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A proposal for tsunami mitigation by using coastal vegetations: Some findings from southern coastal area of Central Java, Indonesia.

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Abstract

This research was conducted at the southern coastal area of central Java Island, Indonesia. It is aimed to identify several coastal vegetation characteristics for development of guideline for planning and design of tsunami mitigation. Survey method was applied to observe common coastal vegetation in the research area. Data collected from the survey consisted of vegetation parameters and coastal morphology. All selected vegetations were analyzed for their allometry relation of each species, maximum density, correlation between breaking moment and trunk diameter of each tree species, and correlation between trunk diameter and spacing between trees for each species. For coastal morphology, it was focused on topography and elevation from sea level.

The results show that trees with the hard wood will be stronger to hold the pull moment on the main trunk. Younger trees with smaller diameter tend to be more flexible, thus they will unbreakable during the test. The other trees which have flexible trunk such as T*erminalia catappa* and *Anacardium occidentale* were often pulled out their roots than broken on their trunks. To obtain more extensive characteristic, it is necessary to carry out advanced measurements, especially on the older trees which have more than 10 cm diameter.

Coastal areas consist of mud and sand materials tend to have a high tsunami risk, although mitigation treatments were different for both types. At the muddy area, the recommended vegetation are *Avicennia marina* and *Rhizophora mucronata*, meanwhile *Casuarina equisetifolia* and *Anacardium occidentale*, due to their high flexibility, will be more suitable on the sandy coast. Both types should be planted parallel to the shoreline. Casuarina is planted in the frontline followed by Anacardium behind it.

Introduction

The southern coastal area of Java Island, Indonesia, is recognized as one of the high tsunami risk area. This region experienced to tsunamis in 1994 and 2006, resulted in huge fatalities. Both significant tsunamis in South Java were recognized as 'tsunami earthquakes'. It is provided by the larger tsunamis than expected in consideration to the earthquake magnitudes (Geist, 1999; Seno, 2007; Lavigne et al. 2007). In Banyuwangi area, tsunami occurred on 3 June 1994. It was triggered by an earthquake with moment magnitude (Mw) 7.6 and killed 238 people (Latief et al. 2000). The next tsunami happened on 17 July 2006, destroyed a wider area from eastern part of West Java Province through Yogyakarta Special Region. It was triggered by an earthquake Mw 7.7, located in 34 km of depth in the Indian Ocean.

Based on the reality that south Java region is very vulnerable to tsunamis, it is necessary to do tsunami mitigation. For tsunami mitigation purpose at that region, coastal forest is considered as an option to reduce the damage due to tsunami attack. Ohira et al. (2012) explained that "a 100 m of forest width could reduce 17.6% of the inundation flux".

The characteristic of vegetation combined with local tsunami potential is the essential factors to asses the effectiveness of the vegetation to reduce tsunami wave (Chaeroni and Widagdo, 2011). However, the coastal forest condition is depending on the local environment (Kordi, 2012), thus it is necessary to examine some prospective vegetation for tsunami mitigation.

This paper presents some finding of the research conducted in a part of southern coastal area of Central Java region, from Parangtritis (Yogyakarta) to Cilacap (West Java). The samples including some coastal areas as follows: 1) Parangkusumo; 2) Samas; 3) Glagah; 4) Ketawang; 5) Suwug; 6) Karangbolong; 7) Ayah; 8) Widara Payung; 9) Adipala; and 10) Kalipucang (Figure 1). Vegetation observed and examined were "Pandan" (*Pandanus odoratissimus*), "Akasia" (*Acacia auriculiformis*), "Bakau" (*Rhizopora mucronata*), "Cemara udang" (*Casuarina equisetifolia*), "Api – api" (*Avicenia marina*), "Ketapang" (*Terminalia catappa*), "Jambu mete" (*Anacardium occidentale*), and "Waru" (*Hibiscus tiliaceus*).

Objective

The objective of this research is to find the breaking capacity and allometry of several coastal vegetations to support the development of guideline for planning and design of tsunami mitigative coastal forest.

Figure 1. Location of the research area.

Methodology

Identification of Coastal Vegetation Types

The vegetation had been surveyed namely *Pandanus odoratissimus, Acacia auriculiformis, Rhizopora mucronata, Casuarina equisetifolia, Avicenia marina, Terminalia catappa, Anacardium occidentale,* and *Hibiscus tiliaceu.* All mentioned vegetations are commonly found in the coastal area, though A*cacia auriculiformis, Casuarina equisetifolia, Terminalia catappa, Anacardium occidentale* and *Hibiscus tiliaceus* also could be found outside of the coastal area.

Measurement of Coastal Trees Size and coastal topography

Trees size was measured in the field by using measurement tape. Topography was measured by using abney level, geological compass, tape measure, Garmin GPS - 76CSx series, Laser Ace telemetry and yallon. It was done by ploting position, azimuth profiling, back azimuth, and ranging, as the profiling method conducted with 3 yalon to obtain the slope data per segment (Figure 2).

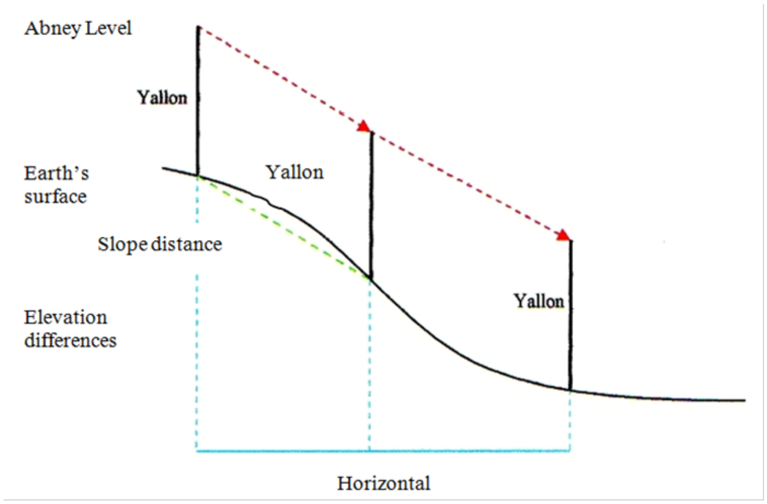

Figure 2. Profilling scheme.

Breaking capacity measurement of coastal trees

Breaking capacity was directly measured in the field by pulling test using a force-gauge (Figure 2 - 3). Each experiment was conducted at least three times for each species. The breaking moment of a tree trunk or a 1¬st-order branch was calculated by the force and the arm length from the breaking node to the forcing point. The elasticity was also measured by using the following equation.

$$EI = (\frac{l_{arm}^{3}}{3})(\frac{F}{Def})$$

Where: F is the force acting on tree trunk or branch (N), E is a Young coefficient (Nm-2), I is the second moment of area (m4), larm is the arm length (m) from the breaking node of the branch to the forcing point, and Def is a deflection (m).

Measurement of breaking moment was started by identification of the dominant coastal vegetation with a high population level and various sizes to establish some vegetation which represent variation of trunk diameter (DBH) for the test. Some important parameter of vegetation were measured and recorded at the working sheet. After setting up the test equipment and measurement tool on the vegetation, breaking moment test were executed by pulling gradually from the deflection (def) at 10 cm, 20 cm, continuously, following by recording the measured force acting (F). To minimize branch influence to the results, it is necessary to give a notice related to the presence of vegetation's branchs around the test location. All data taken were recorded refer to the test location.

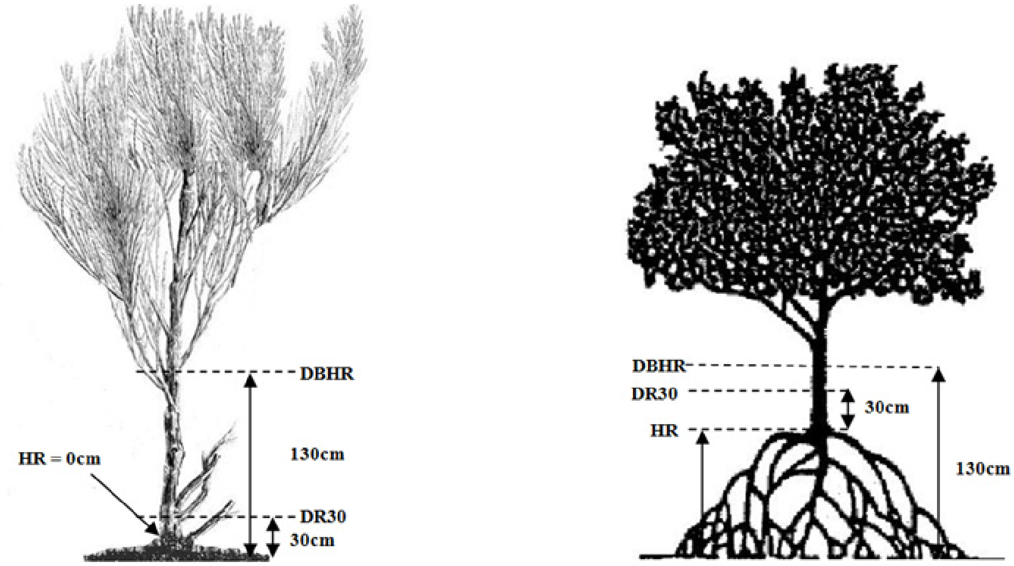

Figure 3. Trees parameter for breaking moment determination (Sunarto et al, 2009). Where: HR – height, from root to soil; DR30 – trunk diameter at 30 cm above the root; DBH – trunk diameter at chest height level (1.3m above the soil)

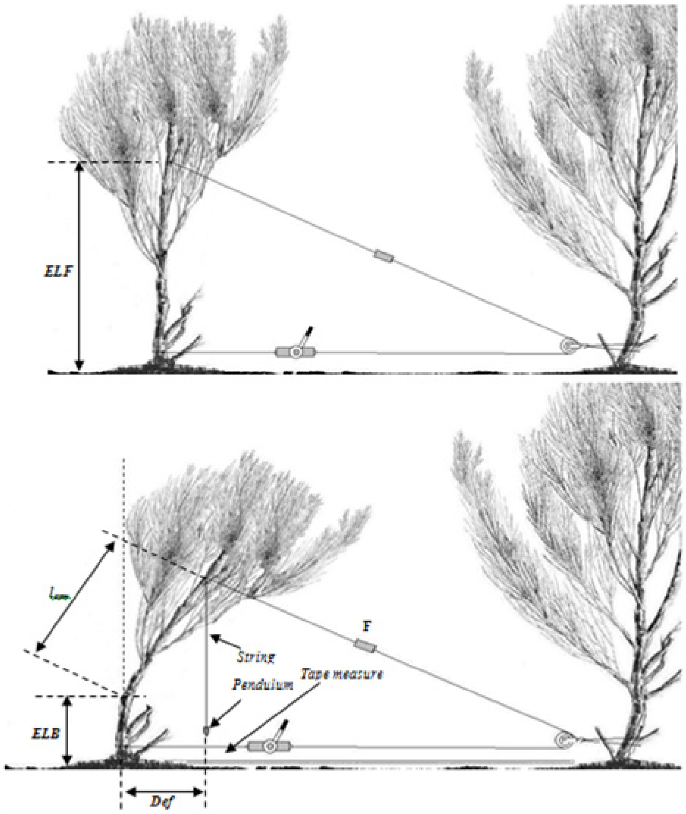

Figure 4. Breaking moment test variables (Sunarto et al, 2009). ELF - Height of forcing point; ELB - Height of breaking node; larm - The arm length (ELF-ELB); def – The deflection of trunk (measured using tape measure above the ground/soil); F – The force acting on tree trunk or branch (measured using force gauge)

Vegetation sampling

Vegetation sampling was conducted using the nested sampling (plot), which are 20 x 20 m for tree, 10 x 10 m for the poles, 5 x 5 m for sapling, shrubs, and 2 x 2 for herbs (Figure 5). Random sampling technique was applied within transectline to the land (stratified random sampling).

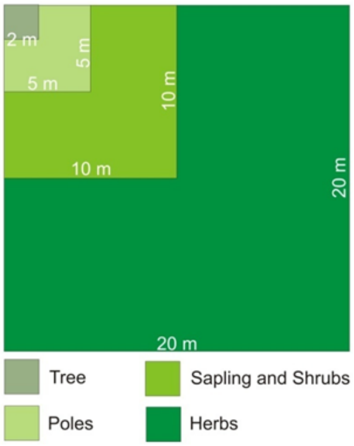

Figure 5. Nested sampling (plot) for vegetation sampling.

Vegetation analysis

Vegetation data was analyzed by using Diversity Index of Shanon-Wiener (Dumbois and Ellenberg, 1974) as follows.

$$\text{Density of Type A} = \frac{\text{Sum of Individual}}{\text{Unit Area}} \qquad (1)$$

$$\text{Relative Density of Type A (DR)} = \frac{\text{Density of Type A}}{\text{Sum of All Types Density}} \times 100\% \qquad (2)$$

$$\text{Domination of Type A} = \frac{\text{Sum of base area of type A}}{\text{Hectare}} \qquad (3)$$

$$\text{Relative Domination of Type A (DoR)} = \frac{\text{Domination of Type A}}{\text{Sum of All Types Domination}} \times 100\% \qquad (4)$$

$$\text{Frequency of Type A} = \frac{\text{Sum of Quadrate of Type A}}{\text{Sum of All Quadrate}} \qquad (5)$$

$$\text{Relative Frequency of Type A (FR)} = \frac{\text{Frequency of Type A}}{\text{Sum of All Types Frequency}} \times 100\% \qquad (6)$$

$$\text{INP (Important Value Index) type A} = \text{DR} + \text{DoR} + \text{FR} \qquad (7)$$

$$\text{ID} = -\sum \text{pi} \log \text{pi} \qquad (8)$$

Where: ID: Diversity Index; Type A: certain vegetation type (e.g. type A); pi: Result from important value of vegetation type, divided by important value of all vegetation type.

Results and discussion

Diversity Index and Vegetation Characteristic

The diversity Index in coastal area is relative low. The species found in the research area are the adaptive species to high level of water salinity and strong wind. The other factor influencing diversity index in this area is less water contents in the sandy area. This condition apparently forced certain species undergo some adaptation to the extreme condition. The adaptation on plant may happen structurally and physiologically. The diversity index in research area is shown at Figure 6 and Table 1. Meanwhile, vegetation distribution in research area is shown at Table 2.

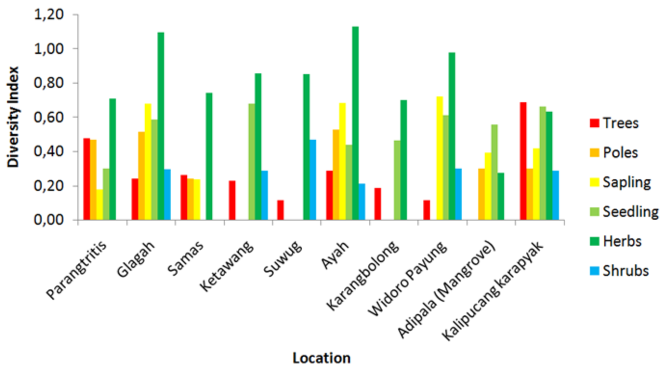

Figure 6. Diversity index in research area.

Table 1. Diversity index.

No	Location	Trees	Poles	Sapling	Seedling	Herbs	Shrubs
1	Parangtritis	0.48	0.47	0.18	0.3	0.71	0
2	Glagah	0.24	0.52	0.68	0.59	1.09	0.3
3	Samas	0.26	0.24	0.24	0	0.74	0
4	Ketawang	0.23	0	0	0.68	0.86	0.29
5	Suwug	0.11	0	0	0	0.85	0.47
6	Ayah	0.29	0.53	0.69	0.44	1.13	0.21
7	Karangbolong	0.19	0	0	0.46	0.7	0
8	Widoro Payung	0.11	0	0.72	0.61	0.98	0.3
9	Adipala (Mangrove)	0	0.3	0.39	0.56	0.27	0
10	Kalipucang Karapyak	0.69	0.3	0.42	0.67	0.63	0.29

Table 2. Vegetation distribution in research area.

No	Location	Vegetation	Herbs and Shrubs
1	Parangtritis	“Gamal” (*Gliricidia sepium*), *Acacia mangium*, cashew fruit (*Anacardium occidentale*) and “Siwalan” (*Borassus flabellifer*)	*Vinca rosea, Melochia corchorifolia, Alternanthera sp, Cyperus pedunculatus, Brachiaria eruciformis, Calotropis gigantean, Ipomea marginata* and *Passiflora foetida*
2	Glagah	“Pandan” (*Pandanus tectorius* and *Pandanus odoratissimus*), *Morinda cytrifolia, Terminalia cattapa, Gliricidia sepium, Borassus flabelliver* and “Kelor” (*Moringa oleifera*)	*Passiflora foetida, Ipomea pescaprae, Ischaemum timorense, Synedrella nodiflora, Cynodon dactylon, Cyperus rotundus, Mimosa pudica, Brachiaria mutica, Calotropis gigantean, Tephrosia purpurea, Uraria lagopoides* and *Spinifex squarosus*
3	Samas	*Casuarina equisetifolia, Acacia mangium*, coconut (*Cocos nucifera*) and *Gliricidia sepium*	*Spinifex squarosus, Alternanthera sp, Calotropis gigantean, Brachiaria eruciformis, Uraria lagopoides, Cyperus pedunculatus, Passiflora foetida* and *Tephrosia purpurea*
4	Ketawang	*Cocos nucifera, Acacia mangium, Anacardium occidentale, Gliricidia sepium* and *Terminalia catappa*	*Pandanus odoratissimus, Euphatorium odoratum, Brachiaria mutica, Tridax procumbens, Cyperus pedunculatus, Ischaemum timorense, Digitaria ciliaris, Cyperus rotundus, Polytrias amaura, Ipomea pescaprae* and *Cynodon dactylon*
5	Suwug	Coconut (*Cocos nucifera*), *Acacia mangium* and *Casuarina equisetifolia*	*Pandanus tectorius, Calotropis gigantea, Jatropha podagrica, Stachytarpheta indica, Polytrias amaura, Alternanthera sp, Uraria lagopoides, Phyllanthus simplex, Spinifex squarosus, Ischaemum timorense, Flueggea leucopyrus, Cyperus pedunculatus, Tephrosia purpurea* and *Cyperus rotundus*
6	Ayah	*Casuarina equisetifolia, Hibiscus tiliaceus, Terminalia catappa, Canophylum inophyllum* and *Erytrina sp*	*Pandanus odoratissimus, Euphatorium odoratum, Tridax procumbens, Luffa cylindrical, Porophyllum ruderale, Euphorbia hirta, Cyperus rotundus, Brachiaria eruciformis, Ipomea pescaprae, Ipomea marginata, Uraria lagopoides, Solanum melongena, Polytrias amaura, Synedrella nodiflora Citrullus vulgaris, Alternanthera sp* and *Selaginella doederleinii*
7	Karangbolong	Coconut (*Cocos nucifera*), *Calophyllum inophyllum, Terminalia catappa*, and *Pandanus odoratissimus*	*Ipomea prescaprae*, peanut (*Arachis hypogea*), *Ischaemum timorense, Ciperus rotundus, Rotthboellia sp*, and (*Cynodon dactylon*)
8	Widoro Payung	Coconut trees (*Cocos nucifera*) and *Acacia mangium*	*Pandanus odoratissimus, Eupatorium odoratum, Spinifex squarosus, Brachiaria eruciformis, Cyperus pedunculatus, Ipomea marginata, Calotropis gigantean, Uraria lagopoides, Tephrosia purpurea, Tridax procumbens, Phyllanthus niruri, Stachytarpheta indica, Cynodon dactylon, Polytrias amaura, Dactyloctenium aegyptium* and *Ciperus rotundus*
9	Adipala (Mangrove)	*Rhizopora apiculata, Avicenia marina* and *Soneratia sp*	*Nypa fruticans, Argemone sp* and *Ischaemum muticum*
10	Kalipucang Karapyak	“Keben” (*Baringtonia asiatica*), *Cocos nucifera, Terminalia catappa, Lagerstroemia speciosa, Erythrina sp, Eugenia jambos, Calophyllum inophyllum* and *Thespesia populnea*	*Eleusin indica, Cyperus rotundus, Ischaemum muticum, Imperata cylindrical, Tridax procumbens, Rotthboellia sp, Cynodon dactylon, Pandanus odoratissimus* and *Ficus septica*

Anacardium occidentale, Gliricidia sepium and *Terminalia catappa* that found in Ketawang is still in immature stage. In Suwug, the dominant species that can be found is coconut (*Cocos nucifera*) and *Acacia mangium,* which is why Suwug is known as local farmer coconut farm. On the Suwug beach, *Casuarina equisetifolia* can also be found. In Adipala, west part of Cilacap, the individual level of sapling is prominent in mangrove ecosystem.

The vegetation in the coastal area is typically characterized with adaptive trees to high salinity level of water and wind influence. The changes and the adaptation of trees structure have been made to adapt with extreme salinity condition. The adaptation has been remarked on trees with low branches. The branches free trunk is found nearly closed to the ground, this condition happen especially in sandy coast. Roots system has been known developed well, the root grows longer. It serves to find water sources and to provide support for wind shaky.

The major trees species found in the sandy coast area i.e. Coconut (*Cocos nucifera*), Cashew fruit (*Anacardium occidentale*), Acacia (*Acacia mangium*), casuarina tree (*Casuarina equisetifolia*), Ketapang (*Terminalia catappa*), gamal (*Gliricidia sepium*), siwalan (*Borassus flabellifer*), waru (*Hibiscus tiliaceus*), nyamplung (*Callophyllum inophyllum*) and keben (*Baringtonia asiatica*). Mangrove vegetation is not found in the shore area, although some available individual is present in poles to seedling level. In protected forest, trees diversification is very high.

Pole level on the beach is relatively rare. Mangrove area shows a little amount poles level. The diversity at poles level can be found in protected forest vegetation. Sapling grows below the trees branch and the poles. Human influence gives a big impact to the development of sampling. The rehabilitation of coastal reforestation program is the form of human influence to the sampling development. The program involves planting a certain species of plant i.e. casuarinas trees (*Casuarina equisetifolia*), ketapang (*Terminalia catappa*), nyamplung (*Callophyllum inophyllum*), keben (*Baringtonia asiatica*) and Coconut (*Cocos nucifera*). Sampling diversity increases in mangrove ecosystem. Level of sampling in mangrove ecosystem has a specific domination and unique from species *Rhizopora apiculata*. In protected forest, the sampling levels relatively balance.

Seedling level is extremely influenced by trees ability to produce seeds. Seeds will be spread through the area by spreading mechanism with the assistance of wind, seeds eater animals and water. The spreading seeds will be growing fast during the rain. The highest seedling diversity could be seen in the protected forest and Ketawang area. Shrubs from *Pandanus tectorius* and *Pandanus odoratissimus, Calotropis gigantean,* and *Euphatorium odoratum* are abundantly found. Mangrove area is dominated by *Nypa fruticans* while the virgin forest shows more varied species of shrubs.

Various shrubs have grown and developed with the adapatation ability to extreme condition. During the rainy season the herbs seeding and flowering fastly. The seed will be growing into mature seed and will be spreading with the assistance of wind and several species of birds.

Correlation between breaking moment and tree trunk diameter

According to trunk sturdy, the observed plant could be divided into woody plant, soft plant, and stem plant. Stem plant is not including in this research. Based on the field measurements, the value of breaking moment and elasticity is presented in Figure 7 – Figure 10.

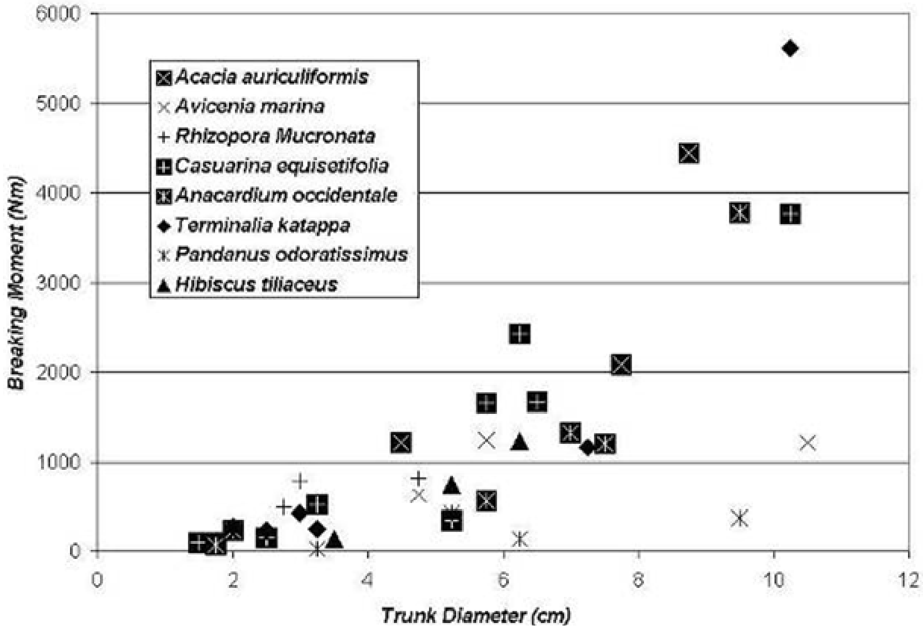

Figure 7. Breaking moment graphic (Nm). Source: data analysis.

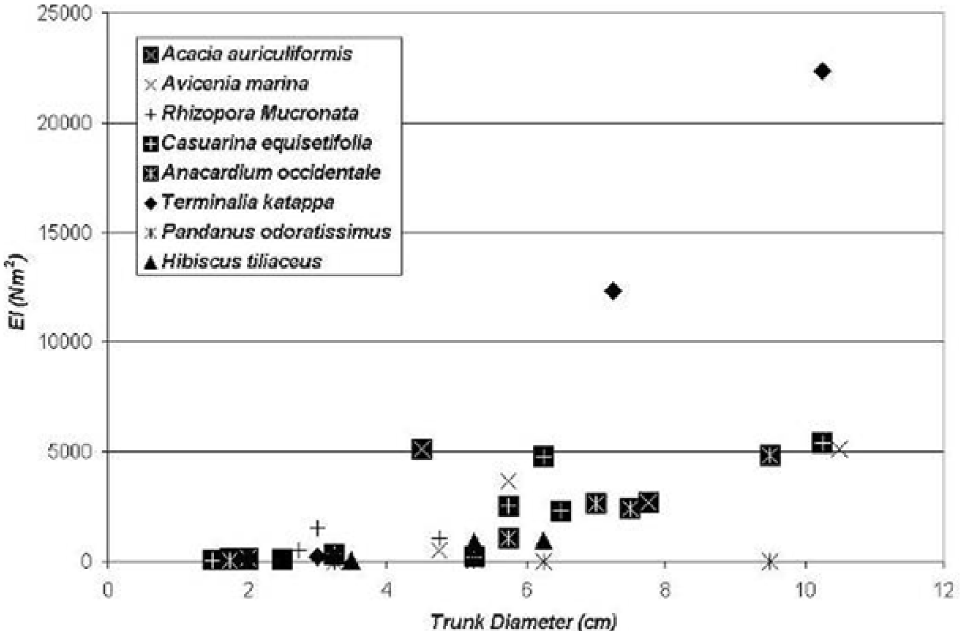

Figure 8. Elasticity Graphic (Nm²). Source: data analysis.

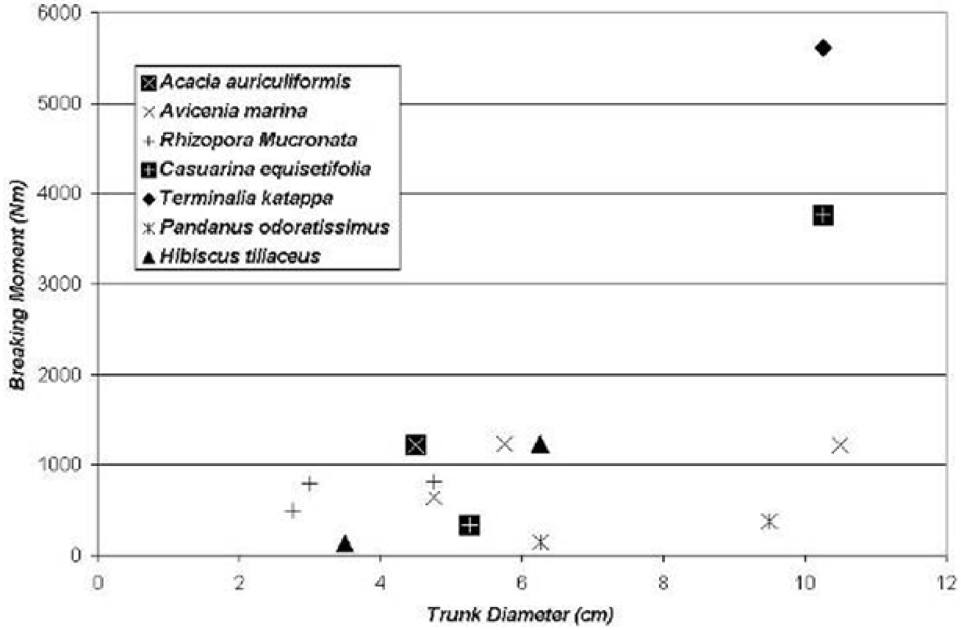

Figure 9. Broken vegetation’s graphic. Source: data analysis.

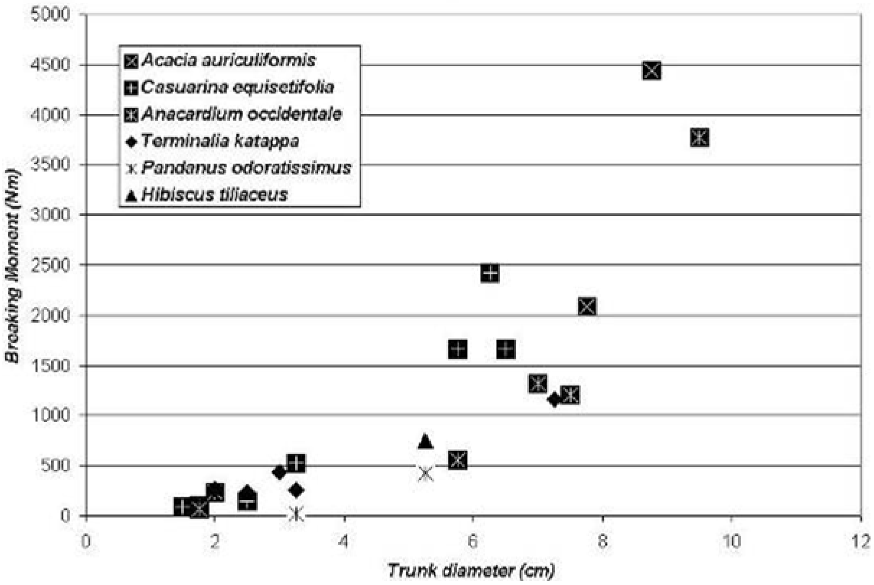

Figure 10. Unbreak vegetation's graphic (Source: data analysis).

According to the results, none of the cashew fruit trees was broken during the test. Cashew fruit (*Anacardium occidentale*) is grouped into woody plant in this research. It is different with soft trees like *Avicenia marina* and *Rhizophora mucronata*, because they were broken in each breaking test. It proofs that soft plant tends to be more fragile in comparison to woody plant. The result for cashew fruit is same with the research conducted by Tanaka et al. (2007) in Ban Thale Nok, Sri Lanka, after the Indian Ocean tsunami on 26 December 2004. The branches of cashew fruit were broken at the edge facing the coast, but most of the trees are still in good condition. A house with distance around 450 meters from the coast and behind the *Anacardium occidentale* trees was not damaged (Tanaka et al. 2007). Pandan (*Pandanus odoratissimus*) 6 cm in size was not broken during the test, meanwhile all plants with diameter above 6 cm were broken during the test (Figure 11). It shows that younger plants are more rigid than mature plants, though its trunk sturdy is grouped into soft plants. Further investigations on breaking moment and elasticity data are presented into characteristic curve and equation trendline. In present investigation characteristic curve of breaking moment and elasticity are approached using square equation n (power equation).

Tanaka et al. (2007) and Thuy et al. (2011) stated that *Pandanus odoratissimus* have many aerial roots, and the moment of the drag force can be shared by the aerial roots. Therefore, they were able to withstand a tsunami of less than 5 m, even with debris attached to the aerial roots and additional force applied. However, if the drag moment exceeded the threshold for the breaking moment when the tsunami water was high, the trunks were broken just above the aerial roots. Considering the limitations of *P. odoratissimus* in reducing tsunami water depth and the other roles that coastal vegetation can play in mitigating tsunami-related damage, a forest with two layers in the vertical direction of *P. odoratissimus* and dense *C. equisetifolia* (mixed culture) was found to be effective for increasing drag and trapping floating debris in Kalutara, Sri Lanka (Tanaka et al. 2009).

Terminalia catappa had never been broken during force test, except trees with 10 in diameter. It was broken after receiving moment of 2,3 kNm (deflection 50 cm). Different situation in Laem Son National Park, Sri Lanka, *T. catappa* is one of trees which categorized as most of the broken or uprooted tree, but it was not washed away but remained in place (Tanaka et al. 2007). In other hands, some cases show that *T. catappa* is the effective tree for escaping from tsunami by climbing it.

Figure 11. All plants with diameter above 6 cm were broken during the test. (Photos taken by Sunarto and Mardiatno)

Acacia (*Acacia auriculiformis*) with trunk below 6 cm was broken during test; however its rigidity is rise sharply as increased in tree life periode. This finding has not supported with sufficient data. It needs several data about diameter range. Acacia tree with 10 cm diameter was not broken during the test however 4,5 kNm and deflected 20 cm long. Comparing to cashew fruit tree, it is already defleated 120 cm long when given 3.8 kNm. This can be concluding cashew frit tree relatively flexible compare to another tree in this study.

Hibiscus tiliaceus trees show relatively low elasticity for plants with trunk less than 6cm but it rose sharply as increased in diameter cm in diameter. It needs further observation to compare force moment each hard woody tree, especially for mature tree with 10cm and 15cm in diameter. This observation will be developed more accurate and representative. There is plant limitation in nature to do this kind of observation.

The data shows all woody plants less than 11 cm in diameters were broken when received breaking moment less than 1.5kNm. Hard woody plant such as Cemara udang (*Casuarina equisetifolia*) was not broken when breaking moment more than 3,5 kNm was given. It is apparently hard woody trees may restrain tsunami force moment or push moment. Tanaka et al. (2007) stated that two layers of vegetation in the vertical direction with *C. equisetifolia* and *P. odoratissimus* exhibited a strong potential to decrease the damage behind the vegetation cover in Kalutara, Sri Lanka.

C. equisetifolia grows at high density when the trunk diameter is small (d < 0.07 m), but at this size it can be broken by a 5 m high tsunami. When the diameter of *C. equisetifolia* was larger than 0.1 m, the trunks were not broken by the tsunami and were effective at that height, but it is presumed that they had little effect in reducing the surface velocity when their diameter is large (d > 0.5 m) with large spaces between trunks (7– 30 m) (Tanaka et al. 2007). Based on Tanaka et al. (2009), dense *C. equisetifolia* grown in beach sand were found to be especially effective in providing protection from tsunami damage due to their density and complex aerial root structure.

This research has observed the trees which stay rigid after force moment test. The trees cannot return into their first condition since the trees have withdrawn from its substrate (soil). From the data we can presume that enormous moment or force is needed to break the trunk than to withdraw them from soil. For this reason trees withdrawn frequently found in after tsunami than trees with broken trunk.

Tsunami Mitigation Model Using Vegetation

Coastal areas consist of different materials and topography conditions tend to have a high tsunami risk. Nevertheless, the mitigation treatments were different for each type. When analysing the mitigation treatments, it is important to identify the correlation among different parameters, such as physical characteristics of the tsunami wave, local topography, features of the existing vegetation, and the nature of the built up environment (Sunarto et al. 2009). The sketch of topography in the research area is shown in Figure 12.

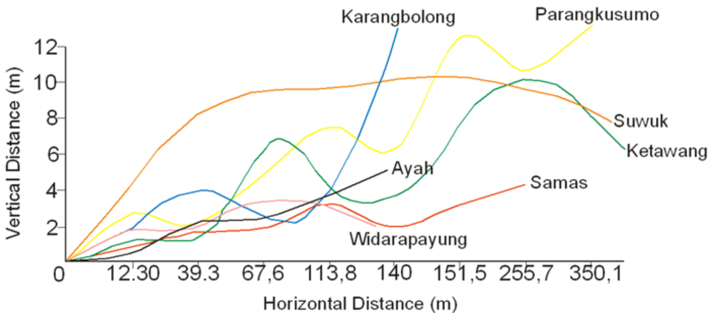

Figure 12. Sketch of topography in research areas (Source: field measurement)

Furthermore, existing coastal vegetation play a hugely important role in coastal community development and in maintaining the coastal environment. Wide, elongated, dense, and mature coastal vegetation growing along the shoreline can help to reduce the devastating impact of a tsunami and storm surge by decreasing their wave energies (Tanaka and Sasaki, 2008; JWRC, 2009; Sunarto et al. 2009). Tanaka et al. (2007) stated some vegetation function when the tsunami happened, i.e. the soft-landing effect, trapping effect, and escaping effect. Some illustration for the function of coastal vegetation during tsunami inundation can be seen in Figure 13.

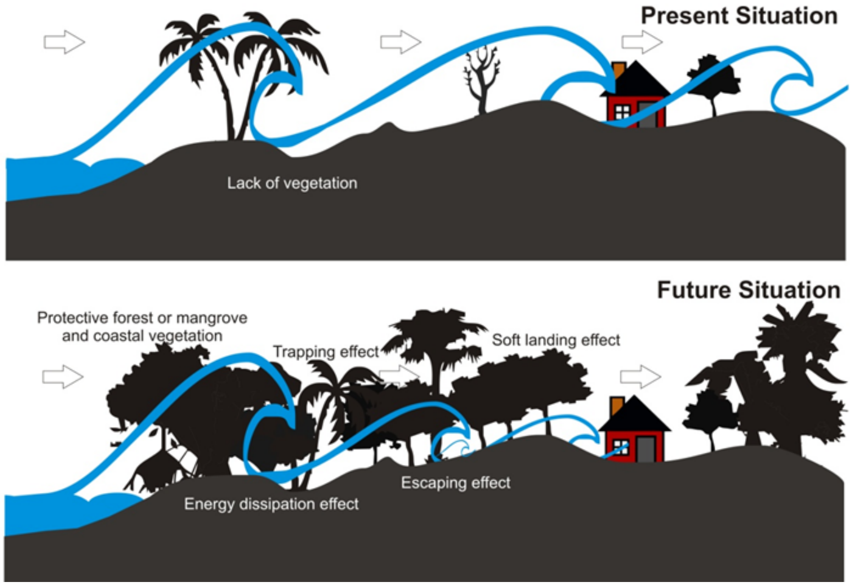

Figure 13. The function of coastal vegetation during tsunami inundation.

In southern coastal area of Central Java, the coastal material consists of two materials, i.e. muddy and sandy materials. Both materials tend to have a high tsunami risk (Mardiatno, 2008). Each material has different ways regarding the mitigation treatments for tsunami risk. At the muddy area, for example in Adipala, the recommended vegetation are "Api – api" (*Avicennia*) and "bakau" (*Rhizophora*) (Figure 14), meanwhile Casuarina and Anacardium, due to their high flexibility will be more suitable on the sandy coast, for example in Ayah (Figure 15). Both types are not recommendend to be planted in a mixing way ("tumpang sari"), but should be better planted in line or parallel to the shoreline. Casuarina should be planted in the frontline and then followed by *Anacardium* behind *Casuarina* line. This way is different comparing to Tanaka et al. (2007); Tanaka and Sasaki (2008); Tanaka et al. (2009); and Thuy et al. (2011). They proposed *Pandanus odoratissimus* and *Casuarina equisetifolia* to reduce the tsunami energy and for protection to tsunami debris from any objects on the coast.

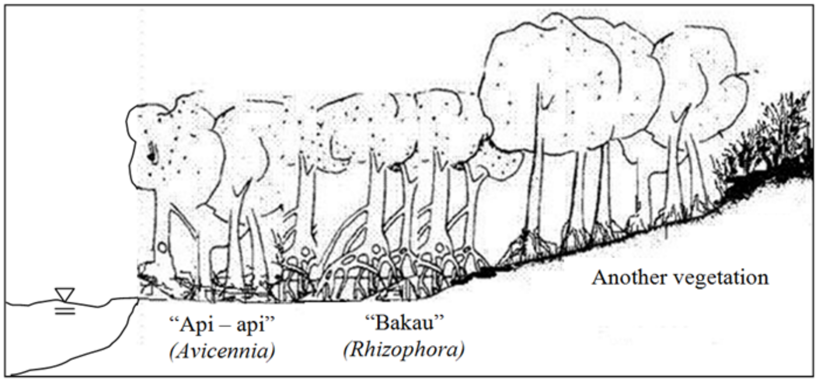

Figure 14. Ilustration for mitigation treatments in muddy coast (ex: Adipala)

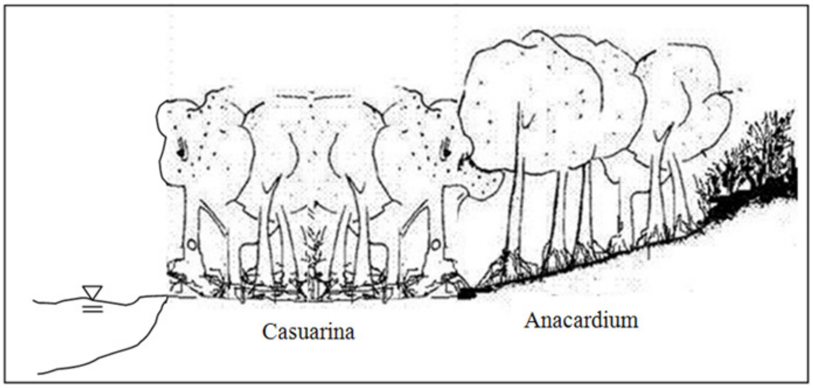

Figure 15. Ilustration for mitigation treatments in sandy coast (ex: Ayah)

Conclusions

Trees with the hard wood will be stronger to hold the pull moment on the main trunk. Younger trees with smaller diameter tend to be more flexible, thus they will unbreakable during the test. The other trees which have flexible trunk such as *Terminalia catappa* and *Anacardium* were oftenly pulled out their roots than broken on their trunks. The more data taken, the more accurate the result, since they will get more comprehensive test. To obtain more extensive characteristic, it is necessary to carry out advanced measurements, especially on the older trees which have more than 10 cm diameter.

Coastal areas consist of mud and sand materials tend to have a high tsunami risk. Nevertheless, the mitigation treatments were different for both types. At the muddy coast, the recommended vegetation are *Avicennia* and *Rhizophora*, meanwhile *Casuarina* and *Anacardium*, due to their high flexibility will be more suitable on the sandy coast. Both types were not recommendend to be planted in a mixing way ("tumpang sari"), but should be better in line or parallel to the shoreline. *Casuarina* should be planted in the frontline followed by *Anacardium*.

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