The existence of coastal forest, its implication for tsunami hazard protection, a case study: in Cilacap-Central Java, Indonesia

Keberadaan hutan pantai, implikasinya untuk pencegahan bahaya tsunami, studi kasus di Cilacap, Jawa Tengah Indonesia

Yudhicara

Geological Agency

Jl. Diponegoro 57 Bandung 40122, West Java, Indonesia, Corresponding e-mail: yudhicara@yahoo.com

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ABSTRACT: The southern coast of Java which is facing to the Indian Ocean has many of natural hazard potential come from the sea. Since 2006 tsunami impacted the southern coast of Java, and caused severely damage especially along the coast of Cilacap (1-7,7 m run up height). People commit to do greening the beach by planting suitable plants such as a Casuarina equisetifolia, Terminalia catappa, and Cocos nucifera. This paper discusses the existence of coastal forests in Cilacap coastal area, their potential ability as a coastal protection from the tsunami wave which cover the density, diameter, height, age, and other parameters that affects the coastal defence against tsunami waves. Some experiences of tsunamis that have occurred, indicating that the above parameters linked to the ability of vegetation to act as a natural barrier against tsunamis. In the case of sandy beaches, such as in Cilacap, Pandanus odorarissimus has more effectiveness than other trees due to its hanging roots that can withstand the tsunami height less than 5 m, able to withstand debris and can withstand the scouring effects of tsunami waves, while Casuarina equisetifolia along Cilacap beaches more dominant than other trees, so it is recommended to increase the diversity of plants as well as increase the density and tree placement setting. By field measurement in order to get parameter applied to some graphs, Cilacap coastal forest does not enough capability for tsunami barrier reflected to the tsunami height experience in this region. Ages could be the important parameter in order to have bigger diameter trunk, higher trees height, and high resistance capacity againts tsunami hazard potential. Compare to Kupang, East Nusa Tenggara, Cilacap coastal forest still young and need some more years to make trees ready act as tsunami reduction.

Keywords: Cilacap coastal forest, Kupang, tsunami, vegetation parameters.

ABSTRAK: *Pantai Selatan Jawa yang berhadapan dengan Samudera Hindia, memiliki banyak potensi mengalami bahaya yang datang dari lautan. Selama tahun 2006, Tsunami telah menimpa sebagian pantai selatan Jawa dan menyebabkan banyak kerusakan parah terutama di sepanjang Pantai Cilacap (tinggi gelombang 1 – 7,7 m). Masyarakat melakukan penghijauan pantai dengan menanam sejumlah pohon yang sesuai dengan kondisi pantai, seperti pohon cemara pantai (Casuarina equisetifolia), ketapang (Terminalia cattapa) dan kelapa (Cocos nucifera). Tulisan ini membahas penyebaran hutan pantai di wilayah pantai Cilacap, kemampuan dan potensi hutan tersebut sebagai pelindung alami pantai dari bahaya gelombang tsunami, yang terdiri dari kerapatannya, diameter, tingginya, umur, dan parameter lainnya yang mempengaruhi daya tahan pantai terhadap gelombang tsunami. Beberapa pengalaman mengenai kejadian yang telah terjadi, memperlihatkan bahwa parameter tersebut di atas mempengaruhi kemampuan tanaman sebagai penahan alamiah terhadap tsunami. Untuk kondisi pantai berpasir seperti Cilacap, tanaman pandan pantai lebih efektif dibandingkan dengan tanaman lainnya, dikarenakan akarnya yang dapat menahan tinggi gelombang kurang dari 5 m, selain itu akar tersebut dapat menahan material dan erosi vertikal gelombang tsunami, sementara di sepanjang pantai Cilacap, tanaman cemara pantai (Casuarina equisetifolia) lebih dominan dibandingkan tanaman lainnya. Kondisi ini dapat direkomendasikan untuk tetap dipertahankan bahkan ditambah jumlahnya. Di lapangan dilakukan pengukuran parameter tanaman pantai dan hasilnya diplot dalam bentuk grafik dan diaplikasikan dalam grafik yang dibuat berdasarkan hasil penelitian terhadap tsunami di beberapa tempat di dunia terutama di Jepang. Berdasarkan tinggi gelombang maksimum yang pernah terjadi di daerah ini (7,7 m), terlihat bahwa hutan pantai Cilacap belum cukup mampu bertindak sebagai penahan gelombang tsunami. Umur merupakan parameter penting agar pohon memiliki diameter yang besar, pohon yang cukup tinggi dan daya tahan terhadap potensi bahaya tsunami. Dibandingkan dengan hutan pantai di Kupang, Nusa Tenggara Timur, hutan* *pantai di Cilacap relatif masih muda dan membutuhkan beberapa tahun lagi untuk dapat memperkecil resiko yang ditimbulkan oleh bahaya tsunami.*

Kata kunci: *Hutan pantai Cilacap, Kupang, tsunami dan parameter vegetasi.*

INTRODUCTION

Cilacap is a region in the Central Java province that has community predominantly living along the southern coast. Cilacap is an important region because it connects West Java, Central Java, Yogyakarta, East Java and other regions in the Eastern of Indonesia.

Iron sand, which is one of the major constituent of Cilacap coastal sediments, is a major mining commodity in this area since long time ago and even still continues nowadays. The progradded coastal type of Cilacap has causing the presence of iron sand spread throughout mainland surround Cilacap region. The iron sand mining along the coast causes scarcity of trees as used throughout for the business of mining. Scarcity of trees can be a cause of the vulnerability of coastal areas as its roles as barrier againts dangers of the ocean waves.

On July 17, 2006, a magnitude Mw 7.7 earthquake has been occurred and produced a tsunami that hits Cilacap and surrounding areas, and caused many casualties and damages on infrastructures. Based on the testimony of several witnesses, some of them have been saved by the existing trees on the crossing way when they evacuated. One family even saved by the only palm tree with 2 m height from the ground.

This paper will describe on vegetation condition in Cilacap region, its existence against tsunami hazard that may occur in the future.

General Review

Tectonically, Java island is controlled by a main tectonic system of subduction between the Indo-Australian and Eurasian plates. There were many earthquakes occured in the region due to this system and some of them causing tsunami. One of them is the last tsunami event of 17 July 2006 caused by Mw7.7 earthquake attacked most of the southern coast of Java, including Cilacap, which has about 8 m of tsunami maximum height and inundated up to 1.5 km inland and swallowed dozens of casualties.

In general, Cilacap is a low-lying topography with a gentle slope, whereas in the old beach ridge located east-west leads to a decline in the topography may be due to deposition of sand content below the surface. The appearance of the field indicates that this type of coastal area of ??research is "prograded coast" indicate lack of balance between the sedimentation and coastal erosion, thus the formation of the beach is now looping back than the old beach ridge sediment deposition in the north Cilacap (Yudhicara et. al., 2008).

Several river flow patterns that develops in this area shows radiating in the far north and west. In the area of the old beach ridge pattern is parallel to follow the flow of long beach, north Kroya are aligned in the flow of Kali Bengawan and Kali Ijo (Dewi, 2010).

According to Naval Hydrooceanography (2007), tides at Cilacap has interval between 0.4 and 1.4 m, while wave has 2-3 m high and oblique to the coastline; longshore current dominantly comes from southeast (sometimes come from the west especially on October-December (wet season). Current come from the southeast is often called as *"south equatorial current"* from Australia to Indian Ocean (Shepard, 1973). While longshore current has the most frequently moves in the opposite direction of the ocean currents, it is probably caused by the presence of a barrier of the island of Nusa Kambangan in the western and Ayah hills in the eastern of Cilacap.

The study area is located in the middle of the southern coast of Cilacap (Figure 1), the region is included to Cilacap sub-district and the forest is taking place at Selok, the place where impacted by the 17 July 2006 tsunami and has the maximum tsunami run up up to 7.7 m (Kongko et. al., 2006).

The place is the location of the 17 July 2006 tsunami source take place (Figure 2). There were big earthquakes have ever occured in this area and causing tsunami (1859, 1904, 1957 and 1973) (WinITDB, 2007) as mentioned in Table 1.

According to Mori et al. (2007) the tsunami run up reach up to 7.7 m height (Figure 3) at Selok, with velocity of 256 km/hr, 3 waves come inland and the second was the highest. Inundation distance was ~500 m caused 18 deaths and one family saved by the 2 m palm tree (survivor testimony).

METHODS

Just one year after the tsunami event, many of institution gave contribution on greening the coastal area to protect from the tsunami hazard that may come in the future. Not only in Cilacap, also in Pangandaran, but this study will discuss about the plants which have planted along the Cilacap coastal area.

RESULTS

Here, various trees such casuarina equisetifolia, terminallia catappa, and cocos nucifera had been planted. Casuarina equisetifolia is plant that could absorp salt so rice field could grow behind the forest, growing fast, salt water tolerance, could live at sandy

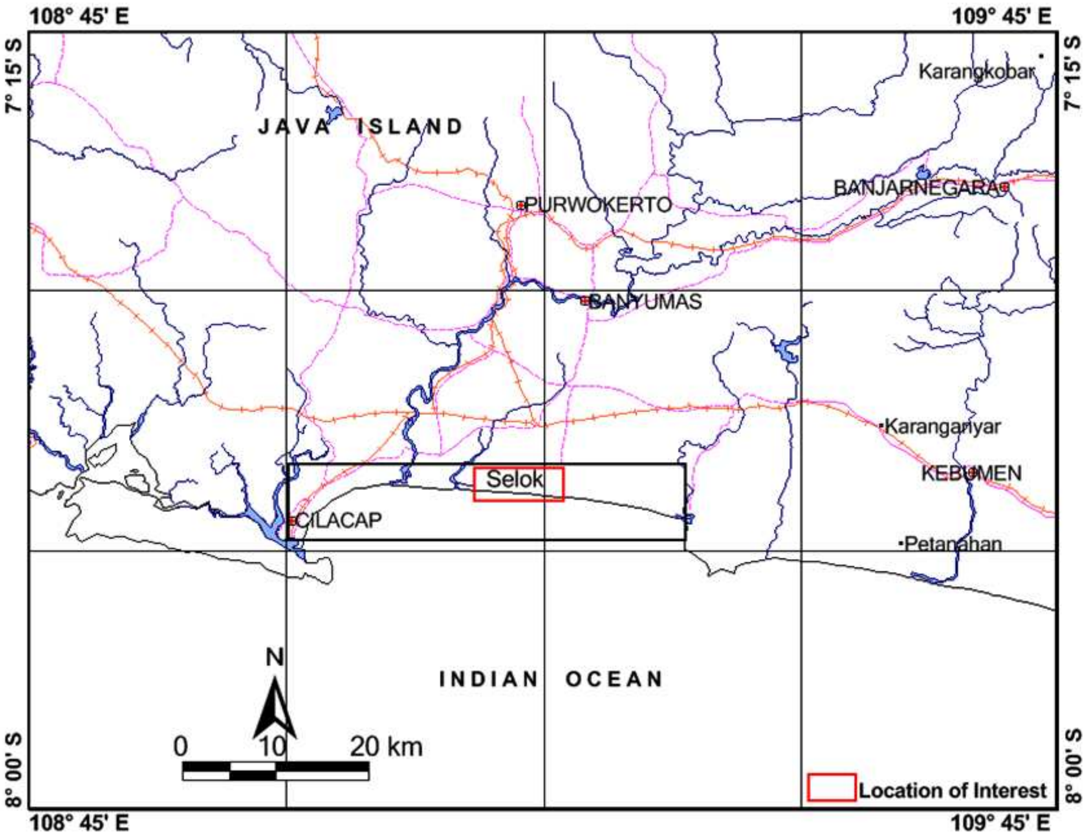

Figure 1. Study area Cilacap and location of interest (Selok)

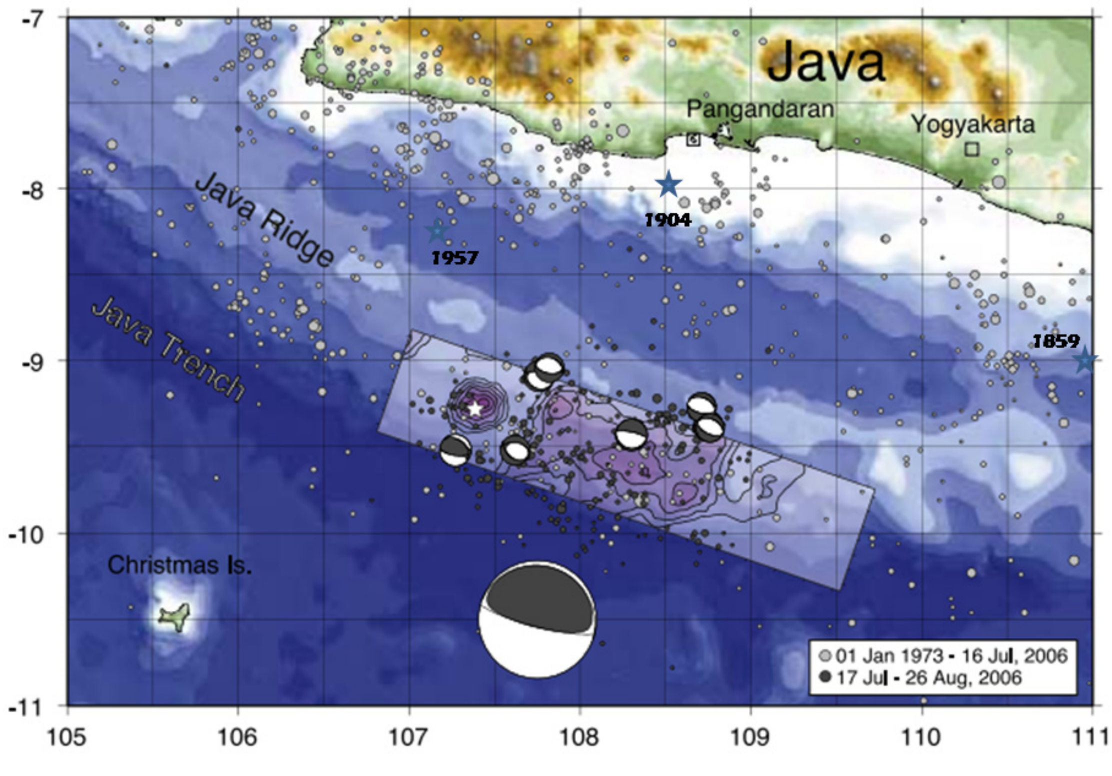

Figure 2. Focal mechanism of the main shock and aftershocks of the 17 July 2006 earthquake (Modified from: Ammon et al., 2006).

Table 1. Historical Tsunami event in the south of Java (WinITDB, 2007).

DATE	POSITION		DEPTH (km)	MAG. (Ms)	MAX. TSUNAMI HEIGHT (m)	LOCATION
	LAT	LONG				
1 April 1840	7.40	110.00	150	7.0	-	Southern Java
20 October 1859	9.00	111.00	33	-	-	Southern Java
7 September 1904	8.00	109.00	33	-	-	Cilacap, Southern Java
26 September 1957	8.20	107.30	33	5.5	-	Southern Java
17 July 2006	9.33	107.27	10	7.7	7.5	Pangandaran_

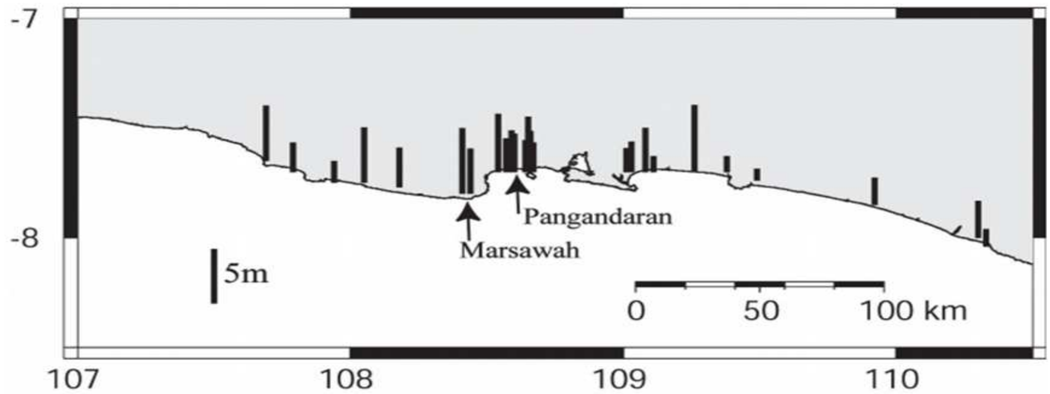

Figure 3. Tsunami run-up heights of 7.7 was measured by Kongko et al. (2006) and Ministry of Marine Affairs and Fisheries et al. (2006) in Mori et al., 2007

environment, has 20-40 maximum height; while Terminalia catappa has the maximum of of 20 m height.

Vegetation ages are ~ 4 years old; Forest area was 80 m x 400 m at one side; recently reduced width caused by sand mining activity; Measuring area 60 m x 120 m; Average height 12.4m.

Beach profiling was measured by total station, corrected by daily tides prediction, and beach slope measured by geological compass. Plant parameters such as vegetation density, stem diameter (at breast height for tree-types vegetation or ground level for smaller types), spacing, and height were measured by a hypsometer and measuring tape.

The forest is located at about 12.1 m from the shoreline, behind 1.8 m height dunes. Consist of variastion of three types of trees, such as Casuarina equisetifolia, Terminalia cattapa and Cocos nucifera (Table 2), located in an area of 80 m x 400 m. Recently, it has been reduced by sand mining activity, hence the measuring area is 60 m x 120 m (0,72 Ha). Below is a table shows the range of trees measurements.

According to Tanaka et. al. (2010) coastal vegetation can reduce tsunami forces by it's survival capacity. The survival capacity of a coastal vegetation belt depends on the single-tree capacity within the belt. The effective resistance decreases along with decrease in survived tree numbers (Shuto [1987]; Tanaka et al. [2007, 2008]; Yanagisawa et al. [2008]). Once trees are broken or collapsed, they have no longer capable of reducing tsunami force. Yanagisawa et al. [2008] concluded that until the mangrove trees were destroyed by tsunami they possibly acted as a resistance against tsunami flow, however, the reduction of tsunami energy during tree destruction process is considered to be minor because tsunami has a long wave period and penetrates continuously across the vegetation belt area long after the trees have been destroyed.

The investigation results of Tanaka et. al., (2006) and Shuto (1987), are applied to analyze the capacity of the existence coastal forest in the study area. We compiled our tree measurements to a graph in order to know the relationship between tree's height and tree's spacing. According to this graph, Casuarina equisetifolia which has average height of 12.4 m should have an average tree spacing of 2.6 m (Figure 5). Using this result, it can determine the number of trees per unit square by the following approach:

Casuarina, 12.4 m height,
(tree/m^2) = 1.000/(average spacing)^2= 1.000/(2.6)^2 = 0.148
(tree/100m^2)= 100 x 0.148 = 14.8

Based on the calculation, it can be arranged for unit square is ~ 15 trees.

Figure 4. Casuarina equisetifolia forest are planted in front of rice field face to the ocean.

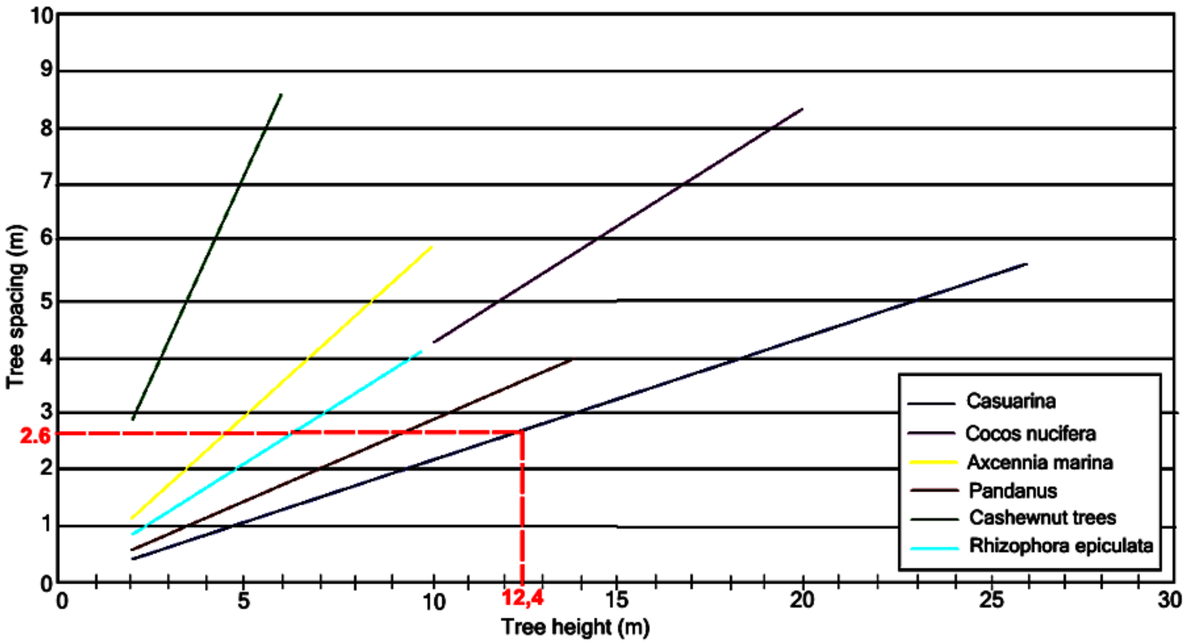

Figure 5. Relationship between tree height and tree spacing (Tanaka et. al., 2006)

Table 2. Vegetation parameters of Selok coastal forest.

A. Species	B. Range of height (m)	C. Average trees height (m)	D. Range of stem diameter (cm)	E. Average stem diameter (cm)	F. Space (m)	G. Amount of trees in 0,72 Ha	H. Density (m^3/ha)
Casuarina equisetifolia	8 – 18		6 – 20	20	3 – 4	340	0,0472
Cocos nucifera	3 – 4		17 – 45	35	5 – 10	12	0,00167
Terminalia cattapa	3 – 7		5 – 11	10	10 – 15	38	0,00528

Tree height information is very important to analyze breaking moment to work onto trees trunk diameter (Tanaka et. al., 2007). Degree of damage to tree in term of trunk diameter and tsunami height above the ground surface according to Shuto's graph (1987), Cilacap coastal forest located on the area that trees has potential to be cut off and has no effect against tsunami.

According to the average tree diameters, Cilacap coastal forest has potential of has broken when tsunami heigh reach 5 m (Figure 7).

According to the width of forest and tsunami flow depth, Cilacap coastal forest could reduce tsunami velocity and cause no damage to the forest.

According to the effect to coastal topography, based on beach profiling measurement (Table 3), Cilacap coasal forest at Selok has land slope steeper

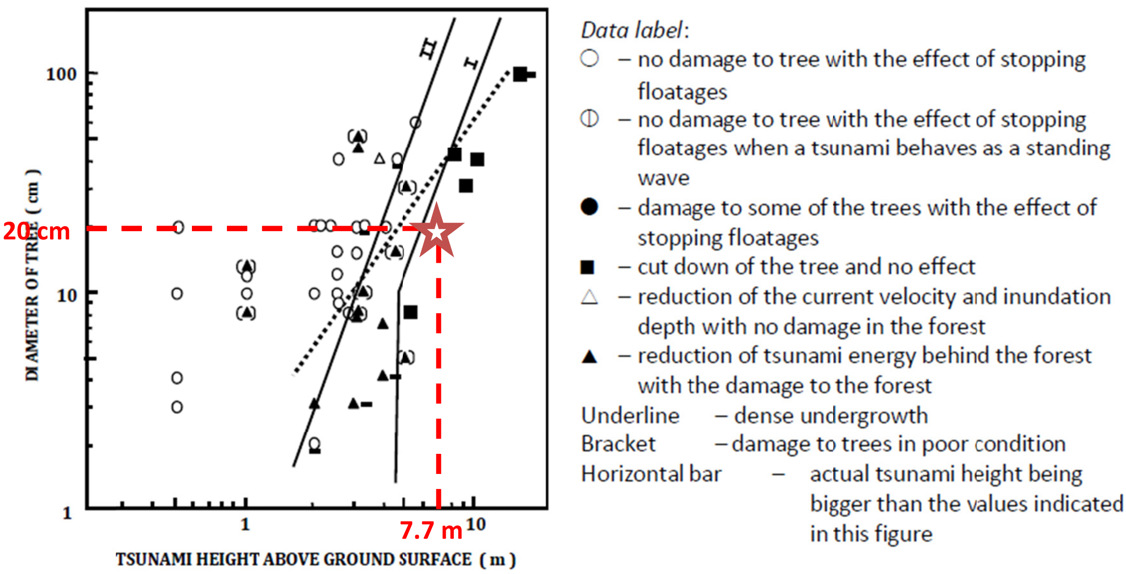

Figure 6. Degree of damage to tree in term of trunk diameter and tsunami height above the groung surface (Shuto, 1987)

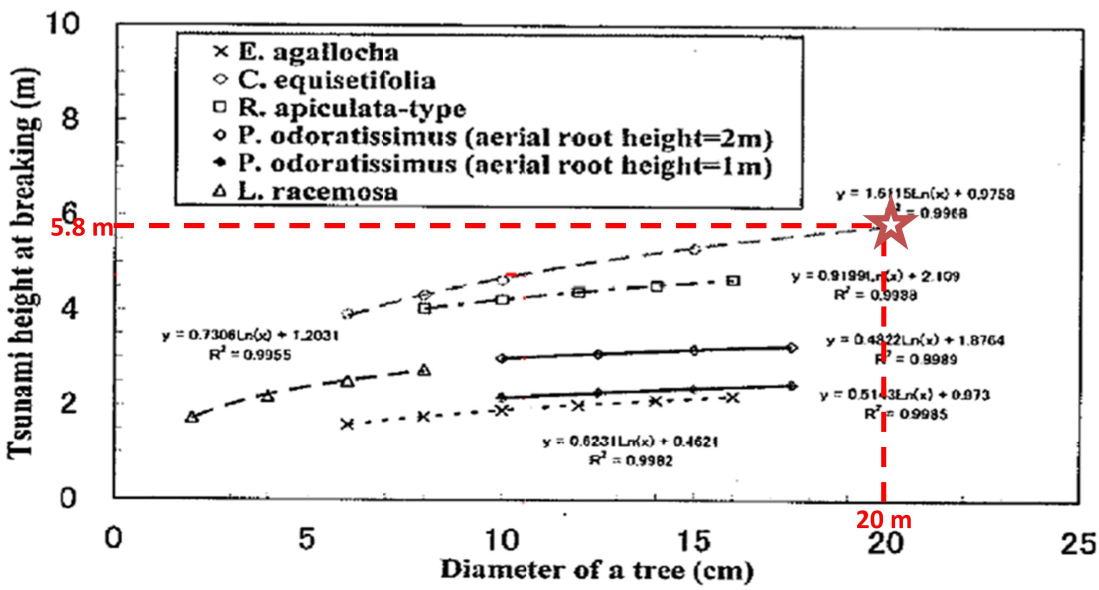

Figure 7. Relation of trees diameter and tsunami height at breaking (Tanaka et.al., 2006)

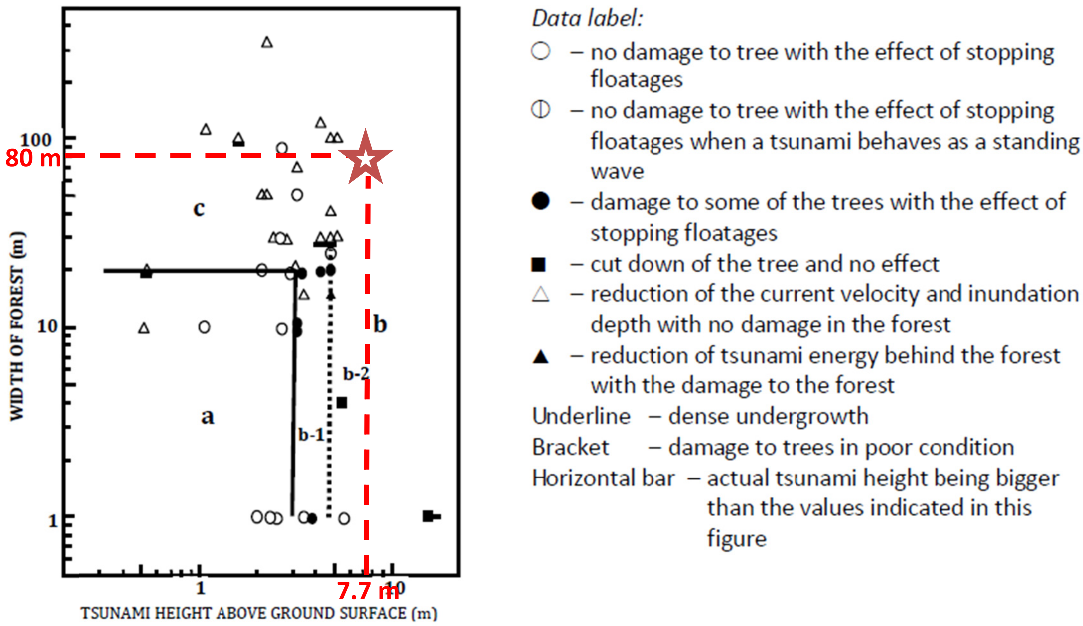

Figure 8. Effect of vegetation width to the tsunami height (Shuto, 1987).

Table 3. Beach profile along the coast of Cilacap (Yudhicara et.al., 2008)

NO	LOCATION	LONGITUDE (o)	LATITUDE (o)	MSL (m)	HOR. DIST (m)	BEACH SLOPE(o)	HEIGHT DIFF. (m)	HD-MSL
1	Pel. Cilacap	108.9968	7.72769	1.2	14.1	-	1.5	0.3
2	Tambakreja	108.99699	7.74167	1.2	9.8	-	1.2	-0.01
3	Sentolo	109.01968	7.74892	1.3	47.7	6	2.7	1.4
4	Teluk Penyu	109.02194	7.73284	1.3	50.6	6	1.9	0.7
5	Tegalrejo	109.031	7.71664	1.3	22.2	13	3.3	2.0
6	Lengkong	109.06754	7.69308	1.3	60.0	10	3.7	2.3
7	Gombolharjo	109.08744	7.68451	1.3	26.4	3	1.1	-0.2
8	Bunton	109.14326	7.69	1.1	99.0	3	4.4	3.3
9	**Selok**	**109.1842**	**7.69218**	**1**	**92.1**	**2**	**2.8**	**1.8**
10	Widarapayung	109.26389	7.69801	0.8	139.1	3	3.9	3.1
11	Pagubugan	109.29619	7.70211	0.7	75.0	3	2.7	1.9
12	Karang Pakis	109.33714	7.70889	0.5	144.2	3	2.8	2.3
13	Jetis	109.36985	7.71637	0.4	107.8	2	2.8	2.4

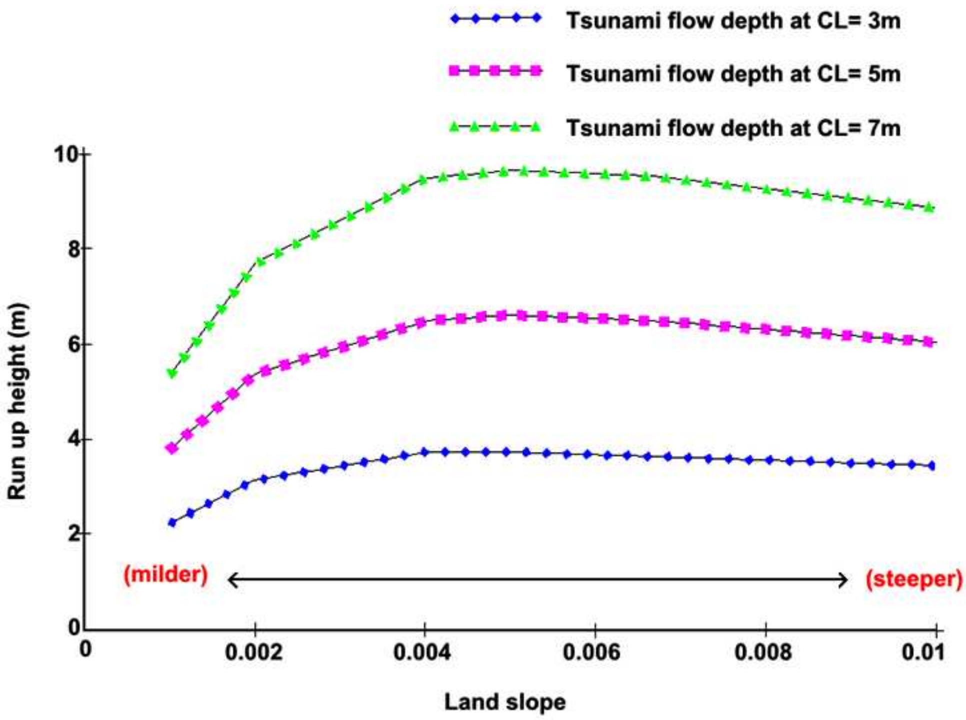

Figure 9. Effect to coastal topography

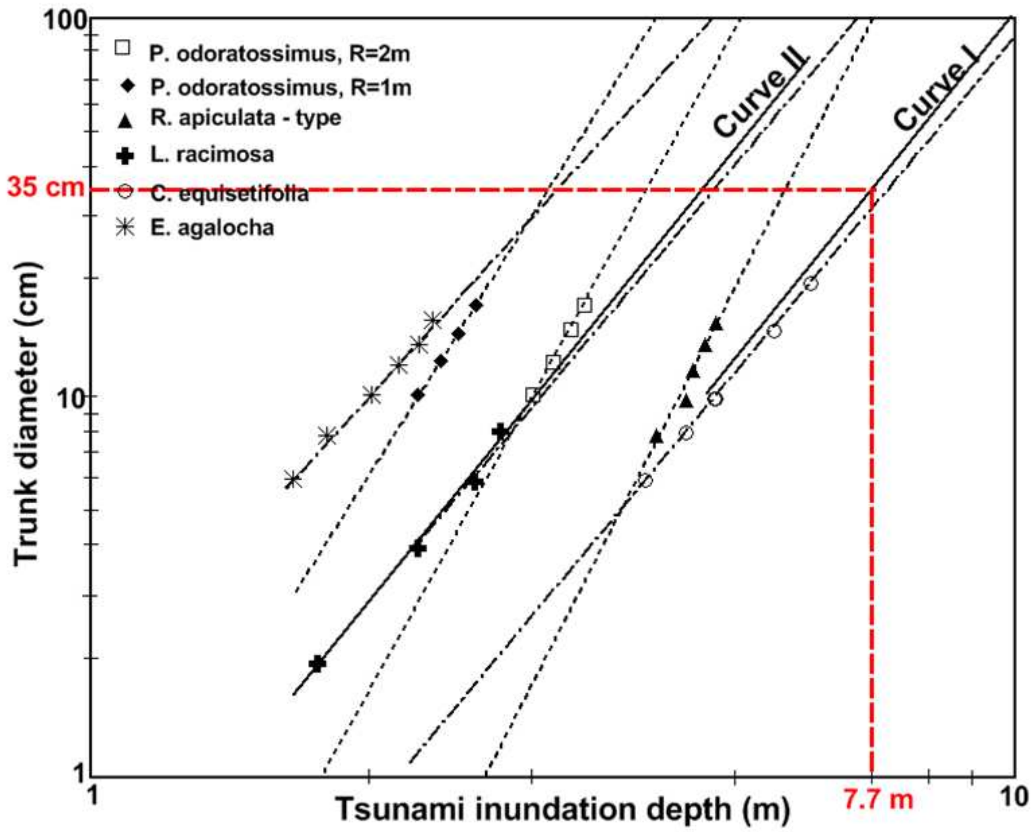

Figure 10. The maximum limit of trees capacity againts tsunami force (Shuto, 1987 and Tanaka et.al., 2006)

Figure 11. Coastal forest of Borassus flabellifer at Lasiana (left) 60-70 years old, and Nunsui (right) has 100 years old (Kurniapraja et.al., 2013).

Table 4. Vegetation parameters of Kupang coastal forest

SPECIES	RANGE OF HEIGHT (m)	RANGE OF STEM DIAMETER (cm)	SPACE (m)	DENSITY (m^3/ha)	AMOUNT OF TREES IN 153 ha
Borassus flabellifer	8,8 – 16	33 - 55	4 – 21	0,023	353
Pithecello dulce	8,5 – 13,3	26 – 51,2	10 – 15		300
Canarium caudatum	6 – 13,5	26,7 - 75	1.74 – 5.9		165

SPECIES	RANGE OF HEIGHT (m)	RANGE OF STEM DIAMETER (cm)	SPACE (m)	DENSITY (m^3/ha)	AMOUNT OF TREES IN 0.72 ha
Pithecello dulce	8,5 – 13,3	26 – 51,2	10 – 15		300
Canarium caudatum	6 – 13,5	26,7 - 75	1.74 – 5.9		165

(0.019), but recently dune has potentially removed due to sand mining activity.

Dunes could act as barrier to protect infrastructures behind it, and could dissipate tsunami energy. But it has potentially removed due to mining activity that dig it out to fill in the area after mining.

According to the maximum limit of trees capacity against tsunami force, Casuarina equisetifolia has the maximum breaking capacity ~35 cm of tree diameter, so Cilacap forest has not enough capacity againts tsunami forces and need some years to make tree diameters wider, and bigger.

Other parts of Cilacap coastal area has noforest so tsunami wave could inundate farther inland

To see how the capacity of coastal forest in Cilacap providing coastal protection against tsunami hazards, in this study, we made comparison with another coastal forest located at Kupang, East Nusa Tenggara. We select two locations which have coastal forest, such as Lasiana and Nunsui, at Kupang city. Coastal forest of Borassus flabellifer at Lasiana, Kupang, has 60-70 years old. Forest area is 153.14 ha (38 m width and 403 m length). We made vegetation parameters measurement (Table 4).

By assuming the same tsunami height as in Cilacap (7.7 m), Kupang coastal forest has trees diameter and forest width which could stop floatages and trees will have no damages. Coastal forest of Borassus flabellifer has 100 years old at Nunsui, Kupang. Here, forest area is ~200 ha (75 m width and 267 m length), has height 10 – 12.5 m; trunk diameter 37 – 54 cm; spacing of 1.26 – 4 m; number of tress about 400; density of 0.026 m.

There is a 30 years old coastal forest of mixing trees species (Tamarindus indica, Pithecellobium dulce, Ficus benjamina, Hibiscus aliaceus, Cocos nucifera and Canarium caudatum (Figure 12).

Figure 12. Forest of mixing trees species (Kurniapraja et.al., 2013)

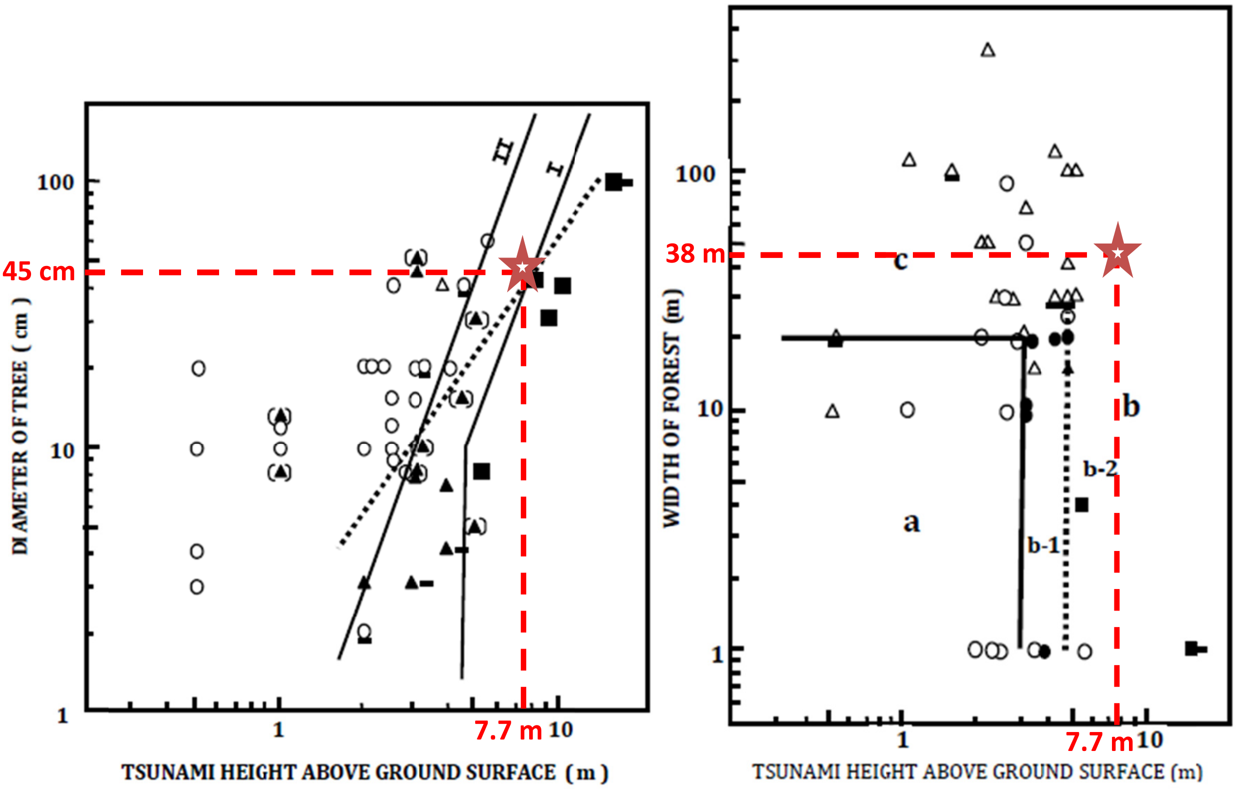

Figure 13. Degree of danage to tree in term of tree diameter (left) and width of forest (right) to the maximum tsunami height.

CONCLUSION

Cilacap costal forest still young (4 years old) has not enough trees parameter to fulfill requirement as tsunami risk reduction. It will need some years to have enough criteria to protect the coast againts tsunami forces.

Other structures (e.g. Dunes) could be the good combination to reduce tsunami flow velocity, flow pressure and flow depth. So it has to be conservated (e.g. Stop sand beach exploration!).

Since Cilacap is a tsunami prone areas, so designing an appropriate coastal forest along the coast become very important. Older forest ages like in Kupang give chance to trees to have bigger diameter, bigger height, supported by appropriate trees spacing and forest density, make this area has a good model as a tsunami hazard protection.

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REFERENCES

[1] Ammon, C.J., Kanamori, H., Lay, T., and Velasco, A.A., 2006. The 2006 Java Tsunami Earthquake. Geophysical Research Letters, Vol. 33, L24308, doi: 10.1029/2006GL028005.2006.

[2] Dewi, R.S., 2010. A GIS-based approach to the selection of evacuation shelter buildings and routes for tsunami risk reduction, a case study of Cilacap coastal area, Indonesia. http://www.itc.nl/library/papers_2010/msc/aes/dewi.pdf.

[3] Indonesian Naval Hidro-Oceanography, 2007. Annual tides prediction of 2008. Jakarta.

[4] Kongko, W., Suranto, Chaeroni, Aprijanto, Zikra, Sujantoko, 2006. Rapid Survey on Tsunami Jawa 17 July 2006.

[5] Kurniapraja, N., Yudhicara, Supartoyo, 2013. Laporan Pemetaan Kawasan Rawan Tsunami wilayah Kupang, Nusa Tenggara Timur, Internal Report, Unpublished.

[6] Ministry of Marine Affairs and Fisheries, 2006. Jawa tsunami 2006.

[7] Mori, J., Mooney, W.D., Kurniawan, S., Anaya, A.I., and Widiyantoro, S., 2007. The 17 July 2006 Tsunami Earthquake in West Java, Indonesia, Seismological Research Letters, Volume 78, Number 2, March/April 2007.

[8] Sheppard, F.P., 1973. Submarine Geology, 3rd ed., p. 102-122. Harper & Row, New York.

[9] Shuto, N., 1987. The effectiveness and limit of tsunami control forest. Coastal Engineering in Japan, 30 (1): 143-153.

[10] Tanaka, N., Sasaki, Y., Mowjood, M.I.M., Jinadasa, K.B.S.N., and Homchuen, S., 2006. Coastal vegetation structures and their functions in tsunami protection: experience of the recent Indian Ocean tsunami, International Consortium of Landscape and Ecological Engineering and Springer 2006.

[11] Tanaka, 2007, N., Sasaki, Y., Mowjood, M.I.M., Jinadasa, K.B.S.N.., Homchuen, 2007, Coastal vegetation structures and their functions in tsunami protectionL Experience of the recent Indian Ocean tsunami. Landscape and Ecological Engineering 3: 33-45.

[12] Tanaka, N., 2008. Effect and limitations of coastal vegetation in Tsunami Protection: Points for Mitigation and future planning, Lecture material of comprehensive tsunami dis. Prev. Training course, workshop on coastal forest for tsunami disaster mitigation, ICHARM, Tsukuba, Japan.

[13] Tanaka, N., 2009. Vegetation bioshields for tsunami mitigation: Review of effectiveness, limitations, construction, and sustainable management, Landscape and Ecololgical Engineering 5: 71-79.

[14] Tanaka, S., Istiyanto, D.C., Kurtbayashi, D., 2010. Planning and design of tsunami-mitigative coastal vegtation belts. Technical note of PWRI, No. 4177.

[15] WinITDB/WRL, 2005. The Integrated Tsunami Database for the World Ocean Version 5.15 of July 31, 2005. CD-ROM, Tsunami Laboratory, ICMMG SD RAS, Novosibirsk Russia.

[16] Yanagisawa, H., Koshimura, S., Goto, K., Miyagi, T., Imamura, T., Ruangssamee, A., and Tanavud, C., 2009. The reduction effects of mangrove forest on a tsunami based on field surveys at Pakarang Cape, Thailand and numerical analysis, Estuarine, Coastal and Shelf, 81,27-37. http://dx.doi.org/10.1016/j.ecss.3008.10.001

[17] Yudhicara, Suantika G., Baheramsyah, I., and Robiana, R., 2008. Laporan Pemetaan Zona Rawan Tsunami di Kawasan Pantai Cilacap, Provinsi Java Tengah, Internal Report, Unpublished.