area [3], on the tsunami disaster. Previous studies have reported on the potential mitigating effects of mangrove forests on the tsunami by investigating the damage caused to mangroves and simulating the 2004 Indian Ocean tsunami in order to investigate the impact on mangroves [12]. In this study, the mitigating effects were verified through interviews about disasters and events related to the tsunami and a geodetic survey comparing whether or not the mangrove forest in similar landform area.

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2 Survey area

2.1 Landforms and vegetation

The field survey was carried out in Medilla (GN Division[1], south side of the national road) and Marakollia (GN Division, north side of the national road), an area 3 km to the east of the central area (bus terminal) of Tangalla (DS Division[1]), on the southern coast of Sri Lanka (Figure 1) [4]. Subsequently, both these areas will be referred to as Medilla. Capes consisting of basement rock were found in the west and the east of the sandy coastline of the extension that stretched for about 7 km. In the vicinity of the cape, a fluvial terrace was found 10 m or more above sea level.

The survey area was located on the west side of sandy coastline (length of 7 km). The area 150 m from the shoreline was a sandhill, and 2–3 km inland, there was a lagoon and swampy lowland. The inland stretch was flatland with the complicated features typical of a drowned valley, and the sandhill along the coastline was divided into parts, with narrowing lagoons that lead to the sea. Guesthouses, resorts, and temples were located on the low sandhill along the coast, and trees such as *Cocos nucifera* were planted. Mangrove forests were found in the lagoon behind the low sandhill and swampy lowland.

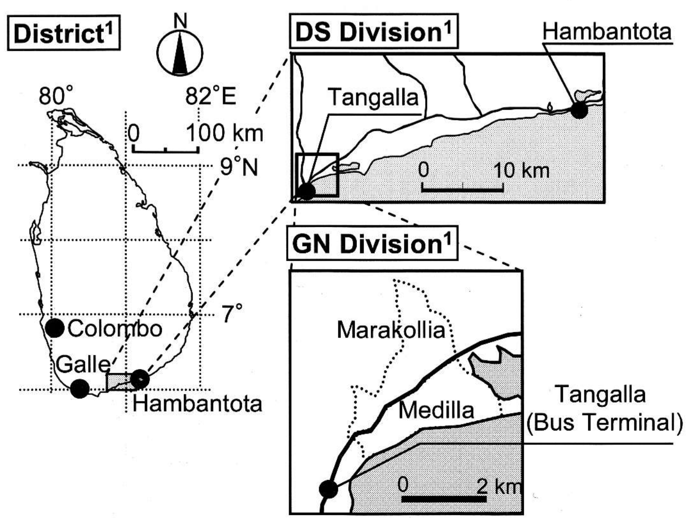

Figure 1: Location of Medilla

To the east of the survey area, a lagoon and latticed river stretched from the sandhill to the national road, while there were mangrove forests on the river shore. To the west of the survey area, a lagoon and narrow mangrove forests were found about 200 m inland; therefore, there was hardly any barrier against the tsunami in the swampy lowland. The mangrove forest was distributed along the lagoon shore between the coast and the national road, with a maximum width of about 900 m and a maximum depth of about 500 m. The type of vegetation [6] was the intermediate zone. According to the field survey, the main species of trees were *Rhizophora mucronata*, *Bruguiera gymnorrhiza*, *Excoecaria agallocha*, *Avicennia marina*, *Lumnitzera racemosa*, and *Aegiceras corniculatum*. The maximum height of the trees was about 8 m. Henceforth, the eastern part of the survey area, where there were mangroves between the coast and the national road, is called the Mangrove Area. On the other hand, the western area, where there were few mangrove forests, is called the Flat Area. Inland from the national road, there was natural vegetation—paddy fields and a grazing area in the swampy lowland—while there were houses located on small stretches of highland, such as the natural levee found there.

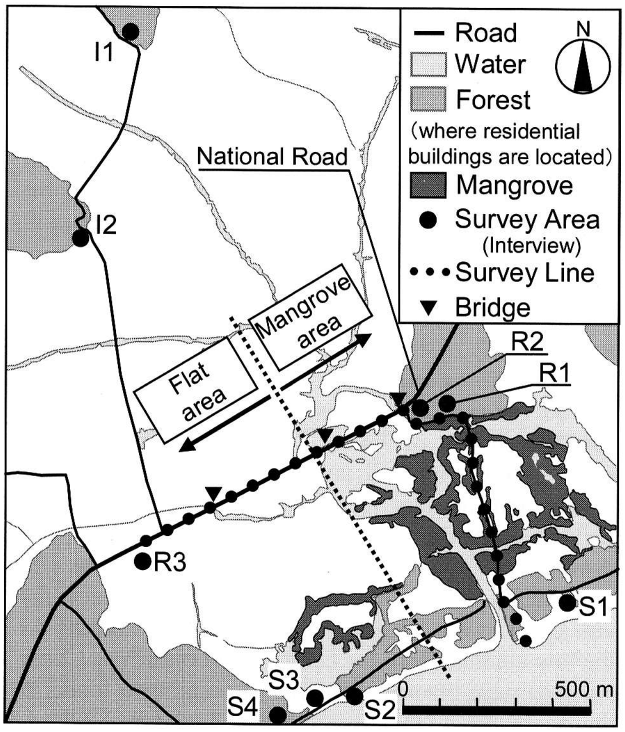

Figure 2: Location of Survey Area

2.2 Statistical surveys on the damage caused by the Indian Ocean tsunami

The total number of affected housing units in Sri Lanka was 260,967 [8]. In the Southern Province[1], the number of affected housing units was 13,493. Further, 4,500 people were killed; 434 people were injured; and 1,341 people went missing [8]. Of the 5,225 housing units in Hambantota (District[1]), 1,019 units were completely damaged; 271, partially damaged (cannot be used); and 1,084, partially damaged (can be used) [9]. Of the 2,770 housing units in Tangalla (DS Division), 277 housing units were completely damaged; 198, partially damaged (cannot be used); and 769, partially damaged (can be used) [9]. Of the 92 housing units in Medilla, 34 were completely damaged; 6, partially damaged (cannot be use d); and 29, partially damaged (can be used) [9]. The government paid 50,000–250,000 rupees (Rs.) as compensation for 34 housing units (completely damaged: 18, partially damaged: 16) in Medilla.

3 Methods

The research methods were interview and geodetic surveys. We obtained information on the tsunami from residents of the survey area on 4 occasions in 2006 - 2008. The survey was conducted in 9 places; these places were classified into 3 areas on the basis of their distance from the coast: Seaside Area (within 100 m: S1–S4), Road Area (about 600 m from the coast: R1–R3) and Inland Area (about 1,200–1,600 m from the coast: I1, I2) (Figure 2). The Seaside Area and Road Area were further classified int o Mangrove Area (S1, R1, R2) and Flat Area (S2, S3, S4, R3).

Table 1 shows the survey date and demographics of interviewers. A local interpreter participated in the interviews (the interpreter translated the questioner's comments from Japanese to Sinhalese and the respondents' comments from Sinhalese to Japanese). In addition to obtaining comments, we confirmed certain information with the respondents on the spot. The duration of each interview was about 30 minutes. The question items were as follows: information about the tsunami in the given area (timing of the wave, height of the wave), earth and sand movement (deposition or erosion and height), damage to houses (damage to buildings, inflow and outflow of furniture), and damage to trees (outflow, inflow, and whether withered). Moreover, when

Table 1: Demographics of respondents and survey area (Interview)

Survey Area	Survey Date 2006 Aug.	2006 Dec.	2007 Dec.	2008 Oct.	Subject: Sex	Whereabouts at the time of the tsunami	Type of Building
S1	○	-	-	○*1	Male, Female	○	guest house
S2	-	○	-	-	Female	○	guest house
S3	-	-	-	○	Male	○	house
S4	-	-	-	○	Male	○	house
R1	-	○	-	-	Female	○	house
R2	○	-	-	○	Male	○	house
R3	-	○	-	○*1	Male	○	restaurant
I1	-	-	○	○	Female	○	house
I2	○	-	-	○*1	Female	-*2	house

*1: The subject was not the same as that of the previous survey.

*2: There were parents in the survey area.

asking people about the place and behavior at the time the tsunami struck, we distinguished between actual experiences and hearsay. The metric system was used for measuring heights and distances. Further, although the respondents provided measurements in feet, measurements were taken on the spot in meters (1 foot = 30cm). We also performed cross-leveling from the seashore to R3 (Figure 2).

4 Results

4.1 Results of the interviews

4.1.1 Seaside Area

S1 (Figure 3)**:** The building was a guesthouse, and there were barrier of trees such as *Cocos nucifera* and *Casuarina equisetifolia* that had been planted. The respondents comprised the following group of people. The sole respondent of the first survey was a man. Men who were in a restaurant at the time the tsunami struck and women who were living in a bungalow participated in the second survey. The first wave reached the floor of the restaurant, and its speed was the same as that of ordinary waves. The height of the second wave was 300 cm and its speed was without comparison. The third wave had come from the east and the southeast, where the bank was broken. Its height was 900–1,050 cm (as tall as a telegraph pole) and its speed was faster than that of the second wave. The respondent (one of the men who participated in the second survey), who held on to a block of wood, was almost driven out to the national road. He then proceeded to run along the road because the intensity of the wave decreased. The height of the backwash was 300 cm and its speed was faster than that of the third wave. Water had returned from the mangrove forest with branches of trees from the mangrove; moreover, *Cocos nucifera* trees had been washed away from the sandhill. From the sea and extending inland, 90–120 cm of surface soil had been washed away and in one place, a hole that was 120–150 cm deep was created. A little black soil from the sea and some clay from the mangrove forest were found.

All the furniture was washed away. Moreover, while *Cocos nucifera* trees had been uprooted, trees from the mangroves were not.

S2 (Figure 4)**:** The building was a guesthouse and restaurant, and there were barriers of trees such as *Cocos nucifera* and *Casuarina equisetifolia* that were planted. The respondent was a woman who was staying in the building. The height of the first wave was 30 cm, and its speed was the same as that of ordinary waves.

The height of the second wave was 350 cm, and the speed was without comparison. The surface soil had been washed away, and a hole that was 300 cm deep was observed in one place (Figure 5). The bank (south from S2) where the mouth of the river was located at one time

Figure 3: Buildings that were completely destroyed by the Tsunami
(Photograph taken immediately after the tsunami)
(photo: offered by the guesthouse owner)

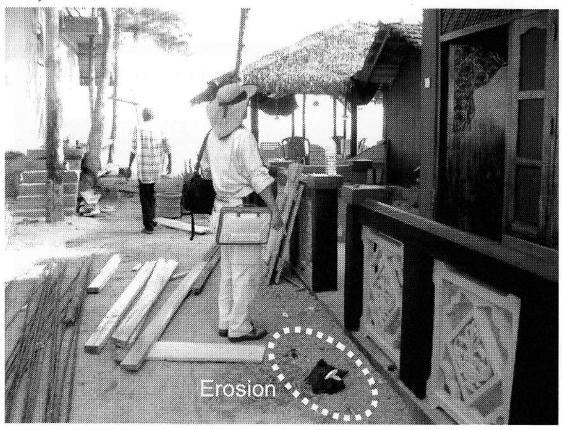

Figure 4: Place where a Hole Was Created (S2)

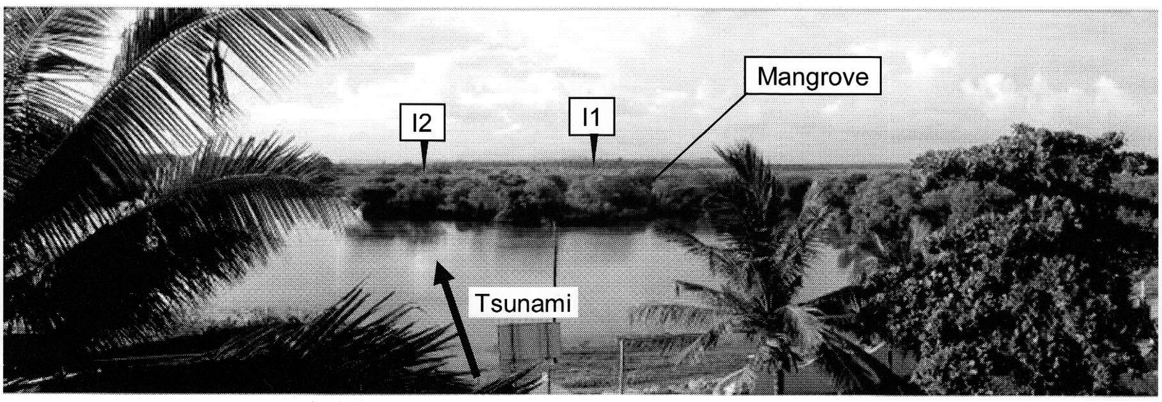

Figure 5: View at S2 and Direction of Tsunami

had been broken by the tsunami. About 5 cm of black soil from the sea was deposited on the first and second floors, and there was more soil deposited on the second floor than there was on the first floor.

All the furniture had been washed away, and so were 30 *Cocos nucifera* trees. However, there was no driftwood or floating wreckage.

S3: The building in this area was a house, and there was only one road. The respondent was a man who was staying in the house. The height of the first wave was 210 cm, and its speed was without comparison. The second wave came 20 minutes after the first wave, and from the same direction. Its height was 150–180 cm and its speed was faster than that of the first wave. Up to 60 cm of the surface soil had been washed away to the lagoon. The building was completely destroyed, and all the furniture and 6 *Cocos nucifera* and 3–4 *Azadirachta indica* trees were swept away. However, there was no driftwood or floating wreckage.

S4: The building in this area was also a house, and there was a road and another house between the coast and S4.

The respondent was a man who was staying in the house. The first wave came from the entrance road and proceeded beyond the roof of the front residence to the field. The height of the wave was 180 cm and its speed was without comparison. The respondent had not seen the second wave because he sought refuge. About 15 cm of the sand had come from another seaside garden was deposited in the area. The wall and the roof were broken, and furniture, the refrigerator, and flower beds had been washed away. Trunks of *Cocos nucifera* trees had been uprooted; however, there was no other floating wreckage.

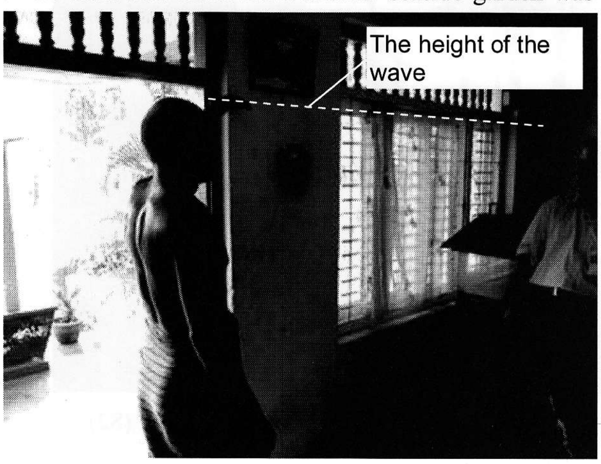

Figure 6 : The Tsunami (First Wave) Reached the Point Indicated by the Line (Interview) (R2)

4.1.2 Road Area

R1: The building in this area was a house. It stretched across the road from the mangrove forest to the west.

The respondent was a woman staying in the house. The first wave had come from the sea; its height was 80 cm and it was not very fast. The woman had not seen the second wave. About 30 cm of black soil from the direction of the coast was deposited in the area. The wall had cracked, and all the furniture and 5 *Citrus aurantifolia* trees were washed away.

Driftwood and floating wreckage were found, and 8 *Cocos nucifera* and 2 *Tectona grandis* trees were withered.

R2: The building in this area consisted of a house and a shop. It was situated in the north along the national road, and stretched across the road from the mangrove forest to the southwest. The respondent was a man who was living in the house. The first wave had come along the road that runs from the coast; its height was 170 cm (the man pointed to the upper end of the entrance (Figure 6)) and its speed was without comparison. The height of the second wave was 230 cm (the respondent said that the wave was higher than the first one) and its speed was without comparison. About 30 cm of black soil from the direction of the coast was deposited along with fish from the sea. The walls of the house had cracked; windows were broken; and all the furniture had been washed away. Fifty trees from the mangrove were uprooted and *Artocarpus hetero phyllus Lam* trees were withered.

R3 (Figure 7)**:** The building in this area was a restaurant with a raised floor that bordered the national road to the north.

The respondents were the man who participated in the first survey and the man who was staying in the neighborhood at the time of the tsunami and had participated in the second survey. The first wave came in after the bank had broken; its height was 60 cm and it was not very fast. The second wave came in mainly from the broken bank and to some extent, from the mangrove forest. Its height was 210 cm that had seen about 200 m

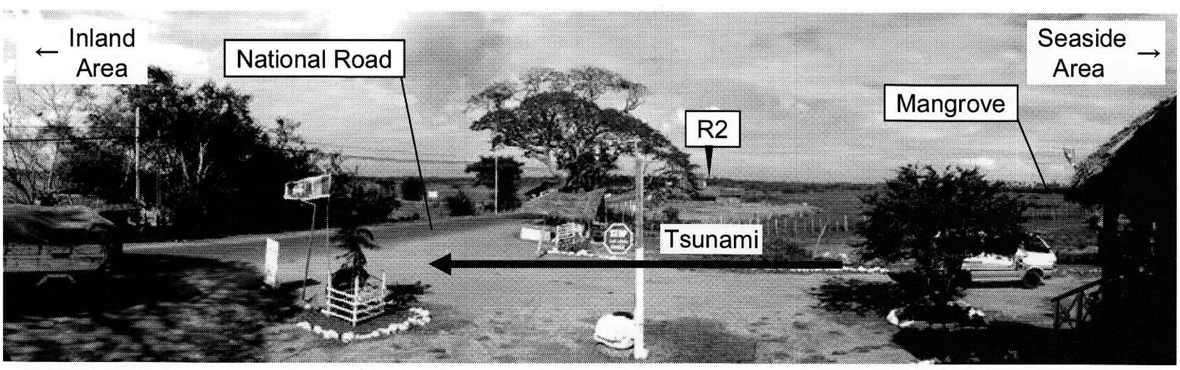

Figure 7: View at R3 and Direction of Tsunami (Road Area)

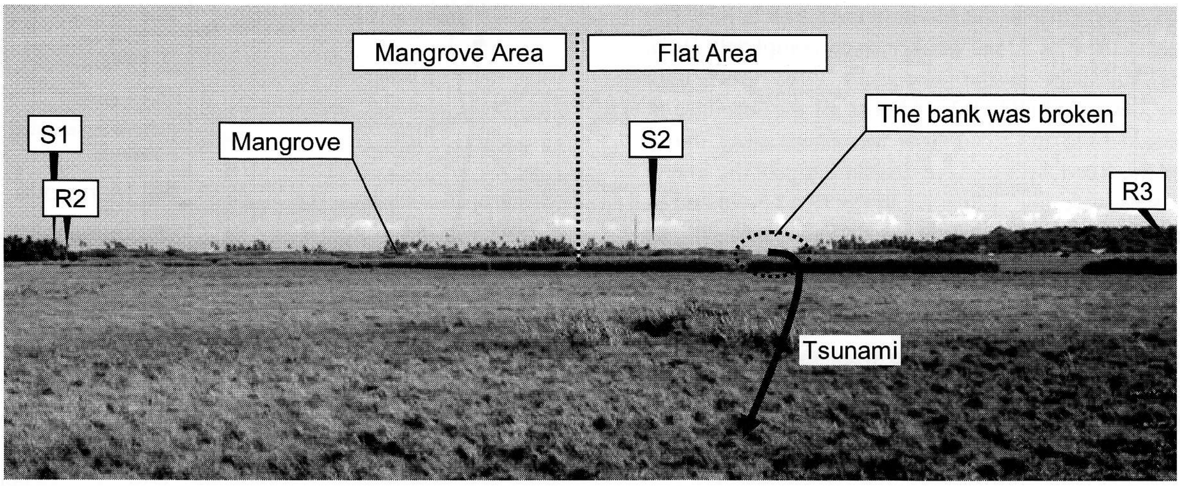

Figure 8: View at I1 and Direction of Tsunami

along and 250 cm in the restaurant, and its speed was without comparison. About 30 cm of black soil that emits a foul smell was deposited in the restaurant from the direction of the coast, and about 60 cm was deposited on the ground. Only the floor and poles of the building were left standing, and all the furniture had been washed away. The floating wreckage consisted of rocks and roots. The refrigerator from the restaurant was also swept away.

4.1.3 Inland Area

I1: The building was a house that was located at the southern end of the village. The respondent was a woman who was living in the house. The first wave came in from where the bank had broken, and reached the road (Figure 8). Its height was 60 cm and its speed was without comparison. Although the wave did not reach the house, furniture, the refrigerator, and corpses were found floating in the paddy fields around the village. Moreover, although *Sonneratia caseolaris* trees were uprooted, trees from the mangroves were not.

I2: The building was a house located at the southern end of the village. Since the respondent was a woman who was not staying in the survey area, her comments were hearsay from her parents, who were residents of the area. The first wave came in from where the bank had broken, and reached the road. Its speed was comparable to that of a bicycle. The wave did not reached the house, and *Sonneratia caseolaris*, *Pandanus odoratissimus*, and *Cocos nucifera* trees and furniture were uprooted and found floating in the fields around the village. The inflow of the wave from the mangrove forest was not confirmed through inspection.

4.2 Results of the geodetic survey

On comparing the height above sea level through level measurement between R2 (Mangrove Area) and R3 (Flat Area), the difference in height was found to be 14 cm; R3 was higher (Figure 9).

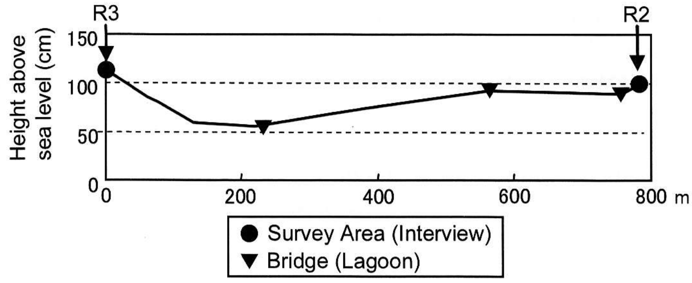

Figure 9: Altitude of National Road (R2~R3)

4.3 Simulation of the direction of the tsunami and damage caused

We arranged a simulation of the direction of the tsunami and damage caused by it as part of the data of the interview survey. In the simulation of the direction of the tsunami (Figure 10), the tsunami flowed from all the coasts, especially from the bank where the mouth of the river was located (between S2 and S3). The inflow of the wave from the Flat Area was confirmed; however, the inflow from the mangrove forest was not confirmed through inspection at L1 and L2. In S4, which was located at the end of the Flat Area, the wave flowed to the flat area. The respondent from S1 was driven out to the Flat Area; he then escaped by running on the road because the intensity of the wave decreased.

The respondent in R3, which is close to the place where the respondent in S1 was driven, said that to some extent, the wave flowed from the Mangrove Area. The height of the first wave was the same as that of ordinary waves, while those of the second and third waves exceeded 2 m in the Seaside Area. The re was a huge backwash between the second and third waves, and there were even backwashes after the third wave. The first wave was not very fast. The speed of the second wave could be compared through the interview survey, because most of the comments about speed were "no comparison." Table 3 shows the damage caused by the tsunami in every survey area. In the Seaside Area, the surface soil was washed away in S1, S2, and S3; however, a little surface soil was deposited near the house that was situated between the coast and S4. In the Road Area, soil that seemed to have come from the sea was deposited; moreover, the degree of deposition in the Flat Area (R3) was higher than that in the Mangrove Area (R1, R2). The building in the Flat Area was destroyed completely (R3), but the buildings in the Mangrove Area were only partially destroyed (R1, R2). Almost all the furniture in the Seaside Area and Road Area was swept away, and it reached the Road Area and the surroundings of the Inland Area. Trees were found floating in the Road Area and in the surroundings of the Inland Area. The species of the trees was mainly *Cocos nucifera*. Furthermore, while the inflow of waves from the mangroves was confirmed in the Road Area, the inflow was not confirmed in the Inland Area. Driftwood resulting from the backwash in the Seaside Area (S1) did not consist of trees from the mangroves but of *Cocos nucifera* trees.

5 Discussions and Conclusion

On comparing the Mangrove Area and Flat Area, it was found that the distance from the coast and height above sea level were the same; however, the direction of waves and extent of damage caused to buildings differed. In addition, when we consider the fact that the waves flowed from the Flat Area in the Inland Area, it seemed that the mangrove forest mitigated the intensity of the tsunami waves. Similarly, the intensity of one wave decreased to the extent that the respondent in S1 who was

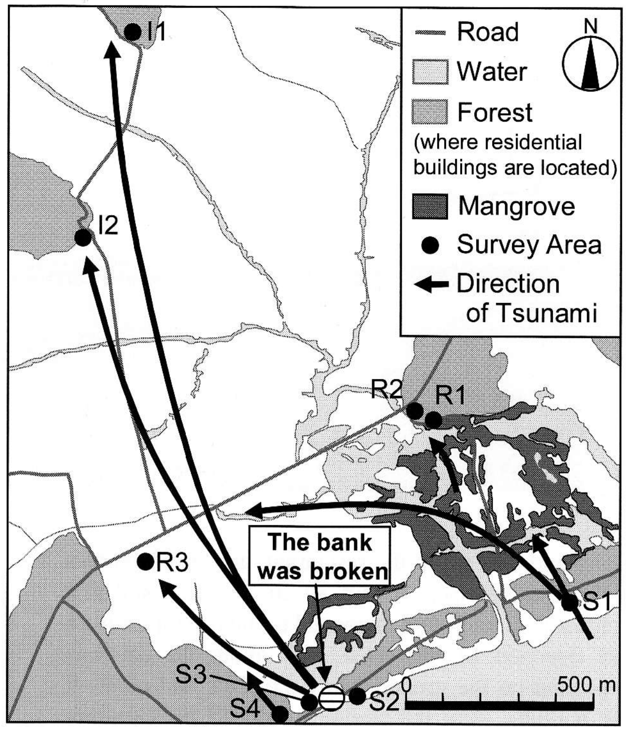

Figure 10: Direction of Tsunami (Pattern diagram)

Table 2: Height and speed of tsunami

Survey Point	The first wave		The second wave		The third wave	
	Height	Speed	Height	Speed	Height	Speed
S1	-	same as that of a normal wave	300	no comparison	1,050	faster than the second wave
S2	30	not so fast	350	no comparison		
S3			210	no comparison	180	no comparison
S4			180	no comparison	-	not see
R1			80	not so fast	-	not see
R2			170	no comparison	230	faster than the first wave
R3			60	not so fast	250	faster than a car
L1			60 ※1	no comparison		
L2			150 ※1	level of bicycle		

unit: cm

※1 did not enter the house

Table 3: Earth and sand movement and damage caused to residential buildings

Survey Area	Earth and sand movement			Damage caused to residential buildings		
	Deposition/erosion	Height	Direction	Damage to buidling	Outflow	Inflow
S1	▼	120	to inland and sea	◎	all	-
S2	▼	300	to inland	◎	furniture	-
S3	▼	60	to inland	◎	all	-
S4	△	15	from sea	○	furniture	-
R1	△	30	from sea	○	furniture	-
R2	△	30	from sea	○	furniture	-
R3	△	60	from sea	◎	furniture	rocks, refrigerator
I1※	-	-	-	-	-	furniture, corpses
I2※	-	-	-	-	-	furniture

unit: cm
※around the village

△: deposition
▼: erosion
- : no change

◎: conpletely destroyed
○: partially damaged
- : not damaged

driven out from the mangrove forest managed to find safety near R3, where the building was destroyed completely. A comparison of the change in the surface soil revealed that the degree of deposition in the Mangrove Area was lower than that in the Flat Area. Thus, it seemed that the mangrove forests heap of earth and sand and reduced the inflow to residence. As a result, it was confirmed that during a tsunami, mangrove forests can mitigate the intensity of waves and reduce the inflow of earth and sand. Therefore, in the future, it is necessary to emphasize the conservation of mangroves in order to reduce the damage caused by a tsunami.

6 Acknowledgements
We would like to express our thanks to everybody cooperated in investigation, especially Mrs. Anke Sandel for providing pictures (Figure 3). This research was conducted using the Grant-in-Aid for Science Research No. 18255007.

Note
1. The administrative divisions in Sri Lanka were classified in the following order: GN Division (Grama Niladhari Division), DS Division (Divisional Secretariat Division), District, and Province [2]. Medilla (GN Division) belongs to Tangalla (DS Division), Hambantota (District), South Province.

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