Additional Thesis Report

A Study on Geometric and Material Properties of the Mangrove Root System in Singapore

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ABSTRACT

Although the effect of wave attenuation by mangrove has been widely observed and studied, the problem pertaining to how to accurately describe the geometrical properties is still remaining unresolved. Also, the material properties of mangrove root have not been comprehensively studied before. This is study is dedicated for the survey on geometric and material properties of mangrove in Singapore for future modeling work.

In this study, two types of mangrove are surveyed, as Sonneratia alba and Rhizophora, for the two survey types of mangroves are mostly abundant in Singapore and Johor River region. Photogrammetry technique has been extensively practiced for capturing the geometrical properties of the mangrove root. Lab testing has been carried out to obtain the material properties of mangrove root.

The geometrical properties studied are mainly root density, root distribution and root height. The material properties studied are the mass density, moisture content and modulus of elasticity of the mangrove roots.

1. Introduction

Mangrove is the general appellation for a collection of types of trees which grows in the intertidal regions. Abundant mangroves can be easily found in the natural reserves along tropical and subtropical coastlines. Various types of mangroves have been observed in the natural reserves in Singapore, such as *rhizophora apiculata*, *rhizophora mucronata* under *rhizophoraceae* and *sonneratia alba*, *sonneratia caseolaris* under *sonneratiaceae*. (Nilus et al., 2010)

Although a wide range of study has been conducted on the wave attenuation effect by the presence of mangrove, the effect of mangrove root system on the changing of flow current profile has never been studied before. In this research, various properties of the mangrove root will be assessed, which would provide fundamental information to the modeling work in the future.

1.1 Background Information

In facilitating the ongoing Singapore-Delft Water Alliance's research, this project serves as a step stone with objective of obtaining insight information and data on mangrove root systems.

Locations for sampling are Berlayer Creek and Pasir Ris Park. Berlayer Creek is rich in mangroves with pneumatophores. However, mangrove with prop roots has also been spotted in Berlayer Creek. Pasir Ris Park is abundant with mangrove with prop roots. Therefore, Berlayer Creek would be considered the primary location for sampling. If the number of sample for prop roots mangrove is insufficient, additional visit to Pasir Ris Park would be made.

1.2 Project Objective

The objective of this research is to assess both geometrical and mechanic properties of the root systems so as to assist the future modeling work with data.

Among those observed mangrove species, two distinct root systems have been spotted, as pneumatophores and prop roots. Based on the viability of sampling, the research scope has been restricted to the flowing two mangrove genera,

Table 1-1 Surveyed Root Systems

Root System	Species
Pneumatophore	*Sonneratiaceae – Sonneratia alba*
Stilt Root	*Rhizophoraceae - Rhizophora*

The geometrical property of this research includes the above ground height of roots, the spatial density of roots etc. The measured mechanical properties include moisture content, material density and Young's Modulus of the roots.

1.3 Methodology

So as to obtain the detailed information about various properties of mangrove roots, different set-ups have been prepared.

The spatial density would be obtained with assistance from photogrammetry software called iWitness. iWitness is a software designed for establishing three dimensional images from images with two dimensional coordinate system. In order to achieve the 2D to 3D transformation, multiple images around the same area or object have to be taken. By aligning the images with referenced common points, a three dimensional coordinate system can be established. The basic idea and processes of such transformation has been shown in the Figure 1-1 and Figure 1-2 below.

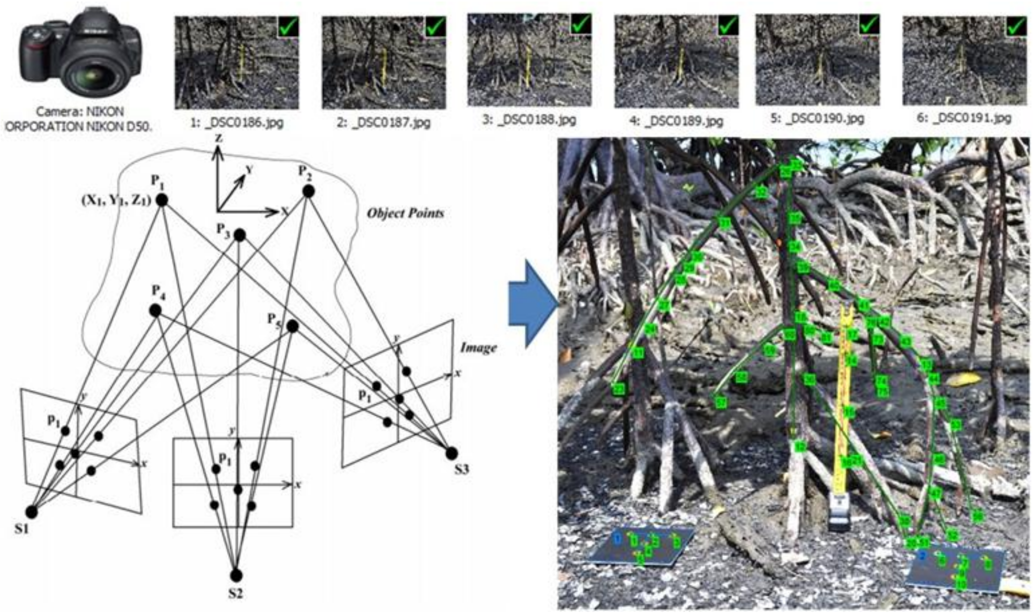


Figure 1-1 Photogrammetric Triangulation to a Rhizophora Tree.

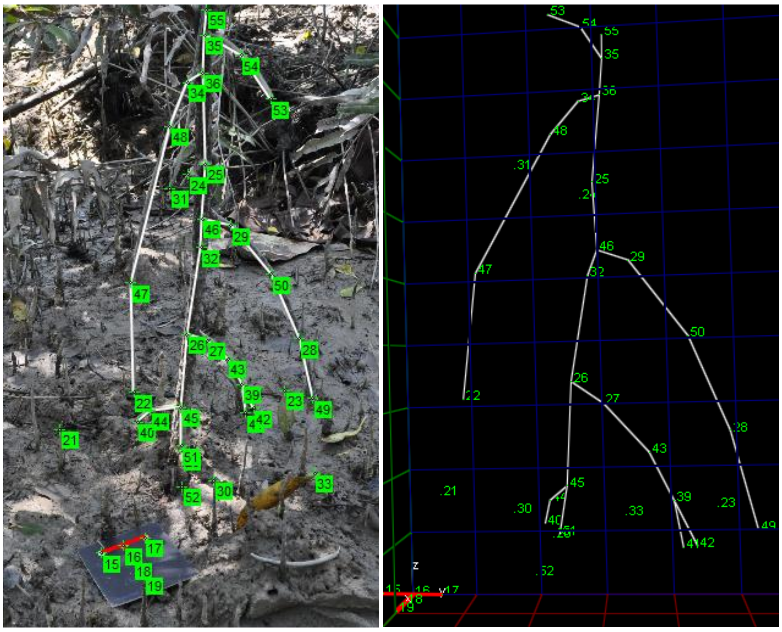


Figure 1-2 Three Dimensional Plot from iWitness Photogrammetric Processes

Once the three dimensional model has been set up, measurements, such as root height and distance from tree stem, can be taken from the model. Root density is also counted from the photos.

The mangrove roots have also been sampled during field work. Tensile test for the young's modulus has been conducted in the lab. Also, the moisture content of the root has been measured.

2. LITERATURE REVIEW

A brief literature study pertaining to various properties of mangroves is presented in this section. Section 2.1 summarizes the study on mangrove from biological perspective. On the other hand, section 2.2 and section 2.3 reviews the geometrical and material properties respectively from engineering perspective.

2.1 MANGROVE ROOTS INFORMATION

2.1.1 TYPE AND ATTRIBUTES OF MANGROVE ROOTS

Mangrove is an ecological entity lives in the intertidal zone of marine coastal environment. Although various genera of mangroves have been identified based on their root system, the functions of each types of root are still largely unknown. However, several common attributes are still widely recognizable. First of all, some types of roots, if not all, structures to support the above ground tree mass. Such function is more observable in the mangrove with stilt roots, like Rhizophora. The meaning of “stilt” reveals the supporting function of this type of roots. Also, some of mangrove root has been identified with salt excreting glands, which has a function in maintaining the salt balance inside the tree. The distinct salt excreting gland sets the critical foundation for mangrove to live in marine coastal environment. Another commonly existed attribute of mangrove root is its breathing function. Both pneumatophores and stilt root mangrove have been identified with small air breathing lenticals. It is a common for mangrove root to be submerged in water for about half a day daily. Also, the air breathing lenticals in root can store small among of air during emerging time and release supply the tree with stored air when the root is submerged in the water. Since in most place of the coastal area, the semi-diurnal is the dominate component. Therefore, within one tidal period, the root would be submerged for half of the tidal cycle, as about six hours, which coincides with the assertion in Mazda (2007)’s book “Manual for preservation and utilization of mangrove ecosystems”. In the book, the author contends that, roots for Sonnaritia cannot survive for more than six-hour of submergence. (Mazda et al., 2007)

Summarized by De Vos (2004), a graphic description of the three types of commonly found mangrove is presented in Figure 2-1 below.

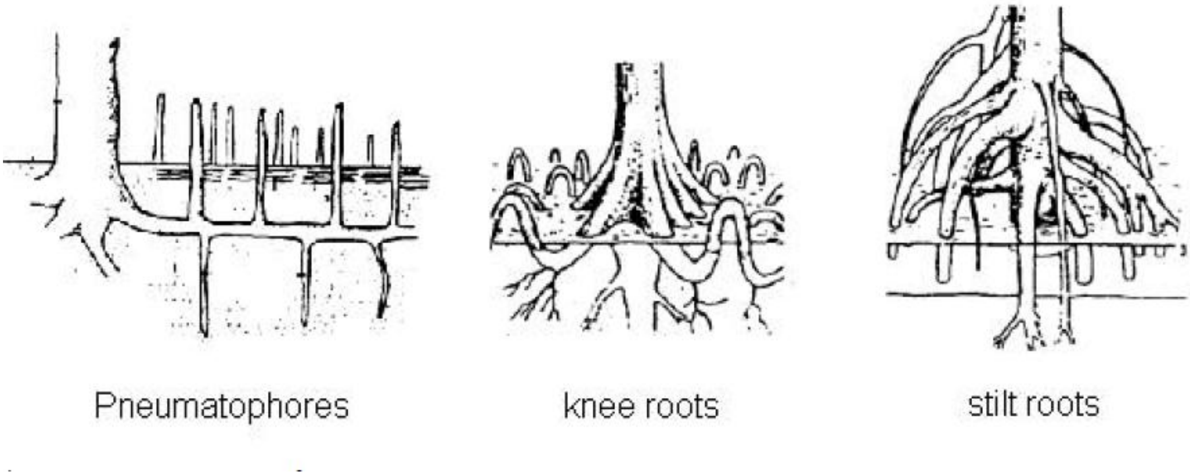


Figure 2-1 Three Types of Commonly Observed Mangrove Root Systems (De Vos, 2004)

Pneumatophore comes from Latin with a meaning of up-rooting. This type of root grows from the horizontal cable roots which expense in underground. The length of pneumatophore is species dependent. According to Tomlinson (1986), Avicennia aerial roots can be 30 cm in length; Sonneratia aerial roots can be 3 meter long.

Knee root is different from tree to tree. In some species, the knee root is part of horizontally growing cable roots. Part of the cable root emerges to surface periodically while growing away from tree stem.

Stilt root is a type of branched aerial prop roots which grows out from main trunk or another stilt root in the lower part of Rhizophoraceae. The name "stilt" refers to the supportive attribution of the roots. (Tomlinson, 1986)

2.1.2 Zonation of Different Genera of Mangroves

Zonation is one of the most recognizable features of different species of mangrove. Bunt (1996) briefly summarizes the finding of zonation feature of mangrove. The graphic representation of relative position from land to sea can be revealed from Figure 2-2 below.

Figure 2-2 General Zonation of Mangrove

Although the zonation feature is widely recognized, the reason behind such zonation remains still unclear. Smith (1992) summarizes a possible explanation from land building and plant succession point of view. In this research, Curtis (1888) makes the earliest claim on the mangrove's capability in land building, especially for Rhizophora mangrove; Davis (1940) summarizes the sequential land building role for a range of intertidal plant. He states that the processes start with sea grasses colonize the sub-tidal area and trap sediments. The trapped sediment provides ground for Rhizophora to grow. More sediment would be trapped from Rhizophora; Further, Rhizophora would be replaced by Avicennia further in land.

Based on field observation in Singapore, the relative position proposed by Bunt (1996) is verified. Sonneratia grows right next to the sea in the intertidal region; Rhizophora colonizes the land relatively inland to Sonneratia; Avicennia grows further inland. However, there is no clear boundary among the position of the three types of mangroves. Especially for Rhizophora and Acicennia, these two types of mangroves almost grow together with each other.

2.2 Geometrical Properties

Although extensive research work has devoted in searching for previous study on the geometrical properties of mangrove, it appears that the prior data upon this feature of mangrove is rarely exist.

The data sets presented in this section is from Mr. Zhang Xiaofeng (2012), a PhD researcher working on the currently on going Singapore-Delft Water Alliance mangrove project. The special density and root height of mangrove based on his survey result is tabulated in the table and figure below.

Spatial Density of Sonneratia alba

Table 2-1 Spatial distribution density of pneumatophore at different distance from main trunk

Location	Species	Spatial density (number/m^2)
Berlayer Creek, P-A1*	*Sonneratia alba*	90
Berlayer Creek, P-A2	*Sonneratia alba*	58
Berlayer Creek, P-A3	*Sonneratia alba*	59
Berlayer Creek, P-B1	*Sonneratia alba*	106
Berlayer Creek, P-B2	*Sonneratia alba*	73
Berlayer Creek, P-B3	*Sonneratia alba*	84

*P-A1, P-A2 and P-A3 at 1 m, 2 m and 3 m away from main trunk respectively for the same *Sonneratia alba* tree. P-B1, P-B2 and P-B3 are in the same fashion but for different tree at Berlayer Creek.

Table 2-2 Spatial distribution density of pneumatophores of mangroves

Location	Species	Spatial density (number/m^2)	Reference
Pasir Ris Park	*Avicennia marina*	98	In this report
Berlayer Creek	*Sonneratia alba*	81	In this report
Benut, Malaysia	*Sonneratia alba*	101	In this report
Johor River, Malaysia	*Avicennia marina*	96	In this report
New Zealand	*Avicennia marina*	40-250	Young and Harvey (1996)
Australia	*Avicennia marina*	50-381	Burchett et al. (1998)
Australia	*Avicennia marina*	24-347	Harty and Cheng (2003)
New Zealand	*Avicennia marina*	80-200	Andrea C (2006)

The data from table 2-1 above suggest that the root density of sonneratia alba decreases as the distance increase from tree trunk. Table 2-2 suggests that Avicennia marina has a higher root density.

Diameter and height of pneumatophore

The height of pneumatophore refers to the above ground root height. The diameter is measured for the woody core of collected sample only. Therefore, the diameter would be larger in natural environment. Avicennia marina and Sonneratia alba are the types of pneumatophore surveyed.

Table 2-3 Diameters and heights of pneumatophore collected

Species	Diameters (mm)		Heights (cm)	
	Mean	STDEV	Mean	STDEV
Entire *Avicennia marina*	8.569	0.767	23.907	4.111
Entire *Sonneratia alba*	7.466	0.821	22.540	3.472
Woody core of *Sonneratia alba*	5.902	0.403	\	\

Based on field observation, it has found that the root of *Avicennia marina* appears in a pencil like shape, the diameter from bottom to the tip is rather uniform. On the contrary, the root of *Sonneratia alba* is rather cone-shaped, which are thicker at the bottom and the diameter decreases as goes to the tip.

2.3 Material Properties

Since mangrove roots are woody and pliant, under flow condition, the shape of the root would be slightly altered. If the mangrove root is modeled with rigid bars, the result of analysis may be inaccurate. Also, some research also concerned with the flow driven vibration frequency of root under submerge condition may match with the natural frequency of the root. In such case, unexpected large amplitude of vibration result from resonance may raise the magnitude of turbulence in flow. Therefore, so as to obtain a more comprehensive and rigorous information regarding to mangrove roots, the material properties of mangrove root system have also been assessed in this project. In this project, the material properties concerned are density, moisture content and Young's Modulus.

Though extensive researches have been made on wood property study, no prior study which dedicated to mangrove root has been found. Several studies regarding to the Young's Modulus of different type of wood has been summarized in table 2-4 by Mr. Zhang (2012).

Table 2-4 Modulus of Elasticity from Tensile Tests of Trees or Roots

Species	Details or common name	Tensile E (MPa)	Reference
Acer sacharinum	Silver maple	600	Beal (Mafian et al., 2009)
Populus	Poplars	200-300	Wu (Mafian et al., 2009)
Salix	Willows	200-300	Hathaway and Penny (Mafian et al., 2009)
	Cherry tree roots	220	Zoltán (2003)
Pseudotsuga menziesii	Douglas-fir	400-600	Commandeur and Pyles (1991)
	Woody plants and roots	204-800	Coutts; Mickovski and Ennos (Melzer et al., 2012)
Arundo donax	Adventitious roots	700	Speck (Melzer et al., 2012)
Galium aparine	First-order lateral roots	235	Goodman (Melzer et al., 2012)
Hedera helix	Intact attachment root	109	Melzer et al. (2012)
Hedera helix	Central cylinder root	220	Melzer et al. (2012)

3. Measurements

Throughout the project period, in total six field trips have been made. Among all the trips, five of them are carried out in Singapore; the other one field survey is conducted in Malaysia. During the field trips, large amount of photos have been taken for photogrammetry analysis. Also, more than 40 pneumatophore samples and 20 Rhizophora root samlpes have been collected for testing purposes. All the geometrical and material results presented in this section are based on photogrammetry analysis results and lab testing results. In this section, the analysis results for Pneumatophore Sonneratia and Rhizophora will be presented in section 3.1 and 3.2 respectively.

3.1 Measurements for Pneumatophore Sonneratia

In this section, the survey result on Sonneratia will be presented. Among all field trips, four field trips have been dedicated for pneumatophores. Three Sonneratia trees have been located and surveyed. A three dimensional model has been built on AutoCAD based on surveyed geometrical properties. Material properties of root samples have also been assessed. The test result suggests that moisture content has a large influence on the modulus of elasticity of the root.

3.1.1 Geometrical Properties of Sonneratia

Although the root density of pneumatophore has been studied by other researchers before, the question that how does the root density varies with tree stem and water remains unresolved. In this study, three trees from Berlayer Creek have been surveyed to the detail to as to capture the spatial root density and root height variation.

<u>Spatial Root Density</u>

Among the tree surveyed trees, one is relatively more mature than the other two. It is rather observable that the roots of relatively mature Sonneratia expends further than which from the other two. In the following analysis, the mature tree is designated as P1; the other two trees are named after P2 and P3. The stem diameter of surveyed Sonneritas can be found in Table 3-1.

Table 3-1 Diameter of Surveyed Sonneratias

	Diameter [mm]
P1	350
P2	160
P3	300

Figure 3-1 Location of the Three Sureyed Sonneratias

In order to assess the spatial distribution of root density, centered in the tree trunk, the ground next to each surveyed tree has been hexagonalized. Refers to Figure 3-2, 12 quadrilaterals have been created for each tree. Six of them form the inner circle; the rest forms the outer circle. Thus, by comparing the root density from inner circle and outer, the root density variation with the distance from tree stem would be clear. The sections in the inner circle are denoted with A; the outer circle section has been denoted with B. Also, same number has been assigned to the sections which share the same direction in inner and outer circle. For instance, section A3 and B3 are in the same orientation from tree stem; A3 is the section in the inner circle; B3 is the section in the outer circle. In addition, by comparing the root density from each section and its relative location from water, the root density distribution pattern in relation to water can be assessed.

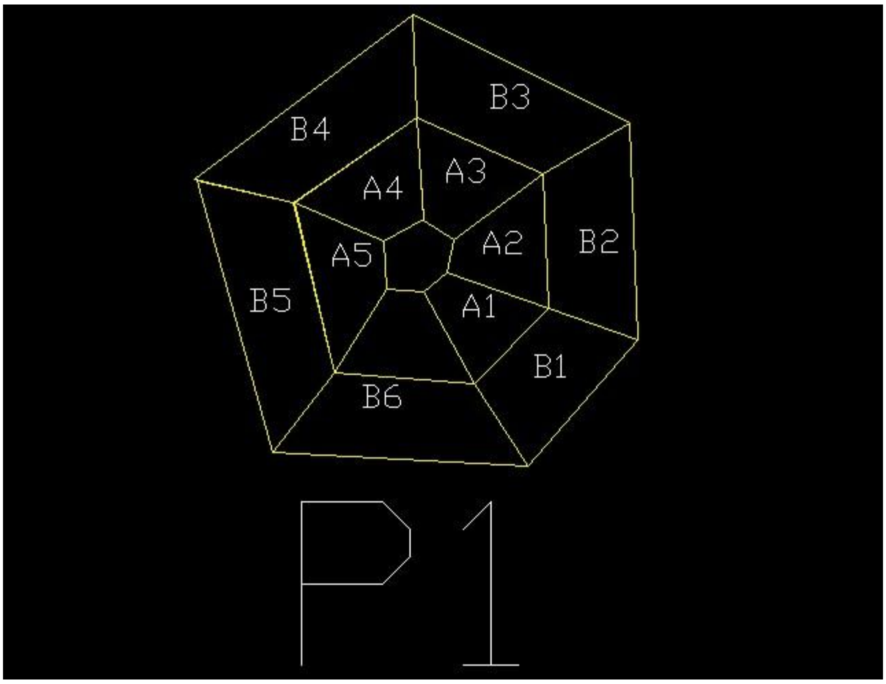


Figure 3-2 Top View of the Sections for Pneumatophore Density Analysis

In addition, for the roots of P1 extends to a larger distance than which from P2 and P3, the edges of the sections normal to the tree trunk in P1 have been marked with 1 meter. However, in P2 and P3, the edges normal to tree trunk are marked with 0.5 meter. Hence, the root density result for P1 in inner circle can be generally regarded as the density within 1 meter range from tree trunk; whereas in P2 and P3, the root density can be regarded as with 0.5 meter range from tree trunk. The spatial root density can be found in Table 3-2 below. The detailed information can be found in Appendix A.

Table 3-2 Root Density Distribution

P1			
Area #	Density	Area #	Density
A1	101.8	B1	53.8
A2	101.1	B2	45.9
A3	131.6	B3	56.5
A4	119.4	B4	66.2
A5	130.5	B5	85.7
A6	119.8	B6	76.0
P2			
A1	178.9	B1	115.7
A2	218.9	B2	102.1
A3	160.7	B3	148.1
A4	142.0	B4	93.4
A5	142.9	B5	86.9

A6	102.5	B6	96.5
P3			
A1	171.8	B1	106.4
A2	144.5	B2	137.1
A3	133.9	B3	67.5
A4	171.8	B4	72.0
A5	218.3	B5	99.4
A6	122.7	B6	54.9

Observe from Table 3-2 above, it is rather clear that, for every section, the root density is higher in inner section than which in the outer section. The averaged root density in inner sections and outer sections are compared in Table 3-3.

Table 3-3 Average Root Density of Inner and Outer Sections

P1 A	117.4	P1 B	64.0
P2 A	157.6	P2 B	107.1
P3 A	160.5	P3 B	89.5

Therefore, conclusion that the root density of pneumatophore is higher close to the tree trunk can be drawn. The average root density for the selected trees within 1 meter from tree trunk is about 120 roots per square meter, which is slightly higher than the data from literature review section. The result is sound in a sense that the previous study on root density has been conducted on random locations, which many of them are further than 1 meter away from the tree trunk.

For each selected pneumatophore, section 3 and 4 are the ones closest to the creek. Observed from Table 3-2, there is no clear pattern which indicates the relation in between spatial root density and distance from water. However, based on field observation, the sections with high root density are the sections close to coastal line.

<u>Root Height and Distance from Tree Trunk</u>

Assisted by iWitness, the root height and distance from tree stem relation can be also assessed. Based on the sections created in the previous section, 5 roots have been randomly selected from each section. By measuring the root height and distance from center of stem, the result is plotted in Figure 3-4 and Figure 3-5. Since more coverage has been surveyed for P1, additional number of root sample has been retrieved from P1 so that the analysis can be extended to a 2 meter diameter range. The plot dedicated for P1 can be found in Figure 3-3. The detailed data can be found in Appendix B of this report.

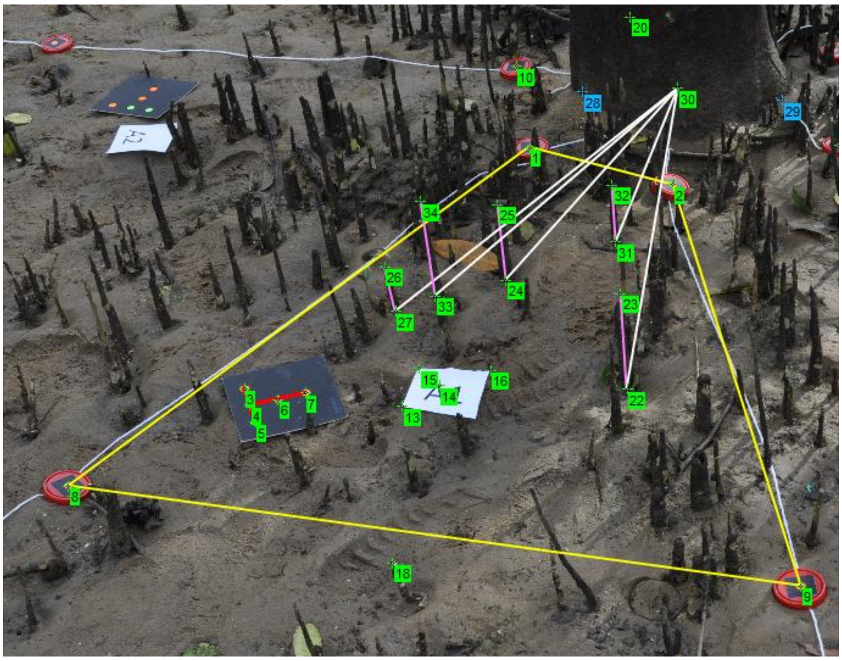


Figure 3-3 Root Height Survey

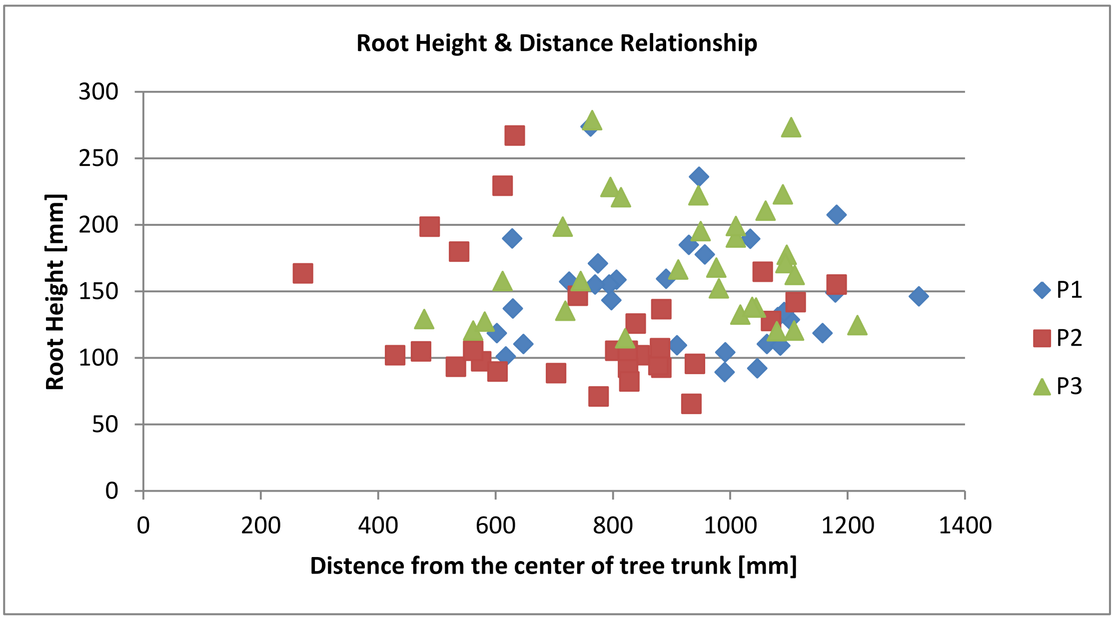


Figure 3-4 Root Height and Distance from Tree Trunk

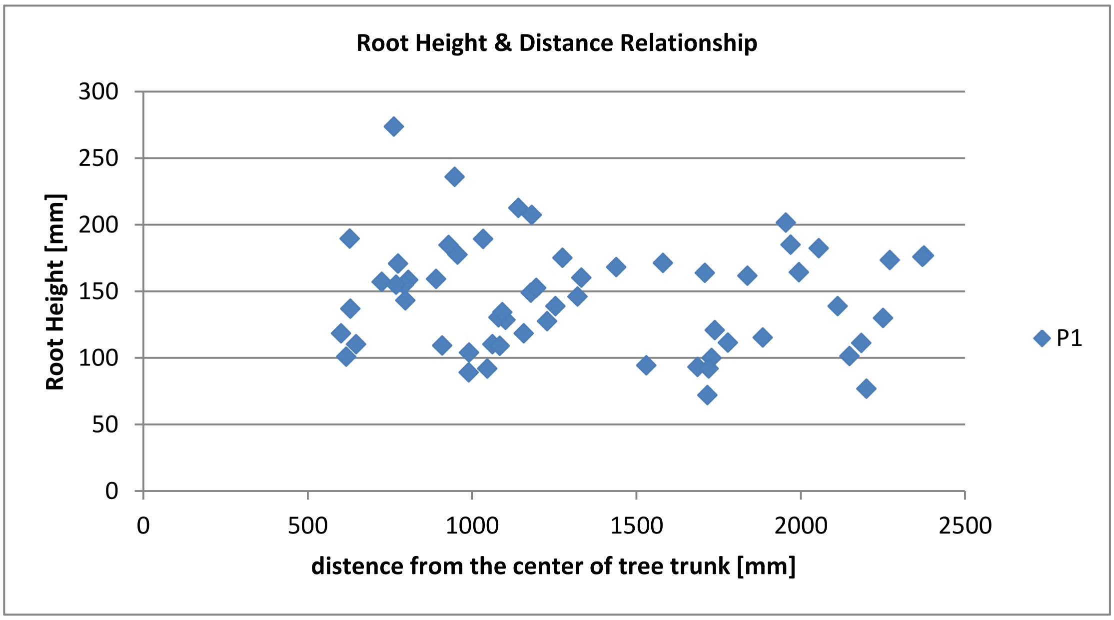


Figure 3-5 Root Height and Distance from Tree Trunk of P1

As shown in Figure 3-4, no clear tendency can be found. However, Figure 3-5 suggests that the root with height larger than 20 cm is rare after 1.5 meter away from tree trunk. The overall averaged height of the sampled root is about 14.6 cm.

In conclusion, the root density decreases as further away from the tree stem. Root taller than 20 cm is rarely to be found at 1.5 meters away from tree stem. However, the relation in between the root density and its relative position to the water remains unclear.

3.1.2 Material Properties of Sonneratia

In this section, the material properties of pneumatophore are presented. The properties concerned in this research are the density of the root, the moisture content of the root and the modulus of elasticity.

<u>Density</u>

Density measurement has been carried out immediately after the samples have been collected from field so as to preserve the moisture content of the root. The volume of root sample is measured with a 100ml measuring cylinder. A Mettler Toledo AE 260 balance is used for obtaining the weight of root samples. By dividing the weight with volume of root sample, the density of sampled roots can be obtained.

In total, 23 root samples have been measured for density. The averaged root density is about 0.706 g/cm^3, the associated standard deviation is about 0.05 g/cm^3. For the standard deviation of density is rather small, conclusion that the density of pneumatophore is about 0.7 g/cm^3 can be drawn. The measured data can be found in the Appendix C.

<u>Moisture Content</u>

The sampled roots have been divided into two groups. One group of the sampled roots is dried in oven for moisture content test; the rest goes to test for modulus of elasticity. In order to obtain the moisture content, an oven with temperature of 103 Degree Celsius has been used. The sampled root has been weighted before and after put into oven. The weight difference before and after should be the weight of water inside the root. However, since no prior study has been conducted for moisture content of pneumatophore, the duration that root sample should stay in the oven is unknown. Therefore, during the oven drying, root samples have been taken out from oven and weight again from time to time so as to monitor the weight changes. The process is terminated when there is no obvious weight changes in the root sample.

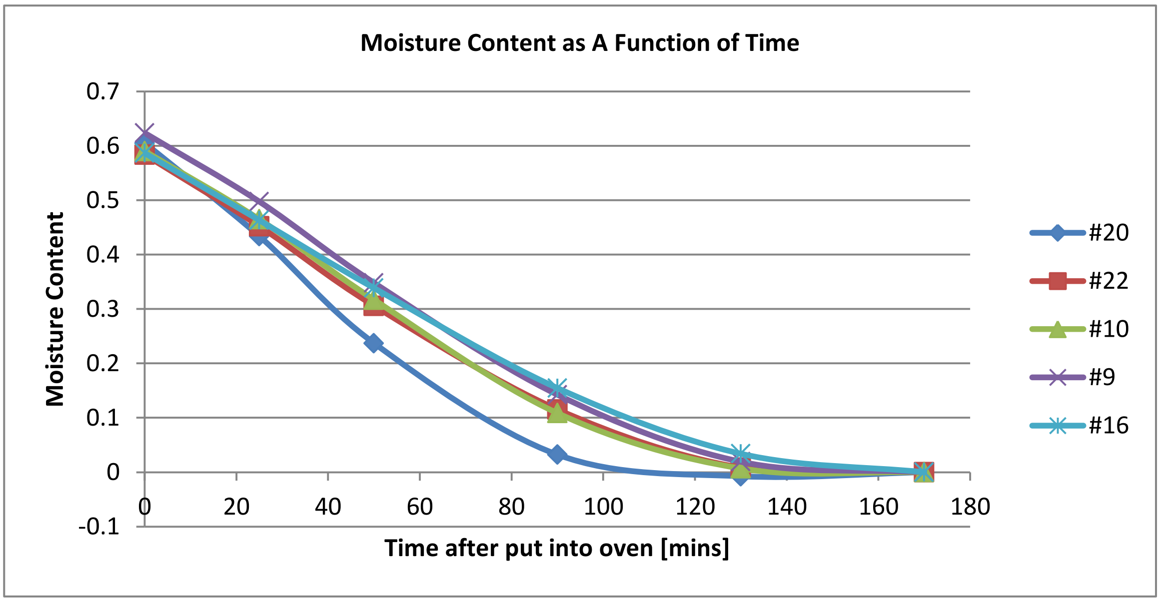


Figure 3-6 Moisture Content as A Function of Time

As shown in Figure 3-6 above, the preferred oven drying duration is about 150 minutes. After 150 minutes of oven heating, the weight of root samples does not change much. Also, the moisture content of root sample is about 60%. The detailed information about the tested moisture content can be found in Appendix D.

Figure 3-7 Fresh vs. Oven dried Root Samples

Modulus of Elasticity

The modulus of elasticity is measured by Young's modulus of the material. In order to obtain the Young's modulus, standard tensile test equipment has been set up. The tensile test is conducted on Shimadzu testing machine with crosshead speed of 1mm/min. The longitudinal deformation is measure by strain gauge sticks to the sample surface.

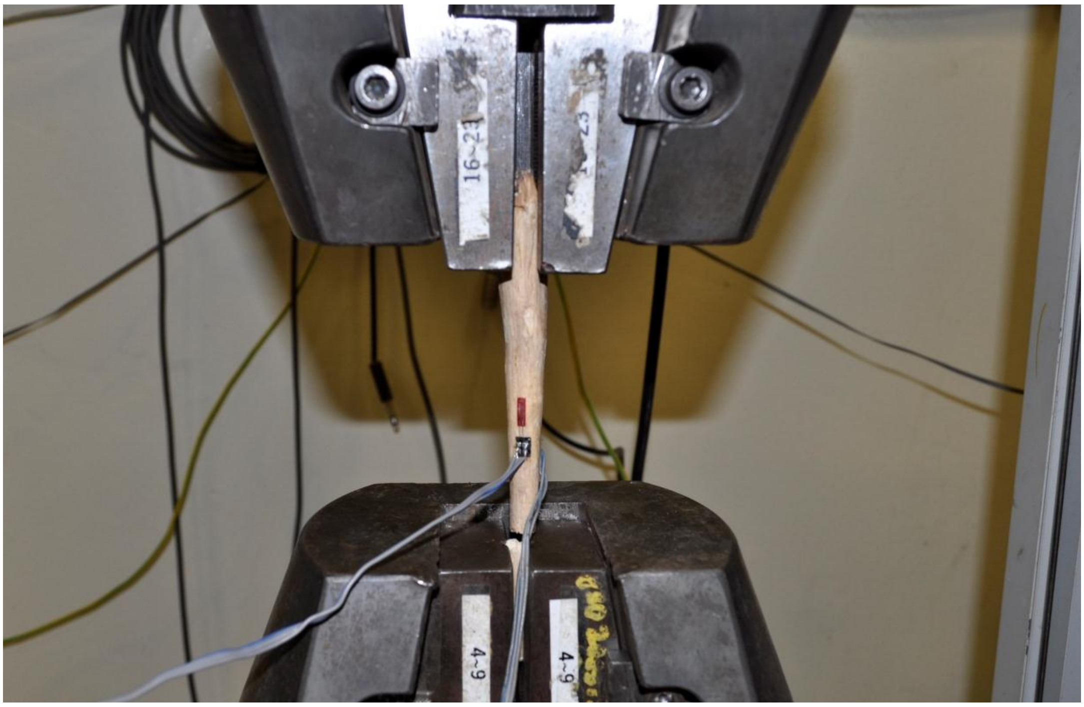


Figure 3-8 Tensile Test for Pneumatophore; picture at the top: Shimadzu test machine with root samples; on the left bottom: samples before test with strain gauge; on the right bottom: samples after test;

Samples have to be further prepared before conducting the tensile test. As shown in Figure 3-9 below, both pneumatophore and rhizophora root has three layers, as bark, woody core and marrow. However, the marrow layer in pneumatophore is almost unobservable. On the contrary, marrow layer covers a large portion of cross section in rhizophora root. Both bark layer and marrow layer are very soft and cannot bear tension. Therefore, in order to prevent slippery during tensile test, the bark layer for pneumatophore has been removed before test.

Figure 3-9 Cross Section View of Pneumatophore and Rhizophora Root

By interpreting test results, Young's modulus of the sampled roots is calculated from stress-strain relation. Only the linear part of the stress-strain curve is used to represent the Young's modulus of root sample. As shown in Figure 3-10, the figure in blue color is plotted from original test result; the portion of result marked with red color is used to calculate the Young's modulus.

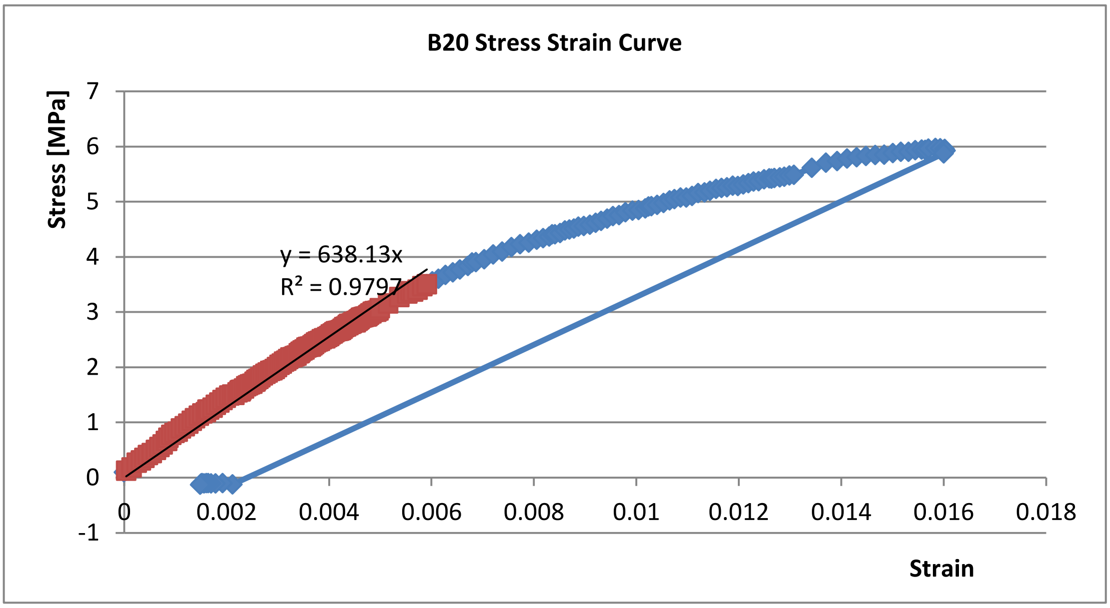
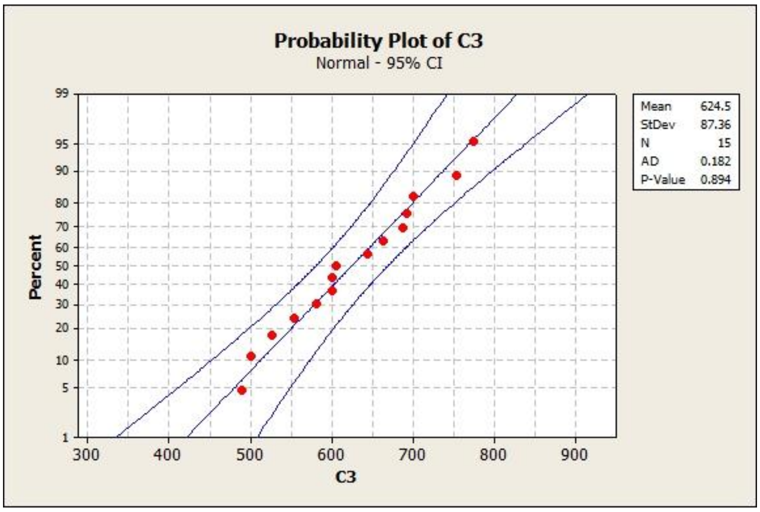


Figure 3-10 Stress-Strain Curve for Sample B20

The calculated Young's modulus for 15 tested samples is summarized in the Figure 3-11 below. The average Young's modulus is about 620 MPa with a standard deviation about 90 MPa. The calculated modulus of elasticity is lower than which calculated by Zhang (2012) which is about 800 MPa. By Checking through the details, Zhang (2012) conducted the test two day after the samples have been collected. The moisture content in his sample would be lower than the test samples in this research. As well presented in previous studies regarding to wood properties, lower moisture content will result in higher modulus of elasticity. Therefore, the margin of difference is understandable.



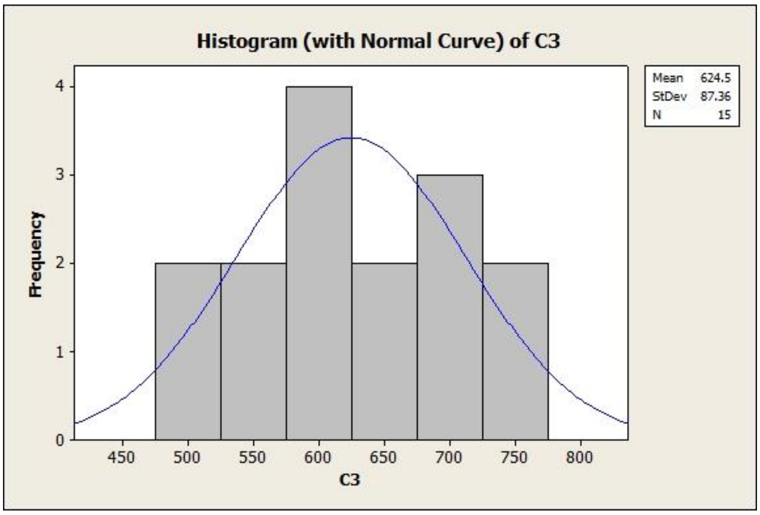


Figure 3-11 Modulus of Elasticity from Test Result

3.1.3 3D MODEL FOR SONNERATIA

According to the information obtained from geometrical property section, a 3-dimensional model has been set up in AutoCAD. As shown in Figure 3-12, the three surveyed sonneratias are plotted with their relative locations. Both tree stems and pneumatophores are simplified with rods. In each divided sections, 5 pneumatophores are plotted with their exact location, the rest are randomly placed. The original number of root in each section is also preserved.

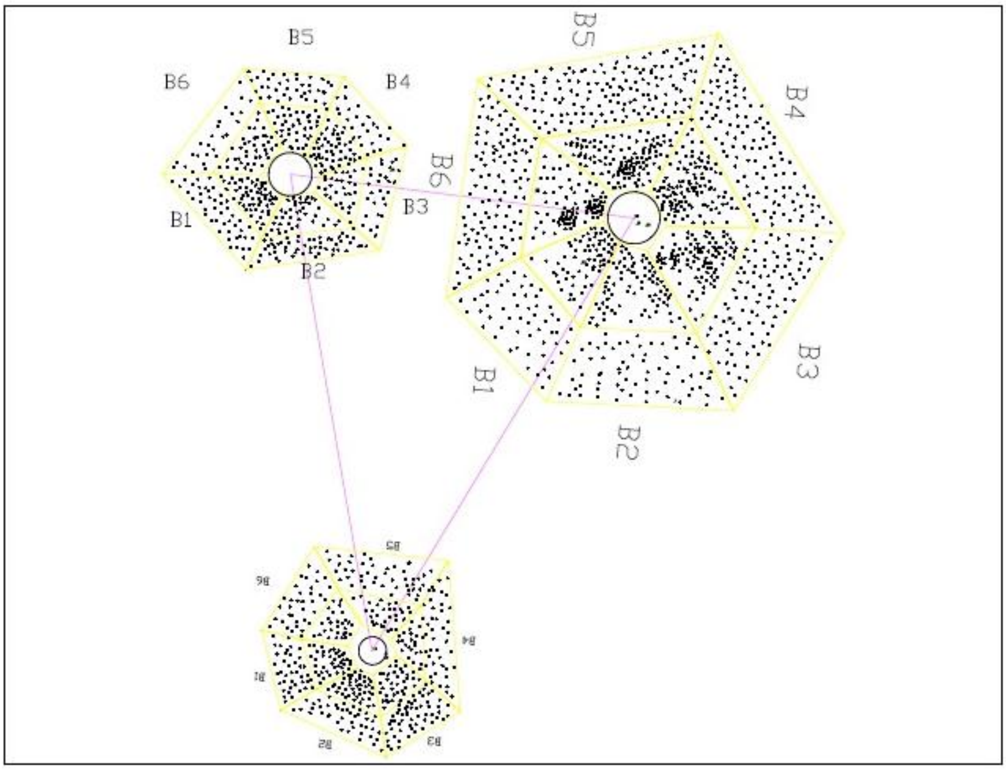


Figure 3-12 Relative Loaction of Surveyed Sonneratia and Pneumatophore

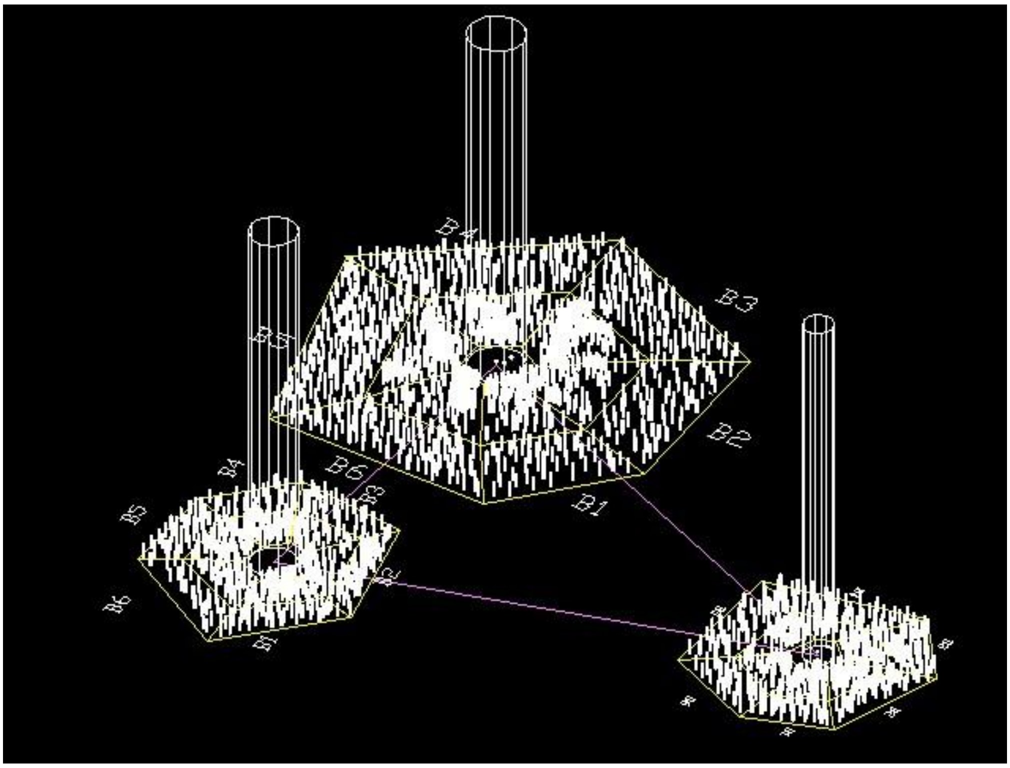


Figure 3-13 3D View of Pneumatophore

3.2 Measurements for Rhizophora

Follows similar conduct as previous section, both geometrical and material properties about rhizophora will be presented in this section. 15 trees have been surveyed for geometrical properties. 8 samples have been tested for material properties. Since root sampling is prohibited in Singapore, the tested rhizophora root is collected from Benut, Malaysia. Benut is also located along Johor River. Therefore, the mangrove should share similar properties as which in Singapore.

3.2.1 Geometrical Properties of Rhizophora Root

For the shape of rhizophora is greatly differ from Pneumatophores, different analysis technique should be adopt so as to capture the effective root density and distribution of rhizophora. In this study, the root density issue is approached from the position of root branch out from tree stem or root. Root which branched out from stem is denoted with primary root; root branched out from primary root is denoted secondary root and so on so forth. For the photogrammetry technique is limited by a practical reason, the geometric properties for rhizophora with level of root higher than tertiary are very difficult to be captured. For photogrammetry requires extensive number of reference point on different photos to establish the 3D model, the designated reference points on rhizophora with high root density would get blocked by the roots from photo to photo. In addition, during the field trip made for rhizophora, the trees with level of root higher than secondary are rarely to be found. Therefore, in this research, the levels of root considered are primary, secondary and tertiary. In this study, the branch-out positions of primary and secondary roots are studied. In such case, once the position is identified, the root density below a designated height can be described in such way. The tertiary root has been ruled out from study, for the number of tertiary root is too few to be put into any distribution analysis.

Refer to Figure 3-14 below, the stem has been marked with white color; the roots with maroon color are primary root which branches out directly from stem; roots marked with blue color are the secondary roots. Roots on the right bottom corner of this rhizophora, marked with red color, are the tertiary roots. The straight red line along the stem is the referencing rule. The blue plate on the left bottom of this figure is the referencing plate which is being used to set up the coordinates of 3D imaging.

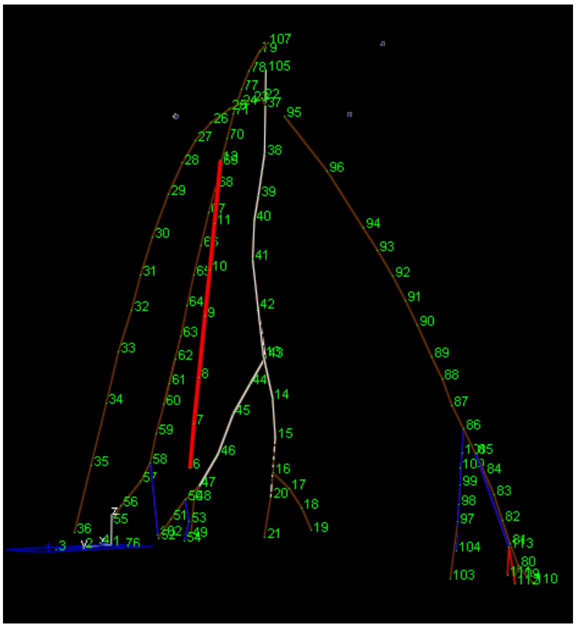


Figure 3-14 Primary, Secondary and Tertiary Root of Rhizophora

As what has been done for the pneumatophores, the first step to conduct for rhizophora is to establish the 3D model of individual rhizophora as demonstrated in Figure 3-15. Then, the information of each branch-out point height has been retrieved for statistical analysis. Based on the data obtained, two types of statistical analysis have been carried out. The first one is based on the directly available data. Different statistical distribution schemes have been test out for fitting. The second type is based on the normalized data. In each tree, the branch-out points for roots have been divided by the height of highest branch-out points. In such case, all the root height has been normalized to a range in between 0 to 1. Therefore, the height of the tree will not have a play. Also, the distribution testing has been carried out subsequently for fitting. The detailed information regarding to branch-out height and normalized branch-out height can be found in section Appendix E in the report.

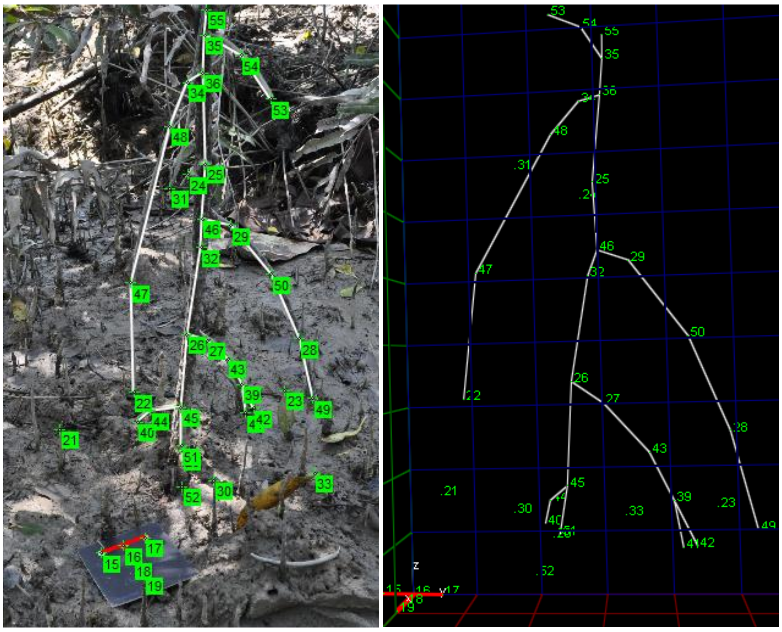


Figure 3-15 3D Imaging for Rhizophora

The primary root and secondary root have been separated for the statistical analysis. Therefore, in the future, in order to predict the root density information, aggregation is required for primary and secondary root. The distribution scheme is tested with software called Easyfit. The test result reveals that both the normalized and non-normalized data of primary roots fits for Beta distribution. It appears that Gamma distribution fits well for the non-normalized secondary root data; Gumbel minimum distribution captures the histogram of normalized secondary root reasonably well.

Primary Root

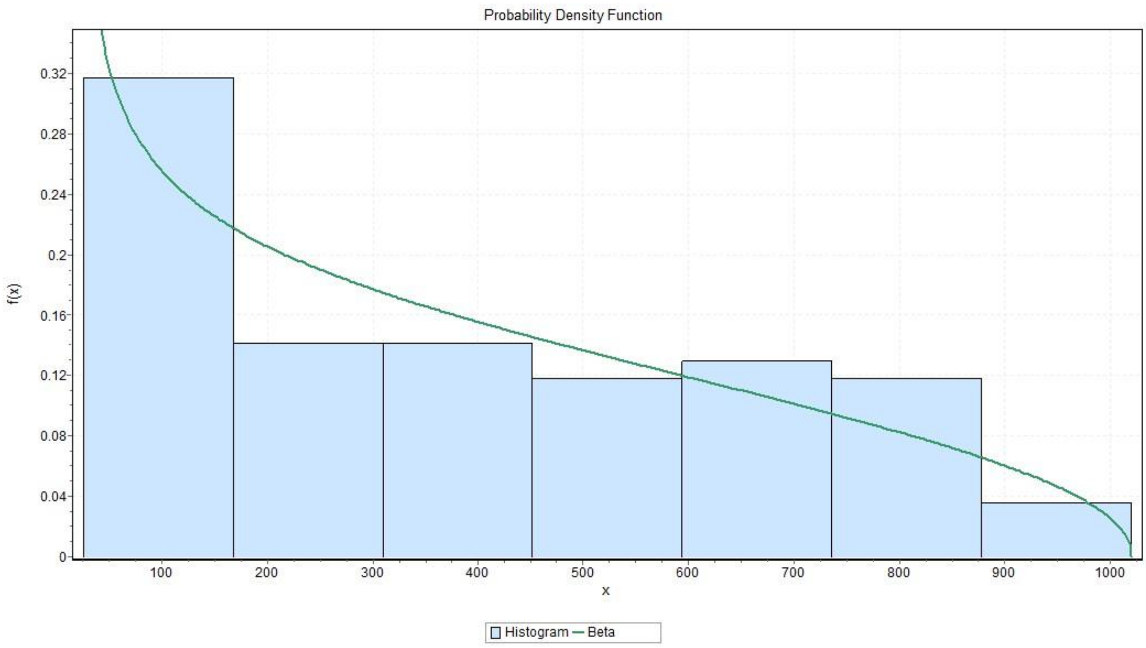


Figure 3-16 Beta Distribution for Primary Root

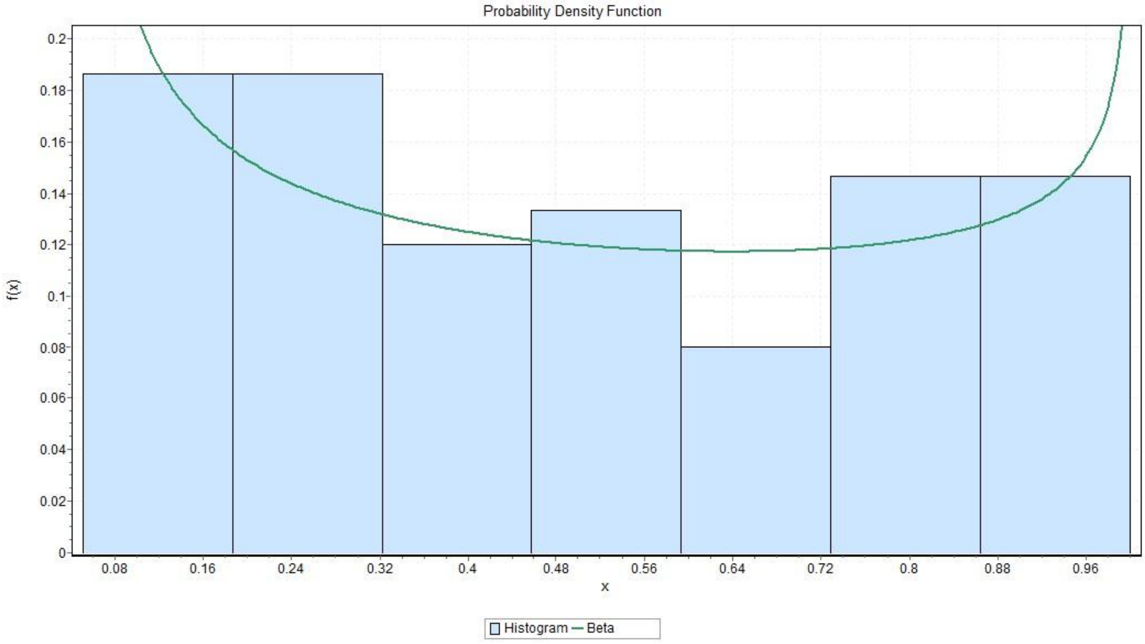


Figure 3-17 Beta Distribution for Normalized Primary Root

Secondary Root

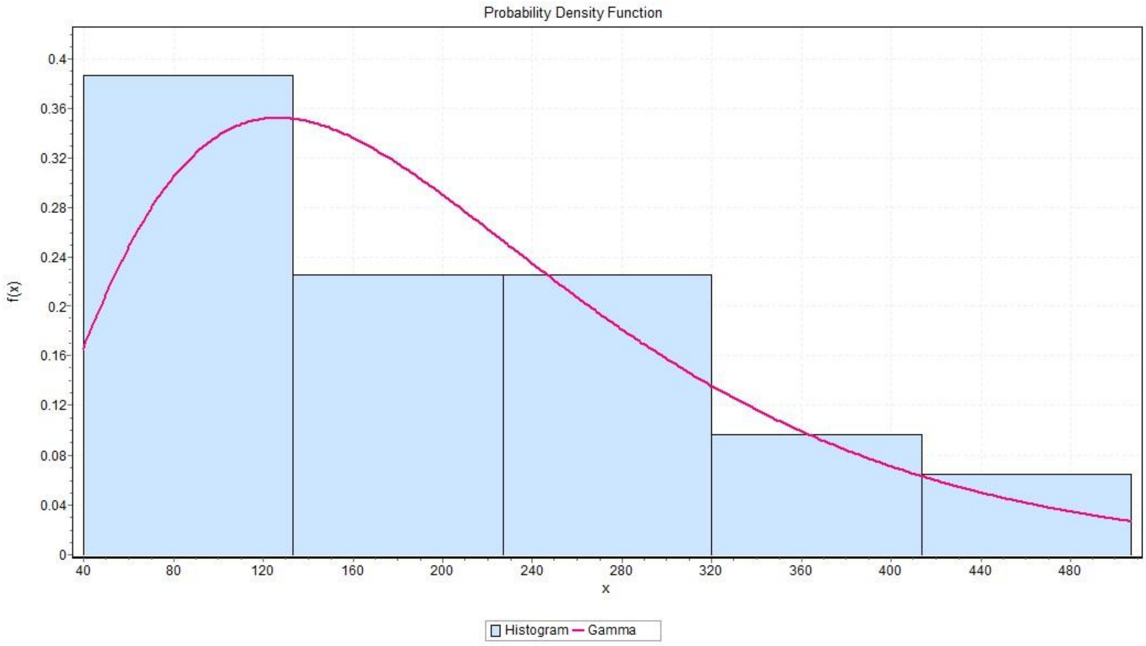


Figure 3-18 Gamma Distribution for Secondary Root

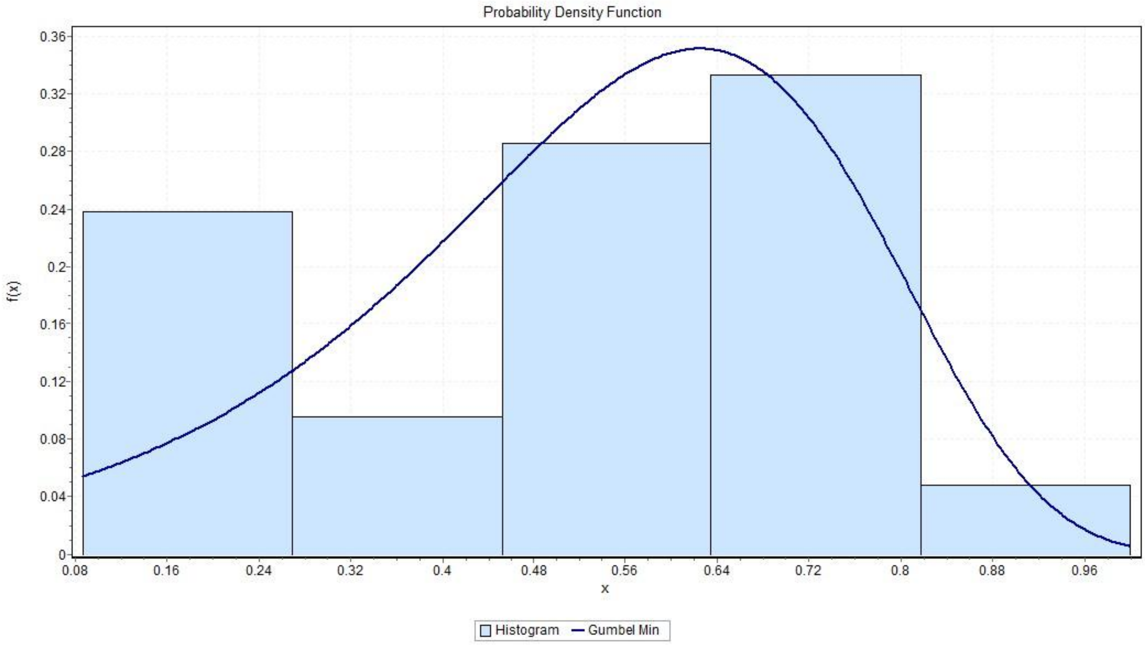


Figure 3-19 Gumbel Minimum Distribution for Normalized Secondary Root

In summary, Gamma distribution captures the shape of the histogram for primary root; lognormal distribution has the best fitting for secondary root. The testing result for other distribution can be found in section Appendix F in this report.

Although relative good agreement has been observed with various distributions, consider the sample size is still small especially for the secondary roots, the credibility of the result is still questionable. Therefore, further survey work on the rhizophora branch-out points is adviced.

3.2.2 Material Properties of Rhizophora Root

Similar approach has been conducted to assess the material properties of rhizophora root as which has been carried out in measuring the pneumatophores. Since the root density issue has been extensively studied by Zhang (2012), the focus of this section is the moisture content and modulus of elasticity. Based on Zhang (2012)'s finding, density of Rhizophora root is about 0.9 g/cm^3, which is slightly higher than the density of pneumatophore.

<u>Moisture Content</u>

Six samples have been tested for moisture content. Judging by size of samples, they have been classified into "old", "mature" and "young" categories. Each category contains two samples. The moisture content result reveals that the "Old" roots have less moisture content than which in the “mature” and “young” categories. However, the difference in between “mature” and “young” is not obvious. The detailed moisture content information is tabulated in Table 3-4.

Table 3-4 Moisture Content of Rhizophora Root

Weight	Before	After	Moisture
#	[g]	[g]	
O1	47.62	22.48	0.527929
O2	52.66	24.62	0.532472
Y1	13.68	5.28	0.614035
Y2	13.4	5.63	0.579851
M1	16.88	6.82	0.595972
M2	17.99	7.44	0.586437

Modulus of Elasticity

In total, eight root samples have been tested for modulus of elasticity. Among the eight samples, two of them fall into the category of “old”; each “mature” and “young” class has three test samples.

Although the test set up is the same, special consideration has to be taken before rhizophora root sample subject to tensile test. Refers to Figure 3-9 in the previous section, rhizophora root has a large soft marrow section. Therefore, the root sample would buckle during the tightening process of the testing machine clam. In such case, no reliable result would be obtained. If the clams grip the root sample loosely so as to prevent bucking, the slippery issue has come to place during testing, which would also result in unreliable result. In order to resolve the dilemma, metal rods with similar diameter of the marrow are inserted to the marrow before testing. In such case, clam can grip the root sample firmly without buckle the test sample. The tight clam also resolves the slippery problem.

Figure 3-20 Rhizophora Root Sample after Test

The test results are summarized in table 3-5 below. The “old” root samples have significantly higher Young’s modulus than the roots from other two categories. The test results also suggest that Rhizophora root has much higher modulus of elasticity than which in pneumatophore.

Table 3-5 Tensile Test Result for Rhizophora Root Samples

#	E [GPa]
O1	23.679
O2	20.177
M1	15.076
M2	14.027
M3	17.03
Y1	15.015
Y2	11.214
Y3	12.457

4. SUMMARY

This study has assessed the geometrical and material properties of two most abundant mangrove species in Singapore region and Johor River region. It appears that, for the sonneratia alba, the root density is higher near the tree trunk; the roots distanced from tree trunk are generally shorter than which near the tree trunk. The primary root from rhizophora follows a Beta distribution.

Both pneumatophore and rhizophora have the moisture content of about 60%. However, the older rhizophora root has less moisture content than which in the younger root. Also, the moisture content has an influence on the modulus of elasticity of the roots. The Young's modulus for fresh pneumatophore is in the range of 500 to 700 MPa. The fresh rhizophora root has much higher modulus of elasticity than which of pneamatophore. The Young's modulus for rhizophora is in the range of thousands of MPa. For the younger rhizophora root, the Young's modulus is also a bit lower.

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APPENDIX

APPENDIX A PNEUMATOPHORE ROOT DENSITY

P1								
Area #	Area [m2]	# of Roots	Density		Area #	Area [m2]	# of Roots	Density
A1	0.658	67	101.8237		B1	1.04	56	53.84615
A2	0.791	80	101.1378		B2	1.481	68	45.91492
A3	0.79	104	131.6456		B3	1.751	99	56.53912
A4	0.821	98	119.3666		B4	1.707	113	66.19801
A5	0.904	118	130.531		B5	1.738	149	85.73072
A6	0.693	83	119.7691		B6	1.513	115	76.00793
P2								
A1	0.218	39	178.8991		B1	0.337	39	115.727
A2	0.201	44	218.9055		B2	0.421	43	102.1378
A3	0.224	36	160.7143		B3	0.385	57	148.0519
A4	0.162	23	141.9753		B4	0.471	44	93.41826
A5	0.231	33	142.8571		B5	0.495	43	86.86869
A6	0.244	25	102.459		B6	0.373	36	96.51475
P3								
A1	0.326	56	171.7791		B1	0.423	45	106.383
A2	0.256	37	144.5313		B2	0.394	54	137.0558
A3	0.224	30	133.9286		B3	0.385	26	67.53247
A4	0.291	50	171.8213		B4	0.375	27	72
A5	0.197	43	218.2741		B5	0.352	35	99.43182
A6	0.326	40	122.6994		B6	0.419	23	54.8926

APPENDIX B ROOT HEIGHT AND DISTANCE FROM TREE TRUNK

P1	Length [mm]			350 mm	
	1	2	3	4	5
A1	189.4	158.7	104	189.6	184.8
	1034.5	806.3	991.6	628.6	929.5
A2	177.5	118.4	157.2	146.07	170.8

	956.7	1157.7	726	1321.9	774.9
A3	154.9	273.8	149	137.1	128.5
	794.2	762.6	1179.1	630.1	1102.2
A4	130.4	110.2	101	92.1	110.4
	1081	1062.9	617.9	1046.6	647.7
A5	159.4	236.1	155	134.3	109.3
	891.2	947.3	769.9	1092.3	909.3
A6	118.5	143.2	207.3	109.1	89.2
	602.4	798	1181.8	1085.4	990.6
B1	176.8	120.8	99.9	138.8	115.3
	2375.7	1739.5	1729	2113.3	1885
B2	185.1	130.1	101.4	111.3	175.9
	1969.5	2250.7	2148.6	2184.4	2370.8
B3	76.9	164.4	161.7	173.6	201.7
	2200.6	1995.3	1838.3	2271.8	1954.8
B4	72.2	212.8	175.3	127.6	93.2
	1716.4	1141.7	1275.3	1228.8	1686.5
B5	182.4	163.9	92.1	171.4	111.4
	2055.8	1709	1720.5	1580.9	1779.3
B6	94.4	160.4	168.2	152.7	138.9
	1530.7	1332.9	1439.2	1195.6	1254.1
P2				160 mm	
A1&B1	104.7	163.4	141.8	92.6	125.8
	473.2	272.2	1111.8	882.9	839.3
A2&B2	93.3	94.5	107.3	154.9	146.7
	532.9	877.9	880.8	1181.4	740.8
A3&B3	229.2	266.9	95.4	136.4	71
	612.4	633.1	939.9	882.8	776.1
A4&B4	164.7	105.2	102	179.68	101.8
	1055.6	804.4	429.3	538.5	846
A5&B5	97.4	92.5	127.7	105.3	105.3
	575.7	825.9	1069.8	825.5	562.2
A6&B6	198.6	88.5	65.4	89.7	82.2
	488.2	703.7	934.2	603.7	828.5
P3				300 mm	
A1&B1	129	166.2	228.4	120.5	152.1
	478.8	911.9	796.3	562.3	980.7
A2&B2	278.5	177.3	198.4	222.9	114.6

	765	1096.5	715.2	1090	821.3
A3&B3	132.3	190.3	157.6	127.2	137.6
	1017.3	1009.9	612.2	581.9	1044.2
A4&B4	199	220.7	222.1	171	138.3
	1010	814.2	946.3	1094.4	1037.8
A5&B5	135.4	195.2	119.8	210.5	167.8
	719.5	949.9	1079.8	1060.8	976.8
A6&B6	120.5	273.3	157.6	162.1	124.5
	1109.3	1103.9	745.3	1110.3	1216.8

APPENDIX C DENSITY OF PNEUMATOPHORE

Pneumatophore Root Sample					
Sample	Volume Measurement			Weight [g]	Density [g/cm3]
	First Measurement	Second Measurement	Volume [cm3]		
1	66/88	88/94	28	20.35	0.726786
2	58/89	88/95	38	24.7	0.65
3	67/83	67/70	19	13.39	0.704737
4	66/100	66/71	39	26.31	0.674615
5	65/95	90/96	36	23.32	0.647778
6	80/93	92/96	17	12.73	0.748824
7	68/81	68/70	15	10.46	0.697333
8	67/83	66/70	19	13.7	0.721053
9	66/75	65/67	11	8.16	0.741818
10	65/79	65/67	16	10.62	0.66375
11	65/84	65/68	22	15.99	0.726818
12	64/81	64/67	20	13.83	0.6915
13	63/79	63/66	19	13.89	0.731053

14	62/74	82/85	15	11.68	0.778667
15	82/93	82/84	13	9.73	0.748462
16	80/97	80/81	18	13.09	0.727222
17	79/93	79/81	16	10.7	0.66875
18	79/90	79/80	14	10.41	0.743571
19	78/92	78/79	15	11.1	0.74
20	77/85	77/78	9	6.84	0.76
21	76/90	76/78	16	9.13	0.570625
22	76/93	76/77	18	11.61	0.645
23	50/84	91/98	41	30.25	0.737805
				AVG	0.706355
				STDEV	0.048561

APPENDIX D PNEUMATOPHORE MOISTURE CONTENT

Oven 103 C

Sample	Weight						
	T = 0 mins	T = 25 mins	T = 50 mins	T = 90 mins	T = 130 mins	T = 170 mins	Moisture Content
20	6.84	4.77	3.54	2.79	2.68	2.7	0.605263
22	11.61	8.82	6.96	5.46	4.87	4.83	0.583979
10	10.62	8.13	6.37	4.88	4.38	4.35	0.590395
9	8.16	6.11	4.71	3.58	3.13	3.07	0.623775
16	13.09	10.08	8.18	6.4	5.6	5.41	0.586707
						AVG	0.598024
						STDEV	0.016576

APPENDIX E NORMALIZED AND NON-NORMALIZED BRANCH-OUT HEIGHT FOR RHIZOPHORA

Non-Normalized		Normalized	
Primary	Secondary	Primary	Secondary
25.2961	39.6639	0.050924	0.086558
32.4628	46.3566	0.059652	0.111546
45.3512	51.1144	0.068629	0.176285
49.3851	70.4711	0.076712	0.205042
51.9525	77.4028	0.091399	0.265626
56.6581	78.7049	0.107574	0.363592
68.3024	81.9671	0.116701	0.373746
91.7276	83.4546	0.120066	0.468441
93.2454	100.9471	0.121151	0.478955
94.6988	109.7442	0.128895	0.533844
97.9357	112.7191	0.141215	0.550821
126.5178	123.0747	0.15946	0.554157
127.0514	154.4143	0.175169	0.634583
127.0514	168.0145	0.184255	0.666873
128.7849	170.5266	0.194438	0.670889
131.6453	184.3474	0.196953	0.684077
140.083	219.4743	0.201092	0.723199
141.282	220.5591	0.201092	0.730136
143.626	226.527	0.20882	0.732524
143.626	253.6789	0.20882	0.787316
143.626	253.9343	0.20882	1
151.9843	279.276	0.231318	
153.9497	282.6286	0.253082	
157.2438	298.792	0.253082	
159.7498	301.6578	0.257162	
159.8989	305.585	0.272338	
159.8989	325.2821	0.277031	
172.2181	399.7567	0.298973	
180.8118	413.153	0.324191	
183.037	458.2356	0.333862	
201.0124	507.0177	0.365257	
207.0489		0.380377	
210.431		0.406967	
210.6854		0.408377	

212.4073		0.411277	
240.3245		0.44627	
280.8815		0.451203	
282.6286		0.460842	
301.5456		0.461397	
342.8295		0.498205	
350.3624		0.501937	
350.7838		0.515729	
358.4947		0.541217	
367.9993		0.544248	
372.249		0.567412	
374.3337		0.577195	
380.5305		0.579899	
419.5869		0.625244	
423.175		0.646536	
424.8151		0.65695	
438.821		0.666953	
470.332		0.719809	
495.0844		0.72647	
499.6653		0.729354	
516.1833		0.735541	
560.1756		0.73839	
568.7057		0.739887	
576.7018		0.746344	
577.168		0.756411	
578.3381		0.758554	
591.616		0.806552	
618.9498		0.814124	
624.9104		0.82522	
627.1898		0.860369	
631.8062		0.868769	
644.986		0.869615	
653.7191		0.874178	
659.5995		0.927449	
664.211		0.985591	
687.7994		0.989086	
703.6581		0.989223	
735.555		0.992742	
744.0911		0.998793	
759.8125		0.99956	

759.9308		1	
760.2651			
765.6751			
781.6577			
825.5714			
840.4059			
846.5028			
852.692			
902.1463			
911.9749			
1020.206			