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THE CONCEPT OF SUSTAINABLE DEVELOPMENT WITH THE MANGROVE *AVICENNIA MARINA* AS A REDUCTOR OF WAVE ENERGY

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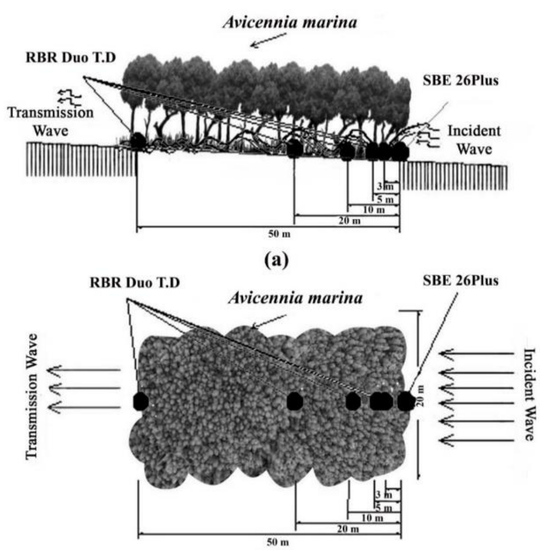
Graphical abstract



Abstract

Coastal building construction is considered risky of abrasion by sea waves. One alternative that can be used as an effort to prevent abrasion is to take advantage of pneumatophore and litter of the *Avicennia marina* mangrove. The purpose of this study was to determine the effectiveness of *Avicennia marina* pneumatophore and litter for attenuating sea waves. The applied research methods were Transect-squared, Spot-check, and Sondani methods. The measurement of wave data employed SBE 26Plus and RBRDuo T.D. They were carried out at 5 stations with thicknesses of 3 m, 5 m, 10 m, 20 m, and 50 m respectively. The obtained raw data was then processed and the largest value of pneumatophore was produced at STA 1. The mangrove was able to attenuate the energy as much as 50% with the ratio of pneumatophore + litter + other factors = 14,93% + 16,44% + 18,63%. At STA 2, the attenuated energy was 54% with a ratio of 10,36% + 7,08% + 36,55%. At STA 3, the attenuated energy was 83% with a ratio of 5,43% + 2,29% + 75,28%. At STA 4, 91% of the energy was attenuated with a ratio of 4,22% + 1,05% + 85,73%. The farthest mangrove, at STA 5, attenuated the energy as much as 92%, with a ratio of 3,90% + 0,48% + 87,62%. It is safe to infer that the suppression of wave energy by pneumatophore and litter on the coast has the greatest effectiveness as the pneumatophore releases optimal bending power and the litter bears the smallest porosity value, while such other factors as large trees, core trees, seedlings, piles, sedimentation, and twigs dominate are more dominant as the mangrove thickness increases.

Keywords: Mangrove *Avicennia marina*; pneumatophore; litter; coastal building, sea waves.

1.0 INTRODUCTION

Indonesia is an archipelago known as a maritime country, a country whose land is less than the sea [1]. Our coastal areas are widely used for such activities as fishery, mining, forestry, recreation, transportation, tourism, land protection, and others. For these reasons, the roles of our coastal areas in supporting various life activities must be protected from various threats. One of the existing threats is abrasion by sea waves.

Abrasion is the process of a coastal area eroded by the energy of destructive ocean waves occurring sustainably and moving towards the shoreline [2]. In addition to abrasion, damage to the coastal ecosystem is always followed by environmental issues such as flooding, sedimentation, decrease in fishery productivity, and the loss of small islands [3]. So, it is of paramount importance to protect the coast from abrasion to prevent damage to the area. One alternative for reducing these impacts is the use of the *Avicennia marina* mangrove.

Avicennia marina on the study site plays an important role in reducing waves leading to abrasion on the coastline. In addition, the wave energy can also move coastal sediment in large quantities and from a long distance and in the long run, it will cause coastline deterioration [4, 5, and 6]. The deterioration of the coastline occurs as a result of the reducing physical function of the mangrove ecosystem. It is therefore necessary to conduct further research in relation to the mangroves potential for land protection from the threat of coastline diminishment in coastal areas.

Factors of ocean wave attenuation in the mangrove ecosystem are pneumatophore, litter, and other factors such as large and core trees, seedlings, poles, piles, sedimentation, and branches. The root system in a mangrove and tree stand is the cause of the mangrove protective function on the coast. In addition, high mangrove litter productivity greatly contributes to attenuating waves, and other factors become more dominant as the mangrove thickness increases. With all that in mind, the purpose of this study was to determine the effectiveness of pneumatophore, litter, and the other factors relating to *Avicennia marina* for reducing waves. The existence of mangroves is essential for the defense in coastal areas with environmentally friendly concepts.

2.0 METHODOLOGY

2.1. Research Location and Time

The research was conducted in Purworejo Village Area, Pasir Sakti District, East Lampung, Lampung Province, Indonesia. The study location was a seaside with dynamic change of a fairly long mangrove cover. Geographically speaking, the island is located at the coordinates of 5°31'S - 105°49'E (see Figure 1). The study was conducted from July 14th, 2017 to July 18th, 2017. The wave recording started every 5 minutes for 2 hours, from 21:45:12 Western Indonesian Time to 23:45:12 Western Indonesian Time.

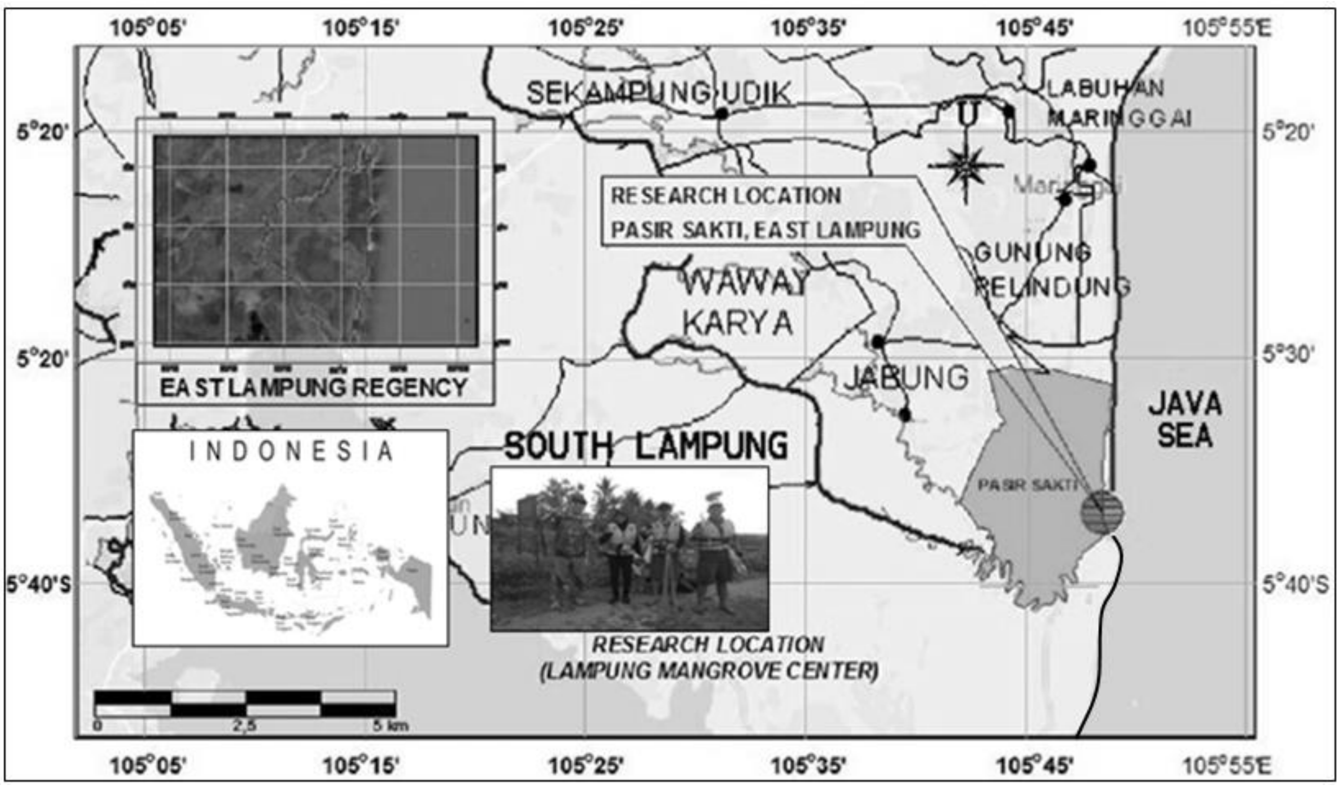


Figure 1 Map of Research Location

2.2. Equipment for Data Collection

2.2.1. Wave Data

For the wave height measurement, RBRDuo T.D and SBE 26Plus tools were employed. Each unit was from the Hydro-Oceanographic Service (DISHIDROS) of the navy. The thicknesses of the measured mangroves at the 5 stations were 3 m, 5 m, 10 m, 20 m, and 50 m respectively. The following are the pictures of the implements (see Figure 2):

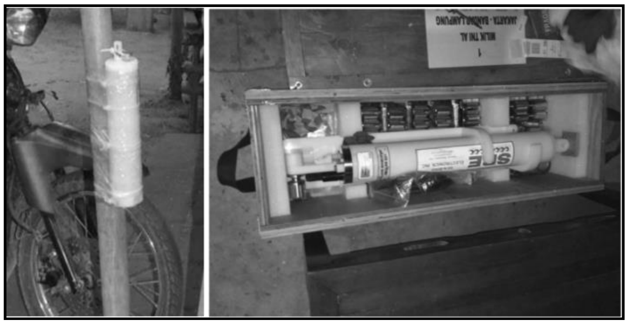


Figure 2. RBRDuo T. D (left) and SBE 26Plus (right).

1. RBRDuo T.D

RBRDuo T.D is a wave-measuring instrument placed on the back of the mangrove. This implement serves as a recorder of going waves perpendicular to the mangrove. The recording process is carried out after the instrument is fixed on a long bamboo functioning as a support pole so that the tool will not fall and sink. This also makes it easier to move it to record waves at another station. Before the recording process on the research site began, the time interval of the recording instrument was first set to match the recording time of SBE 26 (Sea Bird Electronics), which also recorded the waves. The obtained data could be directly exported to Microsoft Excel for convenience in the data processing.

2. SBE 26Plus

SBE 26 (Sea Bird Electronics) is a wave measuring instrument placed on the front of a mangrove. This implement records incoming waves that are perpendicular to the mangrove. Before the recording process is carried out, a buoy needs to put under the implement to prevent it from sinking as the recording process is carried out at the highest tide, at night. A lighting device in the form of a flashing light must be installed at the top of the buoy to make it possible to watch the instrument from a distance and search for it when the recording of the waves ends.

2.2.2. Pneumatophore And Litter Data

The implements involved in collecting the samples of pneumatophore and litter on the research site were as follows:

1. A 30-meter roll meter was used to measure the circumferences of the pneumatophore and litter samples.
2. Snorkeling tools were used to provide better visibility in water.
3. Research sheets were used to record the results of the primary data on in the field.
4. A writing board was used to make it easier to take down the data results in the field.
5. A first-aid kit was prepared in case of an emergency such as a work accident.
6. Spray paint served as the marker of the station points when taking the samples.
7. Life jackets were readied as for safety reasons.
8. Waterproof cameras were used for documentation as they would possibly be rather wet or even fall into the water.
9. The GPS was used to map and identify the sampling points.
10. 1-by-1 meter wood was used to calculate the number of pneumatophores.
11. 100 KN MTS Landmark.

The MTS Landmark was used to determine the strength of the pneumatophores by the tensile test (see Figure 3). The tool is able to test plastic objects, elastomers, aluminum, steel, and alloy material, with a load capacity of up to 150% of the average load, hydraulic power with a pressure of 21 MPa (3000 psi), and the length of the object increasing up to 600 mm or 23.6 inches [7]. The tensile test is the testing of an object to know its strength by pulling both of its sides until it is torn apart. Strength refers to when the material undergoes stress, but does not fracture, so that the tensile and compressive strength of the tested object is known. During the process, the object is given a load so that it undergoes stress and stretch as its length increases [8].

2.3. Data Collection Process

2.3.1. Wave Data

The steps of retrieving and processing the wave data were as follows [9]:

1. Pre-surveying the installation site of the equipment.
2. Preparing and determining the station ordinates and all the necessary equipment.
3. Recording waves at each station at the highest tide, which was nighttime, for 2 hours (see Figure 4).
4. Performing the measurement with SBE 26Plus and RBRDuo T.D, which had been installed by 2 field personnel and technicians from the Hydro-Oceanography Service (DISHIDROS) of the navy.
5. Processing the raw data obtained in the field with the measuring instruments.
6. Processing and analyzing the wave data from each station with Microsoft Exce

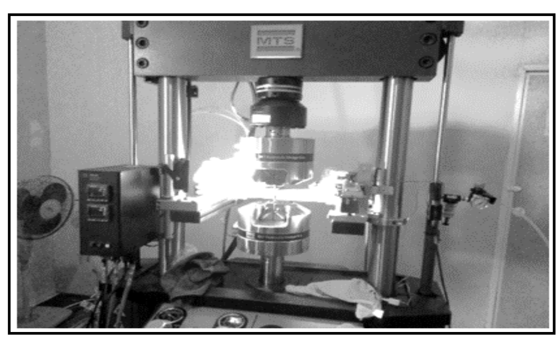


Figure 3. 100 KN MTS Landmark

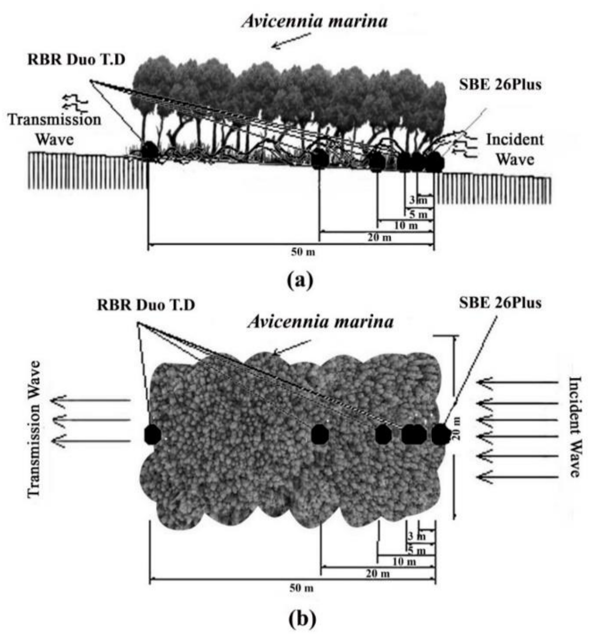


Figure 4. Illustration of Data Retrieval (side view (a), top view (b).

2.3.2. Pneumatophore and Litter Data

The methods used for the data collection encompassed the transect-squared, spot-check, Sondani methods, and laboratory tests. The transect-squared method was carried out by drawing perpendicular lines on the coast and above the lines were placed squares of 20 by 50 meters. The distance between squares was systematically determined based on differences of vegetation structure [10]. The spot-check method was carried out by observing and examining certain zones having special characteristics in the mangrove ecosystem [10]. As for the Sondani method, it was employed to calculate the area and number of pneumatophores in the square area by placing a one-by-one-meter square wood for the calculation [9]. The laboratory tests were performed to determine the strength of the pneumatophores with the 100 KN MTS Landmark for the tensile test. This test was administered in Mechanical Engineering Material Laboratory, Faculty of Engineering, University of Lampung, Lampung Province, Indonesia.

2.4. Research Data

The data was divided into 2, i.e. primary and secondary data. The primary data was obtained directly on the study site such as the data of waves, circumferences of mangroves, pneumatophores, and litter, number of pneumatophores at a 1-by-1-meter distance, and average heights of pneumatophores and litter, while the secondary data was obtained from the related agencies and other parties such as area layouts on a reference map to find the intended stations.

2.5. Data Processing

The data processing involved Microsoft Office applications (Ms. Word and Ms. Excel), with the serial number 6QFDX-PYH2G-PPYFD-C7RJM-BBKQ8. Microsoft Excel is an application primarily for processing numbers. The application was developed by Microsoft Corp. The number processing is needed for the calculation of research results, creation of the relationships between variables, and identification of formulas from charts. The various functions and features Excel has make it possible to process data in various cases [11].

2.5.1. Ocean Waves

Sea waves spreading horizontally carry wave energy. The presence of uneven vegetation or substrates causes decrease in wave energy called wave attenuation. In other words, wave attenuation takes place when a wave loses its energy [9]. The output of a wave measuring instrument is the maximum wave height (Hmaks), which will be used to calculate the wave suppression. Wave attenuation results in the reduction of the wave height. The wave suppression capability (wave deviation) is calculated by figuring out the difference between the maximum wave height in front of the mangroves and the maximum wave height in back of the mangroves. The following is the equation [12]:

$$E = 1/8\ \rho\ g\ H^2 \quad (1)$$

$$\Delta E = 1/8\ \rho\ g\ \Delta H^2 \quad (2)$$

$$\Delta H = Hi - Ht \quad (3)$$

$$\Delta E = Ei - Et \quad (4)$$

2.5.2. Transmission Waves

The transmitted wave energy is smaller than the coming wave energy. The transmission coefficient is defined as the ratio between the height of the transmitted wave and the coming wave (see Equation 5). The figure representing the transmission coefficient indicates the level of the mangrove's ability to attenuate sea waves. The equation of the parameters determining the wave transmission coefficient in this study is as follows [13]:

$$Kt = \left[\frac{Ht}{Hi}\right] \sim (Hi, g, Np) \quad (5)$$

2.5.3. Pneumatophores

Pneumatophores had varying sizes and quantities at each station. Identification and observation were carried out to obtain the required data. After observing the field data, each type density (Di) was calculated. Type density (Di) is the number of forest stands of the i type in an area [10, 9]. The calculation of type density is performed in the following way:

$$D_i = \frac{n_i}{A} \quad (6)$$

2.5.4. Pneumatophore Inhalation Test

The stress and stretch curve is applicable to almost any material. For a certain distance from the point of origin, the stress and stretch experimental value is basically located on one straight line. In this case, Hooke's law is applied. The stress and stretch curve is calculated with the following formula [14]:

$$E = \frac{\sigma}{\varepsilon} \quad (7)$$

2.5.5. Mangrove Litter

The most important contribution of a mangrove forest to the coastal ecosystem is litter. It is estimated that the average productivity of litter is 4.05 gr/m2/day or 14.78 tons/ha/year with leaf litter as the largest contributor. In addition, mangroves serve as coastal protectors, stabilizers, buffers, and preventers of the abrasion caused by currents, waves, and winds [15]. The calculation of the volume of mangrove litter simplified to the circular cylinder and height of the litter is intended to take the average height of the mangrove litter. Look at the Figure 5 and following equations:

$$k = 2a + 2b \quad (8)$$

$$L = a \times b \quad (9)$$

$$V = W \times H \quad (10)$$

2.5.6. Porosity Value

The porosity value is a measure of the unoccupied space between mangroves. Wave resistance is very dependent on the porosity of the outer wall against waves. Other parameters are the period, wave regularity, wave direction, and water depth [16]. The data analysis was performed by calculating the porosity value (Np) of each avicennia sp [17] mangrove clump. Np = 1 indicates the absence of mangroves, and Np = 0 indicates the wall is fully reflective [12]:

$$Np = 1 - \frac{Vt}{Vo} \quad (11)$$

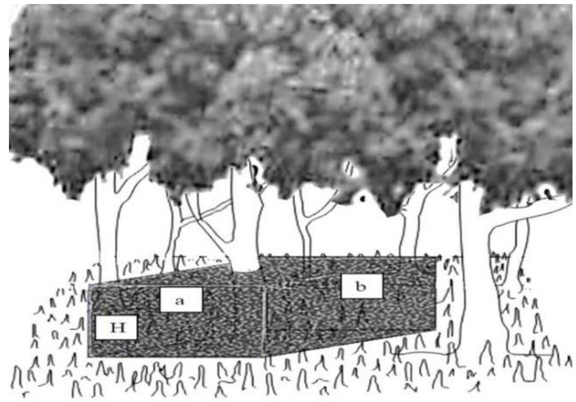


Figure 5. Illustration of Mangrove Litter Volume.

3.0 RESULTS AND DISCUSSION

3.1. Wave Data Processing

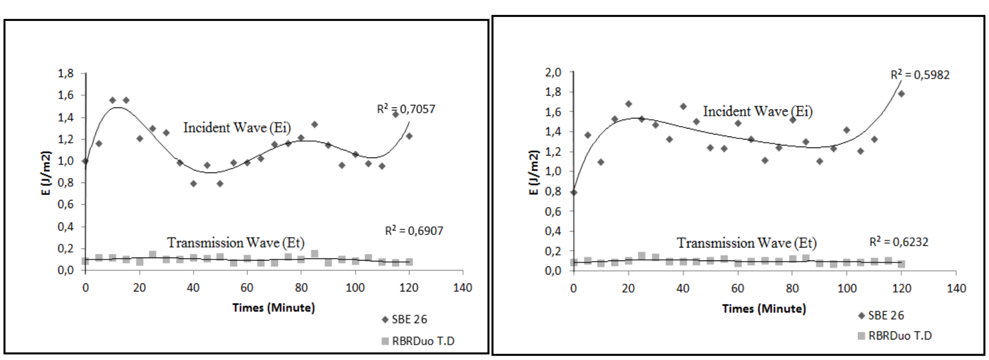
Wave measurements using SBE 26Plus and RBRDuo T.D were performed from July 14th, 2017, to July 18th, 2017. The graphs (see Figure 6) portray the results of the measurements of wave energy entering and leaving the mangroves.

From the graphs, it is inferable that the values of the Ei wave data generated by the wave measuring instrument after the calculation of the wave energy were strong in uniformity, with an R2 value of above 0.5.

The results of the data processing at STA 1 to STA 5 indicate that the wave energy reduction was greater as the width of the thickness distance increased (see Table 1).

Table 1 Results of Wave Data Processing

No.	Station	Incident Wave Average Ei [J/m^2]	Transmission Wave Average Et [J/m^2]	Average of Wave Energy Attenuation E [J/m^2]
1	STA 1 (3m)	1,1277	0,0989	0,5653
2	STA 2 (5m)	1,3792	0,0974	0,7485
3	STA 3 (10m)	1,5964	0,0129	1,3389
4	STA 4 (20m)	1,7596	0,0034	1,6115
5	STA 5 (50m)	1,7428	0,0027	1,6125



(a) (b)

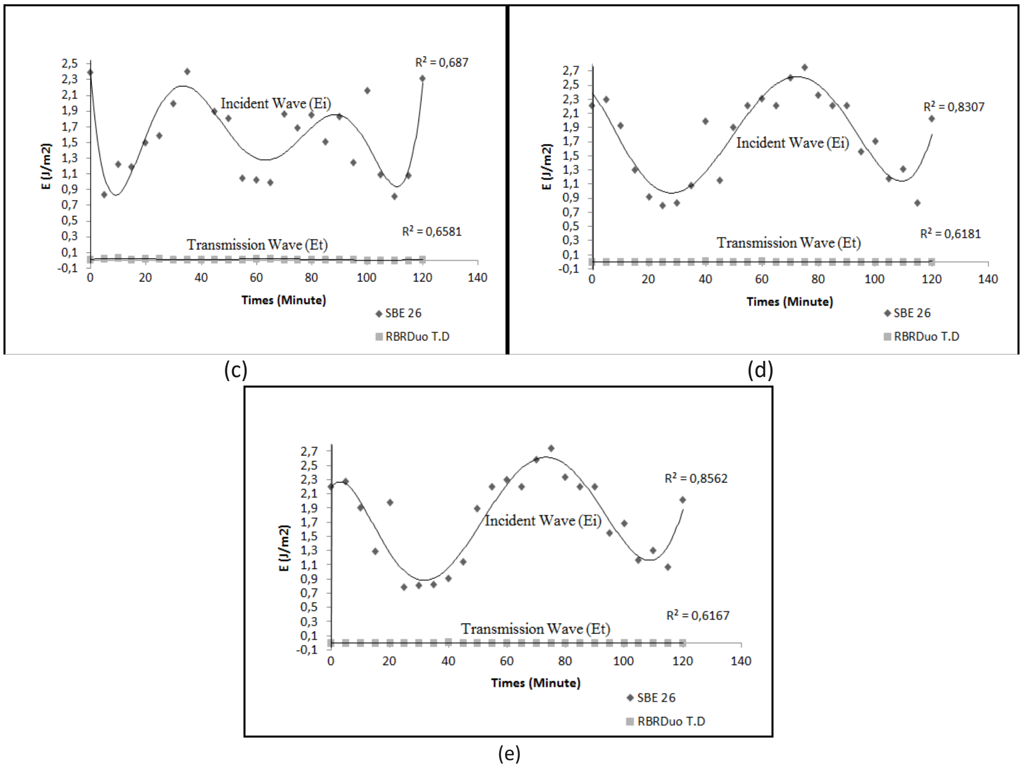


Figure 6 Graphs of Results of Wave Data Calculations; (a) a distance of 3 m, (b) a distance of 5 m, (c) a distance of 10 m, (d) a distance of 20 m, and (e) a distance of 50 m.

3.1.1. Wave Retardant Factors

At the thickness distances of 3 m and 5 m, no seedlings and stakes were found, so the classifications of trees at the distances were poles, core trees, and large trees. At the thickness distances of 10 m, 20 m, and 50 m, there were seedlings, stakes, poles, core trees, and large trees. The longer the distance of the mangrove thickness, the larger the number of tree classifications. It was because the mangrove trees at the front of the mangroves were more susceptible to abrasion and directly encountered tidal waves so that the mangroves in the front rows grew less than those at the back (see Figure 7).

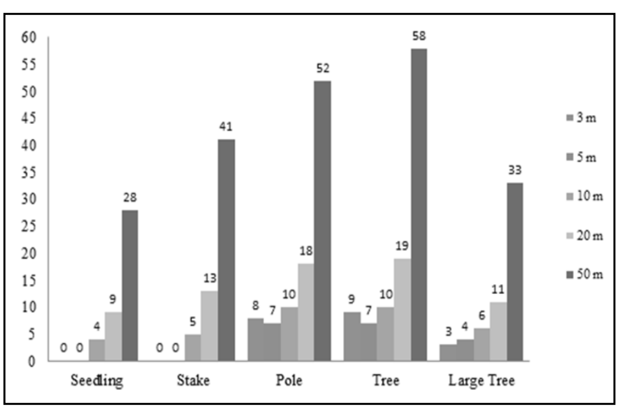


Figure 7 Graph of Wave-inhibiting Factors at Each STA.

3.1.2. Wave Suppression Percentage by Wave Energy Deviation

According to the values of the wave energy attenuation, the following graph of percentages was made (see Figure 8):

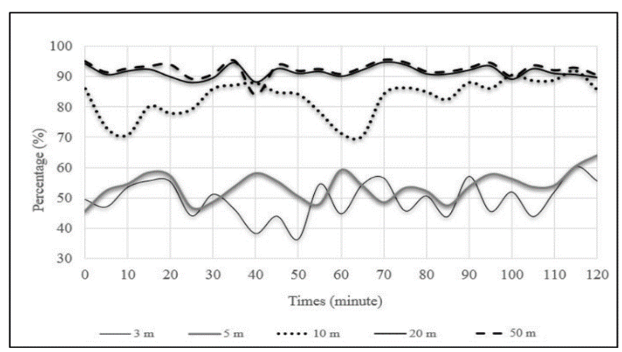


Figure 8 Graph of Percentages of Wave Attenuation Based on Wave Energy Deviation.

In Figure 8, there is a significant difference between the thickness distances ranging from 3 to 5 m and the thickness distances ranging from 10 to 50 m. It is a result of the fact that the wave energy attenuation located near the coastline was not as effective as that at the thickness distances of 10 to 50 m.

3.1.3. Transmission Coefficient Results

The transmission coefficient results are shown in Table 2. Kt = 1 indicates the absence of transmission, and Kt = 0 indicates the total transmission.

Table 2 Transmission Coefficient Results.

Station	Hi Average [m]	Ht Average [m]	Kt Average
STA 1 (3 m)	0,9413	0,2780	0,2953
STA 2 (5 m)	1,0406	0,2765	0,2657
STA 3 (10 m)	1,1092	0,0969	0,0874
STA 4 (20 m)	1,1615	0,0505	0,0435
STA 5 (50 m)	1,1557	0,0448	0,0387

3.2. Pneumatophore Data Processing

The following are the results of the processed data (see Table 3)

Table 3 Results of Processed Data of Pneumatophores.

No.	Station	Width of Observed Area [m²]	Number of Pneumatophores N_{naf} [pieces]	Average Pneumatophore Density [pieces/m²]
1.	STA 1 (3 m)	60	11.844	197,4
2.	STA 2 (5 m)	100	19.140	191,4
3.	STA 3 (10 m)	200	35.640	178,2
4.	STA 4 (20 m)	400	66.240	165,6
5.	STA 5 (50 m)	1.000	155.400	155,4

The following are the pneumatophore samples tested with the 100 KN MTS Landmark :

3.2.1. Laboratory Tensile Tests

The obtained samples of pneumatophores were then taken for laboratory tensile tests with the 100 KN MTS Landmark. The laboratory test results are as follows (see Table 4) :

Table 4 Results of Laboratory Tensile Tests on Pneumatophore Samples.

Data	h_1 [mm]	h_2 [mm]	d [mm]	δ Average [mm]	F Average [Joule]
Sample 1	165	169	4	6,2009	86,7 x 10^{-8}
Sample 2	156	159	5	8,2973	177,9 x 10^{-8}
Sample 3	148	153	6	9,5875	214,5 x 10^{-8}

The pneumatophores hit by the waves had the ability to withstand weight. Based on the laboratory tests, a pneumatophore could withstand a load of 86,7 x 10^{-8} Joules to that of 214,5 x 10^{-8} Joules (See Figure 9).

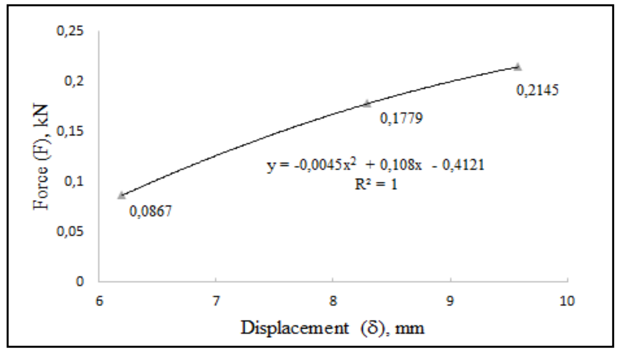


Figure 9 Correlation Graph of Test on Three Samples.

The tests were carried out to determine the values of the pneumatophores' ability to withstand loads based on length gains. Based on the test results, the equation representing the relation between the load and the length gain is $y = -0,0045x^2 + 0,108x - 0,4121$.

3.2.2. The Relationship of Pneumatophore Flexibility in Wave Energy Attenuation

Pneumatophore Flexibility is the ability to return to its original position after being distracted [18, 19]. The results of the lab tests on the samples are as follows (see Table 5) :

Table 5 Results of Pneumatophore Flexibility Tests.

Station	*Pneumatophore Force [Joule]*	*Number of Pneumatophores N_{naf} [pieces]*	*Average Pneumatophore Density* [pieces/m²]	*Rebound* [J/m²]
STA 1 (3m)	1,6 x 10^{-6}	11.844	197,4	315,84 x 10^{-6}
STA 2 (5m)	1,6 x 10^{-6}	19.140	191,4	306,24 x 10^{-6}
STA 3 (10m)	1,6 x 10^{-6}	35.640	178,2	285,12 x 10^{-6}
STA 4 (20m)	1,6 x 10^{-6}	66.240	165,6	264,96 x 10^{-6}
STA 5 (50m)	1,6 x 10^{-6}	155.400	155,4	248,64 x 10^{-6}

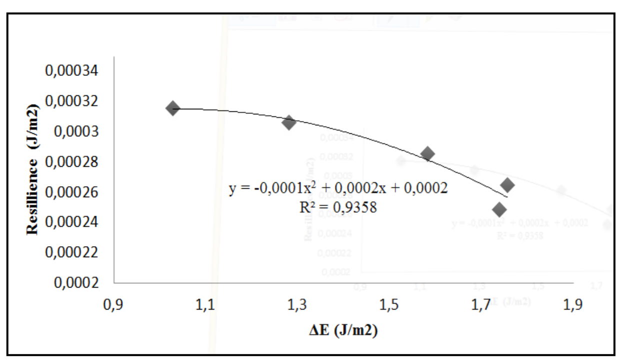


Figure 10 Graph of Pneumatophore Flexibility in Attenuating Wave Energy.

Based on the graph in Figure 10, the flexibility of the pneumatophores affected the wave energy attenuation. Based on the results of the lab tests, the pneumatophores are able to withstand an average load of 159,7 x 10^{-8} Joules or 160 x 10^{-8} Joules rounded. If the load is assumed to be the wave value, then it is not wrong to infer that 1 pneumatophore is able to withstand an average load of 160 x 10^{-8} Joules. The relationship between the flexibility and wave energy attenuation is $y = -0{,}0001x^2 + 0{,}0002x + 0{,}0002$.

3.2.3. Litter Data Processing

Avicennia marina litter's ability to attenuate waves was one of the analyzed variables in this study. The obtained circumference and height of the litter were then processed so as to produce the litter's volume, which was then used to calculate the porosity value at each station. The following are the results of the obtained data (see table 6) :

Table 6 Results of Litter Data Processing

Station	k (m)	H (m)	L (m^2)	Volume (m^3)
STA 1 (3 m)	29,08	0,51	67,27	34,00
STA 2 (5 m)	30,94	0,46	76,13	34,92
STA 3 (10 m)	35,00	0,38	97,44	37,03
STA 4 (20 m)	59,26	0,15	279,32	40,85
STA 5 (50 m)	74,44	0,11	440,75	46,80

1. **Result of Transmission Coefficient (Kt) and Porosity Value (Np) Analysis**

The porosity value includes parameters for the determination of the wave transmission coefficient [13]. Below are the results of the transmission coefficient and porosity value analysis (see Table 7).

Tabel 7 Results of Transmission Coefficient and Porosity Value Analysis

Station	Others	Example
STA 1 (3 m)	**0,2953**	**0,3979**
STA 2 (5 m)	**0,2657**	**0,6644**
STA 3 (10 m)	**0,0874**	**0,8331**
STA 4 (20 m)	**0,0435**	**0,9121**
STA 5 (50 m)	**0,0387**	**0,9595**

Referring to Table 7, the transmission coefficients and porosity values were in inverse proportion. The transmission coefficient decreased as the mangrove thickness increased, while the porosity value increased as the mangrove thickness increased. The magnitude of the transmission coefficient, whose value was the difference between the height of the transmission wave and that of the coming wave, shows the level of mangrove litter's ability to attenuate the waves going through it. The porosity or emptiness value which gets larger indicates less volume density. The occurring transmission coefficient remains strong, which is the cause of the attenuation of small waves.

3.3. Results of *Avicennia marina* Mangrove Data Processing

3.3.1. Relationship between Mangrove Thickness and Wave Energy Deviation

Each mangrove thickness had its own energy attenuation value. The attenuation value was greater as the mangrove thickness increased. The following table describes the relationship between mangrove thickness and Wave Energy Deviation (see Table 8) :

Table 8 Relationship between Mangrove Thickness and Wave Energy Deviation

Station	Wave Energy Deviation (%)
STA 1 (3 m)	50
STA 2 (5 m)	54
STA 3 (10 m)	83
STA 4 (20 m)	91
STA 5 (50 m)	92

The graph in Figure 11 was made on the basis of Table 8. The regression resulted in the equation $y = -0{,}0592x^2 + 4{,}0142x + 39{,}267$. Each mangrove thickness had the ability to attenuate different wave energy. From STA 1 to STA 2, the attenuation percentage increased by 7,08%, from STA 2 to STA 3, by 15,63%, from STA 3 to STA 4, by 22,38%. At STA 3, attenuation percentage was 73,49% and at STA 4, the percentage was 95,87%. At the farthest distance, from STA 4 to STA 5, it increased and decreased, the highest wave energy attenuation occurred at a thickness of 33,9 m, where the attenuation percentage reached 94,5%. The decrease occurred at a thickness of 33,9 m, where the percentage was 2,52 %.

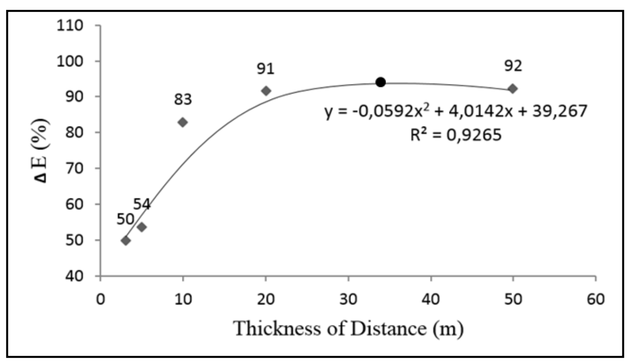


Figure 11. Graph of Relationship between Mangrove Thickness and Wave Energy Deviation.

3.3.2. Relationship of Results of Wave Energy Attenuation Percentages at Five Stations

Wave energy attenuation took place at each station. At each station, the attenuation of each factor varied. The following are the percentages of wave energy attenuation at the stations (see Table 9) :

Table 9 Percentages of Wave Energy Attenuation at Each Station

Station	Wave Attenuation Percentage by Pneumatophore [%]	Wave Attenuation Percentage by Litter [%]	Wave Attenuation Percentage by Other Factors [%]	Wave Energy Deviation [%]
STA 1 (3m)	14,93	16,44	18,63	50
STA 2 (5m)	10,36	7,08	36,55	54
STA 3 (10m)	5,43	2,29	75,28	83
STA 4 (20m)	4,22	1,05	85,73	91
STA 5 (50m)	3,90	0,48	87,62	92

Referring to the table above, the categories were the wave energy attenuation percentages based on pneumatophores, litter, and other factors.

1. Relationship between Energy Attenuation Percentages and Pneumatophores

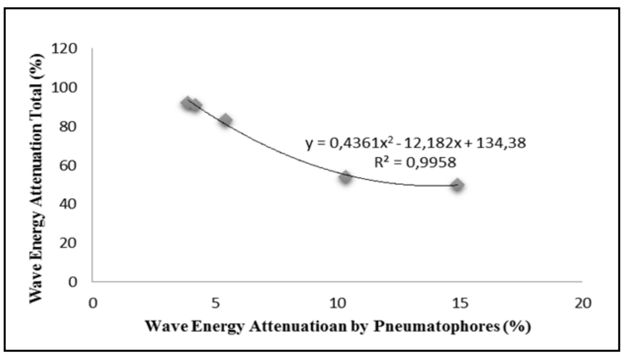


Figure 12 Graph of Relationship between Energy Attenuation Percentages and Pneumatophores.

Pneumatophores' wave energy attenuation at each STA decreased by a different percentage (see Figure 12). At STA 1, the pneumatophores attenuated energy by 14,93%, while at STA 2, by 10,36%, at STA 3, by 5,43%, at STA 4, by 4,22%, and at STA 5, by 3,90%. The pneumatophore attenuation on the coastline was the most effective as the pneumatophores were flexible when submerged in waves. In order to find the percentage of the total energy attenuation by the pneumatophores, the equation $y_1 = 0{,}4361a^2 - 12{,}182a + 134{,}38$ was applied.

2. Relationship between Energy Attenuation Percentages and Litter

Figure 13 shows that the litter was able to attenuate wave energy like the pneumatophores, but the attenuation values were different. At STA 1, the litter attenuated wave energy by 16,44%, while at STA 2, by 7,08%, at STA 3, by 2,29%, at STA 4, by 1,05%, and at STA 5, by 0,48%. The litter attenuation on the coastline was the most effective since the litter had the lowest porosity value. So as to figure out the percentage of the total liter energy attenuation, the equation $y_2 = 0{,}3381b^2 - 8{,}5159b + 98{,}461$ was applied.

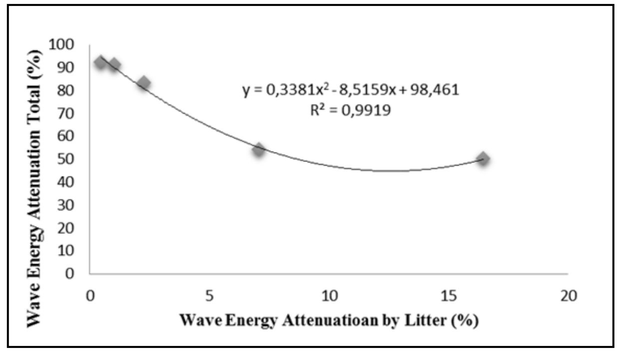


Figure 13 Graph of Relationship between Energy Attenuation Percentages and Litter.

3. Relationship between Energy Attenuation Percentages and Other Factors

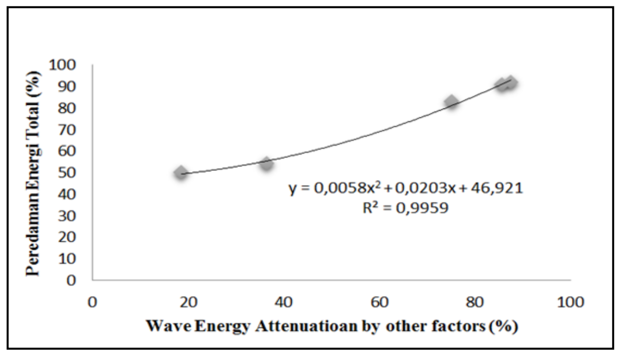


Figure 14 Graph of Relationship between Energy Attenuation Percentages and Other Factors.

Figure 14 shows the farther the other factors from the coastline, the more wave energy they attenuated. In other words, as opposed to the pneumatophores and litter, the attenuation percentage kept increasing starting from STA 2. At STA 1, the other factors attenuated the wave energy by 18,63%, while at STA 2, by 36,55%, at STA 3, by 75,28%, at STA 4, by 85,73%, and at STA 5, by 87,62%. The other factors were large trees, core trees, seedlings, piles, stakes, sedimentation, and twigs. These factors dominated more as the mangrove thickness increased. The percentage of the total energy attenuation by the other factors was calculated through the equation $y_3 = 0{,}0058c^2 + 0{,}0203c + 46{,}921$.

4. Relationship of Energy Attenuation Percentages with Pneumatophores, Litter and Other Factors

In reference to Figure 15, each station had a different percentage and ratio. At STA 1, the mangroves were able to reduce the wave energy by 50% with a ratio of 14,93 (pneumatophores) + 16,44 (litter) + 18,63 (other factors) = 50%. At STA 2, by 54% with a ratio of 10,36 (pneumatophores) + 7,08 (litter) + 36,55 (other factors) = 54%. At STA 3, by 83% with a ratio of 5,43 (pneumatophores) + 2,29 (litter) + 75,28 (other factors) = 83%. At STA 4, by 91% with a ratio of 4,22 (pneumatophores) + 1,05 (litter) + 85,73 (other factors) = 91%. At the station the farthest from the coastline, STA 5, by 92% with a ratio of 3,90 (pneumatophores) + 0,48 (litter) + 87,62 (other factors) = 92%.

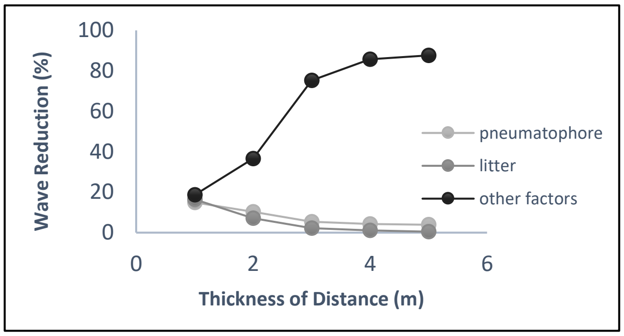


Figure 15 Graph of Relationship of Energy Attenuation Percentages with Pneumatophores, Litter, and Other Factors.

An *Avicennia marina* mangrove pneumatophores and litter are beneficial to attenuating wave energy. It is hoped that the government and society will consider making use of *Avicennia marina* mangroves for natural protection for buildings on the coast. Mangrove forests are viable for building, port, ecotourism, and marine farming construction so that the mangrove ecosystem will not be harmed.

4.0 CONCLUSION

It is safe to conclude that the attenuation of wave energy by pneumatophores and litter on the coast is the highest in effectiveness owing to the bending power of pneumatophores and the low porosity value litter has. As for such other factors as large trees, core trees, seedlings, piles, sedimentation, and twigs, they get more effective as the mangrove gets thicker. It is feasible to use *Avicennia marina* mangroves for natural protection for building, port, ecotourism, and marine farming construction to avoid causing the ecosystem of mangroves any harm.

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