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Rhizophora mucronata SEEDLING GROWTH MODEL AT DIFFERENT SPACINGS USING GULUDAN PLANTING TECHNIQUE

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ABSTRACT
Ecological impacts caused by destruction of mangrove ecosystems results in loss of various species of mangrove flora and fauna. In the long run, it would disrupt the role of mangrove ecosystem. Therefore, degraded mangroves must be rehabilitated properly. For some years, guludan technique has been introduced to grow mangrove seedlings in the submerged area with deep water column. This technique has been applied in the mangrove area of Muara Angke Jakarta using *Rhizophora mucronata* seedlings with spacings of 0.25 m x 0.25 m, 0.5 m x 0.5 m, and 1 m x 1 m. Information on growh models and increments of the seedlings were quite important with respect to the assessment of performance and the success of the planting. This research was aimed at observing growths and increments of *R. mucronata* seedlings planted using guludan technique. Our obtained results showed that diameter growth model of 36 months planted seedlings of *R. mucronata* followed the logistic equation, while the height growth model followed the guludan equation. At the beginning of planting, spacing of 0.25 m x 0.25 m gave optimum diameter and height growths of the seedlings. Generally, wider spacing caused greater diameter growth, whereas denser spacing gave greater height growth.

KEYWORDS: Growth model, Guludan, *Rhizophora mucronata*, Spacing

INTRODUCTION
Mangrove forest is one of coastal ecosystem that is unique and vulnerable. Coastal ecosystem plays an important role, both ecologically and economically, in supporting the livelihood of coastal people. Therefore, a lot of mangrove forest destruction occurs because of various human needs for land usage. Among ecological impacts caused by mangrove forest destruction are the loss of various flora and fauna, which in the long run will disrupt the balance of mangrove ecosystem as well as coastal ecosystem. Rehabilitation of the already disrupted mangrove forest, is urgently needed to maintain the overall functions of mangrove forest.

[6] stated that rehabilitation of mangrove forest should use less spacings than the spacings used for production from mangrove forest. Moreover, mangrove forest rehabilitation should use pioneer mangrove species such as *Avicennia marina* and *Sonneratia alba*. On the other hand, for production from mangrove forest, the species used are *Bruguiera gymnorrhiza*, *Rhizophora mucronata*, *R. stylosa* or *R. apiculata*.

In the last several years, there is a technique called guludan, which is developed to rehabilitate mangrove forest[8]. The guludan technique is applied to grow mangrove seedlings in deeply submerged land (more than 1 m water depth). using guludan made from sacks of soil at the bottom part, and then covered with loose soil at the top part. The loose soil is where the mangrove seedlings are planted. There has been not many studies conducted yet on the mangrove seedlings grown using guludan technique. Therefore, this study is aimed at: 1) formulating models and increments for diameter and height growths for *R. mucronata* seedlings at different spacings, and 2) determining the most ideal spacing which can result to the greatest growth and increment for trunk diameter and height of *R. mucronata* seedlings.

MATERIALS AND METHODS

Data observations on diameter and height of seedlings of *R. mucronata* were conducted from October 2008 through October 2011 at the Mangrove Arboretum Angke Kapuk, located at the side of Sedyatmo Toll, KM 22 through KM 23, Jakarta Province (06º06'45" LS and 106º43'54" BT). This location has water depth of 2-3 m with salinity of 28-30 ppt and pH of 6.88 – 7.52 [7].

Variables observed were trunk diameter and height of *R. mucronata* seedlings (6 months old) planted with 3 different spacings (0.25 x 0.25 m, 0.5 x 0.5 m, and 1 x 1 m) until reaching 36 month old of age. The trunk diameter was measured at 10 cm above land surface using caliper. The trunk height was measured starting from where the diameter measurement was taken, up to the growth using measurement tape. The observations were conducted every 4 months during the 3 years of study. Sampling intensity is presented in Table 1.

Table 1. Sampling intensity conducted in the study

Spacings at guludan	Number of seedlings (ind)	Sampling intensity (%)	Number of sample (ind)
0.25 m x 0.25 m	336	11	36
0.5 m x 0.5 m	99	22	22
1 m x 1 m	30	40	12
Total	465	15	70

Growth models were determined using data obtained. The models were used to predict diameter and height growth of the mangrove seedlings. The models used were non linear regression models developed with software R, using non linear regression analysis. Comparisons among models are presented in Table 2. Model for height growth is presented in Table 3.

Table 2. Comparison of diameter growth models in the study

Models	Equations	References
Gompertz	Yt = a exp(-b exp(-ct))	[9];[11]; [1]
Logistic	Yt = a/(1+ b exp(-ct))	[9]; [11]; [1]
Richard's	$Yt = a/(1+ exp(-bt))^{1/c}$	[11]

Information: Yt = diameter (cm) at t-year
a, b, c = parameters of model

Table 3. Comparison of height models in the study

Models	Equations	References
Power	$Yt = a.t^b$	[14]
Exponential	Yt = a exp (b.t)	[14]
Guludan	$Yt = a(t-b)^2 + c$	[14]
Invers Guludan	Yt = t/(a+b.t)	[14]

Information: Yt = height (m) at t-year
a, b, c = parameters of model

Several techniques were used to choose the best growth model, such as: t – test, Akaike Information Criteria (AIC), Bayesian Information Criteria (BIC) [10], and Root Mean Square Error (RMSE) [13]. The determination coefficient (R^2) and corrected determination coefficient (R^2_{adj}) were used to test the model suitability against the data. The assumption verification model was conducted by drawing a relation graph between predicted value and residual value.
Based on those tests applied to the models developed, it is then determined the best model with criteria as follows:

1. The model has p value < 0.05
2. The model has the least AIC, BIC, and RMSE
3. The model has the greatest R^2 and R^2_{adj}

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4. The model has residual value which are randomly scattered and homoscedastic.

After the best model was chosen, then the mathematical equations were developed to predict the Mean Annual Increment (MAI) and the Current Annual Increment (CAI). MAI is the average of diameter growth model or height growth model over time (f(y)/t). CAI is the differential of diameter growth model or height growth model (dy/dt).

RESULTS AND DISCUSSION

Model for diameter growth for *R. mucronata*

Based on data analysis for diameter growth of *R. mucronata* (Table 4), the best model to predict diameter growth for all spacings is the logistic equation. At the end of the study, diameter of seedlings (3.5 years old of age) reached 3 cm. This diameter is smaller than the one observed in Thailand, which reached 3.53 cm for the same age of seedlings [16]. The different result may have caused by different models used to predict diameter growth and height growth and also caused by different condition for growing the seedlings.

Table 4. Results of comparison of seven indicators for the models chosen for predicting diameter growth at different spacing

Spacings	Equations	Coefficient	p-value	AIC	BIC	RMSE	R^2	R^2_{adj}	Homoscedastic
0.25 m x 0.25 m	Logistic	a = 2.752	<0.0001	85.28	102.68	0.30	0.891	0.890	Yes
		b = 14.066	<0.0001						
		c = 2.793	<0.0001						
	Richard's	a = 2.832	<0.0001	105.68	123.08	0.31	0.883	0.882	Yes
		b = 1.937	<0.0001						
		c = 0.211	<0.0001						
	Gompertz	a = 2.856	<0.0001	111.52	128.93	0.31	0.881	0.880	Yes
		b = 3.728	<0.0001						
		c = 1.758	<0.0001						
0.5 m x 0.5 m	Logistic	a = 2.953	<0.0001	56.24	70.62	0.31	0.898	0.897	Yes
		b = 12.360	<0.0001						
		c = 2.474	<0.0001						
	Richard's	a = 3.084	<0.0001	65.14	79.52	0.23	0.932	0.931	Yes
		b = 1.674	<0.0001						
		c = 0.229	<0.0001						
	Gompertz	a = 3.132	<0.0001	68.10	82.47	0.32	0.894	0.892	Yes
		b = 3.340	<0.0001						
		c = 1.480	<0.0001						
1 m x 1 m	Logistic	a = 3.036	<0.0001	20.27	31.73	0.31	0.912	0.909	Yes
		b = 12.695	<0.0001						
		c = 2.461	<0.0001						
	Richard's	a = 3.201	<0.0001	24.40	35.85	0.30	0.916	0.914	Yes
		b = 1.638	<0.0001						
		c = 0.227	<0.0001						
	Gompertz	a = 3.268	<0.0001	25.70	37.15	0.22	0.949	0.948	Yes
		b = 3.351	<0.0001						
		c = 1.433	<0.0001						

[4] stated that 12 years old *R. mucronata* has 6.2 cm diameter and 0.52 cm/year MAI. In this study, the MAI ofr the 3.5 years old seedlings ranged from 0.78 to 0.87 cm/year (Table 5). This result is due to the fact that in younger age, the increment is higher than that in older age of seedlings.

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Table 5. Prediction model for CAI and MAI of diameter (cm/yr) of R. mucronata at different spacing

Parameter	Spacings	CAI Models	MAI Models
Diameter	0.25 m x 0.25 m	$Y = \frac{2.752x14.066x2.793e^{2.793t}}{(14.066+e^{2.793t})^2}$	$Y = \frac{2.752}{t(1+14.066e^{-2.793t})}$
	0.5 m x 0.5 m	$Y = \frac{2.953x12.360x2.474e^{2.474t}}{(12.360+e^{2.474t})^2}$	$Y = \frac{2.953}{t(1+12.360e^{-2.474t})}$
	1 m x 1 m	$Y = \frac{3.036x12.695x2.461e^{2.461t}}{(12.695+e^{2.461t})^2}$	$Y = \frac{3.036}{t(1+12.695e^{-2.461t})}$

Based on visual comparison for the least model at each spacing (Figure 1) from the beginning of the study up to 2 years old seedlings at 0.25 m x 0.25 m spacing have greater diameter than those at other spacings. At this age range, spacings of 0.5 m x 0.5 m and 1x 1 m gave similar diameter growth.

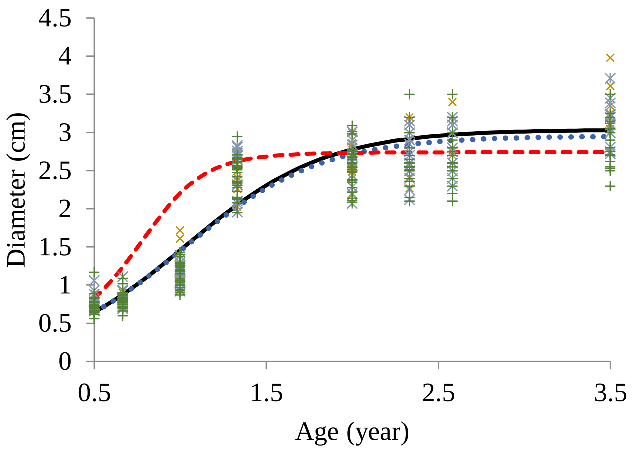

Figure.1:. Models for diameter growth of R. mucronata, based on different spacing over time: (—) model for 1 x 1 m spacing, (…) model for 0.5 m x 0.5 m spacing, (---) model for 0.25 m x 0.25 m spacing, (x) actual 1 x 1 m spacing, (*) actual 0.5 m x 0.5 m spacing, (+) actual 0.25 m x 0.25 m spacing

Generally, at the beginning of the study, the 0.25 m x 0.25 m spacing showed the optimum diameter growth of the seedlings. This may have caused by exposure to light. At the beginning of the study, there were no competition among the seedlings to grow. Besides, all seedlings at all spacings, have full exposure to light. Based on [17], several mangrove species in Australia have low CO_2 capture in average due to full exposure to light caused by the decrease of the photosynthesis efficiency. On the other hand, the leaves that do not experience full exposure to light have normal photosynthesis. [12] discovered that in photosynthesis, the highest CO_2 exchange occurred at the lower part of canopy.

Aside from reducing exposure to light, denser spacing also reduce the exposure to heat and therefore, reduce the condensation. At the beginning of planting, the roots of the seedlings were not yet functioned optimally. [5] also stated that at the increasing exposure to light, with limited nutrition, the seedlings will allocate their growth to roots to fulfill their needs for water and nutrition.

At 2 years old, the seedlings at the 1 m x 1 m spacing showed the greatest diameter growth. On the other hand, the seedlings at the 0.25 m x 0.25 m spacings showed the least diameter growth . The difference in diameter growth indicated that there is already competition occurred to obtain nutrition. More fierce competition happens at denser spacing. Height growth showed different result. Seedlings at 1 m x 1 m showed the least height growth, while seedlings at 0.25 m x 0.25 m showed the greatest height growth. The difference of height growth occurred because seedlings at the denser spacings experienced more fierce competition to obtain light.

Therefore, the growth is focused on the height growth. This result is not in agreement with the result of study conducted by [2]. In that study, the 2 x 1.5 m spacing gave the greatest height growth for *R. mucronata*, while the 1 x 2 m spacing gave the least height growth.

Model for height growth for *R. mucronata*

Height growth of *R. mucronata* is tested with the power, exponential, guludan and invers guludan equations (Table 6). The use of these models is based on the data distribution (Figure 2), where growth of seedlings which were consistently increasing have not shown the ideal growth (sigmoid curve).

Table 6. Results of comparison of seven indicators of the best model chosen to predict height growth of R. mucronata seedlings at different spacing

Spacings	Equations	Coefficient	p-value	AIC	BIC	RMSE	R^2	R^2_{adj}	Homoscedastic
0.25 m x 0.25 m	Power	a = 1.253	<0.0001	49.13	63.05	0.36	0.658	0.656	Yes
		b = 0.433	<0.0001						
	Exponential	a = 0.812	<0.0001	-41.57	-27.65	0.30	0.767	0.766	Yes
		b = 0.354	<0.0001						
	Polynomial	a = 0.176	<0.0001	-54.30	-36.90	0.31	0.760	0.758	Yes
		b = 0.101	0.0049						
		c = 0.968	<0.0001						
	Invers Polynomial	a = 0.318	<0.0001	108.27	122.20	0.44	0.508	0.506	No
		b = 0.453	<0.0001						
0.5 m x 0.5 m	Power	a = 1.203	<0.0001	-23.20	-11.70	0.47	0.369	0.364	Yes
		b = 0.240	<0.0001						
	Exponential	a = 0.884	<0.0001	-72.34	-60.84	0.29	0.760	0.758	Yes
		b = 0.278	<0.0001						
	Polynomial	a = 0.219	<0.0001	-111.50	-97.13	0.22	0.863	0.861	Yes
		b = 0.691	<0.0001						
		c = 1.050	<0.0001						
	Invers Polynomial	a = 0.135	<0.0001	-4.91	6.59	0.56	0.082	0.075	No
		b = 0.705	<0.0001						
1 m x 1 m	Power	a = 1.193	<0.0001	-18.62	-9.46	0.38	0.479	0.472	Yes
		b = 0.259	<0.0001						
	Exponential	a = 0.867	<0.0001	-55.52	-46.35	0.22	0.828	0.826	Yes
		b = 0.272	<0.0001						
	Polynomial	a = 0.203	<0.0001	-87.23	-75.78	0.15	0.915	0.912	Yes
		b = 0.737	<0.0001						
		c = 1.037	<0.0001						
	Invers Polynomial	a = 0.152	<0.0001	-4.59	4.58	0.48	0.162	0.150	No
		b = 0.690	<0.0001						

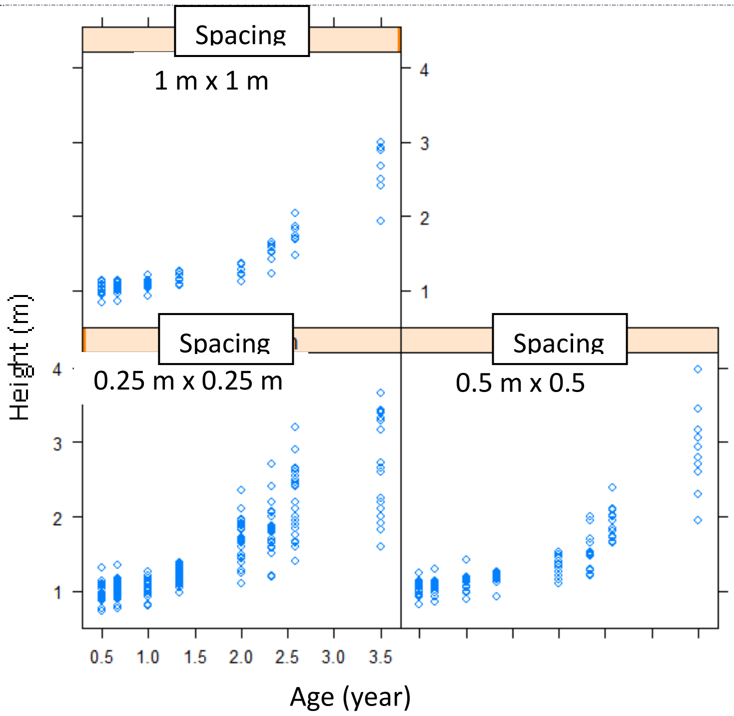

Figure. 2: Data distribution for R. mucronata at 0.25 m x 0.25 m (a), 0.5 m x 0.5 m (b), and 1 x 1 m (c)

Table 6 showed that based on the seven criteria compared, the best model is the guludan model to predict the height growth of *R. mucronata* at all spacings. Based on comparisons among the three chosen models (Figure 3), it is determined that the 0.25 m x 0.25 m spacing is the optimum treatment to produce the greatest height growth of *R. mucronata* seedlings. At the first year, the height of all seedlings for all spacings were similar. However, after the first year, it was clear that the denser the spacings, the greater the height growth. Height growth of the seedlings is consistently increasing and has not shown the ideal growth (sigmoid curve). The maximum height growth in this study is around 3 m. This is still considered as a slow growth, when compared to another study conducted in Thailand which resulted to 4.09 m maximum height [16]. The slow growth in this study is due to salinity in the study site, which ranged from 28 to 30 ppt, whereas *R. mucronata* needs salinity < 20 ppt to grow optimally [7].

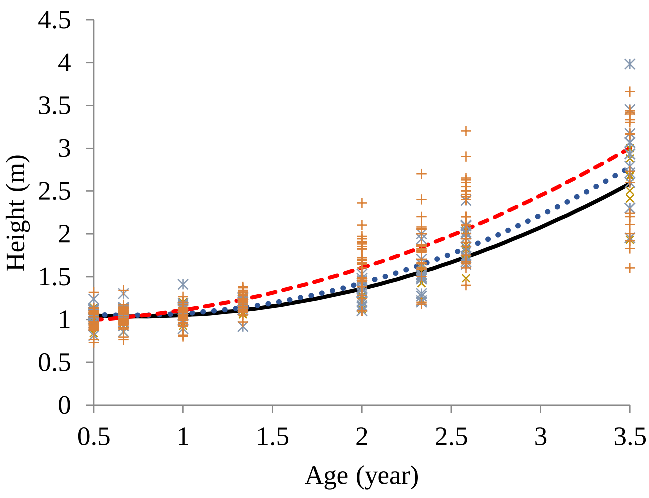

Figure. 3: Models for height growth of R. mucronata, based on different spacing over time: (—) model for 1 m x 1 m spacing, (….) model for 0.5 m x 0.5 m spacing, (---) model for 0.25 m x 0.25 m spacing, (x) actual 1 m x 1 m spacing, (*) actual 0.5 m x 0.5 m spacing, (+) actual 0.25 m x 0.25 m spacing

According to [3], different salinity levels affect height growth of *R. mucronata* seedlings; and the best height growth occurs at low salinity level. Mangrove can grow in saline soil, however, in high or extreme salinity level, the growth is disturbed [15].

Study conducted by [3] showed that *R. mucronata* has the greatest height average at salinity level between 0.0 to 7.5 ppt. Mangrove is salt tolerant plant, but not a plant which needs salt. At salinity level of 22.5 – 30.0 ppt, the height growth of *R. mucronata* aged 1 year and 3 months old, is around 0.01 m and even more lower when compared to height growth resulted from this study, which were 0.04 m for the 1 m x 1 m spacing; 0.05 m for the 0.5 m x 0.5 m spacing; and 0.09 m for the 0.25 m x 0.25 m spacing. These results occurred because the guludan technique was directly applied at the field with grouped seedlings planting system, which created micro climate and nutrition cycle for growth of seedlings.

The MAI for height of *R. mucronata* aged 3.5 years old from this study i.e. 0.74 – 0.86 m/year (Table 7) is relatively similar to the result from a study conducted by [4], which MAI for 12 years old *R. mucronata* was 0.7 m/year.

Table 7 Prediction Model for CAI and MAI for height (m/yr) growth of R. mucronata seedling at different spacing

Parameter	Spacings	CAI Models	MAI Models
Height	0.25 m x 0.25 m	$Y = 2x0.176x(t-1.101)$	$Y = \frac{0.176x(t-0.101)^2 + 0.968}{t}$
	0.5 m x 0.5 m	$Y = 2x0.219x(t-0.691)$	$Y = \frac{0.219x(t-0.691)^2 + 1.050}{t}$
	1 m x 1 m	$Y = 2x0.203x(t-0.737)$	$Y = \frac{0.203x(t-0.737)^2 + 1.037}{t}$

CONCLUSION

Stem diameter and height growths of *R. mucronata* seedlings aged 3.5 years old for each spacings followed logistic and polynomial equations respectively. At the beginning of the study, the seedlings planted with 0.25 m x 0.25 m spacing showed optimum stem diameter and height growths. However, as the study continued, it was clear that the stem diameter growth is greater for the wider spacing, whereas the height growth is greater for the denser spacing.

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