Evaluation of mangrove stand planted for rehabilitation using guludan technique in coastal area of Angke Kapuk, Jakarta

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Evaluation of mangrove stand planted for rehabilitation using guludan technique in coastal area of Angke Kapuk, Jakarta

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Abstract. Guludan technique becomes an alternative for mangrove rehabilitation in the disused fishponds. This technique has been implemented since 2005 on the coast of Jakarta. The wider application of this technique requires several studies in advance to see growth of the mangrove in the already planted guludan. This study aims to measure the growth of mangroves planted by guludan techniques, identify environmental factors that affect their mangrove growth, and analyze their relationship. Measurements were performed on 40 guludan samples which planted by *Rhizopora mucronata* in 2010 - 2013. *R. mucronata* can grew in guludans with highest growth percentage in the 2013 group of 56.53%. The 2010 planting group showed highest average height, average diameter and basal average area of 4.59 m; 3.91 cm and; 28.87 m^2/ha respectively. *S. Caseolaris* grew naturally in guludans and become competitor of *R. mucronata* in obtaining space to grow. The 2012 group was the highest in terms of *S. caseolaris* density, that is 15 individuals/guludan with average height, average diameter and basal area of 9.38 cm, 5.29 m, and 24.79 m^2/ha, respectively. The growth of *R. mucronata*was affected by nutrients (N, P, Ca), clay texture, and other soil factors (CEC and pH), whereas *S. caseolaris* was only affected by nutrients (N, P, and Ca).

1. Introduction

The mangrove area of Indonesia is more than 3.2 million hectares, which covers 26% of the world's total mangrove area and 60% of total mangrove in Southeast Asia [1][2]. Mangrove is a coastal protector and supports many life forms in land and sea [3]. In addition, mangrove can also prevent coastal erosion, trap sediments, provide nutrients, as wildlife habitats, and absorb carbon in the atmosphere [4][5][6]. Its great function and unique ecosystem make it very important to be preserved.

Currently mangroves in many areas are degraded by timber harvesting, infrastructure development, conversion to agricultural land, and conversion to tambak [7][8]. Conversion of mangroves into ponds is suspected to be the largest cause, it is estimated that of 50-80% mangrove ecosystem damage in Java, Sulawesi, Sumatra is caused by conversion to ponds during the period 1980 – 2000[9]. Conversion activities since 1980s now leaves the former ponds that needs to be returned to its original function.

Degraded mangrove forests can either repair themselves or experience secondary successions if the tidal hydrology undisturbe and the flow of water that becomes the path for propagaul is not closed. This process can occur for 15-30 years [10]. This also applies to ex-pond areas, natural mangrove colonization at this site is possible, however it needs to be supported by modifying the physical shape of the pond [11][12].

Mangrove rehabilitation in the ex-ponds has its own difficulties because its characteristic is deeply submerged. Mangrove seedlings are difficult to grow under permanently inundated conditions [13]. The guludan bambu technique is suitable for such condition where the water depth reaches between 1.5 m - 3 m [14].

The guludan bambu technique was introduced in 2005 to rehabilitate coastal areas in North Jakarta [15]. In 2008, this technique was used to rehabilitate 95 ha of damaged mangrove areas in the same location by planting approximately 300,000 mangrove seedlings of *Rhizophora* spp. [13]. This technique applies the concept of creating optimal growing space for seedlings to grow by building giant boxes of size 5 x 10 m from bamboo. This box was filled with piles of sacks containing a mixture of soil and mud to a height of about 20 cm below the surface of the water. Then added a mixture of mineral soil and mud to a height of 20 cm above the surface of the water, this becomes a growing substrate for seedlings. The species used was *R. mucronata* which is commonly used in rehabilitation activities in Indonesia.

Implementation of the guludan bamboo technique is promising considering there are many guludans with well-grown *R. mucronata* stands. The purpose of this study was to investigate the performance of *R.mucronata* grown with the technique of guludan and the factors affecting its growth.

2. Materials and Methods

2.1. Study site
Guludans for mangrove rehabilitation are mostly built in ecotourism area, ElangLaut block, Jakarta. Coordinate location is 6 ° 7 '22.72 "S and 106 ° 44' 39.62" E. This study was conducted from October to December 2016.

2.2. Methods
The data collection was conducted on the guludans planted in 2010, 2011, 2012, and 2013. The samples were 40 units guludan, each 5 units, 5 units, 15 units and 15 units for 2010, 2011, 2012 and 2013 groups respectively. Measurement steps: 1) checking and numbering the guludans; 2) counting tree population and measuring the height and diameter of tree trunks within the guludans. The diameter of the sapling and the tree is the diameter of the stem as high as 1.3 m above the surface of the soil or 10 cm above the supporting root (for trees of the Rhizophoraceae family) if the highest supporting the root is located at a height of 1.3 m or more; 3) measurement of water depth on each side of the guludan as far as 50 cm from the boundary and measurement of water level within the guludans; 4) Take the disturbed soil samples at a depth of 20 cm. Soil samples weighing 500 grams each were analyzed in the laboratory to measure physical characteristics (clay fraction, sand, and mud), salinity, pH and macro nutrient content (N, P, K, Ca, and Mg).

The relationship between the parameters of mangrove stands and the physical environmental factors of the mounds was analyzed by a variant structural equation model (SEM) (Partial Least Square - PLS) with smartPLS software. In this analysis, environmental indicators and stands are divided into several constructs, namely:

1. *R. mucronata*: stand density, diameter, height, basal area
2. *S. caseolaris*: stand density, diameter, height, basal area
3. Nutrients: N, P, K, Mg, Ca, Na
4. Soil texture: fraction of silt, clay, sand
5. Other soil indicators: salinity, CEC, pH
6. Climate: air relative humidity (RH), temperature, water level in guludans

3. Results and Discussion

3.1. Stand characteristic

Mangrove planting with guludan technique uses guludan technique uses tight spacing, i.e. below 1 m × 1 m [16]. At the study site, the spacing used was 0.5 m × 0.5 m. Seedlings were planted in guludan with an area of 5 m × 10 m guludan with 200 seedlings/guludanof *Rhizophora mucronata*. In the first year, the dead seedlings were replaced with new ones. Until 2016, the percentage of survived seedlingss was less than 60% (Figure 1). The guludan planted in 2011 had the lowest percentage of live seedlings (22%), while 2013 was the highest (56.53%).

Sonneratia caseolaris grow naturally in the guludans and its seeds came from parent trees growing on embankment of ex-ponds. Growth of this species even tend to be faster than *R. mucronata*. Its population in 2011 and 2012 groups were at most compared to two other guludans, 12 and 15 individuals respectively.

The growth phase of *R. mucronata*and *S. caseolaris* classified as sapling in all guludans, except *S. caseolaris* in 2010 guludan group. *R. mucronata* diameter growth was slower than *S. caseolaris*, as well as its height. However, in Table 1, the height of *S. caseolaris* was not so far apart. This was because *S. caseolaris* mostly grow in a tilted position.

Table 1. Diameter, height, and basal area of *Rhizophora mucronata* and *Sonneratia caseolaris* in guludans

Species	Planting Year	Density (Ind/guludan)	% survival	Average Diameter (cm)	Average Height (m)	Basal area (m^2/ha)
R. mucronata	2010	93	46.70	3.91	4.59	28.87
	2011	44	22.00	2.59	2.51	6.03
	2012	73	36.67	2.44	2.46	8.81
	2013	113	56.53	2.53	2.61	14.67
S. caseolaris	2010	1	-	12.10	5.96	2.88
	2011	12	-	7.28	4.50	17.23
	2012	15	-	9.38	5.29	24.79
	2013	1	-	9.09	3.78	1.43

Non-mangroves species can be found grow in guludans and categorized as weeds for they interfere with the growth of mangroves. The proportion of guludans attacked by weeds reached 35% of the total guludans (Figure 1), the highest in groups 2012 and 2011 at 53.33% and 40%, respectively.

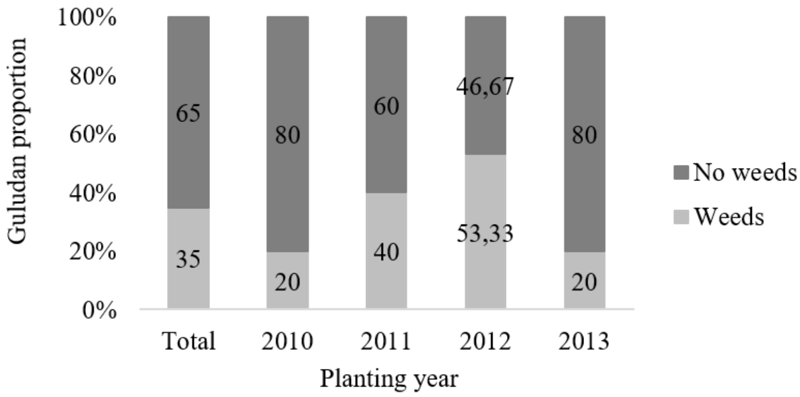

Figure 1. The proportion of guludans attacked by weeds in each group of planting years.

Weeds in the guludans found were *Breyniacoronata, Calopogonium mucunoides, Cayratiatri folia, Imperata cylindrica, Leucaenaleuco cephala, Passiflora foetida* and *Asystasia gangetica*. They were grow on guludans where the soil is still dry. Other species such as *Ipomoea aquatica* and *Eichhornia crassipes* were common in submerged guludans. Weeds grown in guludan can be caused by the use of a mixture of mineral soil as a substrate that contain small seeds of weed plants. The impact caused by the presence of weeds is that it can be a strong competitor that defeats the species planted and can even affect soil productivity [17][18].

Independent sample T-test was done to see whether there is a significant difference between the guludans which have weeds and those with no weeds. Stand parameters used include stand density, diameter, and height of *R. mucronata* and *S. caseolaris*. Test results are shown in Table 2.

Table 2. The results of independent sample t-test.

Response Variable	**t**	**p-value**
R. mucronata density	1.434	0.160
R. mucronata height	0.707	0.484
R. mucronata diameter	0.875	0.387
S. caseolaris density	-2.137	0.039
S. caseolaris height	0.454	0.652
S. caseolaris diameter	0.718	0.477

Table 3. Environmental factors value from each planting years groups.

Indicators	2010	2011	2012	2013
Nutrient				
N (%)	0.00	0.38	0.28	0.22
P (ppm)	7.55	8.95	10.95	10.58
Ca ($cmol^{(+)}$/kg)	23.45	35.90	36.01	29.80
Mg ($cmol^{(+)}$/kg)	11.41	8.79	8.47	8.81
K ($cmol^{(+)}$/kg)	2.55	1.36	2.12	2.00
Na ($cmol^{(+)}$/kg)	5.14	2.81	3.59	3.77
Soil texture				
Silt (%)	26.07	14.06	31.14	24.33
Clay (%)	71.45	30.20	49.57	60.64
Sand (%)	2.48	55.74	19.29	15.04
Other soil factors				
pH	6.1	6.9	6.8	6.6
Soil salinity (dS/m)	0.75	0.74	0.64	0.88
CEC ($cmol^{(+)}$/kg)	23.75	20.75	39.27	36.65
Climate				
Water level in guludan (cm)	4.68	18.32	7.41	10.84
Temperature (°C)	25.50	27.80	29.25	26.43
Relative humidity (%)	73.00	69.80	62.73	72.00

3.2. Environmental factor

The soil samples taken from the study site contain more dominant clay texture than sand and silt, except for the 2011 group where the proportion of sand was larger (Table 3). The texture type of 2011 guludan group was sandy clay loam, while the other were a clay type. The category of soil salinity in all groups were slightly saline, as seen from the EC values of 0.640 dS / m - 0.881 dS / m. Meanwhile, soil pH was slightly acid (range pH 5.6-6.5) to neutral (6.6-7.5). Soil CEC in 2012 and 2013 groups were very high (CEC 25 - 40) while 2010 and 2011 groups in medium category (CEC 17-24). CEC is associated with soil fertility, soil containing a lot of organic material or high clay content will have a higher CEC.

3.3. Relationship between mangrove stand and environmental factors

The model is very useful to describe the relationship between environmental factors and the growth of stands. In SEM analysis, evaluation is carried out on the measurement model (outer model) and structural model (inner model).From the measurement model, it will be seen whether each indicator is able to describe the latent variables significantly.Significance can be seen from the value of the loading factor, the value of loading factor ≥ 0.5 was considered significant [19].

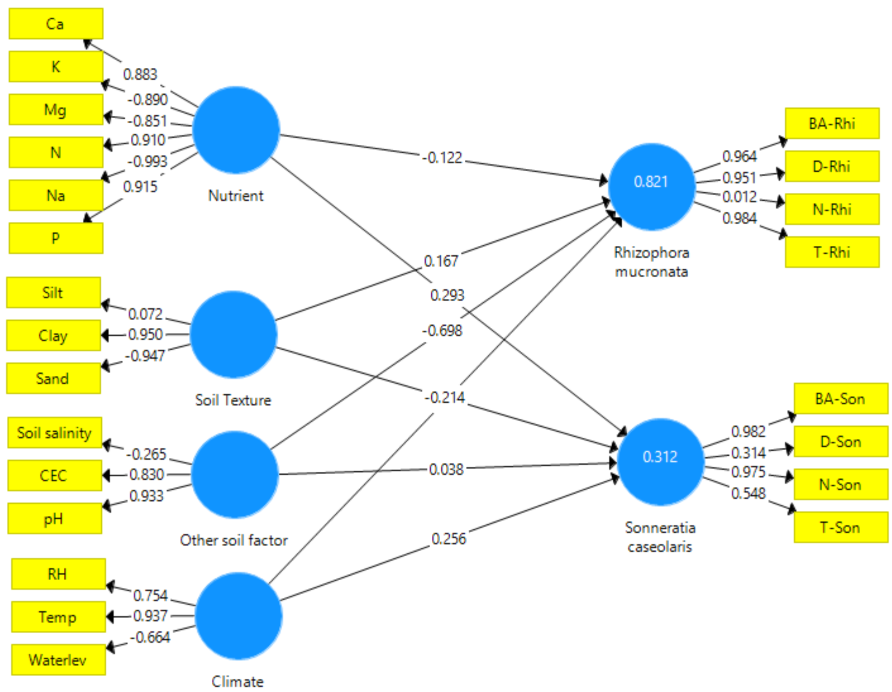

Figure 2. A model of relationship between mangrove stand and environmental factor.

Based on Figure 2, it was found that there were one *R. mucronata* indicators, one *S. caseolaris* indicators, three nutrient indicators, two soil texture indicators, one other soil factor indicator, and one climate indicator were not significantly to compose each latent variables. Therefore, the early PLS model was evaluated without non-significant indicators. The result shown on Figure 3. Figure 3 shown all the significat indicators (with loading factor > 0.5) to compose each latent variables. The model then used to evaluate it structural model (inner model) by examine the relationship between the constructs (exogenous latent variables) with the endogenous latent variables, one of them is based on the R^2 value on the endogenous variables (Table 4).

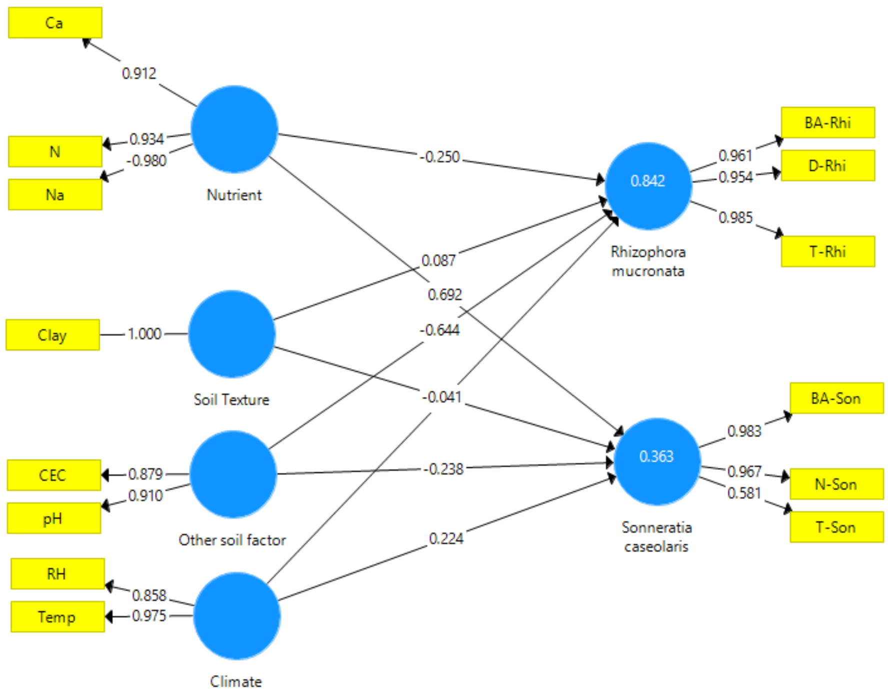

Figure 3. Model of repeat examination of indicator that compose latent variables.

Table 4. *R-square* (*R^2*) of *R. mucronata* and *S. caseolaris*.

	R square
R. mucronata	0.843
S. caseolaris	0.390

R^2 value of *R. mucronata* construct was 0.843, meaning that environmental factors can explain *R. mucronata*growth as much as 84.3% and the rest was explained by other variables not in the model. Likewise the case of *S. caseolaris* with R^2 value of 39.0%, so that environmental factors explain *S. caseolaris* as much as 39.0% and the rest is explained by other variables outside the model.

The next evaluation was examination of inner model to see the direct effect of the latent variables based on t-statistical significance values. The significance value in this study was set at 5% (0.05) so that the value of the t-table used at the 95% confidence level was 2.024. Interconnection relationships were said to be significant if the t-value is greater than the t-table. The result shown on Table 5 and there were several significant relationship. Nutrients, soil texture, and other soil factors have a significant effect on *R. mucronata* stands. Meanwhile, only nutrient extracts have a significant effect on *S. caseolaris*.

Table 5. The result of direct effect examination.

Independent variable	Dependent variable	T	Note
Nutrient	*R. mucronata*	2.977	Significant
Soil texture	*R. mucronata*	2.303	Significant
Other soil factor	*R. mucronata*	7.194	Significant
Climate	*R. mucronata*	1.405	No significant
Nutrient	*S. caseolaris*	2.675	Significant
Soil texture	*S. caseolaris*	0.750	No significant
Other soil factor	*S. caseolaris*	1.330	No significant
Climate	*S. caseolaris*	1.731	No significant

From the model and result of direct effect examination, in general, environmental factors that influence the *R. mucronata* stands were nutrients (N, P, Ca), clay texture, and other soil factors (CEC and pH), whereas *S. caseolaris* was only affected by nutrients (N, P, and Ca).

3.4. Discussion

Implementation of guludan techniques in coastal area of Jakarta is one of the efforts to rehabilitate damaged mangrove areas after conversion into ponds. The mangrove species being planted in the study site was *Rhizophora mucronata* which has a strong root to hold the ground where it stands. At the beginning of planting, as many as 200 individuals of *R. mucronata* were planted on each guludan. Until the study takes place at the end of 2016, the percentage of survived seedlings n the guludan ranges from 22 - 56.53%. The range was quite large because there was a difference in planting time and occupation by *Sonneratia caseolaris* which suppresses the growth of *R. mucronata*.

At the beginning of planting, the soil in the guludan was made higher than 20 cm from the water level in order to prevent mangrove roots from drowning in a long time [16]. Topsoil in some guludan then eroded due to flood events in 2013 [20], until finally the guludan was constantly inundated. Until 2017, all guludans of planting year 2011 and 2012 were inundated, while planting year 2010 and 2013 only half of them. *Sonneratia caseolaris* grows naturally in the flooded guludan like this. The seeds were derived from the parent tree that grows on the barrier of the former pond.

When compared with the results from [21] and [22] which both studied the growth of *R. mucronata* seedlings at 0.5 m × 0.5 m spacing, the percentage of *R. mucronata* life from both study results were higher than this research. This difference is related to the management of guludan and growing substrate. [21]done intensive care for seedlings planted in guludans so that all individuals can survive. While [22] studied *R. mucronata* which was planted in the natural habitat of mangroves with a muddy substrate so that it was suitable for the growth of mangroves planted. Regarding diameter and stem growth [21] showed better results than the results of the study. If guludan treatment is carried out optimally, the growth of the stand will also be optimal.

As *S. caseolaris* grew in the guludan, *R. mucronata* got pressure in obtaining growing space, nutrients, and light for growth. In the 2011 and 2012 guludan, it appeared that *S. caseolaris* was more dominant than R. mucronata when viewed from the basal area. The growth of *S. caseolaris* was faster than *R. mucronata* because it is a pioneer species in the mangrove ecosystem with the fast growth characteristic. Unfortunately, the rapid growth of *S. caseolaris* is not followed by it strong binding ability. The root structure of *S. caseolaris* is a pencil root with pneumatophores that does not penetrate deeply into the soil, in contrast to the *R. mucronata* stilt roots that can bind to the ground on which it stands. Meanwhile, the substrate inside the guludan was a pile of sacks containing a mixture of mud and minerals that were not so solid. This made the trees of *S. caseolaris* tend to grow tilted, even some of them were vulnerable to fall when hit by strong winds. These fallen trees hit the saplings and seedlings of *R. mucronata* around it and made the piles of sacks lifted, torned, then the soil inside were dispersed.

The results of independent sample t-test for the presence of weeds in guludan showed there were no significant differences between guludans with weed and without weeds.However the presence of these weeds actually became a serious threat at the beginning of planting. Several types of weeds found in guludanswere *Breynia coronata*, *Calopogonium mucunoides*, *Cayratia trifolia*, *Leucaena leucocephala*, *Passiflora foetida*, *Asystasia gangetica*, *Eichhornia crassipes*, and *Ipomoea aquatica*. Non-woody liana weeds such as *Breynia coronata*, *Calopogonium mucunoides*, *Passiflora foetida*, and *Cayratia trifolia*covered the stems and canopy of *R. mucronata*. Under these conditions, many *R. mucronata* were broken due to not able to withstand the weight of weeds grew in it canopy and the difficulty of obtaining sunlight.

Rehabilitation protocols with guludan techniques require maintenance activities by eradicating weeds that grow in guludans. Treatment is done until the seeds are three years old. After the age of three years, the seedlings of *R. mucronata* have entered the sapling phase and are considered strong enough to grow without maintenance activities. In fact, after passing through the age of three years there were still some individuals that die because the growing space invaded by weeds. However, the presence of liana in the guludan was not very influential on *R.mucronata* stands that have entered the phase of the tree considering the canopy and the trunk were stronger.

A mixture of mud and mineral soil as growing media bind to each other quite well. The use of sacks so that the soil is not easily carried by water. Sacks were made of thin plastics. Roots *of R. mucronata* easily sliped into the sacks and stuck the roots to the soil. Over time, the sack, as well as its bamboo fence, becomes damaged and decayed, leaving only the accumulated soil. The roots of *R. mucronata* will then hold the soil so that it is not carried by the water.

Based on soil texture, it appeared that clay fractions predominate in almost all groups of guludan. Except for the 2011 guludan group which was dominated by sand fraction, because the planting medium in the sack was indeed mixed with sand. In the natural mangrove ecosystem, there is a soil texture dominated by clay and silt fraction, also soil with more sand fraction. Tropical mangrove forests in the world are generally not specialized in growing on the soil with a certain fraction composition, but the patterns shown show soil texture in mangroves tend to contain clay [23]. The problem is that the dominant soil of the sand fraction is more easily eroded.

Clay content in the soil also affects the CEC, this is related to the ability of soil to bind mineral ions which is nutrient for plant growth. As shown in the nutrient content table, CEC of 2011 guludans group was lowest compared to other groups, although the value (20.75 cmol$^{(+)}$ / kg) was classified as moderate.

The nutrient content that the soil in the guludan has available nutrients that can be used by plants to grow and develop. The most nutrient element that affects mangrove standing growth in the guludan was the N content in the soil, as well as other aquatic ecosystems whose growth is limited by N nutrient content [24]. However, the N content in the guludans were in the low and very low category, it happened because there were quite a lot of guludans that it soil was inundated.

Nevertheless, mangrove stands can grow well despite the nutrient-poor soil conditions, because mangroves have good nutrient management strategies derived from nutrient cycling strategies and efficient nutrient conservation. One of the nutrient conservation strategies is to produce trees with evergreen and sclerophyllous leaves and high root/shoot biomass ratios [25]. Compared to producing new leaves that require more nutrients, the strategy of maintaining these leaves will save more nutrients [24][26].

Leaf longevity of mangroves on average is 16 months, variations derived from the species and latitude [5][27]. In addition, the slow rate of growth is also an indication that the plant is adapting to a nutrient-poor environment. When the environment is optimal for growth, mangroves can show higher growth rates [24]. Calcium (Ca) and pH also greatly influence the growth of mangrove. The calcium contained in the soil in all the guludans was categorized as very high. The presence of calcium which is an important cation in the soil may reduce the effect of soil acidity [28].

4. Conclusion

R mucronata can grow in guludans with the highest growth percentage in the 2013 group (3 years) which is 56.53%, while the other year groups have a lower percentage growth value. Growth of *R. mucronata* in each group were varies. The 2010 planting group showed good growth with highest average height, average diameter and basal average area of 4.59 m; 3.91 cm and; 28.87 m^2/ha respectively. *S. caseolaris*grows naturally in guludans and become competitor of *R. mucronata* in obtaining space to grow in guludans. The 2012 planting year group was the highest in terms of *S. caseolaris* density, that is 15 individuals/guludan with average height, average diameter and basal area of 9.38 cm, 5.29 m, and 24.79 m^2/ha, respectively. The growth of mangrove stand in guludans was influenced by environmental factors: *R. mucronata* by nutrients (N, P, Ca), clay texture, and other soil factors (CEC and pH), whereas *S. caseolaris* was only affected by nutrients (N, P, and Ca).

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