Growth responses of *Rhizophora apiculata* Blume in different soil and sediment conditions

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Abstract. This study aims to determine the growth response of *Rhizophora apiculata* against inundation and different sediment thickness as adaptation strategies. This research was conducted in Wonorejo Mangrove Conservation District Rungkut, Surabaya, Indonesia (07°18'32.7 "S and 112°48'59.1" U). The parameters used include plant height, number of branches and number of leaves. The treatment includes waterlogging and 2 control conditions. The treatment includes thick sediment control, and 2 cm, 4 cm and 8 cm sediment thickness. This study is an experimental research using RAL factorial (4x2). Data were analyzed using factorial ANOVA, followed by Tukey's test 5%. The results of this study indicate that the growth of *R. apiculata* in waterlogging treatment showed significantly effect on plant height, number of leaves and number of branches. While the thickness of the sediment treatment showed significant influence on the height of *R. apiculata.* But in terms of number of branches and leaves, the thickness of the sediment did not showed any significant effect. The interaction between thickness of sediment and waterlogged conditions in pools and land showed significant effect on plant height, while on number of leaves and number of branches, their interaction in pools showed no significant effect.
Key Words: mangrove adaptation, sediment thickness, inundation, waterlogged.

Introduction. Abiotic factors of the environment affect the coastal mangrove vegetation. Environmental characteristics which are influenced by the tide of sea causes some basic properties of mangrove ecosystems, like: a high level of siltation, low oxygen levels, and high salinity. The mangrove ecosystem is very extreme and at the same time very dynamic, and it is among the most rapidly changing, especially in the outer part. Mangrove forests face many threats and damage which can lead to extinction. The threat was caused either by natural causes or by humans. Only a few types of plants that can survive in the mangrove area, and these types are mostly typical of mangroves having already gone through the process of long adaptation and evolution. The root system of mangrove vegetation is able to withstand and precipitate sludge (Katherisan 2003; Naidoo et al 2010) as well to filter contaminated materials (Yong & Tam 2007; Marchand et al 2011; Amaliyah et al 2017).

Ecologically, mangrove communities grow on sludge soil structure which is periodically flooded. The intensity and the water level in the estuary are affected by tide (Thaxton et al 2007). Waterlogging affect the soil physico-chemical parameters, especially redox soil potential, pH and availability of O_2 in the soil (Parent et al 2008), the accumulation of CO_2, induces the anaerobic decomposition of organic matter and reduce iron and manganese (Kozlowski 1997). Ghobadi & Ghobadi (2010) explains waterlogging negative effect on the growth and survival ability of the root system as well as the balance of the growth of roots and shoots. The effect of water inundation including lowering gas exchange between the soil and air can decrease absorption availability process of O_2 to the roots. The O_2 decreasing can also be accelerated by the presence of plants in soil and plant roots absorption for respiration (Bertolde et al 2009). Water inundation also affected lower leaf length and area of leaves on plants, reducing plant height, closing of stomata (Promkhambut et al 2010) and cause early leaf abscission (Kozlowski 1997). In terms of morpho-anatomical changes, waterlogging cause an increase in the number and proportion of aerenchyma vascular cylinder (De Souza et al 2009). The inundation damage severity to crops depends on the phase of plant growth.

The flow of sea water which enters the mangroves brings sediment particles that will eventually be caught between the mangrove roots. The accumulation of sediment that occurs continuously will increase sediment thickness (Furukawa & Wolanski 1996). Research of Xiao et al (2010) on *Myriophyllum spicatum* and *Potamogeton malaianus* shows that the depth of the sediment has significant effect on growth. Atmaja & Soerojo (1994) in their observations show that the sediment from the flow of the river, according to the tide, is capable to cause death in some mangroves, especially *Avicennia* and *Sonneratia.*

Mangrove has different ability to bind sediment. Mangrove species such as bakau betul (*Rhizophora*), api-api (*Avicennia*) and perepat (*Sonneratia)* has a root that is mostly superficial, but they are gripping mud effectively. However, when *Rhizophora* is compared with *Avicennia* and *Sonneratia*, *Rhizophora* zone is capable of binding 20% of the sediment. *Rhizophora* is the dominant plant species in the mangrove areas and it is widely used in mangrove rehabilitation program. The adaptation ability of *Rhizophora* to survive on the littoral habitat can be made possible by the unique shape of the compact root that stuck to the bottom (Katherisan 2003), in which there are root tissues also supporting the establishment of the tree and contain breathing apparatus (pneumatofor), for more oxygen procurement. *Rhizophora* is able to live and grow under low light conditions when compared to *Avicennia* and *Laguncularia* (Thaxton et al 2007).

Some studies reveal that the water level and sediment thickness causes stunted plant growth and can causes plant death, when it reaches extreme level (Suhendra 2006; Piniak 2007; Thaxton et al 2007; Parent et al 2008). However, adaptation strategies relating to growth due to the influence of inundation and the thickness of sediment of *Rhizophora* has not been widely studied. This study aims to determine the growth response of plants from seedlings of *Rhizophora apiculata* against inundation and sediment thickness. So this research is expected to enrich the information on the form and adaptation strategies of *R. apiculata* mainly against inundation and sediment, so it can be used to identify adaptation strategies that support rehabilitation programs in Wonorejo Surabaya mangrove conservation, particularly in the extreme area of mangrove.

Material and Method

Description of the study area. This research was conducted in two places, namely at the Laboratory of Ecology, Department of Biology, Faculty of Science and Technology, Airlangga University and at Wonorejo Mangrove Conservation District Rungkut, Surabaya (07º18'32.7 "S and 112º48'59.1" U).

Seed of *R.* apiculata used in the present study had 3-4 months of age with an average height of 46±2 cm with 3-4 leaves obtained from Surabaya City Agriculture Office nursery around the mangrove forest in Wonorejo.

Experimental treatments. Measurement of environmental factors included, air temperature measurements using a mercury thermometer which has a level of accuracy of up to 1ºC, groundwater salinity was measured using a hand salino-refractometer, and the acidity of the sediment was measured by using a soil pH meter.

The analysis of macro element content of soil nutrients and the type or size of the sediment was carried out to know the condition of the soil which was used in the study. The analysis of the type or size of the sediment was carried out by using 100 g of substrate to be analyzed by particle size sieve method granulometri with mesh size 2:00, 1:00, 0:50, 0:25, 0.125 and 0.063 mm. the Sediment's particles are classified according to a scale of Wenworth (Higgins & Thiel 1988). Sediment, according to the particle size, can be separated as percentage of silt, medium sand, coarse sand, and gravel (Pinto & Santo 2006; Zaleha et al 2010).

The selection of R. apiculata seedlings. The seedlings used in the study have good morphological characteristics: green leaves, shiny and fresh leaves, with wrinkled trunk. The tillage aims to improve the condition of the soil to be clean of weeds so that the root growth maximally. To make homogeneous soil aeration, the soil needs to be processed by stirring evenly manually. After the land preparation, planting holes were performed at a depth of 10 cm, with a drill, at 50 x 50 cm spacing between plants. The plots were separated from each other by rectangular barrier.

The experiments were performed with 10 replicates, each with 4 treatments, so that the number of plants used was 40. The study begins with plants occured for 3 weeks before the plant sample was placed at 4 different sediments (0, 2, 4, and 8 cm) randomly. The experiments were carried out by using a sediment barrier of zinc with different heights, surrounding the individual seedlings. The seedlings were planted in 10 cm deep plots. Furthermore, after three weeks, except the control treatment plants, the remaining sediment is added according to treatment which is 2, 4 and 8 cm. While on non-waterlogged control (both high tide and low tide water does not stagnate on the surface) and waterlogged (range 5-12 cm flooding influenced the tides of the sea).

After *Rhizphora* seedlings are planted, it must be watering sufficiently, so that the plants do not wilt and the root to have always fulfilled availability of water so it can grow maximally. In addition, weeding was performed in an attempt to clear the weeds from the planting area so that the plants grow unrivaled in getting nutrients and water. Furthermore, the checking was performed every 2 weeks for 5 months.

Parameter observation. Parameter to be observed in this research is the growth of plant:

a. Number of primary branches. Primary branches are branches that grow from the stem. While, the secondary branches of the stem are branches that grow from the primary branch. Data retrieval in the number of branches was conducted monthly;
b. Height measurements were made from the start to end of the rod (shoots) up to the base above ground level. Measurements and observations were conducted every 2 weeks for 5 months;
c. Number of all leaves that grow on each crop during the study period.

Statistical analysis. The data obtained in this study are both qualitative and quantitative. Qualitative data were analyzed by descriptive method. While quantitative data were analyzed by statistical test. Statistical data was obtained by factorial design, test analysis of analysis of variance (ANOVA). If the Anova test showed significant effect on treatment, then the Tukey test was used (α = 0.05), significant difference when $p<0.05$.

Analysis of variants of data was conducted to examine the significantly effect of treatments (sediment thickness and water) to the growth of *R. apiculata* seedlings. The Turkey's test was done continuously to know mean (average) difference of plant growth between the treatment of waterlogged and various sediment thicknesses (0, 2, 4 and 8 cm).

Results

The effect of soil conditions in plant height, number of leaves and number of branches of R. apiculata. The differences of *R. apiculata* plants morphology between control and waterloged conditions can be seen in Figure 1 (plant height, number of leaves and shoots branching). *R. apiculata* growth in waterlogged soil (Figure 1b) exhibit better condition than the plants grow on not flooded land (Figure 1a). In flooded condition plant has more leaves and branches than in not flooded land.

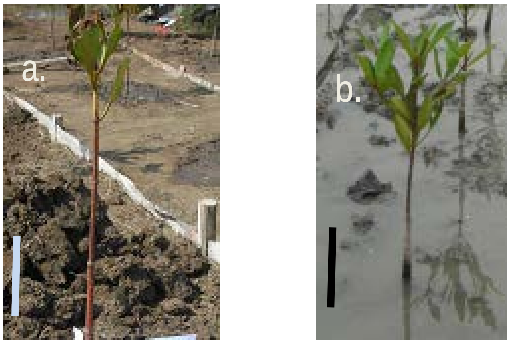

Figure 1. The *Rhizophora apiculata* plant morphology. a - control; b - waterlogging in one of all trial treatments sediment thickness. Bar = 10 cm.

The variables plant height, number of leaves and number of branches of *R. apiculata* show on waterlogged soil conditions substantially higher values than the not inundated control (Figure 2).

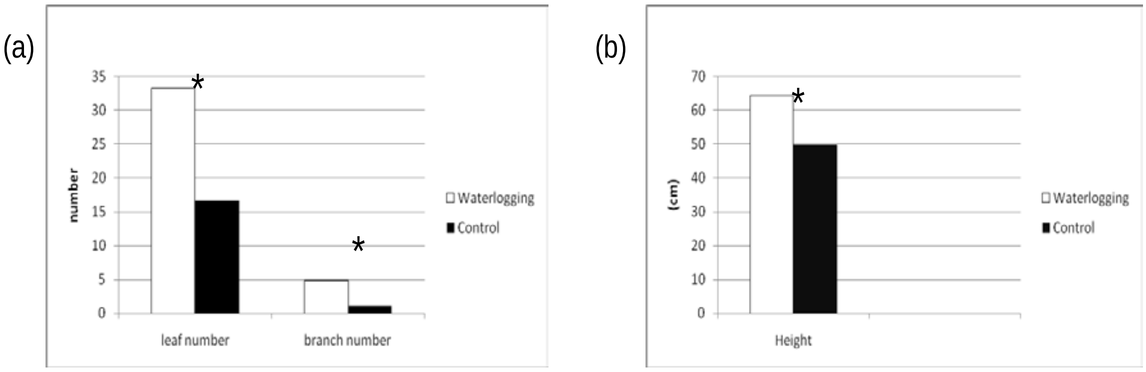

Figure 2. Leaf and branch number of *Rhizophora apiculata* (a), and height (b) comparison between the inundated land and control. *⁾ significant at 0.05.

The result of factorial ANOVA analysis for all variables of *R. apiculata* on land which was not inundated compared with flooded soil conditions showed a significant differences (P = .00; Table 1).

Table 1

ANOVA factorial plant height, leaf number, branch number *Rhizophora apiculata* on the condition of land and sediment thickness

Factor	*Height*			*Leaf number*			*Branch number*		
	d.f.	*SS*	*P*	*d.f.*	*SS*	*P*	*d.f.*	*SS*	*P*
Land	1	254.55	0.00	1	15.024	0.00	1	52.01	0.00
Sediment	3	33.86	0.00	3	0.83	0.47	3	0.17	0.91
Land x Sediment	3	7.74	0.01	3	0.71	0.55	3	0.24	0.87
Error	32			32			32		
Total	40			40			40		

d.f. -degrees of freedom, SS - sum of squares, P - level of significance.

The thickness of sediment against plant height, number of leaves and number of branches of R. apiculata. The abiotic factors of the environment are closely related to the growth and development of mangrove sedimentation (Kumaran et al 2004). In plant height, the high sediment treatment has significant impact (P = 0.000; Table 1). As seen in Figure 3, sediment thickness of 8 cm makes a plant height to be higher than the control treatment and sediment thickness of 2 and 4 cm. The Tukey test showed no difference between sediment treatment of 2 cm and control upon plant height parameter. In contrast difference occurred between the treatment of 4 cm and 8 cm sediment thickness.

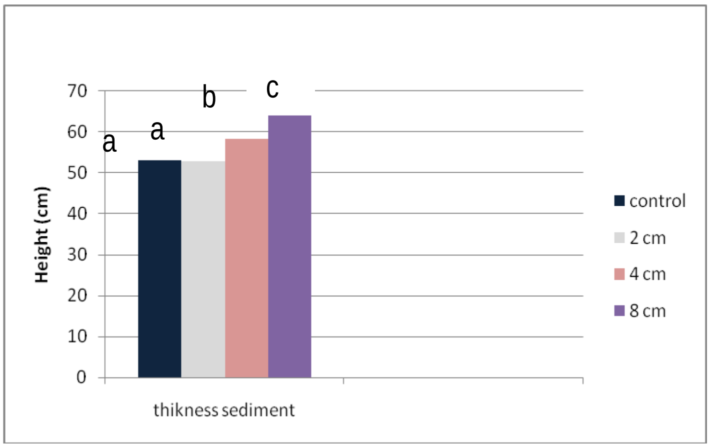

Figure 3. Effect of sediment thickness on plant height *Rhizophora apiculata* at month 5. Mean with different letters in the same column indicate a significant difference according to the Tukey test (P≤0.05).

But in general the sediment treatment did not showed any significant effect on the number of leaves (P=0.47; Table 1). This is reinforced by Figure 4 which explains that the overall number of leaves in the treatment of sediment thickness 4 cm is higher than in the case of the other treatments.

While in terms of number of branches the sediment treatment did not showed significant affect (P=0.91; Table 1). However, Figure 5, emphasize that the sediment thickness of 4 cm shows a higher number of branches than other treatments.

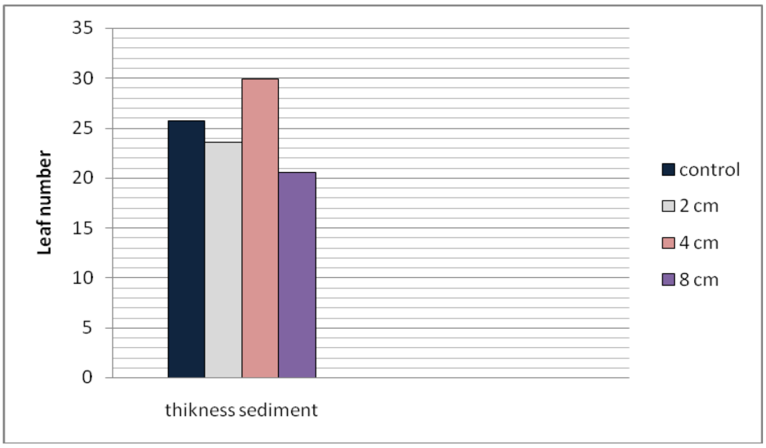

Figure 4. Effect of sediment thickness on the number of leaves of *Rhizophora apiculata* in the 5th month.

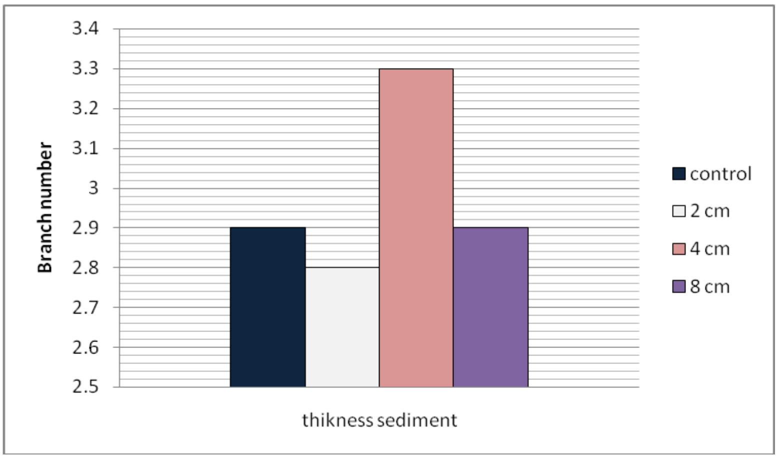

Figure 5. Effect of sediment thickness influence on the number of branches of *Rhizophora apiculata* in the 5th month.

Discussion. *Rhizophora apiculata* on land not inundated compared with flooded soil showed significant difference, this condition showed that the puddle factor has an impact on the survival of plants (De Souzal et al 2009). Waterlogged land conditions will push the low availability of oxygen (hypoxia), because the soil pores are filled with water so that it can be lowering the concentration of oxygen in the soil (Nishiuchi et al 2012). Due to the waterlogged conditions, the content of O_2 remains in the ground faster when there are plants (Setter & Waters 2003).

Anoxia soil conditions due to inundation causing genetic, morphologic, and physiologic changes (Xiao et al 2010). This is due to the low availability of oxygen in the soil which will inhibit the metabolism of the plants (Promkhambut et al 2010; Naoki & Toshihiro 2009). However, the research conducted by Arsana et al (2003) on rice plants showed that flooding increased plant height. This finding is similar with the results of the present study showing growth, leaf area, number of leaves and number of branches higher in waterlogged soil conditions than on non-flooded land. The aerial system *R. apiculata* has good adaptation abilities (Purnobasuki & Suzuki 2005; Amaliyah et al 2017) so that the mechanism of photosynthesis and respiration can run optimally. This structure is commonly associated with the aerenchyma that allows the entry of O_2 and diffusion for the submerged roots (Bertolde et al 2009). The roots of mangrove are able to facilitate the absorption of oxygen and translocate to the roots submerged by providing contact with air plants when environmental conditions are waterlogged. This adaptation can facilitate plant to maintain the growth of shoots during the period of inundation.

Germination has a strategic response to regeneration and the formation of buds (Xiao et al 2010), as it is shown in Figure 3-5, where the increasing of plant height, number of leaves and number of branches was significantly affected by sediment thickness. Although plants height showed significant differences to the treatment of sediment, but number of leaves and number of branches did not showed significant differences. This is due to the *Rhizophora* tolerance to sediment accretion (Thampanya et al 2002; Promkhambut et al 2010). Different taxa of mangrove probably cope differently with the stress due to burial (reducing sediment conditions and less oxygen provided to root system) (Thampanya et al 2002). However, only a few researches have explained the negative influence of sediment on plant growth. Crowe & Hay (2004) describe that the sedimentation caused a reduction in photosynthetic activity affecting the primary productivity, due to the reduced light penetration through the water column. This is similar to our findings, where the number of leaves on the treatment of 8 cm sediment was lower compared to the other treatment (Figure 4). As known the light intensity helped boost the growth of seedlings of *Rhizophora*, and it is showed by the increasing number of stilt root, elongation of shoots, number and wide of leaves (Katherisan & Rajendran 2002).

Conclusions. All treatments applied to *R. apiculata* concerning sediment thickness, flooded and unflooded land showed significant effect on plant height, number of leaves and number of branches. In the treatment of sediment was not observed any significant effect in terms of number of leaves and number of branches of *R. apiculata*. In contrast in plant height, different sediment thickness showed significant influence. The interaction between thickness of the sediment and waterlogged treatments in pools and land showed a significant effect on plant height, while on number of leaves and number of branches, their interaction of treatments showed no significant effect.

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