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1 **Carbon Stocks of *Rhizophora apiculata* and *Sonneratia alba* of Mangrove Forest**
2 **in Ngurah Rai Forest Park, Bali Province, Indonesia**

3
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13 **Keywords:** carbon growth and stocks, edaphic, salinity
14

15 **Abstract**

16 Mangrove forest is a typical tropical and subtropical forest, which is affected by sea
17 tides. This study aimed to investigate the effect of pH, seawater salinity, and edaphic
18 factors on carbon growth and stocks. The research plots were developed by
19 employing transect method with a size of 20 m x 50 m for three plots along the beach.
20 The pH value of plot A= 6.82, plot B= 6.90, and plot C= 7.26. The analysis of CEC
21 elements found that plot A= 30.0, plot B= 25.2, and plot C= 25.4. The value of N-Total
22 showed that plot A= 0.07, plot B= 0,07, and plot C= 0.04. The value of organic carbon
23 was plot A= 2.1, plot B= 2.6, and plot C= 0.81. The results showed that the diameter
24 of *Rhizophora apiculata* type in plot A, B, and C was 8.3±2.3 cm, 8.4±2.8 cm, and
25 8.9±3.3 cm respectively, and that of *Sonneratia alba* type in plot A, B, and C was
26 10.4±1.8 cm, 9.0±3.8 cm, and 8.5±1.5 cm respectively. The biomass value of *R.*
27 *apiculata* in plot A was 36.12 ton ha⁻¹, B= 38.60 ton ha⁻¹, and C= 45.94 ton ha⁻¹, and
28 the biomass value of *S. alba* in plot A, B, and C was 56.27 ton ha⁻¹, 48. ton ha⁻¹, and
29 36.25 ton ha⁻¹ respectively. The value of carbon contents in *R. apiculata* in plot A, B,
30 and C was 18.06 ton ha⁻¹, 19.30 ton ha⁻¹, and 22.97 ton ha⁻¹ successively. In addition,

31 the value of carbon content in *S. alba* was 28.13 ton ha⁻¹ in plot A, 24.47 ton ha⁻¹ in
32 plot B, and 18.12 ton ha⁻¹ in plot C.

33

34 **Introduction**

35 Indonesia has the biggest mangrove ecosystems in the world, consisting of 27% (16.9
36 million ha) from the total mangrove forests in the world, and becomes the center of the
37 distribution of species biodiversity and mangrove ecosystems (Spalding *et al.*, 2014),
38 however, it experienced rapid and dramatic destruction (Setyawan *et al.*, 2003).
39 Mangrove is a valuable treasure for Indonesian biodiversity with huge ecological and
40 economical significances (Hema and Devi, 2015). Mangrove ecosystems also have a
41 high economic value, either directly or indirectly, because the ecosystems have become
42 one of meaningful income sources for the society and the country.

43 Mangrove forest is a typical tropical and subtropical forest type, growing along the
44 beach and estuary affected by sea tides. Mangroves are generally found around coastal
45 areas protected from the onslaught of waves and gently sloping terrain. Mangroves
46 optimally grow in coastal areas with large estuary and in deltas whose water flow
47 contains a lot of mud. On the contrary, mangroves do not optimally grow in coastal
48 areas with no estuary. Mangrove is a valuable treasure for its biodiversity, ecologically
49 and economically (Hema and Devi, 2015). Thus, services, approaches, and
50 improvements to nearby society needs to be done in order to understand the mangrove
51 ecosystems (Mukherjee *et al.*, 2014; Nguyen *et al.*, 2019). The role of mangroves the
52 natural hazards and it is difficult for mangroves to grow in steep, choppy coasts with
53 strong tidal currents because it does not allow the deposition of mud that is needed as a
54 substrate for its growth (Spalding *et al.*, 2014). Reduced-impact logging method can
55 directly decrease emissions becaused using mono-cable winch on forest floors induced
56 by logs skidding on top soil and injured with bark broken intensity for remaining stands
57 (Ruslim 2011; Ruslim *et al.*, 2016; Chien, 2019).

58 The land of mangrove forests in terms of the habitat and the ecosystems is a diffused
59 environment that is formed by the encounter between marine environment and land
60 environment which have a big impact on human life or even for their ecosystem balance.

61 Since mangrove forest is always affected by excessive water throughout the year and is

62 sometimes interspersed with drying in some parts in a short time, it may involve a
63 chemical reaction of soil oxidation radicals. Since mangrove forest growing in
64 inhospitable environment in tropics and sub-tropics are equipped with very efficient free
65 radical foraging system to withstand the variation of stress conditions (Thathoi *et al.*,
66 2013). Mangrove plants may grow in different types of soil; therefore, their vegetation,
67 species composition and structure may vary considerably at the global, regional, local
68 region (Sherman *et al.*, 2003)

69
70 The height and time of seawater flooding in particular locations during the high tide can
71 also determine the salinity. The salinity is of factors determining the spread of
72 mangroves. In addition, the salinity also becomes the limiting factor for particular
73 species. Even though some mangrove species have a high mechanism adaptation
74 towards salinity, however, if fresh water supply is not available, this will make soil and
75 water salinity reach an extreme condition which is potential to threaten its life (Chen and
76 Ye, 2014; Nyangon *et al.*, 2019).

77
78 Mangrove forests as any other forests have a significant role as a carbon dioxide (CO₂)
79 sink in the air. Carbon dioxide sink has a significant relation to tree biomass. Trees
80 during photosynthesis process absorb CO₂ and convert it into organic carbon
81 (carbohydrate) which is merged into the body of the trees. Mangrove can also provide
82 food and shelter for various organisms, either in land or in water (Ekka and Pandit,
83 2012).

84
85 Essentially, the atmosphere receives more carbon than it ejects, as a result of burning
86 fossil fuels, motor vehicles, and industrial machines which make carbon accumulated
87 (IPCC, 2003). On the other hand, tropical forest deforestation also contributes in
88 supplying carbon to the atmosphere (Defries *et al.*, 2002). This function is a part of
89 ecosystem service which is not traded in the market but highly contributes to the human
90 welfares (Barbier *et al.*, 2011; Liqueete *et al.*, 2013; Ezebilo, 2016). Carbon stock was
91 estimated from mangrove biomass referred as 50% of the value of biomass (Komiyaama

92 *et al.*, 2005). Measurement of biomass was done in a non-destructive way. It was
93 determined based on data from measurements of tree volume Bismark, 2008).
94 On the other hand, the amount of CO₂ absorption decreases as a result of deforestation,
95 the change of land use, and residential development. The carbon accumulation in the
96 atmosphere provokes greenhouse effects as sunlight shortwave trapped in the
97 atmosphere that increases the temperature of the earth atmosphere. One of the forest
98 ecosystems that is able to reduce the greenhouse effect and functions as climate
99 change mitigation is mangrove forest (Komiya *et al.*, 2008). For the sake of human
100 beings, the result of our observation showed that the stretch of mangroves and corals is
101 the ecosystem that is most often rated, meanwhile the stretch of seaweed is not really
102 taken into account (Mehvar *et al.*, 2018).

103

104 **Methodology**

105 *Time and Location*

106 The present study was conducted in mangrove forest located in the area of Kuta
107 Municipality forest park, Bali Province (Fig 1).

108

109 **Fig 1.** Research location (■), Kuta Municipality forest park, Bali Province, Indonesia

110

111

112 *Procedures*

113 As adjusted to the research goals and objectives, this study consisted of 1) the
114 making of transect lines from the seashore to the shore for the zoning of mangrove
115 forest; 2) the making of sample plots along the transect lines; 3) the determination of
116 tree species in the sample plots 4) measuring the tree diameter and height in the sample
117 plots 5) testing the edaphic nature (soil physic/chemistry) in the sample plots and 6)
118 testing the parameters of mangrove forest water such as substracts, salinity, water pH,
119 and carbon stock estimation. The sample plots were made by employing transect
120 method with a size of 20 m x 50 m for three plots along the beach. The measurement
121 was conducted based on commonly used criteria, which was the diameter of chest-tall
122 tree trunks (130 cm) or the topmost roots of the soil surface.

123 *Data analysis*

124 *Productivity of mangrove stand*

125 Data of mangrove species identification results were tabulated in Microsoft Excel to
126 calculate the potentials of mangrove species at the studied area. Analysis of mangrove
127 wood was done by calculating the total volume of standing stock (including height,
128 diameter, basal area, and volume).

129 *Basal area calculation*

130 The conversion of the diameter obtained by using a diameter measuring tool was done
131 by applying the following formula:

132

$$133 \quad g = \frac{1}{4} \pi d^2$$

134 With g = basal area (m²); and d = diameter breast height (cm);

135

136 *Volume calculation*

137 The tree volume was measured by using Ruchaemi formula (2006) as follow:

138

$$139 \quad V = \frac{1}{4} \pi d^2 \times h \times f$$

140 With V = Tree volume (m³); d = diameter breast height (cm); h = tree height (m) and f =
141 form factor

142 *Physical and chemical testing of the soil*

143 The method used for parameter analysis of physical and chemical properties of the
144 soil was based on Bogor soil research center and Wenworth scale. The place for soil
145 analysis was in the soil laboratory of the Forest Rehabilitation Center
146 Mulawarman University, Samarinda East Kalimantan.

147

148 **Result and Discussions**

149 *Soil Reaction (pH H₂O)*

150 The pH value of particular water and soil reflects the balance between acid and base
151 concentration in the water. The pH value of water is affected by some factors, such as

152 photosynthesis activity, biology activity, temperature, oxygen content, and the existence
153 of cations and anions in the water (Aksornkoae, 1993). The results of soil pH
154 measurement in sample plots are presented on the Table 1.

155 **Table 1.** Test result data pH H₂O and of the soil in sample plots

156

157 The Table 1 shows that the mangrove forest soil inspected had a varying pH value. Plot
158 C which was located closest to the beach had a neutral pH with highest average (7.49),
159 while plot B which was located between plot A and plot C had an acidic pH with much
160 lower value (4.99). On the other hand, plot A which was located furthest from the beach
161 also had a neutral pH with average value of 7.03. The low pH value of the soil in plot B
162 was because the mangrove stands in that plot produced more litter than in plot A and C.
163 Through the decomposition process, besides producing minerals, the litter also secreted
164 organic acid that made the soil pH become sour. The more litter produced in plot C than
165 in the other plots was also indicated by the more organic carbon contents available (plot
166 B= 2.60%; plot A= 2.10%; plot C= 0.81%).

167

168 The influence of frequency and time and the duration of water logging towards the pH
169 value of mangrove forest soil was also reported by Nursin *et al.*, (2014) through their
170 study in Balinggi sub-district, Parigi Moutong region, Central Sulawesi. The other studies
171 that revealed the same phenomenon were Ragil *at al.*, (2017) through their study in
172 mangrove forest in Mempawah Region, West Kalimantan. The result of this study about
173 mangrove soil pH was compared to the other related studies such as 7) found that the
174 mangrove soil pH in Muara Resort, Selangor, was 7.7, whereas Kamariah (2014) found
175 that the mangrove forest in Mamuju Region, West Sulawesi had a pH value of 5.98-6.12.
176 Onrizal and Kusmana (2008) informed soil and water quality take effect on mangrove
177 growth in mangrove rehabilitation activities at east coast of North Sumatera.

178 Regarding soil pH values in mangrove forests, Hasrun (2013) stated that the water with
179 pH value of < 4 is categorized as highly sour and potentially threaten the life of
180 organisms. On the other hand, the water with pH value of > 9.5 is classified as highly
181 alkaline and could also result in death for organisms and reduce productivity. On the

182 contrary, plants can easily absorb carbon when the soil has a neutral pH (Setiawan *et al.*,
183 2013).

184
185 The correlation of seawater pH and total volume is shown in details through the
186 following Fig 2 and Fig 3.

187
188 **Fig 2.** The correlation of seawater pH and total volume of *Rhizophora alba* tree

189

190

191 **Fig 3.** The correlation of seawater pH and total volume of *R. apiculata* tree

192

193 As shown on Fig. 2, the seawater pH was increasing from the direction of plot A (closest
194 to land) to plot c (closest to sea), and it affected the decreasing of the tree total volume.
195 From this phenomena, it can concluded that *S. alba* mangrove had a less tolerant nature
196 towards seawater pH on particular limits. On the contrary, Fig. 3 shows that the volume
197 of *R apiculata* tree increased as the seawater pH increased. It proved that this type of
198 mangrove was tolerant to the seawater pH.

199

200 *Organic Carbon (C)*

201 Soil organic matter is of soil components derived from the rest of dead animals and
202 plants, both in the form of original and weathered tissues. The main resources of soil
203 organic matter in the sample plots were the litters of mangrove stands such as the
204 components of leaves, twigs, branches, stems and roots. According to Lee *et al.*, (2014),
205 organic matter has a productive function to support plant biomass production and a
206 protective function to keep the soil fertility and soil biotic stability.

207

208 Generally, the soil C concentration of the sample plots had a status of very low to
209 moderate with values between 0.81 to 2.60%. the lowest C concentration was found in
210 plot C which was located closest to the beach. The higher frequency and duration of the
211 waterlogging in plot C do not only limit the chance of piles of dropping organic matter on
212 the forest floor, but also limit the rate of decomposition of organic matter on the forest

213 floor. Ferreira *et al.*, (2007) stated that the decomposition of soil organic matter under
214 mangrove stands is highly affected by frequency, duration of waterlogging, and
215 distribution of its subtract particle size. In addition, Sufardi at al., (2017) argued that the
216 decomposition of organic matter in waterlogged soil works slowly because anaerob
217 bacteria are less efficient compared to aerob microflora which is more variegated.

218
219 The estimation of soil carbon concentration in mangrove forests in the study areas was
220 in line with that reported by Handoko at al., (2017) who conducted a study in Balinggi
221 sub-district, Parigi Region, Central Sulawesi. She found that soil carbon concentration in
222 that area was 0.34-2.34%. A higher figure was reported from a study by Ragil *et al.*,
223 (2017) stating that the soil C concentration was 3.99-5.05% (high to very high), based
224 on their study conducted in mangrove forest in Mempawah Region, West Kalimantan.

225
226 *Total Nitrogen*

227 Nitrogen is an essential element for plants, functioning to improve vegetative growth.
228 The main resource of N in forest mangrove soil is the litters produced by mangrove
229 stands as well as other dead organic material components that have been accumulated
230 on the forest floor. The decomposition of the organic matter to be minerals, including N,
231 is highly affected by inundation periodization. The anaerobic conditions when the floor
232 flooded causes litter decomposing microorganisms restricted, otherwise, in aerobic
233 conditions when the floor is not flooded, the microorganism activity increases. The total
234 N concentration in mangrove forest soil in the sample plots is presented on Table 1.

235
236 Table 1 shows that soil N concentration in the depth of 0-60 cm in the sample plots was
237 very low, only about 0.04-0.10%. In plot A and B, the soil N concentration in the depth of
238 0-30 cm was higher than that in the depth of 30-60 cm. However, in plot C, the soil N
239 concentration in both layers was similar. The impact of the flood on organic material
240 mineralization process to be N could be seen from the lower N concentration in the
241 depth of 0-30 cm in plot C which was bordering with the beach compared to plot A and B
242 respectively. Plot was located the furthest from the beach, whereas plot C was located
243 in between plot C and A.

244 The estimations of soil N concentration value as reported by the researchers are as
245 follows: 0.27-0.45% (status: moderate) in mangrove forest in Mangunharjo, Semarang
246 Region (Chrisyariati *et al.*, 2014); and 0.29-0.43% (status: moderate) in mangrove forest
247 in Mamuju Region, West Sulawesi (Malik *et al.*, 2019).

248

249 *Cation Exchange Capacity (CEC)*

250 Overall, the average value of CEC for the mangrove soil studied in the depth of 0-60 cm,
251 categorized as high, was 25.2 – 30.0 me 100g⁻¹. In plot A and B, the CEC value of
252 topsoil and subsoil was relatively similar, while in plot C there was a significant
253 difference. As mentioned before, there are two factors affecting the high and low of soil
254 CEC, namely organic matter content and its mineral clay content. The result shows that
255 the highest CEC value for mangrove forest soil in this study was in the depth of 0-30 cm
256 in plot C (31,6 me 100 g⁻¹). Since the soil organic matter content was lower than that in
257 the other plots (see Table 4), the factor causing the high CEC value of the soil in the
258 depth of 0-30 cm was the clay content which was higher than in plot B or plot A (Table
259 1). In the layer of 30-60 cm, the CEC value of the soil in plot C significantly decreased to
260 19.3 me 100g⁻¹ even though the clay content was not really different from that in the
261 layer of 0-30 cm (11.5%). This is interesting because despite its lower clay content,
262 10.6%, the soil in the depth of 30-60 cm in plot A had a higher CEC value (30.1 me
263 100g⁻¹) than in plot C. I may be because the soil in plot A had higher organic matter
264 content (2.10%) than in plot C (0.77%).

265

266 Cation Exchange Capacity (CEC) is the soil chemical nature highly related to the soil
267 fertility. The soil with higher CEC is able to absorb and provide nutrients better than the
268 soil with lower CEC. The soils with organic matter content or with higher clay content
269 consisted of higher CEC compared to the soils with lower or sandy organic matter
270 content (Soewandita, 2008). The CEC value of soil is influenced by the soil weathering
271 level, organic matter content and the number of alkali cations in the soil. The soil with
272 higher organic matter content had higher CEC, so did young soil with newly started
273 weathering level, and soils with further weathering levels had low CEC value.

274

275 *The Condition of Mangrove Forest Stands In Ngurah Rai Forest Park*

276 The mangrove in plot A (Distal zone or the furthest zone from sea), plot B (Middle zone or
277 middle zone), and plot C (Proximal zone, the closest zone from sea) was carried out an
278 inventory covering number of trees, diameter at breast height (DBH), the height of free
279 trunk (TBC), the total height (TTL), the width of basal area (LBD), and the total volume
280 (VT). Besides, the calculation was also done towards the amount of biomass and the
281 content of carbon stands in each of those researches. The types of mangrove available
282 in the research plots only consisted of *R. apiculata* and *S. alba*.

283

284 *The Density and Types of Tree Stands*

285 The number of trees in a research plot was not the same. Plot B had the most number of
286 trees, including 272 trees, each of 162 trees of *R. apiculata* type and 110 trees of *S.*
287 *alba*. Plot C had 220 trees, each of 110 trees of *R. apiculata* and *S. alba*. In the hectare
288 unit, the numbers of trees in each plot were: plot A 1.950 trees, plot C 2.200 trees and
289 plot B 2.720 trees, the total of trees 438 ha⁻¹ and 517 ha⁻¹ reached the study result in
290 Mentawir Village Balikpapan, Kalimantan Timur of 2,300 ha⁻¹, Lahjie *et al.*, 2019;
291 Kristiningrum *et al.*, (2019). The stand density of mangrove forests in eastern coast of
292 North Sumatera varied from 1,692 ind ha⁻¹ to 2,990 ind ha⁻¹ (Onrizal *et al.*, 2019a).

293

294 The density of mangrove tree stands in each plot tended to be influenced by each clay
295 content. Plot B with the highest tree density (2720 trees ha⁻¹), also had the highest clay
296 content (11,40-14,30%). Followed by plot C with the number of 2.200 trees ha⁻¹ and clay
297 content 11, 50-12,70%, and plot A with the number of 1950 trees ha⁻¹ and clay content
298 6,50-10,60%. As described by Hossain and Nuruddin (2016), clay fragment is a
299 supporting factor of the regeneration process, where the clay particle in the form of mud
300 will catch the mangrove fruit that falls when it is ripe. This process determined whether a
301 zone was dense or not.

302

303 Comparing the study results from Tolangara and Ahmad (2017) in Bacan mangrove
304 forest, Halmahera Selatan Regency which resulted in the density of the tree of 1.500 ha⁻¹
305 ¹ so the number of trees per hectare in Mangrove Forest in Tahura Ngurah Rai for the

306 three observing plots were considered denser. But if compare with the study result of
307 Handoko *et al.*, (2017) at 12 research plots of mangrove forest in the area of South
308 Rupert Island, Pekanbaru, with the density value ranges between 2.592 trees ha⁻¹ until
309 8.148 trees ha⁻¹, therefore the tree stands of mangrove forest in Tahura Ngurah Rai was
310 much lower.

311
312 The types of *R. apiculata* and *S. alba* were the two types of mangroves that were
313 available in all research plots lying from the seashore (plot C) to the land (plot B and plot
314 A). Generally outermost zone of mangrove with high salinity occupied by *Avicennia*
315 associated with *Sonneratia* spp., while *Rhizophora* was located in the middle zone and
316 *Bruguiera* grew in the furthest zone of the beach with much lower salinity. Onrizal *et al.*
317 (2019b) said in muddy areas with high salinity levels which can grow *R. apiculata*
318 species. The phenomenon of *Rhizophora* domination in the research area was suspected
319 to be related to the low salinity of its water ecosystem. The typical water salinity in the
320 research area of 14,8 -19,6% in reality was much lower than those reported by other
321 researcher. The factors that influence high and low water salinity were evaporation and
322 rainfall. The higher the level of evaporation of seawater, the higher the salinity would be.
323 The higher rainfall, then the lower salinity would be.

324
325 *Trunk Diameter*
326 Based on attachment 1-6, it was known that trunk diameter of tree type *R. apiculata* in
327 each research plot was : plot A = 8,3 ± 3,8 cm, plot B = 8,4 ± 2,8 cm and plot C 8,9 ± 3,3
328 cm then the average value of trunk diameter for the whole plots was 8,56 cm. in terms of
329 the diversity of trunk diameter of each plot, it can be concluded that the growth of trunk
330 diameter in plot A stands was more identical than other plots. Meanwhile, in plot C the
331 growth of trunk diameter was largely diverse.

332
333 *S. alba* type tended to have a bigger trunk diameter. In plot A, its value was = 10,4 ± 1,8
334 cm, plot b = 9,0 ± 3,8 cm, plot C = 8,5 ± 1,5 cm so the average value for all plots was 9,3
335 cm. Trunk diameter of *R. apiculata* was bigger in plot A and even smaller in plot B and
336 plot C which located further from the beach. Meanwhile, type *S. alba* showed the

337 opposite. The closer to the land, the bigger the diameter was. Due to that matter, it was
338 suspected that the growth of *R.apiculata* was better than the salinity in higher waters.

339
340 Climate affected the development of mangrove and the physical factor of its growing
341 place was substrate and waters. Further, Alwikado (2014) reported that climate also
342 affected the growth of mangrove through the light element, rainfall, temperature, and
343 wind. The diameter growth and mangrove diameter increment growth were also
344 influenced by many factors of its growing place including the substrate. The substrate in
345 this study referred to a substrate containing soft mud. Furthermore, Hastuti *et al.*, (2012)
346 added that growth was the result of the interaction of various physiological processes.
347 The physiological process referred to as photosynthesis, respiration, and transpiration.
348 While the results that were reported by Kusmana *et al.*, (2003) in mangrove Center
349 Lampung were obtained from the diameter value of 7,5 – 9,7 cm. Moreover, Pattipeilohy
350 (2014) in Minahasa Utara Sub-district obtained the diameter value of 11 cm.

351
352 *Tree Height*

353 As shown by its diameter growth, the average of total height growth of trees type *S. alba*
354 (15,99m) was bigger than tree type *R. apiculata* (12, 19 m). Hence, it can be concluded
355 that as a whole that the condition of mangrove habitats in the research area is more
356 suitable for *S. alba* than for *R. apiculata*.

357
358 The results of the total height growth of trees type *R. apiculata* in each plot was: plot A =
359 $13,08 \pm 2,34$ m, plot B = $10,57 \pm 2,91$ m, plot C = $12,91 \pm 2,68$ m while for type *R.*
360 *alba* plot A= $15, 58 \pm 5,99$ m, plot B = $16,28 \pm 5,88$ m, plot C = $16,11 \pm 1,9$ m. For type *R.*
361 *apiculata*, plot A resulted in a bigger height growth with a smaller coefficient of variation
362 than those grew in other plots. The height growth and diameter of tree is not only
363 depending on the space and surface canopy, relative humidity as well as root system,
364 but also influenced by climate and soil fertility. Cuenca *et al.*, (2015) stated the factors
365 were complex and affected towards the distribution and mangrove growth including
366 salinity, tidal drying, disturbance, warming, and predation. Meanwhile, Toknok (2006) in
367 Donggala obtained the value of 13-20 m..

368

369 *The Width of Basal Area*

370 According to the estimation conducted in the research location, Ngurah Rai Forest Park,
371 Denpasar, it was revealed that the widths of the basal area of *A. apiculata* in plot A, B,
372 and C were 0.006 m² tree⁻¹, 0.006 m² tree⁻¹, and 0.007 m² tree⁻¹ respectively. The
373 average width of the basal area was 0.006 m² tree⁻¹. On the other hand, the widths of
374 the basal area of *S. alba* were 0.009 m² tree⁻¹ in plot A, 0.008 m² tree⁻¹ in plot B, 0.006
375 m² tree⁻¹ in plot C, and 0.008 m² tree⁻¹ on average. Meanwhile, Aswita and Syahputra
376 (2012) on their study in Seuruway sub-district, Aceh Taming Region, Aceh Province,
377 reported that the width of the basal area of mangrove stands was 0.004 m² tree⁻¹.

378

379 *Stand Biomass and Carbon Content*

380 The result showed that the average biomass of mangrove forest stands in the research
381 location was 87.38 ton ha⁻¹, consisting of *R. apiculata* biomass of 40.22 ton ha⁻¹ (46%)
382 and *S. alba* biomass of 47.16 ton ha⁻¹ (54%). *S. alba* in plot A (located the furthest from
383 the beach) and plot B (located in the middle) were higher than in plot C (located closest
384 to the beach). The accumulation of the three plots was higher (12.7 ton ha⁻¹) compared
385 to the finding of the research conducted by Bindu *et al.*, (2018). As shown on Table 2, in
386 terms of the average number of trees in the three plots, actually, *S. alba* had a fewer
387 number (107 trees) than *R. apiculata* (131 trees), however, in terms of tree average
388 diameter and height (D=9.30 cm; T=15.99 m), *S. alba* had a bigger size than *R.*
389 *apiculata* (D=8.56 cm; T= 12.19 m).

390

391 **Table 2.** Biomass and carbon content of each species of mangrove at Plot A, Plot B
392 and Plot C.

393

394 Biomass is defined as the total number of organisms on the surface of a tree and is
395 measured by using the ton unit of dry weight per area (Brown, 2004). The amount of
396 biomass in particular mangrove forest is obtained from measuring the diameter, height,
397 and wood density of each type of mangroves (Rachmawati *et al.*, 2014). Mangrove
398 ecosystem has an ecological function to absorb and store carbon. Mangroves absorb

399 CO₂ during the photosynthesis process and then change it into carbohydrate by storing
400 it in form of biomass in roots, stems, branches, and leaves. According to Kauffman *et al.*,
401 (2012), carbon stocks in mangrove forests are higher than that in any other forests,
402 where the biggest carbon stocks are contained in mangrove sediments. When
403 compared to the biomass estimation from other studies the biomass of mangrove forest
404 stands in research location was much lower. It may be affected by the difference of the
405 number of trees ha⁻¹, the size of stem diameter, height as well as the wood density of
406 types of mangroves making up of stands. Rachmawati *et al.*, (2014) revealed that the
407 biomass of mangrove stands in Wilayah Pesisir Muara Gembong, Bekasi Region was
408 108.6 ton ha⁻¹. Meanwhile according to Kristiningrum *et al.*, (2019) the average value of
409 mangrove forest carbon at the studied area in Mentawir Village is 50.73 tons C ha⁻¹. In
410 addition, Bachmid *et al.*, (2018) found that the biomass of mangrove stands in
411 Kuburaya Region, West Kalimantan, was 189.2 ton ha⁻¹. Kristiningrum *et al.*, 2019
412 informed the biomass of mangrove forests in Mentawir which is part of the Balikpapan
413 Bay Area is one and a half times higher than that in Siberut Island, West Sumatra, which
414 is 49.13 tons ha⁻¹ (Bismark 2008). Kusmana *et al.*, (2003) stated that muddy sediments
415 are generally richer in organic matter compared to sandy sediments.

416
417 The relation between organic carbon and total volume of *R. apiculata* and *S. alba* can be
418 seen at Fig 4 and Fig. 5.

419
420

421 **Fig 4.** The relation between organic C and total volume of *S. alba*

422
423
424

425 **Fig 5.** The relation between organic C and total volume of *R. apiculata*

426

427 Fig. 4 shows that in *S. alba* the organic C content was decreasing from plot A (closest to
428 land) to plot C (closest to sea), and so did the total volume of the trees. It can be
429 concluded that *S. alba* really needs organic C to increase its total volume. On the

430 contrary, Fig. 5 shows that in *R. apiculata* the organic C value decreased, however, the
431 tree total volume was increasing. It proves that *R. apiculata* is able survive in the areas
432 with lower organic C.

433
434 The average value of water pH was 7.03% in plot A, 4.99% in plot B, and 7.49% in plot
435 C. Furthermore, the organic C value was 2.1% in plot A, 2.6% in plot B, and 0.81% in
436 plot C. On the other hand, the total N value was 0.07% in plot A, 0.07% in plot B, and
437 0.04% in plot C. The CEC value was 30.0 me 100g⁻¹ in plot A, 25 me 100g⁻¹ in plot B,
438 and 25.4 me 100g⁻¹ in plot C. The basal area of *R. apiculata* was 0.006 m² tree⁻¹ in plot
439 A, 0.006 m² tree⁻¹ in plot B, and 0.007 m² tree⁻¹, whereas the basal area of *S. alba* was
440 0.009 m² tree⁻¹ in plot A, 0.008 m² tree⁻¹ in plot B, and 0.006 m² tree⁻¹ in plot C. The
441 biomass value per ha for *R. apiculata* was 36.12 ton ha⁻¹ in plot A, 38.60 ton ha⁻¹ in plot
442 B, and 36.25 ton ha⁻¹ in plot C, meanwhile the biomass value of *S. alba* was 56.27 ton
443 ha⁻¹ in plot A, 38.60 ton ha⁻¹ in plot B, and 36.25 ton ha⁻¹ in plot C. The value of carbon
444 stock per ha for *R. apiculata* was 18.06 ton ha⁻¹ in plot A, 19.20 ton ha⁻¹ in plot B, and
445 22.97 ton ha⁻¹ in plot C. On the other hand, the value carbon stock per ha for *S. alba*
446 was 28.13 ton ha⁻¹ in plot A, 24.47 ton ha⁻¹ in plot B, and 22.97 ton ha⁻¹ in plot C.

447

448 **Conclusions**

449 The results showed that the diameter of *R. apiculata* type in plot A, B, and C was
450 8.3±2.3 cm, 8.4±2.8 cm, and 8.9±3.3 cm respectively, and that of *Rhizophora alba* type
451 in plot A, B, and C was 10.4±1.8 cm, 9.0±3.8 cm, and 8.5±1.5 cm respectively. The
452 biomass value of *R. apiculata* in plot A was 36.12 ton ha⁻¹, B= 38.60 ton ha⁻¹, and C=
453 45.94 ton ha⁻¹, and the biomass value of *S. alba* in plot A, B, and C was 56.27 ton ha⁻¹,
454 48. Ton ha⁻¹, and 36.25 ton ha⁻¹ respectively. The value of carbon contents in *R.*
455 *apiculata* in plot A, B, and C was 18.06 ton ha⁻¹, 19.30 ton ha⁻¹, and 22.97 ton ha⁻¹
456 successively. In addition, the value of carbon content in *S. alba* was 28.13 ton ha⁻¹ in
457 plot A, 24.47 ton ha⁻¹ in plot B, and 18.12 ton ha⁻¹ in plot C.

458

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460

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464

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Table 1. Test result data pH H₂O and of the soil in sample plots

No	Parameter	Methode	Unit	Data Analisis								
				Plot A			Plot B			Plot C		
				0-30	30-60	Average	0-30	30-60	Average	0-30	30-60	Average
1	pH H ₂ O	Electrode	-	6.74	7.32	7.03	5.38	4.59	4.99	7.57	7.40	7.49
2	Ca ⁺⁺	AAS	meq100gr ⁻¹	8.59	9.93	9.26	2.22	2.35	2.29	10.80	1.89	6.35
3	Mg ⁺⁺	AAS	meq100gr ⁻¹	4.56	4.28	4.42	4.49	4.56	4.53	8.13	5.83	6.98
4	Na ⁺	AAS	meq100gr ⁻¹	13.38	13.23	13.305	13.44	13.44	13.44	10.18	9.39	9.79
5	K ⁺	AAS	meq100gr ⁻¹	2.89	2.24	2.565	3.70	4.12	3.91	1.89	1.66	1.78
6	KTK	Hitung	meq100gr ⁻¹	30.00	30.10	30.05	24.51	25.97	25.24	31.58	19.27	25.43
9	Total N	Kjeldahl	%	0.10	0.04	0.07	0.08	0.06	0.07	0.04	0.04	0.04
10	C. Organic	Walkley and Black	%	2.29	1.92	2.105	2.71	2.49	2.60	0.84	0.77	0.81

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Table 2. Biomass and carbon content of each species of mangrove at Plot A, Plot B and Plot C.

647

No	Plot	Biomass (ton ha ⁻¹)		Carbon (ton ha ⁻¹)	
		<i>R.</i>	<i>S.</i>	<i>R.</i>	<i>S.</i>
		<i>apiculata</i>	<i>alba</i>	<i>apiculata</i>	<i>alba</i>
1	Plot A	36.12	56.27	18.06	28.13
2	Plot B	38.60	48.95	19.30	24.47
3	Plot C	45.94	36.25	22.97	18.12
	Total	120.66	141.47	60.33	70.72
	Average	40.22	47.16	20.11	23.57
	Average total	87.38		43.68	

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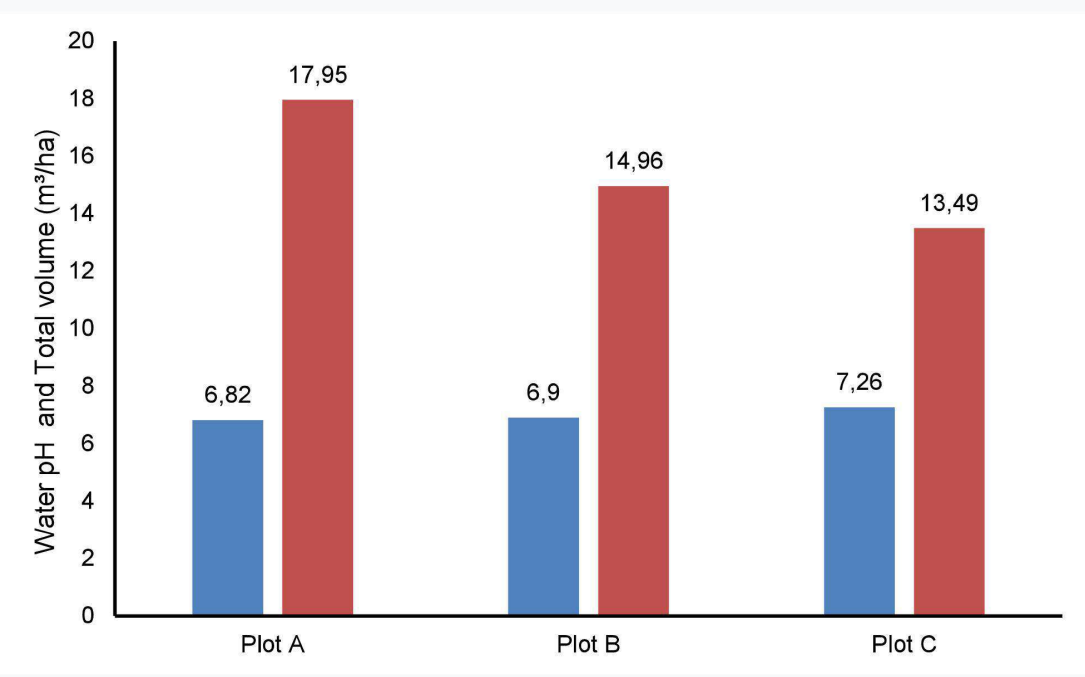
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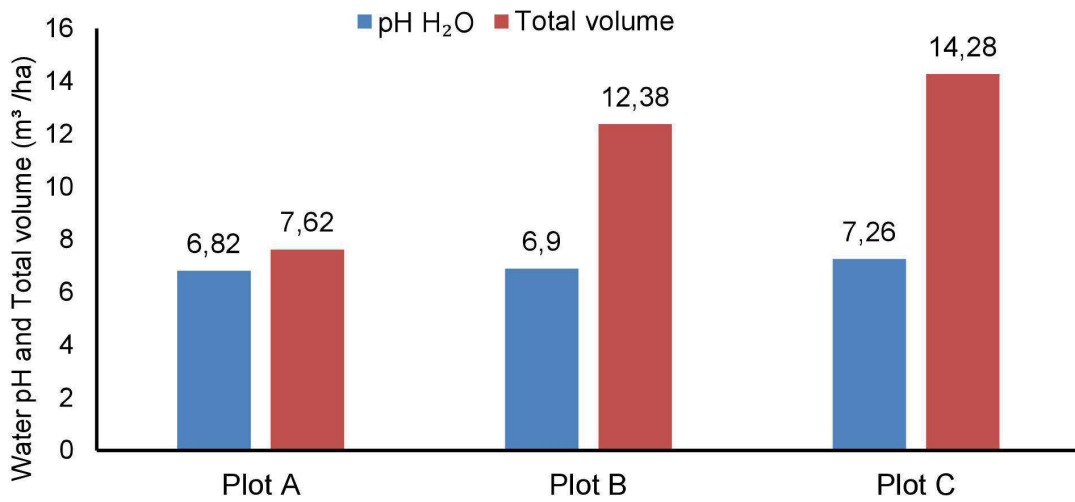
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Fig 2. The correlation of seawater pH and total volume of *Rhizophora alba* tree



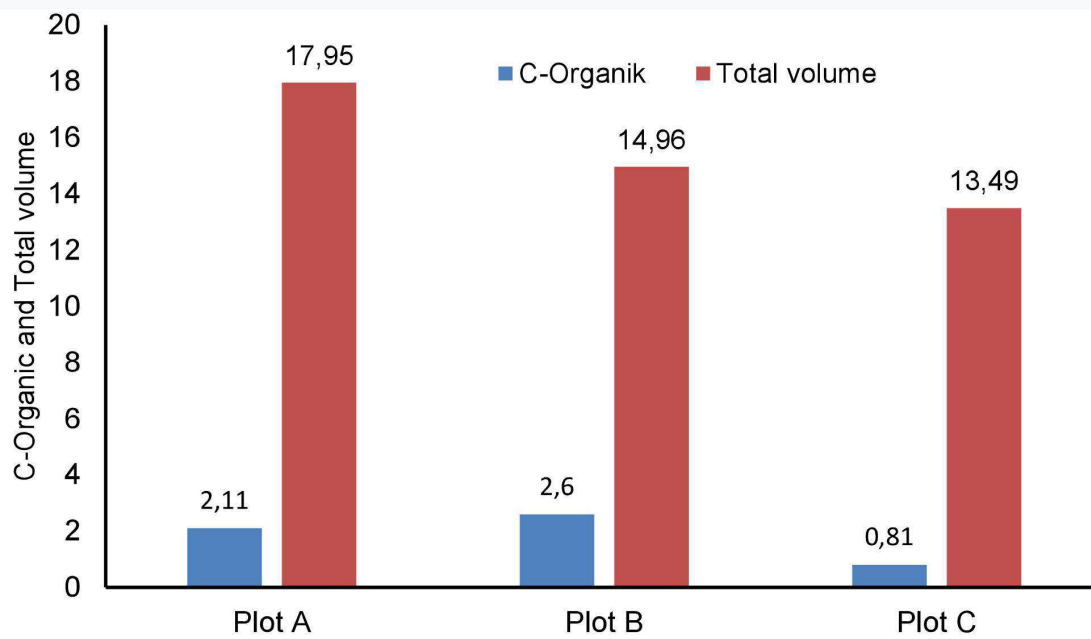
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Fig 3. The correlation of seawater pH and total volume of *R. apiculata* tree

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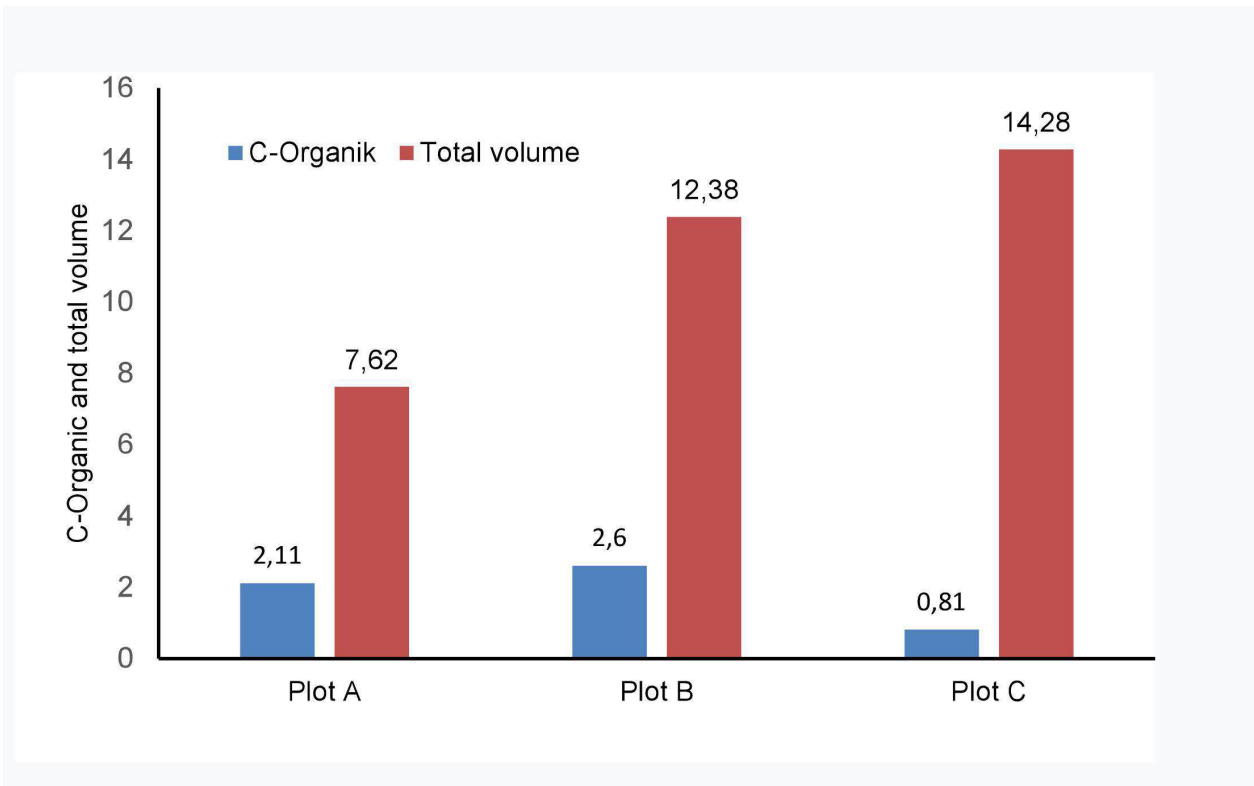
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Fig 4. The relation between organic C and total volume of *S. alba*

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Fig 5. The relation between organic C and total volume of *R. apiculata*

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Carbon stocks of *Rhizophora apiculata* and *Sonneratia alba* of mangrove forest in ngurah rai forest park, bali province, Indonesia

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Abstract

Mangrove forest is a typical tropical and subtropical forest, which is affected by sea tides. This study aimed to investigate the effect of pH, seawater salinity, and edaphic factors on carbon growth and stocks. The research plots were developed by employing transect method with a size of 20m x 50m for three plots along the beach. The pH value of plot A= 6.82, plot B= 6.90, and plot C= 7.26. The analysis of CEC elements found that plot A= 30.0, plot B= 25.2, and plot C= 25.4. The value of N-Total showed that plot A= 0.07, plot B= 0.07, and plot C= 0.04. The value of organic carbon was plot A= 2.1, plot B= 2.6, and plot C= 0.81. The results showed that the diameter of *Rhizophora apiculata* type in plot A, B, and C was 8.3±2.3cm, 8.4±2.8cm, and 8.9±3.3cm respectively, and that of *Sonneratia alba* type in plot A, B, and C was 10.4±1.8cm, 9.0±3.8cm, and 8.5±1.5cm respectively. The biomass value of *R. apiculata* in plot A was 36.12ton ha⁻¹, B= 38.60ton ha⁻¹, and C= 45.94ton ha⁻¹, and the biomass value of *S. alba* in plot A, B, and C was 56.27ton ha⁻¹, 48.ton ha⁻¹, and 36.25ton ha⁻¹ respectively. The value of carbon contents in *R. apiculata* in plot A, B, and C was 18.06ton ha⁻¹, 19.30ton ha⁻¹, and 22.97ton ha⁻¹ successively. In addition, the value of carbon content in *S. alba* was 28.13ton ha⁻¹ in plot A, 24.47ton ha⁻¹ in plot B, and 18.12ton ha⁻¹ in plot C.

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Introduction

Indonesia has the biggest mangrove ecosystems in the world, consisting of 27% (16.9 million ha) from the total mangrove forests in the world, and becomes the center of the distribution of species biodiversity and mangrove ecosystems (Spalding *et al.*, 2014), however, it experienced rapid and dramatic destruction (Setyawan *et al.*, 2003). Mangrove is a valuable treasure for Indonesian biodiversity with huge ecological and economical significances (Hema and Devi, 2015). Mangrove ecosystems also have a high economic value, either directly or indirectly, because the ecosystems have become one of meaningful income sources for the society and the country.

Mangrove forest is a typical tropical and subtropical forest type, growing along the beach and estuary affected by sea tides. Mangroves are generally found around coastal areas protected from the onslaught of waves and gently sloping terrain. Mangroves optimally grow in coastal areas with large estuary and in deltas whose water flow contains a lot of mud. On the contrary, mangroves do not optimally grow in coastal areas with no estuary. Mangrove is a valuable treasure for its biodiversity, ecologically and economically (Hema and Devi, 2015). Thus, services, approaches, and improvements to nearby society needs to be done in order to understand the mangrove ecosystems (Mukherjee *et al.*, 2014; Nguyen *et al.*, 2019). The role of mangroves the natural hazards and it is difficult for mangroves to grow in steep, choppy coasts with strong tidal currents because it does not allow the deposition of mud that is needed as a substrate for its growth (Spalding *et al.*, 2014). Reduced-impact logging method can directly decrease emissions because using mono-cable winch on forest floors induced by logs skidding on top soil and injured with bark broken intensity for remaining stands (Ruslim 2011; Ruslim *et al.*, 2016; Chien, 2019).

The land of mangrove forests in terms of the habitat and the ecosystems is a diffused environment that is formed by the encounter between marine

environment and land environment which have a big impact on human life or even for their ecosystem balance. Since mangrove forest is always affected by excessive water throughout the year and is sometimes interspersed with drying in some parts in a short time, it may involve a chemical reaction of soil oxidation radicals. Since mangrove forest growing in inhospitable environment in tropics and sub-tropics are equipped with very efficient free radical foraging system to withstand the variation of stress conditions (Thathoi *et al.*, 2013). Mangrove plants may grow in different types of soil; therefore, their vegetation, species composition and structure may vary considerably at the global, regional, local region (Sherman *et al.*, 2003)

The height and time of seawater flooding in particular locations during the high tide can also determine the salinity. The salinity is of factors determining the spread of mangroves. In addition, the salinity also becomes the limiting factor for particular species. Even though some mangrove species have a high mechanism adaptation towards salinity, however, if fresh water supply is not available, this will make soil and water salinity reach an extreme condition which is potential to threaten its life (Chen and Ye, 2014; Nyangon *et al.*, 2019).

Mangrove forests as any other forests have a significant role as a carbon dioxide (CO₂) sink in the air. Carbon dioxide sink has a significant relation to tree biomass. Trees during photosynthesis process absorb CO₂ and convert it into organic carbon (carbohydrate) which is merged into the body of the trees. Mangrove can also provide food and shelter for various organisms, either in land or in water (Ekka and Pandit, 2012).

Essentially, the atmosphere receives more carbon than it ejects, as a result of burning fossil fuels, motor vehicles, and industrial machines which make carbon accumulated (IPCC, 2003). On the other hand, tropical forest deforestation also contributes in supplying carbon to the atmosphere (Defries *et al.*,

2002). This function is a part of ecosystem service which is not traded in the market but highly contributes to the human welfares (Barbier *et al.*, 2011; Liquete *et al.*, 2013; Ezebilo, 2016). Carbon stock was estimated from mangrove biomass referred as 50% of the value of biomass (Komiya *et al.*, 2005). Measurement of biomass was done in a non-destructive way. It was determined based on data from measurements of tree volume Bismark, 2008).

On the other hand, the amount of CO₂ absorption decreases as a result of deforestation, the change of land use, and residential development. The carbon accumulation in the atmosphere provokes greenhouse effects as sunlight shortwave trapped in the atmosphere that increases the temperature of the earth atmosphere. One of the forest ecosystems that is able to reduce the greenhouse effect and functions as climate change mitigation is mangrove forest (Komiya *et al.*, 2008). For the sake of human beings, the result of our observation showed that the stretch of mangroves and corals is the ecosystem that is most often rated, meanwhile the stretch of seaweed is not really taken into account (Mehvar *et al.*, 2018).

During the high tide, the seawater often goes further to the inland. At this time the soil absorbs various nutrients from underground water. Enrichment of the soil on the surface can also occur through the movement of water. Therefore, the nature of the soil under the mangrove vegetation is also related to the chemical components under the groundwater. On the other hand, mangrove roots are essential for the coastal environment due to its function that can retain the soil under the mangrove forest from the seawater, so it can strengthen the coastline and maintain the land around the roots as an environment that is suitable for marine life breed.

The height and time of seawater-flooding in Ngurah Rai Forest Park during the high tide can determine salinity. The salinity is one of the determining factors of the mangroves spread. In addition, the salinity also becomes the limiting factor for particular species.

Even though some mangrove species have a high mechanism adaptation towards salinity, however, if freshwater supply is not available, this will make soil and water salinity reach an extreme condition which is potential to threaten its life.

Based on the above descriptions, it can be stated that the spread of mangrove species is mainly affected by the condition of the waters where it grows while the growth of mangrove stands is influenced by edaphic conditions which cover physical characteristics and soil fertility where it grows. Mangrove forests like any other forests have a significant role including absorbing carbon dioxide (CO₂) in the air so that its existence contributes to controlling climate change. The ability of mangrove forests in absorbing CO₂ is depending on the amount of stands biomass and carbon content of the soil where the forest grows. In order to support the function of Ngurah Rai Forest Park, especially as a means of developing science and educational facilities supporting cultivation, tourism, and recreation, a study that can reveal the relationship between mangrove stands and their habitats is important to be conducted. From the above background this study aims to: (i) How is the physical condition and soil fertility of the mangrove forests in Ngurah Rai Forest Park and how many edaphic factors that affect the growth of mangrove stands. (ii) To measure the physical characteristics, chemical characteristics (pH, cation exchange capacity (CEC) and soil fertility (organic material components, total Nitrogen) of the mangrove forest habitat in Ngurah Rai Forest Park (iii) To evaluate the growth conditions of the mangrove forest habitat in Ngurah Rai Forest Park, including the number of trees, tree height, tree diameter, basal area, stand volume, stand biomass, and the content of carbon stands.

Materials and methods

Time and Location

The present study was conducted in mangrove forest located in the area of Kuta Municipality forest park, Bali Province (Fig 1).



Fig. 1. Research location (■), Kuta Municipality forest park, Bali Province, Indonesia.

Procedures

As adjusted to the research goals and objectives, this study consisted of 1) the making of transect lines from the seashore to the shore for the zoning of mangrove forest; 2) the making of sample plots along the transect lines; 3) the determination of tree species in the sample plots 4) measuring the tree diameter and height in the sample plots 5) testing the edaphic nature (soil physic/chemistry) in the sample plots and 6) testing the parameters of mangrove forest water such as subtracts, salinity, water pH, and carbon stock estimation. The sample plots were made by employing transect method with a size of 20m x 50m for three plots along the beach. The measurement was conducted based on commonly used criteria, which was the diameter of chest-tall tree trunks (130cm) or the topmost roots of the soil surface.

Data analysis

Productivity of mangrove stand

Data of mangrove species identification results were tabulated in Microsoft Excel to calculate the potentials of mangrove species at the studied area. Analysis of mangrove wood was done by calculating the total volume of standing stock (including height, diameter, basal area, and volume).

Basal area calculation

The conversion of the diameter obtained by using a diameter measuring tool was done by applying the following formula:

$$g = \frac{1}{4} \pi d^2$$

With g = basal area (m^2); and d = diameter breast height (cm);

Volume calculation

The tree volume was measured by using Ruchaemi formula (2006) as follow:

$$V = \frac{1}{4} \pi d^2 \times h \times f$$

With V = Tree volume (m^3); d = diameter breast height (cm); h = tree height (m) and f = form factor

Physical and chemical testing of the soil

The method used for parameter analysis of physical and chemical properties of the soil was based on Bogor soil research center and Wenworth scale. The place for soil analysis was in the soil laboratory of the Forest Rehabilitation Center Mulawarman University, Samarinda East Kalimantan.

Result and discussions

Soil Reaction (pH H₂O)

The pH value of particular water and soil reflects the balance between acid and base concentration in the

water. The pH value of water is affected by some factors, such as photosynthesis activity, biology activity, temperature, oxygen content, and the existence of

cations and anions in the water (Aksornkoae, 1993). The results of soil pH measurement in sample plots are presented on the Table 1.

Table 1. Test result data pH H₂O and of the soil in sample plots.

No	Parameter	Method	Unit	Data Analisis								
				Plot A			Plot B			Plot C		
				0-30	30-60	Average	0-30	30-60	Average	0-30	30-60	Average
1	pH H ₂ O	Electrode	-	6.74	7.32	7.03	5.38	4.59	4.99	7.57	7.40	7.49
2	Ca ⁺⁺	AAS	meq100gr ⁻¹	8.59	9.93	9.26	2.22	2.35	2.29	10.80	1.89	6.35
3	Mg ⁺⁺	AAS	meq100gr ⁻¹	4.56	4.28	4.42	4.49	4.56	4.53	8.13	5.83	6.98
4	Na ⁺	AAS	meq100gr ⁻¹	13.38	13.23	13.305	13.44	13.44	13.44	10.18	9.39	9.79
5	K ⁺	AAS	meq100gr ⁻¹	2.89	2.24	2.565	3.70	4.12	3.91	1.89	1.66	1.78
6	KTK	Hitung	meq100gr ⁻¹	30.00	30.10	30.05	24.51	25.97	25.24	31.58	19.27	25.43
9	Total N	Kjeldahl	%	0.10	0.04	0.07	0.08	0.06	0.07	0.04	0.04	0.04
10	C. Organic	Walkley and Black	%	2.29	1.92	2.105	2.71	2.49	2.60	0.84	0.77	0.81

The Table 1 shows that the mangrove forest soil inspected had a varying pH value. Plot C which was located closest to the beach had a neutral pH with highest average (7.49), while plot B which was located between plot A and plot C had an acidic pH with much lower value (4.99). On the other hand, plot A which was located furthest from the beach also had a neutral pH with average value of 7.03. The low pH value of the soil in plot B was because the mangrove stands in that plot produced more litter than in plot A and C. Through the decomposition process, besides producing minerals, the litter also secreted organic acid that made the soil pH become sour. The more litter produced in plot C than in the other plots was also indicated by the more organic carbon contents available (plot B= 2.60%; plot A= 2.10%; plot C= 0.81%).

The influence of frequency and time and the duration of water logging towards the pH value of mangrove forest soil was also reported by Nursin *et al.* (2014) through their study in Balinggi sub-district, Parigi Moutong region, Central Sulawesi. The other studies that revealed the same phenomenon were Ragil *et al.* (2017) through their study in mangrove forest in Mempawah Region, West Kalimantan. The result of this study about mangrove soil pH was compared to the other related studies such as 7) found that the mangrove soil pH in Muara Resort, Selangor, was 7.7, whereas Kamariah (2014) found that the mangrove forest in Mamuju Region, West Sulawesi had a pH

value of 5.98-6.12. Onrizal and Kusmana (2008) informed soil and water quality take effect on mangrove growth in mangrove rehabilitation activities at east coast of North Sumatera.

Regarding soil pH values in mangrove forests, Hasrun *et al.* (2013) stated that the water with pH value of < 4 is categorized as highly sour and potentially threaten the life of organisms. On the other hand, the water with pH value of > 9.5 is classified as highly alkaline and could also result in death for organisms and reduce productivity. On the contrary, plants can easily absorb carbon when the soil has a neutral pH (Setiawan *et al.*, 2013).

The correlation of seawater pH and total volume is shown in details through the following Fig 2 and Fig 3.

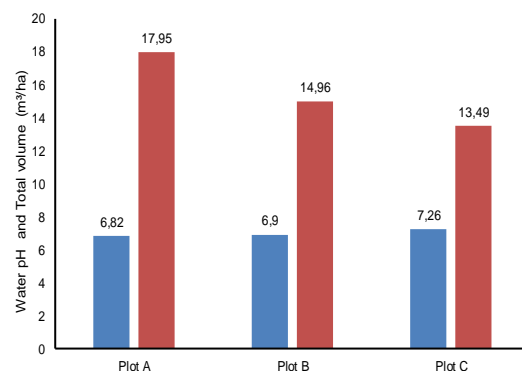


Fig. 2. The correlation of seawater pH and total volume of *Rhizophora alba* tree.

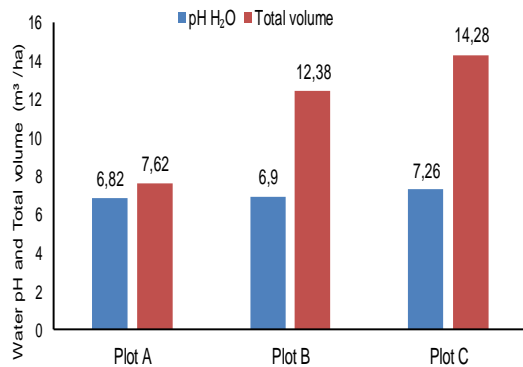


Fig. 3. The correlation of seawater pH and total volume of *R. apiculata* tree.

As shown on Fig. 2, the seawater pH was increasing from the direction of plot A (closest to land) to plot c (closest to sea), and it affected the decreasing of the tree total volume. From this phenomena, it can concluded that *S. alba* mangrove had a less tolerant nature towards seawater pH on particular limits. On the contrary, Fig. 3 shows that the volume of *R. apiculata* tree increased as the seawater pH increased. It proved that this type of mangrove was tolerant to the seawater pH.

Organic Carbon (C)

Soil organic matter is of soil components derived from the rest of dead animals and plants, both in the form of original and weathered tissues. The main resources of soil organic matter in the sample plots were the litters of mangrove stands such as the components of leaves, twigs, branches, stems and roots. According to Lee *et al.* (2014), organic matter has a productive function to support plant biomass production and a protective function to keep the soil fertility and soil biotic stability.

Generally, the soil C concentration of the sample plots had a status of very low to moderate with values between 0.81 to 2.60%. the lowest C concentration was found in plot C which was located closest to the beach. The higher frequency and duration of the waterlogging in plot C do not only limit the chance of piles of dropping organic matter on the forest floor,

but also limit the rate of decomposition of organic matter on the forest floor. Ferreira *et al.* (2007) stated that the decomposition of soil organic matter under mangrove stands is highly affected by frequency, duration of waterlogging, and distribution of its substract particle size.

The estimation of soil carbon concentration in mangrove forests in the study areas was in line with that reported by Handoko *et al.* (2017) who conducted a study in Balinggi sub-district, Parigi Region, Central Sulawesi. She found that soil carbon concentration in that area was 0.34-2.34%. A higher figure was reported from a study by Ragil *et al.* (2017) stating that the soil C concentration was 3.99-5.05% (high to very high), based on their study conducted in mangrove forest in Mempawah Region, West Kalimantan.

Total Nitrogen

Nitrogen is an essential element for plants, functioning to improve vegetative growth. The main resource of N in forest mangrove soil is the litters produced by mangrove stands as well as other dead organic material components that have been accumulated on the forest floor. The decomposition of the organic matter to be minerals, including N, is highly affected by inundation periodization. The anaerobic conditions when the floor flooded causes litter decomposing microorganisms restricted, otherwise, in aerobic conditions when the floor is not flooded, the microorganism activity increases. The total N concentration in mangrove forest soil in the sample plots is presented on Table 1.

Table 1 shows that soil N concentration in the depth of 0-60cm in the sample plots was very low, only about 0.04-0.10%. In plot A and B, the soil N concentration in the depth of 0-30cm was higher than that in the depth of 30-60cm. However, in plot C, the soil N concentration in both layers was similar. The impact of the flood on organic material mineralization process to be N could be seen from the lower N concentration in the depth of 0-30cm in plot C which was bordering with the beach compared to plot A and B respectively. Plot was located

the furthest from the beach, whereas plot C was located in between plot C and A.

The estimations of soil N concentration value as reported by the researchers are as follows: 0.27-0.45% (status: moderate) in mangrove forest in Mangunharjo, Semarang Region (Chrisyariati *et al.*, 2014); and 0.29-0.43% (status: moderate) in mangrove forest in Mamuju Region, West Sulawesi (Malik *et al.*, 2019).

Cation Exchange Capacity (CEC)

Overall, the average value of CEC for the mangrove soil studied in the depth of 0-60cm, categorized as high, was 25.2 – 30.0 me 100g⁻¹. In plot A and B, the CEC value of topsoil and subsoil was relatively similar, while in plot C there was a significant difference. As mentioned before, there are two factors affecting the high and low of soil CEC, namely organic matter content and its mineral clay content. The result shows that the highest CEC value for mangrove forest soil in this study was in the depth of 0-30cm in plot C (31,6 me 100g⁻¹). Since the soil organic matter content was lower than that in the other plots (see Table 4), the factor causing the high CEC value of the soil in the depth of 0-30cm was the clay content which was higher than in plot B or plot A (Table 1). In the layer of 30-60cm, the CEC value of the soil in plot C significantly decreased to 19.3 me 100g⁻¹ even though the clay content was not really different from that in the layer of 0-30cm (11.5%). This is interesting because despite its lower clay content, 10.6%, the soil in the depth of 30-60cm in plot A had a higher CEC value (30.1 me 100g⁻¹) than in plot C. I may be because the soil in plot A had higher organic matter content (2.10%) than in plot C (0.77%).

Cation Exchange Capacity (CEC) is the soil chemical nature highly related to the soil fertility. The soil with higher CEC is able to absorb and provide nutrients better than the soil with lower CEC. The soils with organic matter content or with higher clay content consisted of higher CEC compared to the soils with lower or sandy organic matter content (Soewandita,

2008). The CEC value of soil is influenced by the soil weathering level, organic matter content and the number of alkali cations in the soil. The soil with higher organic matter content had higher CEC, so did young soil with newly started weathering level, and soils with further weathering levels had low CEC value.

The Condition of Mangrove Forest Stands In Ngurah Rai Forest Park

The mangrove in plot A (Distal zone or the furthest zone from sea), plot B (Middle zone or middle zone), and plot C (Proximal zone, the closest zone from sea) was carried out an inventory covering number of trees, diameter at breast height (DBH), the height of free trunk (TBC), the total height (TTL), the width of basal area (LBD), and the total volume (VT). Besides, the calculation was also done towards the amount of biomass and the content of carbon stands in each of those researches. The types of mangrove available in the research plots only consisted of *R. apiculata* and *S. alba*.

The Density and Types of Tree Stands

The number of trees in a research plot was not the same. Plot B had the most number of trees, including 272 trees, each of 162 trees of *R. apiculata* type and 110 trees of *S. alba*. Plot C had 220 trees, each of 110 trees of *R. apiculata* and *S. alba*. In the hectare unit, the numbers of trees in each plot were: plot A 1.950trees, plot C 2.200 trees and plot B 2.720trees, the total of trees 438ha⁻¹ and 517ha⁻¹ reached the study result in Mentawir Village Balikpapan, Kalimantan Timur of 2,300ha⁻¹, Lahjie *et al.*, 2019; Kristiningrum *et al.* (2019). The stand density of mangrove forests in eastern coast of North Sumatera varied from 1,692ind ha⁻¹ to 2,990ind ha⁻¹ (Onrizal *et al.*, 2019a).

The density of mangrove tree stands in each plot tended to be influenced by each clay content. Plot B with the highest tree density (2720 trees ha⁻¹), also had the highest clay content (11,40-14,30%). Followed by plot C with the number of 2.200 trees ha⁻¹ and clay content 11, 50-12,70%, and plot A with the number of 1950 trees ha⁻¹ and clay content 6,50-10,60%. As described by Hossain and Nuruddin (2016), clay

fragment is a supporting factor of the regeneration process, where the clay particle in the form of mud will catch the mangrove fruit that falls when it is ripe. This process determined whether a zone was dense or not.

Comparing the study results from Tolangara and Ahmad (2017) in Bacan mangrove forest, Halmahera Selatan Regency which resulted in the density of the tree of 1.500 ha^{-1} so the number of trees per hectare in Mangrove Forest in Tahura Ngurah Rai for the three observing plots were considered denser. But if compare with the study result of Handoko *et al.* (2017) at 12 research plots of mangrove forest in the area of South Rupa Island, Pekanbaru, with the density value ranges between $2.592 \text{ trees ha}^{-1}$ until $8.148 \text{ trees ha}^{-1}$, therefore the tree stands of mangrove forest in Tahura Ngurah Rai was much lower.

The types of *R. apiculata* and *S. alba* were the two types of mangroves that were available in all research plots lying from the seashore (plot C) to the land (plot B and plot A). Generally outermost zone of mangrove with high salinity occupied by *Avicennia* associated with *Sonneratia* spp., while *Rhizophora* was located in the middle zone and *Bruguiera* grew in the furthest zone of the beach with much lower salinity. Onrizal *et al.* (2019b) said in muddy areas with high salinity levels which can grow *R. apiculata* species. The phenomenon of *Rhizophora* domination in the research area was suspected to be related to the low salinity of its water ecosystem. The typical water salinity in the research area of 14,8 -19,6% in reality was much lower than those reported by other researcher. The factors that influence high and low water salinity were evaporation and rainfall. The higher the level of evaporation of seawater, the higher the salinity would be. The higher rainfall, then the lower salinity would be.

Trunk Diameter

Based on attachment 1-6, it was known that trunk diameter of tree type *R. apiculata* in each research plot was : plot A = $8,3 \pm 3,8\text{cm}$, plot B = $8,4 \pm 2,8\text{cm}$ and plot C $8,9 \pm 3,3\text{cm}$ then the average value of

trunk diameter for the whole plots was $8,56\text{cm}$. in terms of the diversity of trunk diameter of each plot, it can be concluded that the growth of trunk diameter in plot A stands was more identical than other plots. Meanwhile, in plot C the growth of trunk diameter was largely diverse.

S. alba type tended to have a bigger trunk diameter. In plot A, its value was = $10,4 \pm 1,8\text{cm}$, plot b = $9,0 \pm 3,8\text{cm}$, plot C = $8,5 \pm 1,5\text{cm}$ so the average value for all plots was $9,3\text{cm}$. Trunk diameter of *R. apiculata* was bigger in plot A and even smaller in plot B and plot C which located further from the beach. Meanwhile, type *S. alba* showed the opposite. The closer to the land, the bigger the diameter was. Due to that matter, it was suspected that the growth of *R.apiculata* was better that the salinity in higher waters.

Climate affected the development of mangrove and the physical factor of its growing place was substrate and waters. Further, Alwikado (2014) reported that climate also affected the growth of mangrove through the light element, rainfall, temperature, and wind. The diameter growth and mangrove diameter increment growth were also influenced by many factors of its growing place including the substrate. The substrate in this study referred to a substrate containing soft mud. Furthermoe, Hastuti and Budhihastuti (2016) added that growth was the result of the interaction of various physiological processes. The physiological process referred to as photosynthesis, respiration, and transpiration. While the results that were reported by Kusmana *et al.* (2003) in mangrove Center Lampung were obtained from the diameter value of $7,5 - 9,7\text{cm}$. Moreover, Pattipeilohy (2014) in Minahasa Utara Sub-district obtained the diameter value of 11cm .

Tree Height

As shown by its diameter growth, the average of total height growth of trees type *S. alba* ($15,99\text{m}$) was bigger than tree type *R. apiculata* ($12,19\text{m}$). Hence, it can be concluded that as a whole that the condition of mangrove habitats in the research area is more suitable for *S. alba* than for *R. apiculata*.

The results of the total height growth of trees type *R. apiculata* in each plot was: plot A = $13,08 \pm 2,34$ m, plot B = $10,57 \pm 2,91$ m, plot C = $12,91 \pm 2,68$ m while for type *R. alba* plot A = $15,58 \pm 5,99$ m, plot B = $16,28 \pm 5,88$ m, plot C = $16,11 \pm 1,9$ m. For type *R. apiculata*, plot A resulted in a bigger height growth with a smaller coefficient of variation than those grew in other plots. The height growth and diameter of tree is not only depending on the space and surface canopy, relative humidity as well as root system, but also influenced by climate and soil fertility. Cuenca *et al.* (2015) stated the factors were complex and affected towards the distribution and mangrove growth including salinity, tidal drying, disturbance, warming, and predation. Meanwhile, Toknok (2006) in Donggala obtained the value of 13-20m.

The Width of Basal Area

According to the estimation conducted in the research location, Ngurah Rai Forest Park, Denpasar, it was revealed that the widths of the basal area of *A. apiculata* in plot A, B, and C were $0.006\text{m}^2 \text{ tree}^{-1}$, $0.006\text{m}^2 \text{ tree}^{-1}$, and $0.007\text{m}^2 \text{ tree}^{-1}$ respectively. The average width of the basal area was $0.006\text{m}^2 \text{ tree}^{-1}$. On the other hand, the widths of the basal area of *S. alba* were $0.009\text{m}^2 \text{ tree}^{-1}$ in plot A, $0.008\text{m}^2 \text{ tree}^{-1}$ in plot B, $0.006\text{m}^2 \text{ tree}^{-1}$ in plot C, and $0.008\text{m}^2 \text{ tree}^{-1}$ on average. Meanwhile, Aswita and Syahputra (2012) on their study in Seuruy sub-district, Aceh Taming Region, Aceh Province, reported that the width of the basal area of mangrove stands was $0.004\text{m}^2 \text{ tree}^{-1}$.

Stand Biomass and Carbon Content

The result showed that the average biomass of mangrove forest stands in the research location was 87.38ton ha^{-1} , consisting of *R. apiculata* biomass of 40.22ton ha^{-1} (46%) and *S. alba* biomass of 47.16ton ha^{-1} (54%). *S. alba* in plot A (located the furthest from the beach) and plot B (located in the middle) were higher than in plot C (located closest to the beach). The accumulation of the three plots was higher (12.7ton ha^{-1}) compared to the finding of the research conducted by Bindu *et al.* (2018). As shown on Table 2, in terms of the average number of trees in the three

plots, actually, *S. alba* had a fewer number (107 trees) than *R. apiculata* (131 trees), however, in terms of tree average diameter and height (D= 9.30cm ; T= 15.99 m), *S. alba* had a bigger size than *R. apiculata* (D= 8.56cm ; T= 12.19 m).

Table 2. Biomass and carbon content of each species of mangrove at Plot A, Plot B and Plot C.

No	Plot	Biomass (ton ha ⁻¹)		Carbon (ton ha ⁻¹)	
		<i>R. apiculata</i>	<i>S. alba</i>	<i>R. apiculata</i>	<i>S. alba</i>
1	Plot A	36.12	56.27	18.06	28.13
2	Plot B	38.60	48.95	19.30	24.47
3	Plot C	45.94	36.25	22.97	18.12
	Total	120.66	141.47	60.33	70.72
	Average	40.22	47.16	20.11	23.57
	Average total	87.38		43.68	

Biomass is defined as the total number of organisms on the surface of a tree and is measured by using the ton unit of dry weight per area (Brown, 2004). The amount of biomass in particular mangrove forest is obtained from measuring the diameter, height, and wood density of each type of mangroves (Rachmawati *et al.*, 2014). Mangrove ecosystem has an ecological function to absorb and store carbon. Mangroves absorb CO₂ during the photosynthesis process and then change it into carbohydrate by storing it in form of biomass in roots, stems, branches, and leaves. According to Kauffman *et al.* (2012), carbon stocks in mangrove forests are higher than that in any other forests, where the biggest carbon stocks are contained in mangrove sediments. When compared to the biomass estimation from other studies the biomass of mangrove forest stands in research location was much lower. It may be affected by the difference of the number of trees ha⁻¹, the size of stem diameter, height as well as the wood density of types of mangroves making up of stands. Rachmawati *et al.* (2014) revealed that the biomass of mangrove stands in Wilayah Pesisir Muara Gembong, Bekasi Region was 108.6ton ha^{-1} . Meanwhile according to Kristiningrum *et al.* (2019) the average value of mangrove forest carbon at the studied area in Mentawir Village is $50.73\text{tons C ha}^{-1}$. In addition, Bachmid *et al.* (2018) found that the biomass of

mangrove stands in Kuburaya Region, West Kalimantan, was 189.2ton ha⁻¹. Kristiningrum *et al.*, 2019 informed the biomass of mangrove forests in Mentawir which is part of the Balikpapan Bay Area is one and a half times higher than that in Siberut Island, West Sumatra, which is 49.13tons ha⁻¹ (Bismark 2008). Kusmana *et al.* (2003) stated that muddy sediments are generally richer in organic matter compared to sandy sediments.

The relation between organic carbon and total volume of *R. apiculata* and *S. alba* can be seen at Fig 4 and Fig. 5.

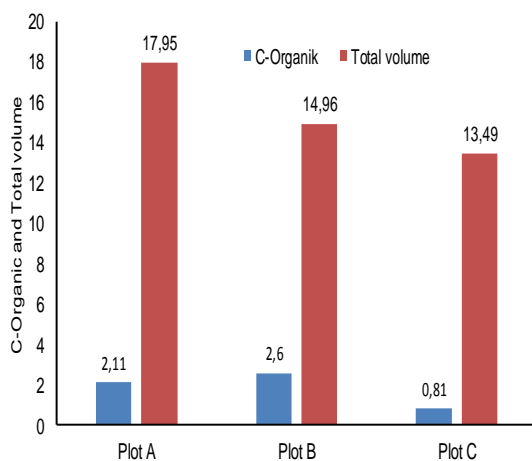


Fig. 4. The relation between organic C and total volume of *S. Alba*.

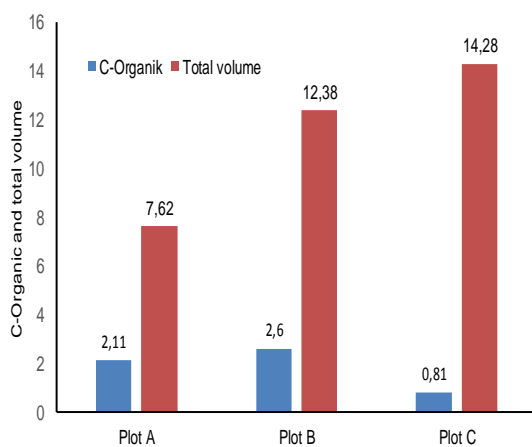


Fig. 5. The relation between organic C and total volume of *R. apiculata*.

Fig. 4 shows that in *S. alba* the organic C content was decreasing from plot A (closest to land) to plot C (closest to sea), and so did the total volume of the trees. It can be concluded that *S. alba* really needs organic C to increase its total volume. On the contrary, Fig. 5 shows that in *R. apiculata* the organic C value decreased, however, the tree total volume was increasing. It proves that *R. apiculata* is able survive in the areas with lower organic C.

The average value of water pH was 7.03% in plot A, 4.99% in plot B, and 7.49% in plot C. Furthermore, the organic C value was 2.1% in plot A, 2.6% in plot B, and 0.81% in plot C. On the other hand, the total N value was 0.07% in plot A, 0.07% in plot B, and 0.04% in plot C. The CEC value was 30.0 me 100g⁻¹ in plot A, 25 me 100g⁻¹ in plot B, and 25.4 me 100g⁻¹ in plot C. The basal area of *R. apiculata* was 0.006 m² tree⁻¹ in plot A, 0.006 m² tree⁻¹ in plot B, and 0.007 m² tree⁻¹, whereas the basal area of *S. alba* was 0.009 m² tree⁻¹ in plot A, 0.008 m² tree⁻¹ in plot B, and 0.006 m² tree⁻¹ in plot C. The biomass value per ha for *R. apiculata* was 36.12ton ha⁻¹ in plot A, 38.60ton ha⁻¹ in plot B, and 36.25ton ha⁻¹ in plot C, meanwhile the biomass value of *S. alba* was 56.27ton ha⁻¹ in plot A, 38.60ton ha⁻¹ in plot B, and 36.25ton ha⁻¹ in plot C. The value of carbon stock per ha for *R. apiculata* was 18.06ton ha⁻¹ in plot A, 19.20ton ha⁻¹ in plot B, and 22.97ton ha⁻¹ in plot C. On the other hand, the value carbon stock per ha for *S. alba* was 28.13ton ha⁻¹ in plot A, 24.47ton ha⁻¹ in plot B, and 22.97ton ha⁻¹ in plot C.

Conclusions

The results showed that the diameter of *R. apiculata* type in plot A, B, and C was 8.3±2.3cm, 8.4±2.8cm, and 8.9±3.3cm respectively, and that of *Rhizophora alba* type in plot A, B, and C was 10.4±1.8cm, 9.0±3.8cm, and 8.5±1.5cm respectively. The biomass value of *R. apiculata* in plot A was 36.12ton ha⁻¹, B= 38.60ton ha⁻¹, and C= 45.94ton ha⁻¹, and the biomass value of *S. alba* in plot A, B, and C was 56.27ton ha⁻¹, 48.ton ha⁻¹, and 36.25ton ha⁻¹ respectively. The value of carbon contents in *R. apiculata* in plot A, B, and C was 18.06ton ha⁻¹, 19.30ton ha⁻¹, and 22.97ton ha⁻¹

successively. In addition, the value of carbon content in *S. alba* was 28.13ton ha⁻¹ in plot A, 24.47ton ha⁻¹ in plot B, and 18.12ton ha⁻¹ in plot C.

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31 **Carbon Stocks of *Rhizophora appiculata* and *Sonneratia alba* of Mangrove**
32 **Forest in Ngurah Rai Forest Park, Bali Province, Indonesia**

33

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62 **Abstract**

63 Mangrove forest is a typical tropical and subtropical forest, which is affected by sea
64 tides. This study aimed to investigate the effect of pH, seawater salinity, and edaphic
65 factors on carbon growth and stocks. The research plots were developed by employing
66 transect method with a size of 20 m x 50 m for three plots along the beach. The pH
67 value of plot A= 6.82, plot B= 6.90, and plot C= 7.26. The analysis of CEC elements
68 found that plot A= 30.0, plot B= 25.2, and plot C= 25.4. The value of N-Total showed
69 that plot A= 0.07, plot B= 0,07, and plot C= 0.04. The value of organic carbon was plot
70 A= 2.1, plot B= 2.6, and plot C= 0.81. The results showed that the diameter of
71 *Rhizophora apiculata* type in plot A, B, and C was 8.3±2.3 cm, 8.4±2.8 cm, and 8.9±3.3
72 cm respectively, and that of *Sonneratia alba* type in plot A, B, and C was 10.4±1.8 cm,
73 9.0±3.8 cm, and 8.5±1.5 cm respectively. The biomass value of *R. apiculata* in plot A
74 was 36.12 ton ha⁻¹, B= 38.60 ton ha⁻¹, and C= 45.94 ton ha⁻¹, and the biomass value of
75 *S. alba* in plot A, B, and C was 56.27 ton ha⁻¹, 48. ton ha⁻¹, and 36.25 ton ha⁻¹
76 respectively. The value of carbon contents in *R. apiculata* in plot A, B, and C was 18.06
77 ton ha⁻¹, 19.30 ton ha⁻¹, and 22.97 ton ha⁻¹ successively. In addition, the value of carbon
78 content in *S. alba* was 28.13 ton ha⁻¹ in plot A, 24.47 ton ha⁻¹ in plot B, and 18.12 ton ha⁻¹
79 ¹ in plot C.

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93 INTRODUCTION

94 Indonesia has the biggest mangrove ecosystems in the world, consisting of 27% (16.9
95 million ha) from the total mangrove forests in the world, and becomes the center of the
96 distribution of species biodiversity and mangrove ecosystems (Spalding *et al.*, 2014),
97 however, it experienced rapid and dramatic destruction (Setyawan *et al.*, 2003).
98 Mangrove is a valuable treasure for Indonesian biodiversity with huge ecological and
99 economical significances (Hema and Devi, 2015). Mangrove ecosystems also have a
100 high economic value, either directly or indirectly, because the ecosystems have become
101 one of meaningful income sources for the society and the country.

102
103 Mangrove forest is a typical tropical and subtropical forest type, growing along the beach
104 and estuary affected by sea tides. Mangroves are generally found around coastal areas
105 protected from the onslaught of waves and gently sloping terrain. Mangroves optimally
106 grow in coastal areas with large estuary and in deltas whose water flow contains a lot of
107 mud. On the contrary, mangroves do not optimally grow in coastal areas with no estuary.
108 Mangrove is a valuable treasure for its biodiversity, ecologically and economically
109 (Hema and Devi, 2015). Thus, services, approaches, and improvements to nearby
110 society needs to be done in order to understand the mangrove ecosystems (Mukherjee
111 *et al.*, 2014; Nguyen *et al.*, 2019). The role of mangroves the natural hazards and it is
112 difficult for mangroves to grow in steep, choppy coasts with strong tidal currents
113 because it does not allow the deposition of mud that is needed as a substrate for its
114 growth (Spalding *et al.*, 2014). Reduced-impact logging method can directly decrease
115 emissions becaused using mono-cable winch on forest floors induced by logs skidding
116 on top soil and injured with bark broken intensity for remaining stands (Ruslim 2011;
117 Ruslim *et al.*, 2016; Chien, 2019).

118
119 The land of mangrove forests in terms of the habitat and the ecosystems is a diffused
120 environment that is formed by the encounter between marine environment and land
121 environment which have a big impact on human life or even for their ecosystem balance.
122 Since mangrove forest is always affected by excessive water throughout the year and is
123 sometimes interspersed with drying in some parts in a short time, it may involve a

124 chemical reaction of soil oxidation radicals Since mangrove forest growing in
125 inhospitable environment in tropics and sub-tropics are equipped with very efficient free
126 radical foraging system to withstand the variation of stress conditions (Thathoi *et al.*,
127 2013). Mangrove plants may grow in different types of soil; therefore, their vegetation,
128 species composition and structure may vary considerably at the global, regional, local
129 region (Sherman *et al.*, 2003)

130
131 The height and time of seawater flooding in particular locations during the high tide can
132 also determine the salinity. The salinity is of factors determining the spread of
133 mangroves. In addition, the salinity also becomes the limiting factor for particular
134 species. Even though some mangrove species have a high mechanism adaptation
135 towards salinity, however, if fresh water supply is not available, this will make soil and
136 water salinity reach an extreme condition which is potential to threaten its life (Chen and
137 Ye, 2014; Nyangon *et al.*, 2019).

138
139 Mangrove forests as any other forests have a significant role as a carbon dioxide (CO₂)
140 sink in the air. Carbon dioxide sink has a significant relation to tree biomass. Trees
141 during photosynthesis process absorb CO₂ and convert it into organic carbon
142 (carbohydrate) which is merged into the body of the trees. Mangrove can also provide
143 food and shelter for various organisms, either in land or in water (Ekka and Pandit,
144 2012).

145
146 Essentially, the atmosphere receives more carbon than it ejects, as a result of burning
147 fossil fuels, motor vehicles, and industrial machines which make carbon accumulated
148 (IPCC, 2003). On the other hand, tropical forest deforestation also contributes in
149 supplying carbon to the atmosphere (Defries at al., 2002). This function is a part of
150 ecosystem service which is not traded in the market but highly contributes to the human
151 welfares (Barbier *et al.*, 2011; Liqueete *et al.*, 2013; Ezebilo, 2016). Carbon stock was
152 estimated from mangrove biomass referred as 50% of the value of biomass (Komiyaama
153 *et al.*, 2005). Measurement of biomass was done in a non-destructive way. It was
154 determined based on data from measurements of tree volume Bismark, 2008).

155 On the other hand, the amount of CO₂ absorption decreases as a result of deforestation,
156 the change of land use, and residential development. The carbon accumulation in the
157 atmosphere provokes greenhouse effects as sunlight shortwave trapped in the
158 atmosphere that increases the temperature of the earth atmosphere. One of the forest
159 ecosystems that is able to reduce the greenhouse effect and functions as climate
160 change mitigation is mangrove forest (Komiyama *et al.*, 2008). For the sake of human
161 beings, the result of our observation showed that the stretch of mangroves and corals is
162 the ecosystem that is most often rated, meanwhile the stretch of seaweed is not really
163 taken into account (Mehvar *et al.*, 2018).

164

165 **MATERIALS AND METHODS**

166 *Time and Location*

167 The present study was conducted in mangrove forest located in the area of Kuta
168 Municipality forest park, Bali Province (Fig 1).

169

170 **Fig 1. Research location (■), Kuta Municipality forest park, Bali Province, Indonesia**

171

172 *Procedures*

173 As adjusted to the research goals and objectives, this study consisted of 1) the making
174 of transect lines from the seashore to the shore for the zoning of mangrove forest; 2) the
175 making of sample plots along the transect lines; 3) the determination of tree species in
176 the sample plots 4) measuring the tree diameter and height in the sample plots 5)
177 testing the edaphic nature (soil physic/chemistry) in the sample plots and 6) testing the
178 parameters of mangrove forest water such as substracts, salinity, water pH, and carbon
179 stock estimation. The sample plots were made by employing transect method with a size
180 of 20 m x 50 m for three plots along the beach. The measurement was conducted based
181 on commonly used criteria, which was the diameter of chest-tall tree trunks (130 cm) or
182 the topmost roots of the soil surface.

183 *Data analysis*

184 *Productivity of mangrove stand*

185 Data of mangrove species identification results were tabulated in Microsoft Excel to
186 calculate the potentials of mangrove species at the studied area. Analysis of mangrove
187 wood was done by calculating the total volume of standing stock (including height,
188 diameter, basal area, and volume).

189

190 *Basal area calculation*

191 The conversion of the diameter obtained by using a diameter measuring tool was done
192 by applying the following formula:

193

$$194 \quad g = \frac{1}{4} \pi d^2$$

195 With g = basal area (m^2); and d = diameter breast height (cm);

196

197 *Volume calculation*

198 The tree volume was measured by using Ruchaemi formula (2006) as follow:

199

$$200 \quad V = \frac{1}{4} \pi d^2 \times h \times f$$

201 With V = Tree volume (m^3); d = diameter breast height (cm); h = tree height (m) and f =
202 form factor

203

204 *Physical and chemical testing of the soil*

205 The method used for parameter analysis of physical and chemical properties of the soil
206 was based on Bogor soil research center and Wenworth scale. The place for soil
207 analysis was in the soil laboratory of the Forest Rehabilitation Center

208 Mulawarman University, Samarinda East Kalimantan.

209

210 **RESULT AND DISCUSSIONS**

211 *Soil Reaction (pH H₂O)*

212 The pH value of particular water and soil reflects the balance between acid and base
213 concentration in the water. The pH value of water is affected by some factors, such as

214 photosynthesis activity, biology activity, temperature, oxygen content, and the existence
215 of cations and anions in the water (Aksornkoae, 1993). The results of soil pH
216 measurement in sample plots are presented on the Table 1.

217

218 **Table 1. Test result data pH H₂O and of the soil in sample plots**

219

220 The Table 1 shows that the mangrove forest soil inspected had a varying pH value. Plot
221 C which was located closest to the beach had a neutral pH with highest average (7.49),
222 while plot B which was located between plot A and plot C had an acidic pH with much
223 lower value (4.99). On the other hand, plot A which was located furthest from the beach
224 also had a neutral pH with average value of 7.03. The low pH value of the soil in plot B
225 was because the mangrove stands in that plot produced more litter than in plot A and C.
226 Through the decomposition process, besides producing minerals, the litter also secreted
227 organic acid that made the soil pH become sour. The more litter produced in plot C than
228 in the other plots was also indicated by the more organic carbon contents available (plot
229 B= 2.60%; plot A= 2.10%; plot C= 0.81%).

230

231 The influence of frequency and time and the duration of water logging towards the pH
232 value of mangrove forest soil was also reported by Nursin *et al.*, (2014) through their
233 study in Balinggi sub-district, Parigi Moutong region, Central Sulawesi. The other studies
234 that revealed the same phenomenon were Ragil *at al.*, (2017) through their study in
235 mangrove forest in Mempawah Region, West Kalimantan. The result of this study about
236 mangrove soil pH was compared to the other related studies such as 7) found that the
237 mangrove soil pH in Muara Resort, Selangor, was 7.7, whereas Kamariah (2014) found
238 that the mangrove forest in Mamuju Region, West Sulawesi had a pH value of 5.98-6.12.
239 Onrizal and Kusmana (2008) informed soil and water quality take effect on mangrove
240 growth in mangrove rehabilitation activities at east coast of North Sumatera.

241 Regarding soil pH values in mangrove forests, Hasrun (2013) stated that the water with
242 pH value of < 4 is categorized as highly sour and potentially threaten the life of
243 organisms. On the other hand, the water with pH value of > 9.5 is classified as highly
244 alkaline and could also result in death for organisms and reduce productivity. On the

245 contrary, plants can easily absorb carbon when the soil has a neutral pH (Setiawan *et al.*,
246 2013).

247
248 The correlation of seawater pH and total volume is shown in details through the
249 following Fig 2 and Fig 3.

250

251 **Fig 2. The correlation of seawater pH and total volume of *Rhizophora alba* tree**

252

253 **Fig 3. The correlation of seawater pH and total volume of *R. apiculata* tree**

254

255 As shown on Fig. 2, the seawater pH was increasing from the direction of plot A (closest
256 to land) to plot c (closest to sea), and it affected the decreasing of the tree total volume.

257 From this phenomena, it can concluded that *S. alba* mangrove had a less tolerant nature
258 towards seawater pH on particular limits. On the contrary, Fig. 3 shows that the volume
259 of *R apiculata* tree increased as the seawater pH increased. It proved that this type of
260 mangrove was tolerant to the seawater pH.

261

262 *Organic Carbon (C)*

263 Soil organic matter is of soil components derived from the rest of dead animals and
264 plants, both in the form of original and weathered tissues. The main resources of soil
265 organic matter in the sample plots were the litters of mangrove stands such as the
266 components of leaves, twigs, branches, stems and roots. According to Lee *et al.*, (2014),
267 organic matter has a productive function to support plant biomass production and a
268 protective function to keep the soil fertility and soil biotic stability.

269

270 Generally, the soil C concentration of the sample plots had a status of very low to
271 moderate with values between 0.81 to 2.60%. the lowest C concentration was found in
272 plot C which was located closest to the beach. The higher frequency and duration of the
273 waterlogging in plot C do not only limit the chance of piles of dropping organic matter on
274 the forest floor, but also limit the rate of decomposition of organic matter on the forest
275 floor. Ferreira *et al.*, (2007) stated that the decomposition of soil organic matter under

276 mangrove stands is highly affected by frequency, duration of waterlogging, and
277 distribution of its subtract particle size. In addition, Sufardi at al., (2017) argued that the
278 decomposition of organic matter in waterlogged soil works slowly because anaerob
279 bacteria are less efficient compared to aerob microflora which is more variegated.

280
281 The estimation of soil carbon concentration in mangrove forests in the study areas was
282 in line with that reported by Handoko at al., (2017) who conducted a study in Balinggi
283 sub-district, Parigi Region, Central Sulawesi. She found that soil carbon concentration in
284 that area was 0.34-2.34%. A higher figure was reported from a study by Ragil *et al.*,
285 (2017) stating that the soil C concentration was 3.99-5.05% (high to very high), based
286 on their study conducted in mangrove forest in Mempawah Region, West Kalimantan.

287
288 *Total Nitrogen*

289 Nitrogen is an essential element for plants, functioning to improve vegetative growth.
290 The main resource of N in forest mangrove soil is the litters produced by mangrove
291 stands as well as other dead organic material components that have been accumulated
292 on the forest floor. The decomposition of the organic matter to be minerals, including N,
293 is highly affected by inundation periodization. The anaerobic conditions when the floor
294 flooded causes litter decomposing microorganisms restricted, otherwise, in aerobic
295 conditions when the floor is not flooded, the microorganism activity increases. The total
296 N concentration in mangrove forest soil in the sample plots is presented on Table 1.

297
298 Table 1 shows that soil N concentration in the depth of 0-60 cm in the sample plots was
299 very low, only about 0.04-0.10%. In plot A and B, the soil N concentration in the depth of
300 0-30 cm was higher than that in the depth of 30-60 cm. However, in plot C, the soil N
301 concentration in both layers was similar. The impact of the flood on organic material
302 mineralization process to be N could be seen from the lower N concentration in the
303 depth of 0-30 cm in plot C which was bordering with the beach compared to plot A and B
304 respectively. Plot was located the furthest from the beach, whereas plot C was located
305 in between plot C and A.

306 The estimations of soil N concentration value as reported by the researchers are as
307 follows: 0.27-0.45% (status: moderate) in mangrove forest in Mangunharjo, Semarang
308 Region (Chrisyariati *et al.*, 2014); and 0.29-0.43% (status: moderate) in mangrove forest
309 in Mamuju Region, West Sulawesi (Malik *et al.*, 2019).

310

311 *Cation Exchange Capacity (CEC)*

312 Overall, the average value of CEC for the mangrove soil studied in the depth of 0-60 cm,
313 categorized as high, was 25.2 – 30.0 me 100g⁻¹. In plot A and B, the CEC value of
314 topsoil and subsoil was relatively similar, while in plot C there was a significant
315 difference. As mentioned before, there are two factors affecting the high and low of soil
316 CEC, namely organic matter content and its mineral clay content. The result shows that
317 the highest CEC value for mangrove forest soil in this study was in the depth of 0-30 cm
318 in plot C (31,6 me 100 g⁻¹). Since the soil organic matter content was lower than that in
319 the other plots (see Table 4), the factor causing the high CEC value of the soil in the
320 depth of 0-30 cm was the clay content which was higher than in plot B or plot A (Table
321 1). In the layer of 30-60 cm, the CEC value of the soil in plot C significantly decreased to
322 19.3 me 100g⁻¹ even though the clay content was not really different from that in the
323 layer of 0-30 cm (11.5%). This is interesting because despite its lower clay content,
324 10.6%, the soil in the depth of 30-60 cm in plot A had a higher CEC value (30.1 me
325 100g⁻¹) than in plot C. I may be because the soil in plot A had higher organic matter
326 content (2.10%) than in plot C (0.77%).

327

328 Cation Exchange Capacity (CEC) is the soil chemical nature highly related to the soil
329 fertility. The soil with higher CEC is able to absorb and provide nutrients better than the
330 soil with lower CEC. The soils with organic matter content or with higher clay content
331 consisted of higher CEC compared to the soils with lower or sandy organic matter
332 content (Soewandita, 2008). The CEC value of soil is influenced by the soil weathering
333 level, organic matter content and the number of alkali cations in the soil. The soil with
334 higher organic matter content had higher CEC, so did young soil with newly started
335 weathering level, and soils with further weathering levels had low CEC value.

336

337 *The Condition of Mangrove Forest Stands In Ngurah Rai Forest Park*

338 The mangrove in plot A (Distal zone or the furthest zone from sea), plot B (Middle zone or
339 middle zone), and plot C (Proximal zone, the closest zone from sea) was carried out an
340 inventory covering number of trees, diameter at breast height (DBH), the height of free
341 trunk (TBC), the total height (TTL), the width of basal area (LBD), and the total volume
342 (VT). Besides, the calculation was also done towards the amount of biomass and the
343 content of carbon stands in each of those researches. The types of mangrove available
344 in the research plots only consisted of *R. apiculata* and *S. alba*.

345

346 *The Density and Types of Tree Stands*

347 The number of trees in a research plot was not the same. Plot B had the most number of
348 trees, including 272 trees, each of 162 trees of *R. apiculata* type and 110 trees of *S.*
349 *alba*. Plot C had 220 trees, each of 110 trees of *R. apiculata* and *S. alba*. In the hectare
350 unit, the numbers of trees in each plot were: plot A 1.950 trees, plot C 2.200 trees and
351 plot B 2.720 trees, the total of trees 438 ha⁻¹ and 517 ha⁻¹ reached the study result in
352 Mentawir Village Balikpapan, Kalimantan Timur of 2,300 ha⁻¹, Lahjie *et al.*, 2019;
353 Kristiningrum *et al.*, (2019). The stand density of mangrove forests in eastern coast of
354 North Sumatera varied from 1,692 ind ha⁻¹ to 2,990 ind ha⁻¹ (Onrizal *et al.*, 2019a).

355

356 The density of mangrove tree stands in each plot tended to be influenced by each clay
357 content. Plot B with the highest tree density (2720 trees ha⁻¹), also had the highest clay
358 content (11,40-14,30%). Followed by plot C with the number of 2.200 trees ha⁻¹ and clay
359 content 11, 50-12,70%, and plot A with the number of 1950 trees ha⁻¹ and clay content
360 6,50-10,60%. As described by Hossain and Nuruddin (2016), clay fragment is a
361 supporting factor of the regeneration process, where the clay particle in the form of mud
362 will catch the mangrove fruit that falls when it is ripe. This process determined whether a
363 zone was dense or not.

364

365 Comparing the study results from Tolangara and Ahmad (2017) in Bacan mangrove
366 forest, Halmahera Selatan Regency which resulted in the density of the tree of 1.500 ha⁻¹
367 ¹ so the number of trees per hectare in Mangrove Forest in Tahura Ngurah Rai for the

368 three observing plots were considered denser. But if compare with the study result of
369 Handoko *et al.*, (2017) at 12 research plots of mangrove forest in the area of South
370 Rupas Island, Pekanbaru, with the density value ranges between 2.592 trees ha⁻¹ until
371 8.148 trees ha⁻¹, therefore the tree stands of mangrove forest in Tahura Ngurah Rai was
372 much lower.

373
374 The types of *R. apiculata* and *S. alba* were the two types of mangroves that were
375 available in all research plots lying from the seashore (plot C) to the land (plot B and plot
376 A). Generally outermost zone of mangrove with high salinity occupied by *Avicennia*
377 associated with *Sonneratia* spp., while *Rhizophora* was located in the middle zone and
378 *Bruguiera* grew in the furthest zone of the beach with much lower salinity. Onrizal *et al.*
379 (2019b) said in muddy areas with high salinity levels which can grow *R. apiculata*
380 species. The phenomenon of *Rhizophora* domination in the research area was suspected
381 to be related to the low salinity of its water ecosystem. The typical water salinity in the
382 research area of 14,8 -19,6‰ in reality was much lower than those reported by other
383 researcher. The factors that influence high and low water salinity were evaporation and
384 rainfall. The higher the level of evaporation of seawater, the higher the salinity would be.
385 The higher rainfall, then the lower salinity would be.

386 387 *Trunk Diameter*

388 Based on attachment 1-6, it was known that trunk diameter of tree type *R. apiculata* in
389 each research plot was : plot A = 8,3 ± 3,8 cm, plot B = 8,4 ± 2,8 cm and plot C 8,9 ± 3,3
390 cm then the average value of trunk diameter for the whole plots was 8,56 cm. in terms of
391 the diversity of trunk diameter of each plot, it can be concluded that the growth of trunk
392 diameter in plot A stands was more identical than other plots. Meanwhile, in plot C the
393 growth of trunk diameter was largely diverse.

394
395 *S. alba* type tended to have a bigger trunk diameter. In plot A, its value was = 10,4 ± 1,8
396 cm, plot b = 9,0 ± 3,8 cm, plot C = 8,5 ± 1,5 cm so the average value for all plots was 9,3
397 cm. Trunk diameter of *R. apiculata* was bigger in plot A and even smaller in plot B and
398 plot C which located further from the beach. Meanwhile, type *S. alba* showed the

399 opposite. The closer to the land, the bigger the diameter was. Due to that matter, it was
400 suspected that the growth of *R.apiculata* was better than the salinity in higher waters.

401
402 Climate affected the development of mangrove and the physical factor of its growing
403 place was substrate and waters. Further, Alwikado (2014) reported that climate also
404 affected the growth of mangrove through the light element, rainfall, temperature, and
405 wind. The diameter growth and mangrove diameter increment growth were also
406 influenced by many factors of its growing place including the substrate. The substrate in
407 this study referred to a substrate containing soft mud. Furthermore, Hastuti *et al.*, (2012)
408 added that growth was the result of the interaction of various physiological processes.
409 The physiological process referred to as photosynthesis, respiration, and transpiration.
410 While the results that were reported by Kusmana *et al.*, (2003) in mangrove Center
411 Lampung were obtained from the diameter value of 7,5 – 9,7 cm. Moreover, Pattipeilohy
412 (2014) in Minahasa Utara Sub-district obtained the diameter value of 11 cm.

413 414 *Tree Height*

415 As shown by its diameter growth, the average of total height growth of trees type *S. alba*
416 (15,99m) was bigger than tree type *R. apiculata* (12, 19 m). Hence, it can be concluded
417 that as a whole that the condition of mangrove habitats in the research area is more
418 suitable for *S. alba* than for *R. apiculata*.

419
420 The results of the total height growth of trees type *R. apiculata* in each plot was: plot A =
421 $13,08 \pm 2,34$ m, plot B = $10,57 \pm 2,91$ m, plot C = $12,91 \pm 2,68$ m while for type *R.*
422 *alba* plot A= $15, 58 \pm 5,99$ m, plot B = $16,28 \pm 5,88$ m, plot C = $16,11 \pm 1,9$ m. For type *R.*
423 *apiculata*, plot A resulted in a bigger height growth with a smaller coefficient of variation
424 than those grew in other plots. The height growth and diameter of tree is not only
425 depending on the space and surface canopy, relative humidity as well as root system,
426 but also influenced by climate and soil fertility. Cuenca *et al.*, (2015) stated the factors
427 were complex and affected towards the distribution and mangrove growth including
428 salinity, tidal drying, disturbance, warming, and predation. Meanwhile, Toknok (2006) in
429 Donggala obtained the value of 13-20 m..

430 *The Width of Basal Area*

431 According to the estimation conducted in the research location, Ngurah Rai Forest Park,
432 Denpasar, it was revealed that the widths of the basal area of *A. apiculata* in plot A, B,
433 and C were 0.006 m² tree⁻¹, 0.006 m² tree⁻¹, and 0.007 m² tree⁻¹ respectively. The
434 average width of the basal area was 0.006 m² tree⁻¹. On the other hand, the widths of
435 the basal area of *S. alba* were 0.009 m² tree⁻¹ in plot A, 0.008 m² tree⁻¹ in plot B, 0.006
436 m² tree⁻¹ in plot C, and 0.008 m² tree⁻¹ on average. Meanwhile, Aswita and Syahputra
437 (2012) on their study in Seuruway sub-district, Aceh Taming Region, Aceh Province,
438 reported that the width of the basal area of mangrove stands was 0.004 m² tree⁻¹.

439

440 *Stand Biomass and Carbon Content*

441 The result showed that the average biomass of mangrove forest stands in the research
442 location was 87.38 ton ha⁻¹, consisting of *R. apiculata* biomass of 40.22 ton ha⁻¹ (46%)
443 and *S. alba* biomass of 47.16 ton ha⁻¹ (54%). *S. alba* in plot A (located the furthest from
444 the beach) and plot B (located in the middle) were higher than in plot C (located closest
445 to the beach). The accumulation of the three plots was higher (12.7 ton ha⁻¹) compared
446 to the finding of the research conducted by Bindu *et al.*, (2018). As shown on Table 2, in
447 terms of the average number of trees in the three plots, actually, *S. alba* had a fewer
448 number (107 trees) than *R. apiculata* (131 trees), however, in terms of tree average
449 diameter and height (D=9.30 cm; T=15.99 m), *S. alba* had a bigger size than *R.*
450 *apiculata* (D=8.56 cm; T= 12.19 m).

451

452 **Table 2.** Biomass and carbon content of each species of mangrove at Plot A, Plot B
453 and Plot C.

454

455 Biomass is defined as the total number of organisms on the surface of a tree and is
456 measured by using the ton unit of dry weight per area (Brown, 2004). The amount of
457 biomass in particular mangrove forest is obtained from measuring the diameter, height,
458 and wood density of each type of mangroves (Rachmawati *et al.*, 2014). Mangrove
459 ecosystem has an ecological function to absorb and store carbon. Mangroves absorb
460 CO₂ during the photosynthesis process and then change it into carbohydrate by storing

461 it in form of biomass in roots, stems, branches, and leaves. According to Kauffman *et al.*,
462 (2012), carbon stocks in mangrove forests are higher than that in any other forests,
463 where the biggest carbon stocks are contained in mangrove sediments. When
464 compared to the biomass estimation from other studies the biomass of mangrove forest
465 stands in research location was much lower. It may be affected by the difference of the
466 number of trees ha⁻¹, the size of stem diameter, height as well as the wood density of
467 types of mangroves making up of stands. Rachmawati *et al.*, (2014) revealed that the
468 biomass of mangrove stands in Wilayah Pesisir Muara Gembong, Bekasi Region was
469 108.6 ton ha⁻¹. Meanwhile according to Kristiningrum *et al.*, (2019) the average value of
470 mangrove forest carbon at the studied area in Mentawir Village is 50.73 tons C ha⁻¹. In
471 addition, Bachmid *et al.*, (2018) found that the biomass of mangrove stands in
472 Kuburaya Region, West Kalimantan, was 189.2 ton ha⁻¹. Kristiningrum *et al.*, 2019
473 informed the biomass of mangrove forests in Mentawir which is part of the Balikpapan
474 Bay Area is one and a half times higher than that in Siberut Island, West Sumatra, which
475 is 49.13 tons ha⁻¹ (Bismark 2008). Kusmana *et al.*, (2003) stated that muddy sediments
476 are generally richer in organic matter compared to sandy sediments.

477
478 The relation between organic carbon and total volume of *R. apiculata* and *S. alba* can be
479 seen at Fig 4 and Fig. 5.

480

481 **Fig 4. The relation between organic C and total volume of *S. alba***

482

483 **Fig 5. The relation between organic C and total volume of *R. apiculata***

484

485 Fig. 4 shows that in *S. alba* the organic C content was decreasing from plot A (closest to
486 land) to plot C (closest to sea), and so did the total volume of the trees. It can be
487 concluded that *S. alba* really needs organic C to increase its total volume. On the
488 contrary, Fig. 5 shows that in *R. apiculata* the organic C value decreased, however, the
489 tree total volume was increasing. It proves that *R. apiculata* is able survive in the areas
490 with lower organic C.

491

492 The average value of water pH was 7.03% in plot A, 4.99% in plot B, and 7.49% in plot
493 C. Furthermore, the organic C value was 2.1% in plot A, 2.6% in plot B, and 0.81% in
494 plot C. On the other hand, the total N value was 0.07% in plot A, 0.07% in plot B, and
495 0.04% in plot C. The CEC value was 30.0 me 100g⁻¹ in plot A, 25 me 100g⁻¹ in plot B,
496 and 25.4 me 100g⁻¹ in plot C. The basal area of *R. apiculata* was 0.006 m² tree⁻¹ in plot
497 A, 0.006 m² tree⁻¹ in plot B, and 0.007 m² tree⁻¹, whereas the basal area of *S. alba* was
498 0.009 m² tree⁻¹ in plot A, 0.008 m² tree⁻¹ in plot B, and 0.006 m² tree⁻¹ in plot C. The
499 biomass value per ha for *R. apiculata* was 36.12 ton ha⁻¹ in plot A, 38.60 ton ha⁻¹ in plot
500 B, and 36.25 ton ha⁻¹ in plot C, meanwhile the biomass value of *S. alba* was 56.27 ton
501 ha⁻¹ in plot A, 38.60 ton ha⁻¹ in plot B, and 36.25 ton ha⁻¹ in plot C. The value of carbon
502 stock per ha for *R. apiculata* was 18.06 ton ha⁻¹ in plot A, 19.20 ton ha⁻¹ in plot B, and
503 22.97 ton ha⁻¹ in plot C. On the other hand, the value carbon stock per ha for *S. alba*
504 was 28.13 ton ha⁻¹ in plot A, 24.47 ton ha⁻¹ in plot B, and 22.97 ton ha⁻¹ in plot C.

505

506 **CONCLUSIONS**

507 The results showed that the diameter of *R. apiculata* type in plot A, B, and C was
508 8.3±2.3 cm, 8.4±2.8 cm, and 8.9±3.3 cm respectively, and that of *Rhizophora alba* type
509 in plot A, B, and C was 10.4±1.8 cm, 9.0±3.8 cm, and 8.5±1.5 cm respectively. The
510 biomass value of *R. apiculata* in plot A was 36.12 ton ha⁻¹, B= 38.60 ton ha⁻¹, and C=
511 45.94 ton ha⁻¹, and the biomass value of *S. alba* in plot A, B, and C was 56.27 ton ha⁻¹,
512 48. Ton ha⁻¹, and 36.25 ton ha⁻¹ respectively. The value of carbon contents in *R.*
513 *apiculata* in plot A, B, and C was 18.06 ton ha⁻¹, 19.30 ton ha⁻¹, and 22.97 ton ha⁻¹
514 ¹successively. In addition, the value of carbon content in *S. alba* was 28.13 ton ha⁻¹ in
515 plot A, 24.47 ton ha⁻¹ in plot B, and 18.12 ton ha⁻¹ in plot C.

516

517

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522

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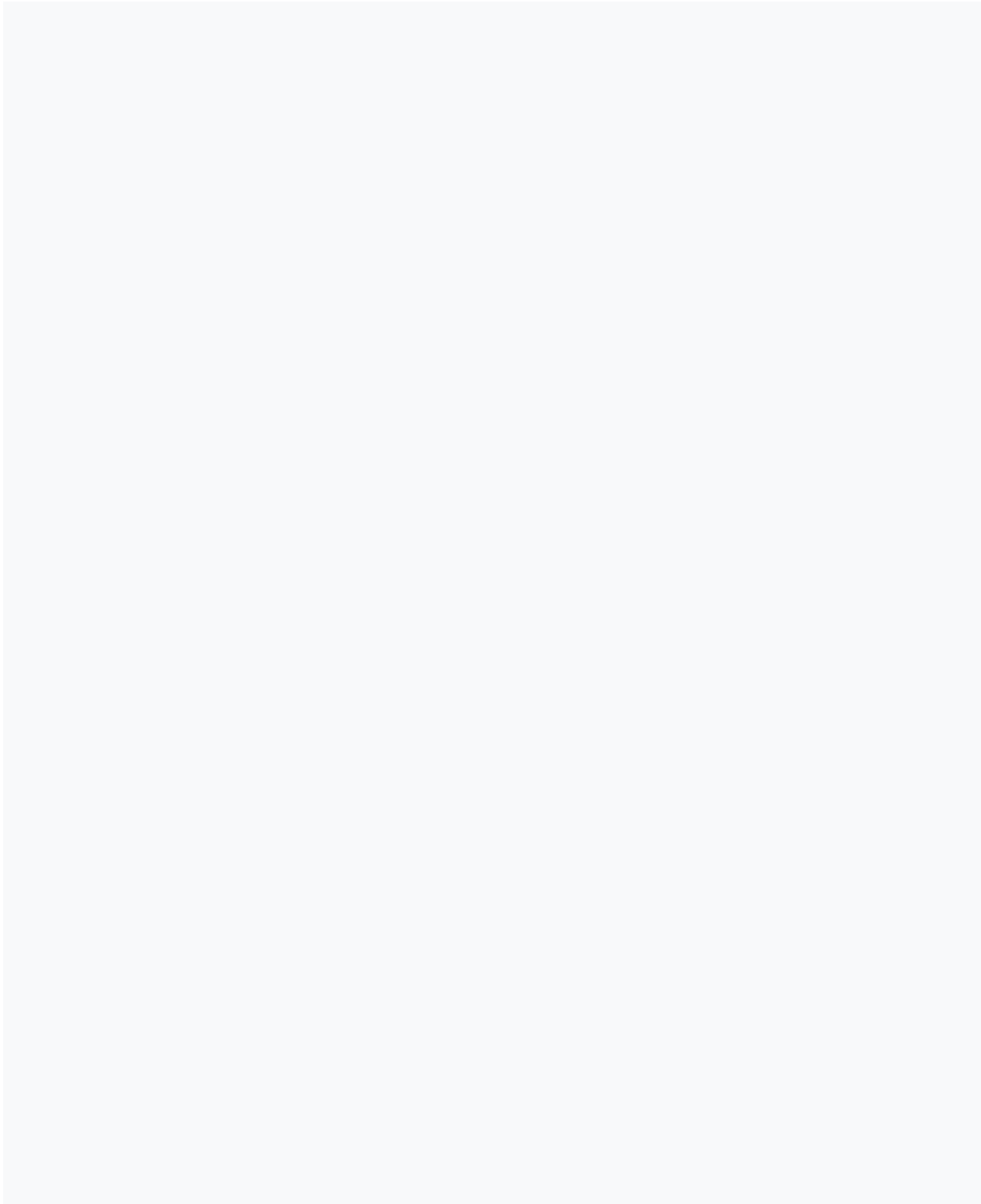
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707 **Table 1.** Test result data pH H₂O and of the soil in sample plots

No	Parameter	Method	Unit	Data Analysis								
				Plot A			Plot B			Plot C		
				0-30	30-60	Average	0-30	30-60	Average	0-30	30-60	Average
1	pH H ₂ O	Electrode	-	6.74	7.32	7.03	5.38	4.59	4.99	7.57	7.40	7.49
2	Ca ⁺⁺	AAS	meq100gr ⁻¹	8.59	9.93	9.26	2.22	2.35	2.29	10.80	1.89	6.35
3	Mg ⁺⁺	AAS	meq100gr ⁻¹	4.56	4.28	4.42	4.49	4.56	4.53	8.13	5.83	6.98
4	Na ⁺	AAS	meq100gr ⁻¹	13.38	13.23	13.305	13.44	13.44	13.44	10.18	9.39	9.79
5	K ⁺	AAS	meq100gr ⁻¹	2.89	2.24	2.565	3.70	4.12	3.91	1.89	1.66	1.78
6	KTK	Hitung	meq100gr ⁻¹	30.00	30.10	30.05	24.51	25.97	25.24	31.58	19.27	25.43
9	Total N	Kjeldahl	%	0.10	0.04	0.07	0.08	0.06	0.07	0.04	0.04	0.04
10	C. Organic	Walkley and Black	%	2.29	1.92	2.105	2.71	2.49	2.60	0.84	0.77	0.81

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711 **Table 2.** Biomass and carbon content of each species of mangrove at Plot A, Plot B
712 and Plot C.

No	Plot	Biomass (ton ha ⁻¹)		Carbon (ton ha ⁻¹)	
		R.	S.	S.	S.
		<i>apiculata</i>	<i>alba</i>	<i>R. apiculata</i>	<i>alba</i>
1	Plot A	36.12	56.27	18.06	28.13
2	Plot B	38.60	48.95	19.30	24.47
3	Plot C	45.94	36.25	22.97	18.12
	Total	120.66	141.47	60.33	70.72
	Average	40.22	47.16	20.11	23.57
	Average total	87.38		43.68	

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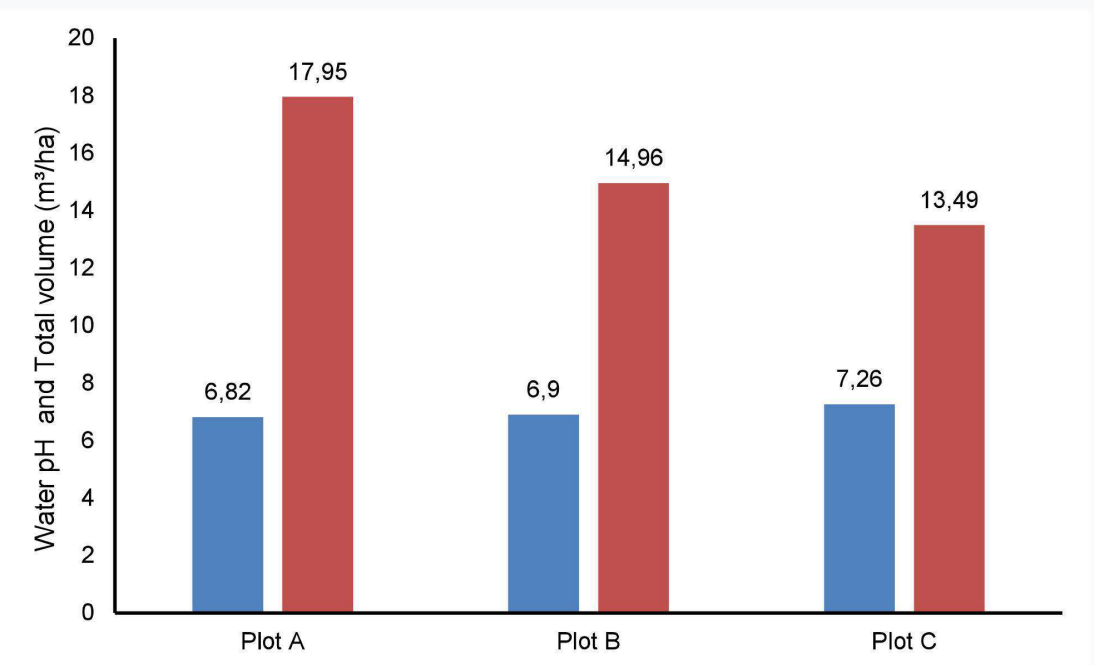
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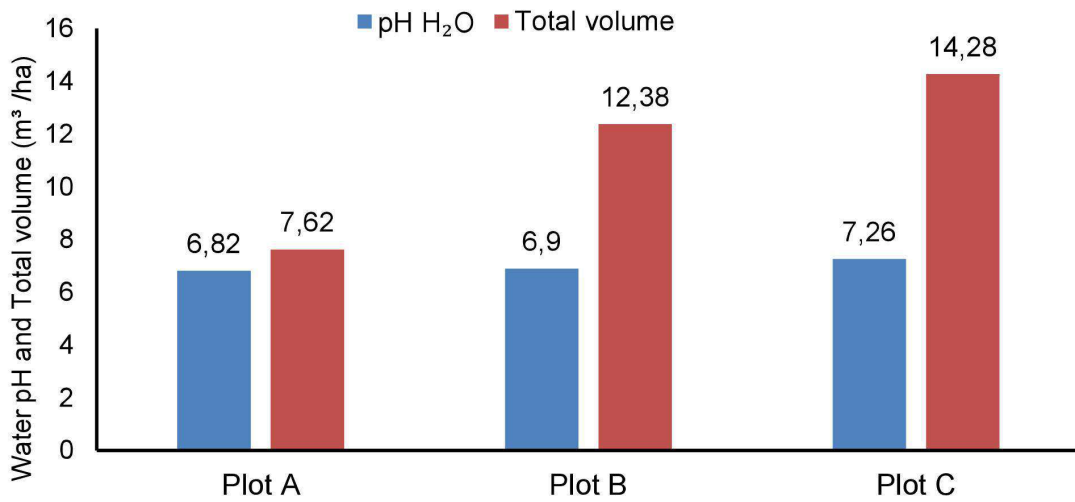
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Fig 2. The correlation of seawater pH and total volume of *Rhizophora alba* tree



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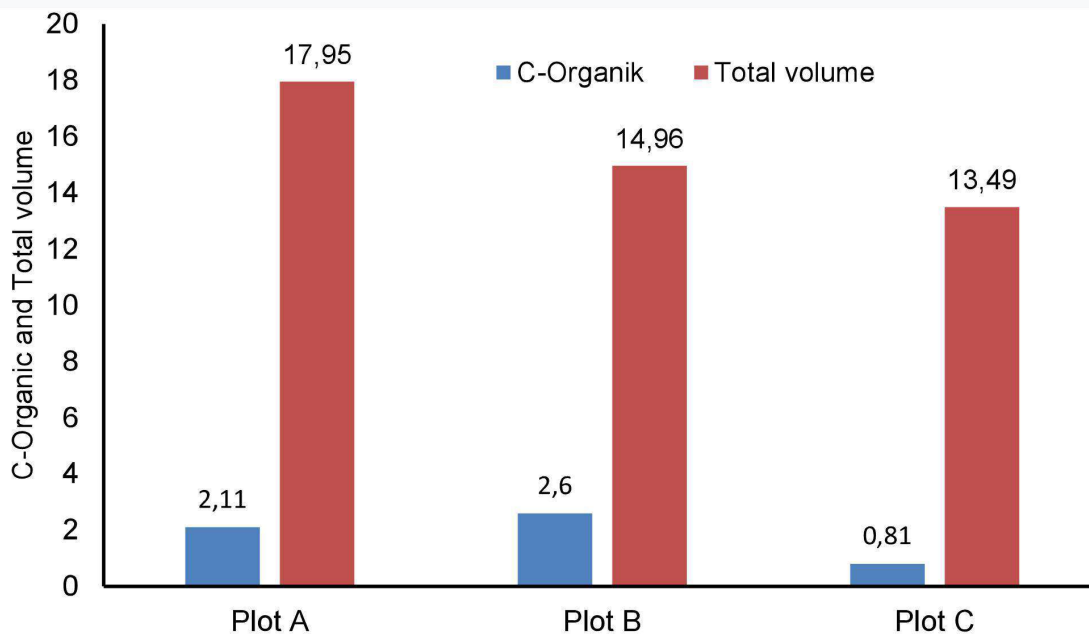
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738 **Fig 3.** The correlation of seawater pH and total volume of *R. apiculata* tree

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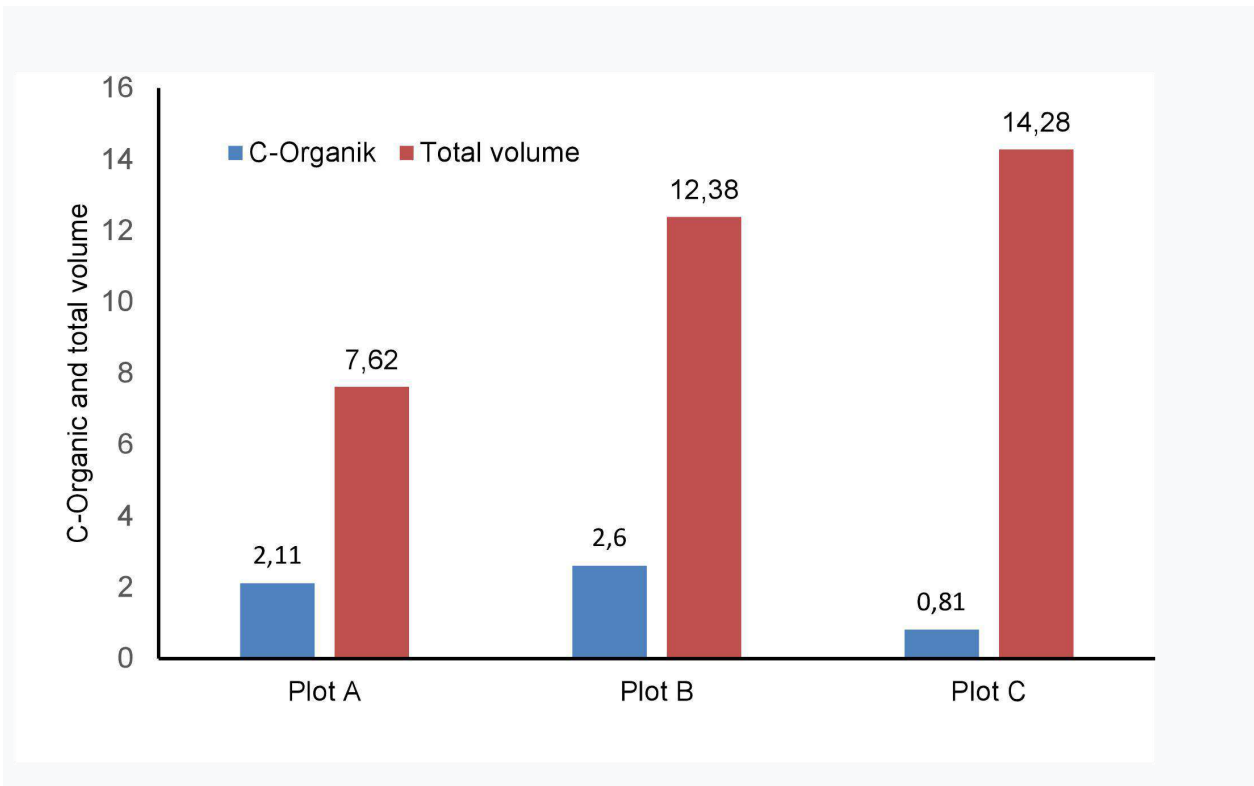


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743 **Fig 4.** The relation between organic C and total volume of *S. alba*

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Fig 5. The relation between organic C and total volume of *R. apiculata*

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1 **Carbon Stocks of *Rhizophora appiculata* and *Sonneratia alba* of Mangrove**
2 **Forest in Ngurah Rai Forest Park, Bali Province, Indonesia**

3
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14 **Keywords:** carbon growth and stocks, edaphic, salinity

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32 **Abstract**

33 Mangrove forest is a typical tropical and subtropical forest, which is affected by sea
34 tides. This study aimed to investigate the effect of pH, seawater salinity, and edaphic
35 factors on carbon growth and stocks. The research plots were developed by employing
36 transect method with a size of 20 m x 50 m for three plots along the beach. The pH
37 value of plot A= 6.82, plot B= 6.90, and plot C= 7.26. The analysis of CEC elements
38 found that plot A= 30.0, plot B= 25.2, and plot C= 25.4. The value of N-Total showed
39 that plot A= 0.07, plot B= 0,07, and plot C= 0.04. The value of organic carbon was plot
40 A= 2.1, plot B= 2.6, and plot C= 0.81. The results showed that the diameter of
41 *Rhizophora apiculata* type in plot A, B, and C was 8.3±2.3 cm, 8.4±2.8 cm, and 8.9±3.3
42 cm respectively, and that of *Sonneratia alba* type in plot A, B, and C was 10.4±1.8 cm,
43 9.0±3.8 cm, and 8.5±1.5 cm respectively. The biomass value of *R. apiculata* in plot A
44 was 36.12 ton ha⁻¹, B= 38.60 ton ha⁻¹, and C= 45.94 ton ha⁻¹, and the biomass value of
45 *S. alba* in plot A, B, and C was 56.27 ton ha⁻¹, 48. ton ha⁻¹, and 36.25 ton ha⁻¹
46 respectively. The value of carbon contents in *R. apiculata* in plot A, B, and C was 18.06
47 ton ha⁻¹, 19.30 ton ha⁻¹, and 22.97 ton ha⁻¹ successively. In addition, the value of carbon
48 content in *S. alba* was 28.13 ton ha⁻¹ in plot A, 24.47 ton ha⁻¹ in plot B, and 18.12 ton ha⁻¹
49 in plot C.

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63 INTRODUCTION

64 Indonesia has the biggest mangrove ecosystems in the world, consisting of 27% (16.9
65 million ha) from the total mangrove forests in the world, and becomes the center of the
66 distribution of species biodiversity and mangrove ecosystems (Spalding *et al.*, 2014),
67 however, it experienced rapid and dramatic destruction (Setyawan *et al.*, 2003).
68 Mangrove is a valuable treasure for Indonesian biodiversity with huge ecological and
69 economical significances (Hema and Devi, 2015). Mangrove ecosystems also have a
70 high economic value, either directly or indirectly, because the ecosystems have become
71 one of meaningful income sources for the society and the country.

72
73 Mangrove forest is a typical tropical and subtropical forest type, growing along the beach
74 and estuary affected by sea tides. Mangroves are generally found around coastal areas
75 protected from the onslaught of waves and gently sloping terrain. Mangroves optimally
76 grow in coastal areas with large estuary and in deltas whose water flow contains a lot of
77 mud. On the contrary, mangroves do not optimally grow in coastal areas with no estuary.
78 Mangrove is a valuable treasure for its biodiversity, ecologically and economically
79 (Hema and Devi, 2015). Thus, services, approaches, and improvements to nearby
80 society needs to be done in order to understand the mangrove ecosystems (Mukherjee
81 *et al.*, 2014; Nguyen *et al.*, 2019). The role of mangroves the natural hazards and it is
82 difficult for mangroves to grow in steep, choppy coasts with strong tidal currents
83 because it does not allow the deposition of mud that is needed as a substrate for its
84 growth (Spalding *et al.*, 2014). Reduced-impact logging method can directly decrease
85 emissions becaused using mono-cable winch on forest floors induced by logs skidding
86 on top soil and injured with bark broken intensity for remaining stands (Ruslim 2011;
87 Ruslim *et al.*, 2016; Chien, 2019).

88
89 The land of mangrove forests in terms of the habitat and the ecosystems is a diffused
90 environment that is formed by the encounter between marine environment and land
91 environment which have a big impact on human life or even for their ecosystem balance.
92 Since mangrove forest is always affected by excessive water throughout the year and is
93 sometimes interspersed with drying in some parts in a short time, it may involve a

94 chemical reaction of soil oxidation radicals Since mangrove forest growing in
95 inhospitable environment in tropics and sub-tropics are equipped with very efficient free
96 radical foraging system to withstand the variation of stress conditions (Thathoi *et al.*,
97 2013). Mangrove plants may grow in different types of soil; therefore, their vegetation,
98 species composition and structure may vary considerably at the global, regional, local
99 region (Sherman *et al.*, 2003)

100
101 The height and time of seawater flooding in particular locations during the high tide can
102 also determine the salinity. The salinity is of factors determining the spread of
103 mangroves. In addition, the salinity also becomes the limiting factor for particular
104 species. Even though some mangrove species have a high mechanism adaptation
105 towards salinity, however, if fresh water supply is not available, this will make soil and
106 water salinity reach an extreme condition which is potential to threaten its life (Chen and
107 Ye, 2014; Nyangon *et al.*, 2019).

108
109 Mangrove forests as any other forests have a significant role as a carbon dioxide (CO₂)
110 sink in the air. Carbon dioxide sink has a significant relation to tree biomass. Trees
111 during photosynthesis process absorb CO₂ and convert it into organic carbon
112 (carbohydrate) which is merged into the body of the trees. Mangrove can also provide
113 food and shelter for various organisms, either in land or in water (Ekka and Pandit,
114 2012).

115
116 Essentially, the atmosphere receives more carbon than it ejects, as a result of burning
117 fossil fuels, motor vehicles, and industrial machines which make carbon accumulated
118 (IPCC, 2003). On the other hand, tropical forest deforestation also contributes in
119 supplying carbon to the atmosphere (Defries *et al.*, 2002). This function is a part of
120 ecosystem service which is not traded in the market but highly contributes to the human
121 welfares (Barbier *et al.*, 2011; Liqueete *et al.*, 2013; Ezebilo, 2016). Carbon stock was
122 estimated from mangrove biomass referred as 50% of the value of biomass (Komiyama
123 *et al.*, 2005). Measurement of biomass was done in a non-destructive way. It was
124 determined based on data from measurements of tree volume Bismark, 2008).

125 On the other hand, the amount of CO₂ absorption decreases as a result of deforestation,
126 the change of land use, and residential development. The carbon accumulation in the
127 atmosphere provokes greenhouse effects as sunlight shortwave trapped in the
128 atmosphere that increases the temperature of the earth atmosphere. One of the forest
129 ecosystems that is able to reduce the greenhouse effect and functions as climate
130 change mitigation is mangrove forest (Komiyama *et al.*, 2008). For the sake of human
131 beings, the result of our observation showed that the stretch of mangroves and corals is
132 the ecosystem that is most often rated, meanwhile the stretch of seaweed is not really
133 taken into account (Mehvar *et al.*, 2018).

134
135 During the high tide, the seawater often goes further to the inland. At this time the soil
136 absorbs various nutrients from underground water. Enrichment of the soil on the surface
137 can also occur through the movement of water. Therefore, the nature of the soil under
138 the mangrove vegetation is also related to the chemical components under the
139 groundwater. On the other hand, mangrove roots are essential for the coastal
140 environment due to its function that can retain the soil under the mangrove forest from
141 the seawater, so it can strengthen the coastline and maintain the land around the roots
142 as an environment that is suitable for marine life breed.

143 The height and time of seawater-flooding in Ngurah Rai Forest Park during the high tide
144 can determine salinity. The salinity is one of the determining factors of the mangroves
145 spread. In addition, the salinity also becomes the limiting factor for particular species.
146 Even though some mangrove species have a high mechanism adaptation towards
147 salinity, however, if freshwater supply is not available, this will make soil and water
148 salinity reach an extreme condition which is potential to threaten its life.

149 Based on the above descriptions, it can be stated that the spread of mangrove species
150 is mainly affected by the condition of the waters where it grows while the growth of
151 mangrove stands is influenced by edaphic conditions which cover physical
152 characteristics and soil fertility where it grows. Mangrove forests like any other forests
153 have a significant role including absorbing carbon dioxide (CO₂) in the air so that its
154 existence contributes to controlling climate change. The ability of mangrove forests in

155 absorbing CO₂ is depending on the amount of stands biomass and carbon content of the
156 soil where the forest grows. In order to support the function of Ngurah Rai Forest Park,
157 especially as a means of developing science and educational facilities supporting
158 cultivation, tourism, and recreation, a study that can reveal the relationship between
159 mangrove stands and their habitats is important to be conducted. From the above
160 background this study aims to: (i) How is the physical condition and soil fertility of the
161 mangrove forests in Ngurah Rai Forest Park and how many edaphic factors that affect
162 the growth of mangrove stands. (ii) To measure the physical characteristics, chemical
163 characteristics (pH, cation exchange capacity (CEC) and soil fertility (organic material
164 components, total Nitrogen) of the mangrove forest habitat in Ngurah Rai Forest Park (iii)
165 To evaluate the growth conditions of the mangrove forest habitat in Ngurah Rai Forest
166 Park, including the number of trees, tree height, tree diameter, basal area, stand volume,
167 stand biomass, and the content of carbon stands.

168

169 **MATERIALS AND METHODS**

170 *Time and Location*

171 The present study was conducted in mangrove forest located in the area of Kuta
172 Municipality forest park, Bali Province (Fig 1).

173

174 **Fig 1. Research location (■), Kuta Municipality forest park, Bali Province, Indonesia**

175

176 *Procedures*

177 As adjusted to the research goals and objectives, this study consisted of 1) the making
178 of transect lines from the seashore to the shore for the zoning of mangrove forest; 2) the
179 making of sample plots along the transect lines; 3) the determination of tree species in
180 the sample plots 4) measuring the tree diameter and height in the sample plots 5)
181 testing the edaphic nature (soil physic/chemistry) in the sample plots and 6) testing the
182 parameters of mangrove forest water such as subtracts, salinity, water pH, and carbon
183 stock estimation. The sample plots were made by employing transect method with a size
184 of 20 m x 50 m for three plots along the beach. The measurement was conducted based

185 on commonly used criteria, which was the diameter of chest-tall tree trunks (130 cm) or
186 the topmost roots of the soil surface.

187

188 *Data analysis*

189 *Productivity of mangrove stand*

190 Data of mangrove species identification results were tabulated in Microsoft Excel to
191 calculate the potentials of mangrove species at the studied area. Analysis of mangrove
192 wood was done by calculating the total volume of standing stock (including height,
193 diameter, basal area, and volume).

194

195 *Basal area calculation*

196 The conversion of the diameter obtained by using a diameter measuring tool was done
197 by applying the following formula:

198

$$199 \quad g = \frac{1}{4} \pi d^2$$

200 With g = basal area (m²); and d = diameter breast height (cm);

201

202 *Volume calculation*

203 The tree volume was measured by using Ruchaemi formula (2006) as follow:

204

$$205 \quad V = \frac{1}{4} \pi d^2 \times h \times f$$

206 With V = Tree volume (m³); d = diameter breast height (cm); h = tree height (m) and f =
207 form factor

208

209 *Physical and chemical testing of the soil*

210 The method used for parameter analysis of physical and chemical properties of the soil
211 was based on Bogor soil research center and Wenworth scale. The place for soil
212 analysis was in the soil laboratory of the Forest Rehabilitation Center
213 Mulawarman University, Samarinda East Kalimantan.

214

215

216 **RESULT AND DISCUSSIONS**

217 *Soil Reaction (pH H₂O)*

218 The pH value of particular water and soil reflects the balance between acid and base
219 concentration in the water. The pH value of water is affected by some factors, such as
220 photosynthesis activity, biology activity, temperature, oxygen content, and the existence
221 of cations and anions in the water (Aksornkoae, 1993). The results of soil pH
222 measurement in sample plots are presented on the Table 1.

223

224 **Table 1. Test result data pH H₂O and of the soil in sample plots**

225

226 The Table 1 shows that the mangrove forest soil inspected had a varying pH value. Plot
227 C which was located closest to the beach had a neutral pH with highest average (7.49),
228 while plot B which was located between plot A and plot C had an acidic pH with much
229 lower value (4.99). On the other hand, plot A which was located furthest from the beach
230 also had a neutral pH with average value of 7.03. The low pH value of the soil in plot B
231 was because the mangrove stands in that plot produced more litter than in plot A and C.
232 Through the decomposition process, besides producing minerals, the litter also secreted
233 organic acid that made the soil pH become sour. The more litter produced in plot C than
234 in the other plots was also indicated by the more organic carbon contents available (plot
235 B= 2.60%; plot A= 2.10%; plot C= 0.81%).

236

237 The influence of frequency and time and the duration of water logging towards the pH
238 value of mangrove forest soil was also reported by Nursin *et al.*, (2014) through their
239 study in Balinggi sub-district, Parigi Moutong region, Central Sulawesi. The other studies
240 that revealed the same phenomenon were Ragil *at al.*, (2017) through their study in
241 mangrove forest in Mempawah Region, West Kalimantan. The result of this study about
242 mangrove soil pH was compared to the other related studies such as 7) found that the
243 mangrove soil pH in Muara Resort, Selangor, was 7.7, whereas Kamariah (2014) found
244 that the mangrove forest in Mamuju Region, West Sulawesi had a pH value of 5.98-6.12.
245 Onrizal and Kusmana (2008) informed soil and water quality take effect on mangrove
246 growth in mangrove rehabilitation activities at east coast of North Sumatera.

247 Regarding soil pH values in mangrove forests, Hasrun *et al.*, (2013) stated that the
248 water with pH value of < 4 is categorized as highly sour and potentially threaten the life
249 of organisms. On the other hand, the water with pH value of > 9.5 is classified as highly
250 alkaline and could also result in death for organisms and reduce productivity. On the
251 contrary, plants can easily absorb carbon when the soil has a neutral pH (Setiawan *et al.*,
252 2013).

253
254 The correlation of seawater pH and total volume is shown in details through the
255 following Fig 2 and Fig 3.

256
257 **Fig 2. The correlation of seawater pH and total volume of *Rhizophora alba* tree**

258
259 **Fig 3. The correlation of seawater pH and total volume of *R. apiculata* tree**

260
261 As shown on Fig. 2, the seawater pH was increasing from the direction of plot A (closest
262 to land) to plot c (closest to sea), and it affected the decreasing of the tree total volume.
263 From this phenomena, it can concluded that *S. alba* mangrove had a less tolerant nature
264 towards seawater pH on particular limits. On the contrary, Fig. 3 shows that the volume
265 of *R apiculata* tree increased as the seawater pH increased. It proved that this type of
266 mangrove was tolerant to the seawater pH.

267
268 **Organic Carbon (C)**

269 Soil organic matter is of soil components derived from the rest of dead animals and
270 plants, both in the form of original and weathered tissues. The main resources of soil
271 organic matter in the sample plots were the litters of mangrove stands such as the
272 components of leaves, twigs, branches, stems and roots. According to Lee *et al.*, (2014),
273 organic matter has a productive function to support plant biomass production and a
274 protective function to keep the soil fertility and soil biotic stability.

275
276 Generally, the soil C concentration of the sample plots had a status of very low to
277 moderate with values between 0.81 to 2.60%. the lowest C concentration was found in

278 plot C which was located closest to the beach. The higher frequency and duration of the
279 waterlogging in plot C do not only limit the chance of piles of dropping organic matter on
280 the forest floor, but also limit the rate of decomposition of organic matter on the forest
281 floor. Ferreira *et al.*, (2007) stated that the decomposition of soil organic matter under
282 mangrove stands is highly affected by frequency, duration of waterlogging, and
283 distribution of its subtract particle size.

284
285 The estimation of soil carbon concentration in mangrove forests in the study areas was
286 in line with that reported by Handoko *et al.*, (2017) who conducted a study in Balinggi
287 sub-district, Parigi Region, Central Sulawesi. She found that soil carbon concentration in
288 that area was 0.34-2.34%. A higher figure was reported from a study by Ragil *et al.*,
289 (2017) stating that the soil C concentration was 3.99-5.05% (high to very high), based
290 on their study conducted in mangrove forest in Mempawah Region, West Kalimantan.

291
292 *Total Nitrogen*
293 Nitrogen is an essential element for plants, functioning to improve vegetative growth.
294 The main resource of N in forest mangrove soil is the litters produced by mangrove
295 stands as well as other dead organic material components that have been accumulated
296 on the forest floor. The decomposition of the organic matter to be minerals, including N,
297 is highly affected by inundation periodization. The anaerobic conditions when the floor
298 flooded causes litter decomposing microorganisms restricted, otherwise, in aerobic
299 conditions when the floor is not flooded, the microorganism activity increases. The total
300 N concentration in mangrove forest soil in the sample plots is presented on Table 1.

301
302 Table 1 shows that soil N concentration in the depth of 0-60 cm in the sample plots was
303 very low, only about 0.04-0.10%. In plot A and B, the soil N concentration in the depth of
304 0-30 cm was higher than that in the depth of 30-60 cm. However, in plot C, the soil N
305 concentration in both layers was similar. The impact of the flood on organic material
306 mineralization process to be N could be seen from the lower N concentration in the
307 depth of 0-30 cm in plot C which was bordering with the beach compared to plot A and B

308 respectively. Plot was located the furthest from the beach, whereas plot C was located
309 in between plot C and A.

310
311 The estimations of soil N concentration value as reported by the researchers are as
312 follows: 0.27-0.45% (status: moderate) in mangrove forest in Mangunharjo, Semarang
313 Region (Chrisyariati *et al.*, 2014); and 0.29-0.43% (status: moderate) in mangrove forest
314 in Mamuju Region, West Sulawesi (Malik *et al.*, 2019).

315 316 *Cation Exchange Capacity (CEC)*

317 Overall, the average value of CEC for the mangrove soil studied in the depth of 0-60 cm,
318 categorized as high, was 25.2 – 30.0 me 100g⁻¹. In plot A and B, the CEC value of
319 topsoil and subsoil was relatively similar, while in plot C there was a significant
320 difference. As mentioned before, there are two factors affecting the high and low of soil
321 CEC, namely organic matter content and its mineral clay content. The result shows that
322 the highest CEC value for mangrove forest soil in this study was in the depth of 0-30 cm
323 in plot C (31,6 me 100 g⁻¹). Since the soil organic matter content was lower than that in
324 the other plots (see Table 4), the factor causing the high CEC value of the soil in the
325 depth of 0-30 cm was the clay content which was higher than in plot B or plot A (Table
326 1). In the layer of 30-60 cm, the CEC value of the soil in plot C significantly decreased to
327 19.3 me 100g⁻¹ even though the clay content was not really different from that in the
328 layer of 0-30 cm (11.5%). This is interesting because despite its lower clay content,
329 10.6%, the soil in the depth of 30-60 cm in plot A had a higher CEC value (30.1 me
330 100g⁻¹) than in plot C. I may be because the soil in plot A had higher organic matter
331 content (2.10%) than in plot C (0.77%).

332
333 Cation Exchange Capacity (CEC) is the soil chemical nature highly related to the soil
334 fertility. The soil with higher CEC is able to absorb and provide nutrients better than the
335 soil with lower CEC. The soils with organic matter content or with higher clay content
336 consisted of higher CEC compared to the soils with lower or sandy organic matter
337 content (Soewandita, 2008). The CEC value of soil is influenced by the soil weathering
338 level, organic matter content and the number of alkali cations in the soil. The soil with

339 higher organic matter content had higher CEC, so did young soil with newly started
340 weathering level, and soils with further weathering levels had low CEC value.

341
342 *The Condition of Mangrove Forest Stands In Ngurah Rai Forest Park*
343 The mangrove in plot A (Distal zone or the furthest zone from sea), plot B (Middle zone or
344 middle zone), and plot C (Proximal zone, the closest zone from sea) was carried out an
345 inventory covering number of trees, diameter at breast height (DBH), the height of free
346 trunk (TBC), the total height (TTL), the width of basal area (LBD), and the total volume
347 (VT). Besides, the calculation was also done towards the amount of biomass and the
348 content of carbon stands in each of those researches. The types of mangrove available
349 in the research plots only consisted of *R. apiculata* and *S. alba*.

350
351 *The Density and Types of Tree Stands*
352 The number of trees in a research plot was not the same. Plot B had the most number of
353 trees, including 272 trees, each of 162 trees of *R. apiculata* type and 110 trees of *S.*
354 *alba*. Plot C had 220 trees, each of 110 trees of *R. apiculata* and *S. alba*. In the hectare
355 unit, the numbers of trees in each plot were: plot A 1.950 trees, plot C 2.200 trees and
356 plot B 2.720 trees, the total of trees 438 ha⁻¹ and 517 ha⁻¹ reached the study result in
357 Mentawir Village Balikpapan, Kalimantan Timur of 2,300 ha⁻¹, Lahjie *et al.*, 2019;
358 Kristiningrum *et al.*, (2019). The stand density of mangrove forests in eastern coast of
359 North Sumatera varied from 1,692 ind ha⁻¹ to 2,990 ind ha⁻¹ (Onrizal *et al.*, 2019a).

360
361 The density of mangrove tree stands in each plot tended to be influenced by each clay
362 content. Plot B with the highest tree density (2720 trees ha⁻¹), also had the highest clay
363 content (11,40-14,30%). Followed by plot C with the number of 2.200 trees ha⁻¹ and clay
364 content 11, 50-12,70%, and plot A with the number of 1950 trees ha⁻¹ and clay content
365 6,50-10,60%. As described by Hossain and Nuruddin (2016), clay fragment is a
366 supporting factor of the regeneration process, where the clay particle in the form of mud
367 will catch the mangrove fruit that falls when it is ripe. This process determined whether a
368 zone was dense or not.

369

370 Comparing the study results from Tolangara and Ahmad (2017) in Bacan mangrove
371 forest, Halmahera Selatan Regency which resulted in the density of the tree of 1.500 ha⁻¹
372 so the number of trees per hectare in Mangrove Forest in Tahura Ngurah Rai for the
373 three observing plots were considered denser. But if compare with the study result of
374 Handoko *et al.*, (2017) at 12 research plots of mangrove forest in the area of South
375 Rukat Island, Pekanbaru, with the density value ranges between 2.592 trees ha⁻¹ until
376 8.148 trees ha⁻¹, therefore the tree stands of mangrove forest in Tahura Ngurah Rai was
377 much lower.

378
379 The types of *R. apiculata* and *S. alba* were the two types of mangroves that were
380 available in all research plots lying from the seashore (plot C) to the land (plot B and plot
381 A). Generally outermost zone of mangrove with high salinity occupied by *Avicennia*
382 associated with *Sonneratia* spp., while *Rhizophora* was located in the middle zone and
383 *Bruguiera* grew in the furthest zone of the beach with much lower salinity. Onrizal *et al.*
384 (2019b) said in muddy areas with high salinity levels which can grow *R. apiculata*
385 species. The phenomenon of *Rhizophora* domination in the research area was suspected
386 to be related to the low salinity of its water ecosystem. The typical water salinity in the
387 research area of 14,8 -19,6‰ in reality was much lower than those reported by other
388 researcher. The factors that influence high and low water salinity were evaporation and
389 rainfall. The higher the level of evaporation of seawater, the higher the salinity would be.
390 The higher rainfall, then the lower salinity would be.

391
392 *Trunk Diameter*

393 Based on attachment 1-6, it was known that trunk diameter of tree type *R. apiculata* in
394 each research plot was : plot A = 8,3 ± 3,8 cm, plot B = 8,4 ± 2,8 cm and plot C 8,9 ± 3,3
395 cm then the average value of trunk diameter for the whole plots was 8,56 cm. in terms of
396 the diversity of trunk diameter of each plot, it can be concluded that the growth of trunk
397 diameter in plot A stands was more identical than other plots. Meanwhile, in plot C the
398 growth of trunk diameter was largely diverse.

399

400 *S. alba* type tended to have a bigger trunk diameter. In plot A, its value was = $10,4 \pm 1,8$
401 cm, plot b = $9,0 \pm 3,8$ cm, plot C = $8,5 \pm 1,5$ cm so the average value for all plots was 9,3
402 cm. Trunk diameter of *R. apiculata* was bigger in plot A and even smaller in plot B and
403 plot C which located further from the beach. Meanwhile, type *S. alba* showed the
404 opposite. The closer to the land, the bigger the diameter was. Due to that matter, it was
405 suspected that the growth of *R.apiculata* was better that the salinity in higher waters.

406
407 Climate affected the development of mangrove and the physical factor of its growing
408 place was substrate and waters. Further, Alwikado (2014) reported that climate also
409 affected the growth of mangrove through the light element, rainfall, temperature, and
410 wind. The diameter growth and mangrove diameter increment growth were also
411 influenced by many factors of its growing place including the substrate. The substrate in
412 this study referred to a substrate containing soft mud. Furthermoe, Hastuti and
413 Budhiahastuti (2016) added that growth was the result of the interaction of various
414 physiological processes. The physiological process referred to as photosynthesis,
415 respiration, and transpiration. While the results that were reported by Kusmana *et al.*,
416 (2003) in mangrove Center Lampung were obtained from the diameter value of 7,5 –
417 9,7 cm. Moreover, Pattipeilohy (2014) in Minahasa Utara Sub-district obtained the
418 diameter value of 11 cm.

419 420 *Tree Height*

421 As shown by its diameter growth, the average of total height growth of trees type *S. alba*
422 (15,99m) was bigger than tree type *R. apiculata* (12, 19 m). Hence, it can be concluded
423 that as a whole that the condition of mangrove habitats in the research area is more
424 suitable for *S. alba* than for *R. apiculata*.

425
426 The results of the total height growth of trees type *R. apiculata* in each plot was: plot A =
427 $13,08 \pm 2,34$ m, plot B = $10,57 \pm 2,91$ m, plot C = $12,91 \pm 2,68$ m while for type *R.*
428 *alba* plot A= $15, 58 \pm 5,99$ m, plot B = $16,28 \pm 5,88$ m, plot C - $16,11 \pm 1,9$ m. For type *R.*
429 *apiculata*, plot A resulted in a bigger height growth with a smaller coefficient of variation
430 than those grew in other plots. The height growth and diameter of tree is not only

431 depending on the space and surface canopy, relative humidity as well as root system,
432 but also influenced by climate and soil fertility. Cuenca *et al.*, (2015) stated the factors
433 were complex and affected towards the distribution and mangrove growth including
434 salinity, tidal drying, disturbance, warming, and predation. Meanwhile, Toknok (2006) in
435 Donggala obtained the value of 13-20 m..

436

437 *The Width of Basal Area*

438 According to the estimation conducted in the research location, Ngurah Rai Forest Park,
439 Denpasar, it was revealed that the widths of the basal area of *A. apiculata* in plot A, B,
440 and C were 0.006 m² tree⁻¹, 0.006 m² tree⁻¹, and 0.007 m² tree⁻¹ respectively. The
441 average width of the basal area was 0.006 m² tree⁻¹. On the other hand, the widths of
442 the basal area of *S. alba* were 0.009 m² tree⁻¹ in plot A, 0.008 m² tree⁻¹ in plot B, 0.006
443 m² tree⁻¹ in plot C, and 0.008 m² tree⁻¹ on average. Meanwhile, Aswita and Syahputra
444 (2012) on their study in Seuruway sub-district, Aceh Taming Region, Aceh Province,
445 reported that the width of the basal area of mangrove stands was 0.004 m² tree⁻¹.

446

447 *Stand Biomass and Carbon Content*

448 The result showed that the average biomass of mangrove forest stands in the research
449 location was 87.38 ton ha⁻¹, consisting of *R. apiculata* biomass of 40.22 ton ha⁻¹ (46%)
450 and *S. alba* biomass of 47.16 ton ha⁻¹ (54%). *S. alba* in plot A (located the furthest from
451 the beach) and plot B (located in the middle) were higher than in plot C (located closest
452 to the beach). The accumulation of the three plots was higher (12.7 ton ha⁻¹) compared
453 to the finding of the research conducted by Bindu *et al.*, (2018). As shown on Table 2, in
454 terms of the average number of trees in the three plots, actually, *S. alba* had a fewer
455 number (107 trees) than *R. apiculata* (131 trees), however, in terms of tree average
456 diameter and height (D=9.30 cm; T=15.99 m), *S. alba* had a bigger size than *R.*
457 *apiculata* (D=8.56 cm; T= 12.19 m).

458

459 **Table 2.** Biomass and carbon content of each species of mangrove at Plot A, Plot B
460 and Plot C.

461

462 Biomass is defined as the total number of organisms on the surface of a tree and is
463 measured by using the ton unit of dry weight per area (Brown, 2004). The amount of
464 biomass in particular mangrove forest is obtained from measuring the diameter, height,
465 and wood density of each type of mangroves (Rachmawati et al., 2014). Mangrove
466 ecosystem has an ecological function to absorb and store carbon. Mangroves absorb
467 CO₂ during the photosynthesis process and then change it into carbohydrate by storing
468 it in form of biomass in roots, stems, branches, and leaves. According to Kauffman *et al.*,
469 (2012), carbon stocks in mangrove forests are higher than that in any other forests,
470 where the biggest carbon stocks are contained in mangrove sediments. When
471 compared to the biomass estimation from other studies the biomass of mangrove forest
472 stands in research location was much lower. It may be affected by the difference of the
473 number of trees ha⁻¹, the size of stem diameter, height as well as the wood density of
474 types of mangroves making up of stands. Rachmawati *et al.*, (2014) revealed that the
475 biomass of mangrove stands in Wilayah Pesisir Muara Gembong, Bekasi Region was
476 108.6 ton ha⁻¹. Meanwhile according to Kristiningrum *et al.*, (2019) the average value of
477 mangrove forest carbon at the studied area in Mentawir Village is 50.73 tons C ha⁻¹. In
478 addition, Bachmid *et al.*, (2018) found that the biomass of mangrove stands in
479 Kuburaya Region, West Kalimantan, was 189.2 ton ha⁻¹. Kristiningrum *et al.*, 2019
480 informed the biomass of mangrove forests in Mentawir which is part of the Balikpapan
481 Bay Area is one and a half times higher than that in Siberut Island, West Sumatra, which
482 is 49.13 tons ha⁻¹ (Bismark 2008). Kusmana *et al.*, (2003) stated that muddy sediments
483 are generally richer in organic matter compared to sandy sediments.

484
485 The relation between organic carbon and total volume of *R. apiculata* and *S. alba* can be
486 seen at Fig 4 and Fig. 5.

487

488 **Fig 4. The relation between organic C and total volume of *S. alba***

489

490 **Fig 5. The relation between organic C and total volume of *R. apiculata***

491

492 Fig. 4 shows that in *S. alba* the organic C content was decreasing from plot A (closest to
493 land) to plot C (closest to sea), and so did the total volume of the trees. It can be
494 concluded that *S. alba* really needs organic C to increase its total volume. On the
495 contrary, Fig. 5 shows that in *R. apiculata* the organic C value decreased, however, the
496 tree total volume was increasing. It proves that *R. apiculata* is able survive in the areas
497 with lower organic C.

498
499 The average value of water pH was 7.03% in plot A, 4.99% in plot B, and 7.49% in plot
500 C. Furthermore, the organic C value was 2.1% in plot A, 2.6% in plot B, and 0.81% in
501 plot C. On the other hand, the total N value was 0.07% in plot A, 0.07% in plot B, and
502 0.04% in plot C. The CEC value was 30.0 me 100g⁻¹ in plot A, 25 me 100g⁻¹ in plot B,
503 and 25.4 me 100g⁻¹ in plot C. The basal area of *R. apiculata* was 0.006 m² tree⁻¹ in plot
504 A, 0.006 m² tree⁻¹ in plot B, and 0.007 m² tree⁻¹, whereas the basal area of *S. alba* was
505 0.009 m² tree⁻¹ in plot A, 0.008 m² tree⁻¹ in plot B, and 0.006 m² tree⁻¹ in plot C. The
506 biomass value per ha for *R. apiculata* was 36.12 ton ha⁻¹ in plot A, 38.60 ton ha⁻¹ in plot
507 B, and 36.25 ton ha⁻¹ in plot C, meanwhile the biomass value of *S. alba* was 56.27 ton
508 ha⁻¹ in plot A, 38.60 ton ha⁻¹ in plot B, and 36.25 ton ha⁻¹ in plot C. The value of carbon
509 stock per ha for *R. apiculata* was 18.06 ton ha⁻¹ in plot A, 19.20 ton ha⁻¹ in plot B, and
510 22.97 ton ha⁻¹ in plot C. On the other hand, the value carbon stock per ha for *S. alba*
511 was 28.13 ton ha⁻¹ in plot A, 24.47 ton ha⁻¹ in plot B, and 22.97 ton ha⁻¹ in plot C.

512

513 **CONCLUSIONS**

514 The results showed that the diameter of *R. apiculata* type in plot A, B, and C was
515 8.3±2.3 cm, 8.4±2.8 cm, and 8.9±3.3 cm respectively, and that of *Rhizophora alba* type
516 in plot A, B, and C was 10.4±1.8 cm, 9.0±3.8 cm, and 8.5±1.5 cm respectively. The
517 biomass value of *R. apiculata* in plot A was 36.12 ton ha⁻¹, B= 38.60 ton ha⁻¹, and C=
518 45.94 ton ha⁻¹, and the biomass value of *S. alba* in plot A, B, and C was 56.27 ton ha⁻¹,
519 48. Ton ha⁻¹, and 36.25 ton ha⁻¹ respectively. The value of carbon contents in *R.*
520 *apiculata* in plot A, B, and C was 18.06 ton ha⁻¹, 19.30 ton ha⁻¹, and 22.97 ton ha⁻¹,
521 1successively. In addition, the value of carbon content in *S. alba* was 28.13 ton ha⁻¹ in
522 plot A, 24.47 ton ha⁻¹ in plot B, and 18.12 ton ha⁻¹ in plot C.

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Table 1. Test result data pH H₂O and of the soil in sample plots

No	Parameter	Method	Unit	Data Analisis								
				Plot A			Plot B			Plot C		
				0-30	30-60	Average	0-30	30-60	Average	0-30	30-60	Average
1	pH H ₂ O	Electrode	-	6.74	7.32	7.03	5.38	4.59	4.99	7.57	7.40	7.49
2	Ca ⁺⁺	AAS	meq100gr ⁻¹	8.59	9.93	9.26	2.22	2.35	2.29	10.80	1.89	6.35
3	Mg ⁺⁺	AAS	meq100gr ⁻¹	4.56	4.28	4.42	4.49	4.56	4.53	8.13	5.83	6.98
4	Na ⁺	AAS	meq100gr ⁻¹	13.38	13.23	13.305	13.44	13.44	13.44	10.18	9.39	9.79
5	K ⁺	AAS	meq100gr ⁻¹	2.89	2.24	2.565	3.70	4.12	3.91	1.89	1.66	1.78
6	KTK	Hitung	meq100gr ⁻¹	30.00	30.10	30.05	24.51	25.97	25.24	31.58	19.27	25.43
9	Total N	Kjeldahl	%	0.10	0.04	0.07	0.08	0.06	0.07	0.04	0.04	0.04
10	C. Organic	Walkley and Black	%	2.29	1.92	2.105	2.71	2.49	2.60	0.84	0.77	0.81

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741 **Table 2.** Biomass and carbon content of each species of mangrove at Plot A, Plot B
742 and Plot C.

No	Plot	Biomass (ton ha ⁻¹)		Carbon (ton ha ⁻¹)	
		<i>R.</i>	<i>S.</i>	<i>R.</i>	<i>S.</i>
		<i>apiculata</i>	<i>alba</i>	<i>R. apiculata</i>	<i>alba</i>
1	Plot A	36.12	56.27	18.06	28.13
2	Plot B	38.60	48.95	19.30	24.47
3	Plot C	45.94	36.25	22.97	18.12
	Total	120.66	141.47	60.33	70.72
	Average	40.22	47.16	20.11	23.57
	Average total	87.38		43.68	

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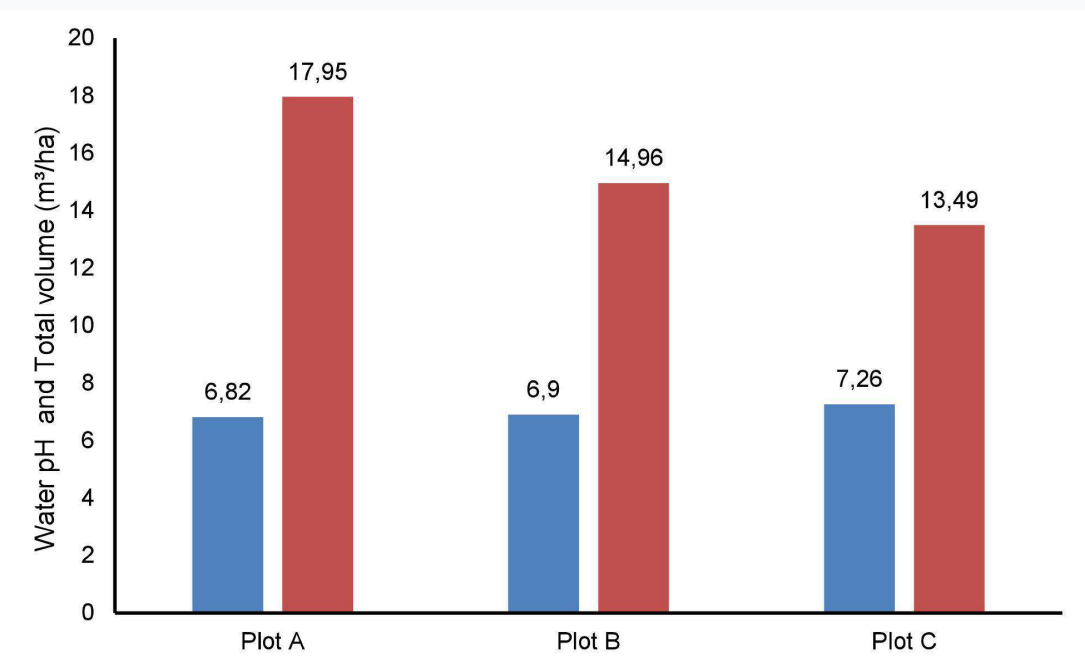
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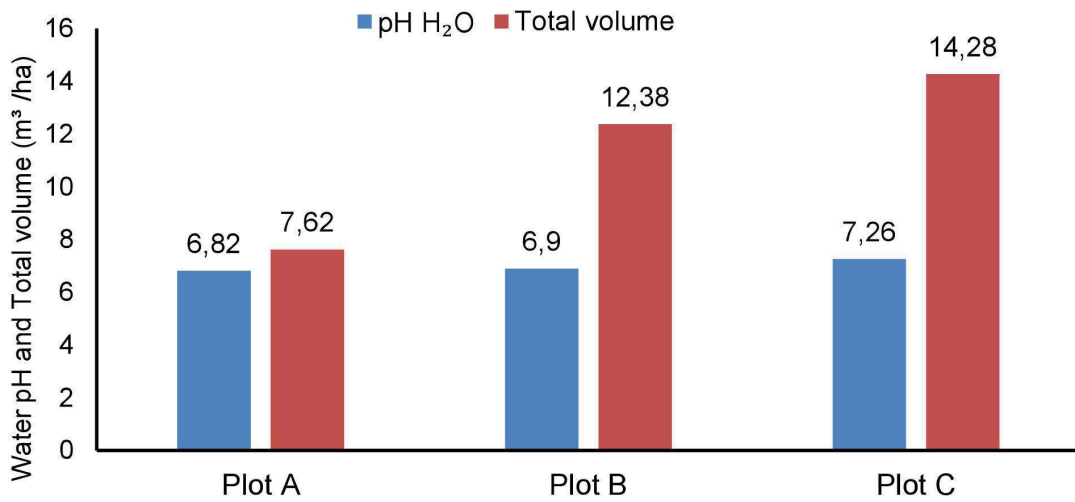
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Fig 2. The correlation of seawater pH and total volume of *Rhizophora alba* tree



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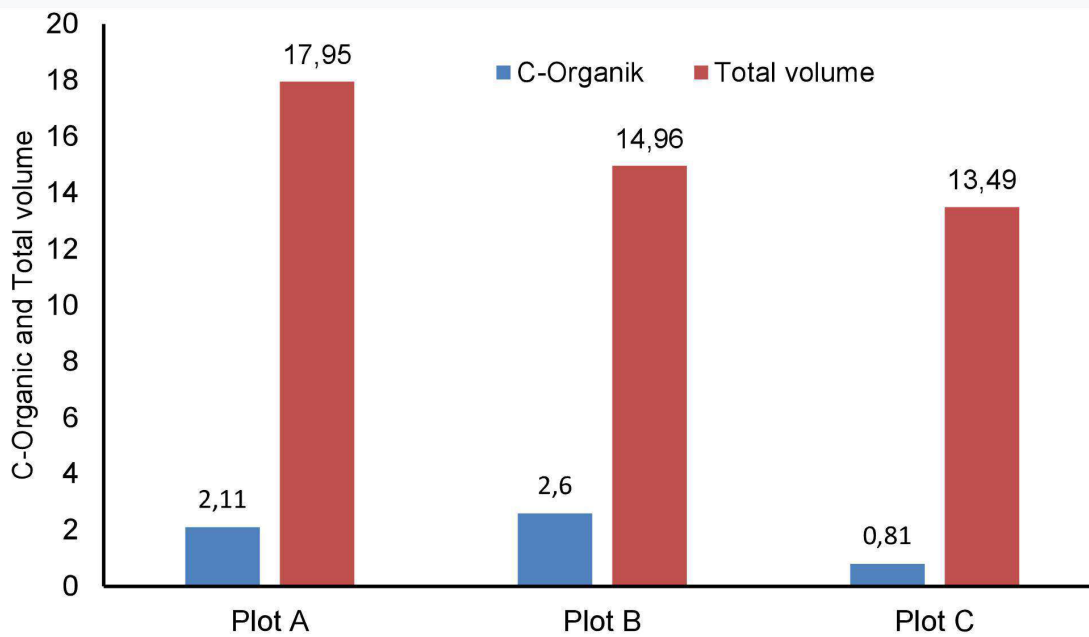
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768 **Fig 3.** The correlation of seawater pH and total volume of *R. apiculata* tree

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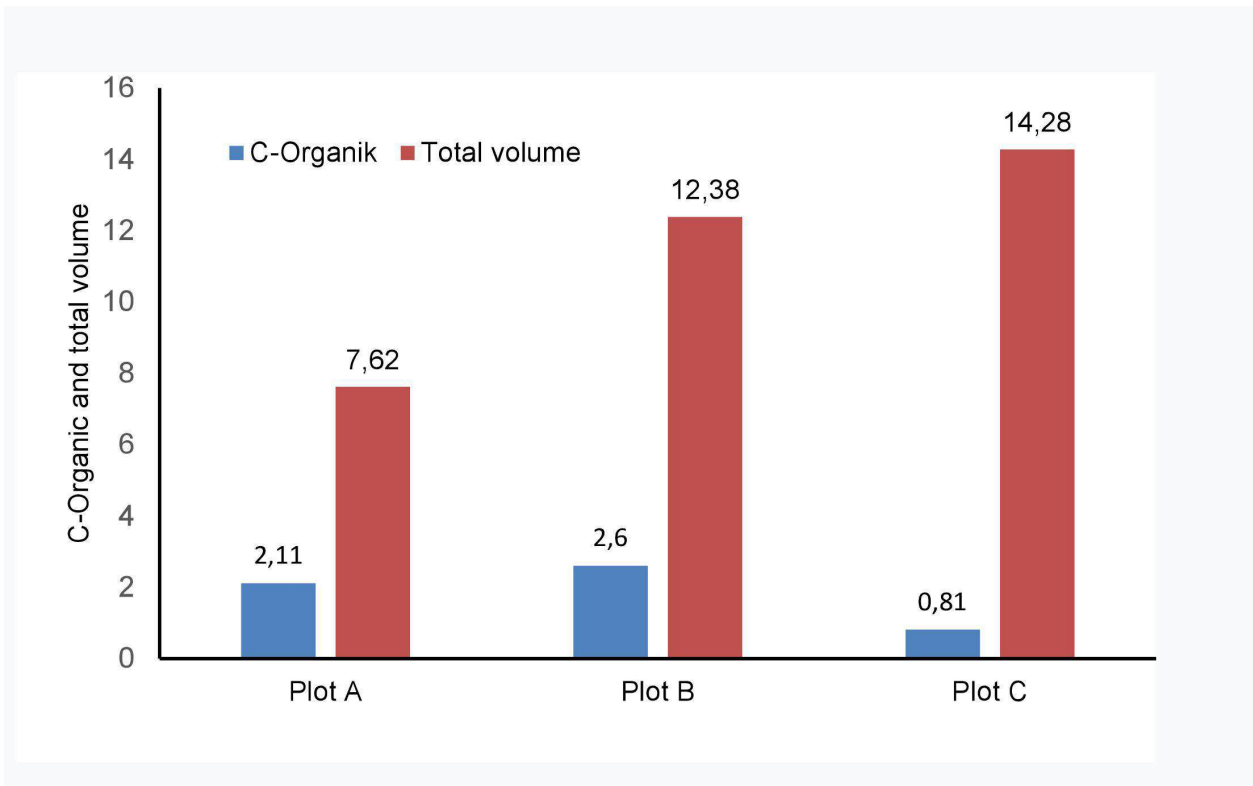


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773 **Fig 4.** The relation between organic C and total volume of *S. alba*

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Fig 5. The relation between organic C and total volume of *R. apiculata*

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2 **Remarks**

3 *It has been decided that the paper can be accepted for publish if revision is made point-by-point
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10 information presented with Motivation and aims of the study]

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31 **Carbon Stocks of *Rhizophora appiculata* and *Sonneratia alba* of Mangrove**
32 **Forest in Ngurah Rai Forest Park, Bali Province, Indonesia**

33

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44 **Keywords:** carbon growth and stocks, edaphic, salinity

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62 **Abstract**

63 Mangrove forest is a typical tropical and subtropical forest, which is affected by sea
64 tides. This study aimed to investigate the effect of pH, seawater salinity, and edaphic
65 factors on carbon growth and stocks. The research plots were developed by employing
66 transect method with a size of 20 m x 50 m for three plots along the beach. The pH
67 value of plot A= 6.82, plot B= 6.90, and plot C= 7.26. The analysis of CEC elements
68 found that plot A= 30.0, plot B= 25.2, and plot C= 25.4. The value of N-Total showed
69 that plot A= 0.07, plot B= 0,07, and plot C= 0.04. The value of organic carbon was plot
70 A= 2.1, plot B= 2.6, and plot C= 0.81. The results showed that the diameter of
71 *Rhizophora apiculata* type in plot A, B, and C was 8.3±2.3 cm, 8.4±2.8 cm, and 8.9±3.3
72 cm respectively, and that of *Sonneratia alba* type in plot A, B, and C was 10.4±1.8 cm,
73 9.0±3.8 cm, and 8.5±1.5 cm respectively. The biomass value of *R. apiculata* in plot A
74 was 36.12 ton ha⁻¹, B= 38.60 ton ha⁻¹, and C= 45.94 ton ha⁻¹, and the biomass value of
75 *S. alba* in plot A, B, and C was 56.27 ton ha⁻¹, 48. ton ha⁻¹, and 36.25 ton ha⁻¹
76 respectively. The value of carbon contents in *R. apiculata* in plot A, B, and C was 18.06
77 ton ha⁻¹, 19.30 ton ha⁻¹, and 22.97 ton ha⁻¹ successively. In addition, the value of carbon
78 content in *S. alba* was 28.13 ton ha⁻¹ in plot A, 24.47 ton ha⁻¹ in plot B, and 18.12 ton ha⁻¹
79 ¹ in plot C.

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93 INTRODUCTION

94 Indonesia has the biggest mangrove ecosystems in the world, consisting of 27% (16.9
95 million ha) from the total mangrove forests in the world, and becomes the center of the
96 distribution of species biodiversity and mangrove ecosystems (Spalding *et al.*, 2014),
97 however, it experienced rapid and dramatic destruction (Setyawan *et al.*, 2003).
98 Mangrove is a valuable treasure for Indonesian biodiversity with huge ecological and
99 economical significances (Hema and Devi, 2015). Mangrove ecosystems also have a
100 high economic value, either directly or indirectly, because the ecosystems have become
101 one of meaningful income sources for the society and the country.

102
103 Mangrove forest is a typical tropical and subtropical forest type, growing along the beach
104 and estuary affected by sea tides. Mangroves are generally found around coastal areas
105 protected from the onslaught of waves and gently sloping terrain. Mangroves optimally
106 grow in coastal areas with large estuary and in deltas whose water flow contains a lot of
107 mud. On the contrary, mangroves do not optimally grow in coastal areas with no estuary.
108 Mangrove is a valuable treasure for its biodiversity, ecologically and economically
109 (Hema and Devi, 2015). Thus, services, approaches, and improvements to nearby
110 society needs to be done in order to understand the mangrove ecosystems (Mukherjee
111 *et al.*, 2014; Nguyen *et al.*, 2019). The role of mangroves the natural hazards and it is
112 difficult for mangroves to grow in steep, choppy coasts with strong tidal currents
113 because it does not allow the deposition of mud that is needed as a substrate for its
114 growth (Spalding *et al.*, 2014). Reduced-impact logging method can directly decrease
115 emissions becaused using mono-cable winch on forest floors induced by logs skidding
116 on top soil and injured with bark broken intensity for remaining stands (Ruslim 2011;
117 Ruslim *et al.*, 2016; Chien, 2019).

118
119 The land of mangrove forests in terms of the habitat and the ecosystems is a diffused
120 environment that is formed by the encounter between marine environment and land
121 environment which have a big impact on human life or even for their ecosystem balance.
122 Since mangrove forest is always affected by excessive water throughout the year and is
123 sometimes interspersed with drying in some parts in a short time, it may involve a

124 chemical reaction of soil oxidation radicals Since mangrove forest growing in
125 inhospitable environment in tropics and sub-tropics are equipped with very efficient free
126 radical foraging system to withstand the variation of stress conditions (Thathoi *et al.*,
127 2013). Mangrove plants may grow in different types of soil; therefore, their vegetation,
128 species composition and structure may vary considerably at the global, regional, local
129 region (Sherman *et al.*, 2003)

130
131 The height and time of seawater flooding in particular locations during the high tide can
132 also determine the salinity. The salinity is of factors determining the spread of
133 mangroves. In addition, the salinity also becomes the limiting factor for particular
134 species. Even though some mangrove species have a high mechanism adaptation
135 towards salinity, however, if fresh water supply is not available, this will make soil and
136 water salinity reach an extreme condition which is potential to threaten its life (Chen and
137 Ye, 2014; Nyangon *et al.*, 2019).

138
139 Mangrove forests as any other forests have a significant role as a carbon dioxide (CO₂)
140 sink in the air. Carbon dioxide sink has a significant relation to tree biomass. Trees
141 during photosynthesis process absorb CO₂ and convert it into organic carbon
142 (carbohydrate) which is merged into the body of the trees. Mangrove can also provide
143 food and shelter for various organisms, either in land or in water (Ekka and Pandit,
144 2012).

145
146 Essentially, the atmosphere receives more carbon than it ejects, as a result of burning
147 fossil fuels, motor vehicles, and industrial machines which make carbon accumulated
148 (IPCC, 2003). On the other hand, tropical forest deforestation also contributes in
149 supplying carbon to the atmosphere (Defries at al., 2002). This function is a part of
150 ecosystem service which is not traded in the market but highly contributes to the human
151 welfares (Barbier *et al.*, 2011; Liqueete *et al.*, 2013; Ezebilo, 2016). Carbon stock was
152 estimated from mangrove biomass referred as 50% of the value of biomass (Komiyama
153 *et al.*, 2005). Measurement of biomass was done in a non-destructive way. It was
154 determined based on data from measurements of tree volume Bismark, 2008).

155 On the other hand, the amount of CO₂ absorption decreases as a result of deforestation,
156 the change of land use, and residential development. The carbon accumulation in the
157 atmosphere provokes greenhouse effects as sunlight shortwave trapped in the
158 atmosphere that increases the temperature of the earth atmosphere. One of the forest
159 ecosystems that is able to reduce the greenhouse effect and functions as climate
160 change mitigation is mangrove forest (Komiyama *et al.*, 2008). For the sake of human
161 beings, the result of our observation showed that the stretch of mangroves and corals is
162 the ecosystem that is most often rated, meanwhile the stretch of seaweed is not really
163 taken into account (Mehvar *et al.*, 2018).

164
165 During the high tide, the seawater often goes further to the inland. At this time the soil
166 absorbs various nutrients from underground water. Enrichment of the soil on the surface
167 can also occur through the movement of water. Therefore, the nature of the soil under
168 the mangrove vegetation is also related to the chemical components under the
169 groundwater. On the other hand, mangrove roots are essential for the coastal
170 environment due to its function that can retain the soil under the mangrove forest from
171 the seawater, so it can strengthen the coastline and maintain the land around the roots
172 as an environment that is suitable for marine life breed.

173 The height and time of seawater-flooding in Ngurah Rai Forest Park during the high tide
174 can determine salinity. The salinity is one of the determining factors of the mangroves
175 spread. In addition, the salinity also becomes the limiting factor for particular species.
176 Even though some mangrove species have a high mechanism adaptation towards
177 salinity, however, if freshwater supply is not available, this will make soil and water
178 salinity reach an extreme condition which is potential to threaten its life.

179 Based on the above descriptions, it can be stated that the spread of mangrove species
180 is mainly affected by the condition of the waters where it grows while the growth of
181 mangrove stands is influenced by edaphic conditions which cover physical
182 characteristics and soil fertility where it grows. Mangrove forests like any other forests
183 have a significant role including absorbing carbon dioxide (CO₂) in the air so that its
184 existence contributes to controlling climate change. The ability of mangrove forests in

185 absorbing CO₂ is depending on the amount of stands biomass and carbon content of the
186 soil where the forest grows. In order to support the function of Ngurah Rai Forest Park,
187 especially as a means of developing science and educational facilities supporting
188 cultivation, tourism, and recreation, a study that can reveal the relationship between
189 mangrove stands and their habitats is important to be conducted. From the above
190 background this study aims to: (i) How is the physical condition and soil fertility of the
191 mangrove forests in Ngurah Rai Forest Park and how many edaphic factors that affect
192 the growth of mangrove stands. (ii) To measure the physical characteristics, chemical
193 characteristics (pH, cation exchange capacity (CEC) and soil fertility (organic material
194 components, total Nitrogen) of the mangrove forest habitat in Ngurah Rai Forest Park (iii)
195 To evaluate the growth conditions of the mangrove forest habitat in Ngurah Rai Forest
196 Park, including the number of trees, tree height, tree diameter, basal area, stand volume,
197 stand biomass, and the content of carbon stands.

198

199

200 **MATERIALS AND METHODS**

201 *Time and Location*

202 The present study was conducted in mangrove forest located in the area of Kuta
203 Municipality forest park, Bali Province (Fig 1).

204

205 **Fig 1.** Research location (■), Kuta Municipality forest park, Bali Province, Indonesia

206

207 *Procedures*

208 As adjusted to the research goals and objectives, this study consisted of 1) the making
209 of transect lines from the seashore to the shore for the zoning of mangrove forest; 2) the
210 making of sample plots along the transect lines; 3) the determination of tree species in
211 the sample plots 4) measuring the tree diameter and height in the sample plots 5)
212 testing the edaphic nature (soil physic/chemistry) in the sample plots and 6) testing the
213 parameters of mangrove forest water such as substracts, salinity, water pH, and carbon
214 stock estimation. The sample plots were made by employing transect method with a size
215 of 20 m x 50 m for three plots along the beach. The measurement was conducted based

216 on commonly used criteria, which was the diameter of chest-tall tree trunks (130 cm) or
217 the topmost roots of the soil surface.

218 *Data analysis*

219 *Productivity of mangrove stand*

220 Data of mangrove species identification results were tabulated in Microsoft Excel to
221 calculate the potentials of mangrove species at the studied area. Analysis of mangrove
222 wood was done by calculating the total volume of standing stock (including height,
223 diameter, basal area, and volume).

224

225 *Basal area calculation*

226 The conversion of the diameter obtained by using a diameter measuring tool was done
227 by applying the following formula:

228

$$229 \quad g = \frac{1}{4} \pi d^2$$

230 With g = basal area (m^2); and d = diameter breast height (cm);

231

232 *Volume calculation*

233 The tree volume was measured by using Ruchaemi formula (2006) as follow:

234

$$235 \quad V = \frac{1}{4} \pi d^2 \times h \times f$$

236 With V = Tree volume (m^3); d = diameter breast height (cm); h = tree height (m) and f =
237 form factor

238

239 *Physical and chemical testing of the soil*

240 The method used for parameter analysis of physical and chemical properties of the soil
241 was based on Bogor soil research center and Wenworth scale. The place for soil
242 analysis was in the soil laboratory of the Forest Rehabilitation Center
243 Mulawarman University, Samarinda East Kalimantan.

244

245 **RESULT AND DISCUSSIONS**

246 *Soil Reaction (pH H₂O)*

247 The pH value of particular water and soil reflects the balance between acid and base
248 concentration in the water. The pH value of water is affected by some factors, such as
249 photosynthesis activity, biology activity, temperature, oxygen content, and the existence
250 of cations and anions in the water (Aksornkoe, 1993). The results of soil pH
251 measurement in sample plots are presented on the Table 1.

252
253 **Table 1. Test result data pH H₂O and of the soil in sample plots**

254
255 The Table 1 shows that the mangrove forest soil inspected had a varying pH value. Plot
256 C which was located closest to the beach had a neutral pH with highest average (7.49),
257 while plot B which was located between plot A and plot C had an acidic pH with much
258 lower value (4.99). On the other hand, plot A which was located furthest from the beach
259 also had a neutral pH with average value of 7.03. The low pH value of the soil in plot B
260 was because the mangrove stands in that plot produced more litter than in plot A and C.
261 Through the decomposition process, besides producing minerals, the litter also secreted
262 organic acid that made the soil pH become sour. The more litter produced in plot C than
263 in the other plots was also indicated by the more organic carbon contents available (plot
264 B= 2.60%; plot A= 2.10%; plot C= 0.81%).

265
266 The influence of frequency and time and the duration of water logging towards the pH
267 value of mangrove forest soil was also reported by Nursin *et al.*, (2014) through their
268 study in Balinggi sub-district, Parigi Moutong region, Central Sulawesi. The other studies
269 that revealed the same phenomenon were Ragil *at al.*, (2017) through their study in
270 mangrove forest in Mempawah Region, West Kalimantan. The result of this study about
271 mangrove soil pH was compared to the other related studies such as 7) found that the
272 mangrove soil pH in Muara Resort, Selangor, was 7.7, whereas Kamariah (2014) found
273 that the mangrove forest in Mamuju Region, West Sulawesi had a pH value of 5.98-6.12.
274 Onrizal and Kusmana (2008) informed soil and water quality take effect on mangrove
275 growth in mangrove rehabilitation activities at east coast of North Sumatera.

276 Regarding soil pH values in mangrove forests, Hasrun *et al.*, (2013) stated that the
277 water with pH value of < 4 is categorized as highly sour and potentially threaten the life

278 of organisms. On the other hand, the water with pH value of > 9.5 is classified as highly
279 alkaline and could also result in death for organisms and reduce productivity. On the
280 contrary, plants can easily absorb carbon when the soil has a neutral pH (Setiawan *et al.*,
281 2013).

282
283 The correlation of seawater pH and total volume is shown in details through the
284 following Fig 2 and Fig 3.

285
286 **Fig 2. The correlation of seawater pH and total volume of *Rhizophora alba* tree**

287
288 **Fig 3. The correlation of seawater pH and total volume of *R. apiculata* tree**

289
290 As shown on Fig. 2, the seawater pH was increasing from the direction of plot A (closest
291 to land) to plot c (closest to sea), and it affected the decreasing of the tree total volume.
292 From this phenomena, it can concluded that *S. alba* mangrove had a less tolerant nature
293 towards seawater pH on particular limits. On the contrary, Fig. 3 shows that the volume
294 of *R apiculata* tree increased as the seawater pH increased. It proved that this type of
295 mangrove was tolerant to the seawater pH.

296
297 **Organic Carbon (C)**

298 Soil organic matter is of soil components derived from the rest of dead animals and
299 plants, both in the form of original and weathered tissues. The main resources of soil
300 organic matter in the sample plots were the litters of mangrove stands such as the
301 components of leaves, twigs, branches, stems and roots. According to Lee *et al.*, (2014),
302 organic matter has a productive function to support plant biomass production and a
303 protective function to keep the soil fertility and soil biotic stability.

304
305 Generally, the soil C concentration of the sample plots had a status of very low to
306 moderate with values between 0.81 to 2.60%. the lowest C concentration was found in
307 plot C which was located closest to the beach. The higher frequency and duration of the
308 waterlogging in plot C do not only limit the chance of piles of dropping organic matter on

309 the forest floor, but also limit the rate of decomposition of organic matter on the forest
310 floor. Ferreira *et al.*, (2007) stated that the decomposition of soil organic matter under
311 mangrove stands is highly affected by frequency, duration of waterlogging, and
312 distribution of its subtract particle size.

313
314 The estimation of soil carbon concentration in mangrove forests in the study areas was
315 in line with that reported by Handoko at al., (2017) who conducted a study in Balinggi
316 sub-district, Parigi Region, Central Sulawesi. She found that soil carbon concentration in
317 that area was 0.34-2.34%. A higher figure was reported from a study by Ragil *et al.*,
318 (2017) stating that the soil C concentration was 3.99-5.05% (high to very high), based
319 on their study conducted in mangrove forest in Mempawah Region, West Kalimantan.

320
321 *Total Nitrogen*

322 Nitrogen is an essential element for plants, functioning to improve vegetative growth.
323 The main resource of N in forest mangrove soil is the litters produced by mangrove
324 stands as well as other dead organic material components that have been accumulated
325 on the forest floor. The decomposition of the organic matter to be minerals, including N,
326 is highly affected by inundation periodization. The anaerobic conditions when the floor
327 flooded causes litter decomposing microorganisms restricted, otherwise, in aerobic
328 conditions when the floor is not flooded, the microorganism activity increases. The total
329 N concentration in mangrove forest soil in the sample plots is presented on Table 1.

330
331 Table 1 shows that soil N concentration in the depth of 0-60 cm in the sample plots was
332 very low, only about 0.04-0.10%. In plot A and B, the soil N concentration in the depth of
333 0-30 cm was higher than that in the depth of 30-60 cm. However, in plot C, the soil N
334 concentration in both layers was similar. The impact of the flood on organic material
335 mineralization process to be N could be seen from the lower N concentration in the
336 depth of 0-30 cm in plot C which was bordering with the beach compared to plot A and B
337 respectively. Plot was located the furthest from the beach, whereas plot C was located
338 in between plot C and A.

339 The estimations of soil N concentration value as reported by the researchers are as
340 follows: 0.27-0.45% (status: moderate) in mangrove forest in Mangunharjo, Semarang
341 Region (Chrisyariati *et al.*, 2014); and 0.29-0.43% (status: moderate) in mangrove forest
342 in Mamuju Region, West Sulawesi (Malik *et al.*, 2019).

343

344 *Cation Exchange Capacity (CEC)*

345 Overall, the average value of CEC for the mangrove soil studied in the depth of 0-60 cm,
346 categorized as high, was 25.2 – 30.0 me 100g⁻¹. In plot A and B, the CEC value of
347 topsoil and subsoil was relatively similar, while in plot C there was a significant
348 difference. As mentioned before, there are two factors affecting the high and low of soil
349 CEC, namely organic matter content and its mineral clay content. The result shows that
350 the highest CEC value for mangrove forest soil in this study was in the depth of 0-30 cm
351 in plot C (31,6 me 100 g⁻¹). Since the soil organic matter content was lower than that in
352 the other plots (see Table 4), the factor causing the high CEC value of the soil in the
353 depth of 0-30 cm was the clay content which was higher than in plot B or plot A (Table
354 1). In the layer of 30-60 cm, the CEC value of the soil in plot C significantly decreased to
355 19.3 me 100g⁻¹ even though the clay content was not really different from that in the
356 layer of 0-30 cm (11.5%). This is interesting because despite its lower clay content,
357 10.6%, the soil in the depth of 30-60 cm in plot A had a higher CEC value (30.1 me
358 100g⁻¹) than in plot C. I may be because the soil in plot A had higher organic matter
359 content (2.10%) than in plot C (0.77%).

360

361 Cation Exchange Capacity (CEC) is the soil chemical nature highly related to the soil
362 fertility. The soil with higher CEC is able to absorb and provide nutrients better than the
363 soil with lower CEC. The soils with organic matter content or with higher clay content
364 consisted of higher CEC compared to the soils with lower or sandy organic matter
365 content (Soewandita, 2008). The CEC value of soil is influenced by the soil weathering
366 level, organic matter content and the number of alkali cations in the soil. The soil with
367 higher organic matter content had higher CEC, so did young soil with newly started
368 weathering level, and soils with further weathering levels had low CEC value.

369

370 *The Condition of Mangrove Forest Stands In Ngurah Rai Forest Park*

371 The mangrove in plot A (Distal zone or the furthest zone from sea), plot B (Middle zone or
372 middle zone), and plot C (Proximal zone, the closest zone from sea) was carried out an
373 inventory covering number of trees, diameter at breast height (DBH), the height of free
374 trunk (TBC), the total height (TTL), the width of basal area (LBD), and the total volume
375 (VT). Besides, the calculation was also done towards the amount of biomass and the
376 content of carbon stands in each of those researches. The types of mangrove available
377 in the research plots only consisted of *R. apiculata* and *S. alba*.

378

379 *The Density and Types of Tree Stands*

380 The number of trees in a research plot was not the same. Plot B had the most number of
381 trees, including 272 trees, each of 162 trees of *R. apiculata* type and 110 trees of *S.*
382 *alba*. Plot C had 220 trees, each of 110 trees of *R. apiculata* and *S. alba*. In the hectare
383 unit, the numbers of trees in each plot were: plot A 1.950 trees, plot C 2.200 trees and
384 plot B 2.720 trees, the total of trees 438 ha⁻¹ and 517 ha⁻¹ reached the study result in
385 Mentawir Village Balikpapan, Kalimantan Timur of 2,300 ha⁻¹, Lahjie *et al.*, 2019;
386 Kristiningrum *et al.*, (2019). The stand density of mangrove forests in eastern coast of
387 North Sumatera varied from 1,692 ind ha⁻¹ to 2,990 ind ha⁻¹ (Onrizal *et al.*, 2019a).

388

389 The density of mangrove tree stands in each plot tended to be influenced by each clay
390 content. Plot B with the highest tree density (2720 trees ha⁻¹), also had the highest clay
391 content (11,40-14,30%). Followed by plot C with the number of 2.200 trees ha⁻¹ and clay
392 content 11, 50-12,70%, and plot A with the number of 1950 trees ha⁻¹ and clay content
393 6,50-10,60%. As described by Hossain and Nuruddin (2016), clay fragment is a
394 supporting factor of the regeneration process, where the clay particle in the form of mud
395 will catch the mangrove fruit that falls when it is ripe. This process determined whether a
396 zone was dense or not.

397

398 Comparing the study results from Tolangara and Ahmad (2017) in Bacan mangrove
399 forest, Halmahera Selatan Regency which resulted in the density of the tree of 1.500 ha⁻¹
400 ¹ so the number of trees per hectare in Mangrove Forest in Tahura Ngurah Rai for the

401 three observing plots were considered denser. But if compare with the study result of
402 Handoko *et al.*, (2017) at 12 research plots of mangrove forest in the area of South
403 Rupert Island, Pekanbaru, with the density value ranges between 2.592 trees ha⁻¹ until
404 8.148 trees ha⁻¹, therefore the tree stands of mangrove forest in Tahura Ngurah Rai was
405 much lower.

406
407 The types of *R. apiculata* and *S. alba* were the two types of mangroves that were
408 available in all research plots lying from the seashore (plot C) to the land (plot B and plot
409 A). Generally outermost zone of mangrove with high salinity occupied by *Avicennia*
410 associated with *Sonneratia* spp., while *Rhizophora* was located in the middle zone and
411 *Bruguiera* grew in the furthest zone of the beach with much lower salinity. Onrizal *et al.*
412 (2019b) said in muddy areas with high salinity levels which can grow *R. apiculata*
413 species. The phenomenon of *Rhizophora* domination in the research area was suspected
414 to be related to the low salinity of its water ecosystem. The typical water salinity in the
415 research area of 14,8 -19,6‰ in reality was much lower than those reported by other
416 researcher. The factors that influence high and low water salinity were evaporation and
417 rainfall. The higher the level of evaporation of seawater, the higher the salinity would be.
418 The higher rainfall, then the lower salinity would be.

419
420 *Trunk Diameter*
421 Based on attachment 1-6, it was known that trunk diameter of tree type *R. apiculata* in
422 each research plot was : plot A = 8,3 ± 3,8 cm, plot B = 8,4 ± 2,8 cm and plot C 8,9 ± 3,3
423 cm then the average value of trunk diameter for the whole plots was 8,56 cm. in terms of
424 the diversity of trunk diameter of each plot, it can be concluded that the growth of trunk
425 diameter in plot A stands was more identical than other plots. Meanwhile, in plot C the
426 growth of trunk diameter was largely diverse.

427
428 *S. alba* type tended to have a bigger trunk diameter. In plot A, its value was = 10,4 ± 1,8
429 cm, plot b = 9,0 ± 3,8 cm, plot C = 8,5 ± 1,5 cm so the average value for all plots was 9,3
430 cm. Trunk diameter of *R. apiculata* was bigger in plot A and even smaller in plot B and
431 plot C which located further from the beach. Meanwhile, type *S. alba* showed the

432 opposite. The closer to the land, the bigger the diameter was. Due to that matter, it was
433 suspected that the growth of *R.apiculata* was better than the salinity in higher waters.

434
435 Climate affected the development of mangrove and the physical factor of its growing
436 place was substrate and waters. Further, Alwikado (2014) reported that climate also
437 affected the growth of mangrove through the light element, rainfall, temperature, and
438 wind. The diameter growth and mangrove diameter increment growth were also
439 influenced by many factors of its growing place including the substrate. The substrate in
440 this study referred to a substrate containing soft mud. Furthermore, Hastuti and
441 Budhahastuti (2016) added that growth was the result of the interaction of various
442 physiological processes. The physiological process referred to as photosynthesis,
443 respiration, and transpiration. While the results that were reported by Kusmana *et al.*,
444 (2003) in mangrove Center Lampung were obtained from the diameter value of 7,5 –
445 9,7 cm. Moreover, Pattipeilohy (2014) in Minahasa Utara Sub-district obtained the
446 diameter value of 11 cm.

447 448 *Tree Height*

449 As shown by its diameter growth, the average of total height growth of trees type *S. alba*
450 (15,99m) was bigger than tree type *R. apiculata* (12, 19 m). Hence, it can be concluded
451 that as a whole that the condition of mangrove habitats in the research area is more
452 suitable for *S. alba* than for *R. apiculata*.

453
454 The results of the total height growth of trees type *R. apiculata* in each plot was: plot A =
455 $13,08 \pm 2,34$ m, plot B = $10,57 \pm 2,91$ m, plot C = $12,91 \pm 2,68$ m while for type *R.*
456 *alba* plot A= $15, 58 \pm 5,99$ m, plot B = $16,28 \pm 5,88$ m, plot C = $16,11 \pm 1,9$ m. For type *R.*
457 *apiculata*, plot A resulted in a bigger height growth with a smaller coefficient of variation
458 than those grew in other plots. The height growth and diameter of tree is not only
459 depending on the space and surface canopy, relative humidity as well as root system,
460 but also influenced by climate and soil fertility. Cuenca *et al.*, (2015) stated the factors
461 were complex and affected towards the distribution and mangrove growth including

462 salinity, tidal drying, disturbance, warming, and predation. Meanwhile, Toknok (2006) in
463 Donggala obtained the value of 13-20 m..

464 *The Width of Basal Area*

465 According to the estimation conducted in the research location, Ngurah Rai Forest Park,
466 Denpasar, it was revealed that the widths of the basal area of *A. apiculata* in plot A, B,
467 and C were 0.006 m² tree⁻¹, 0.006 m² tree⁻¹, and 0.007 m² tree⁻¹ respectively. The
468 average width of the basal area was 0.006 m² tree⁻¹. On the other hand, the widths of
469 the basal area of *S. alba* were 0.009 m² tree⁻¹ in plot A, 0.008 m² tree⁻¹ in plot B, 0.006
470 m² tree⁻¹ in plot C, and 0.008 m² tree⁻¹ on average. Meanwhile, Aswita and Syahputra
471 (2012) on their study in Seuruway sub-district, Aceh Taming Region, Aceh Province,
472 reported that the width of the basal area of mangrove stands was 0.004 m² tree⁻¹.

473

474 *Stand Biomass and Carbon Content*

475 The result showed that the average biomass of mangrove forest stands in the research
476 location was 87.38 ton ha⁻¹, consisting of *R. apiculata* biomass of 40.22 ton ha⁻¹ (46%)
477 and *S. alba* biomass of 47.16 ton ha⁻¹ (54%). *S. alba* in plot A (located the furthest from
478 the beach) and plot B (located in the middle) were higher than in plot C (located closest
479 to the beach). The accumulation of the three plots was higher (12.7 ton ha⁻¹) compared
480 to the finding of the research conducted by Bindu *et al.*, (2018). As shown on Table 2, in
481 terms of the average number of trees in the three plots, actually, *S. alba* had a fewer
482 number (107 trees) than *R. apiculata* (131 trees), however, in terms of tree average
483 diameter and height (D=9.30 cm; T=15.99 m), *S. alba* had a bigger size than *R.*
484 *apiculata* (D=8.56 cm; T= 12.19 m).

485

486 **Table 2.** Biomass and carbon content of each species of mangrove at Plot A, Plot B
487 and Plot C.

488

489 Biomass is defined as the total number of organisms on the surface of a tree and is
490 measured by using the ton unit of dry weight per area (Brown, 2004). The amount of
491 biomass in particular mangrove forest is obtained from measuring the diameter, height,
492 and wood density of each type of mangroves (Rachmawati et al., 2014). Mangrove

493 ecosystem has an ecological function to absorb and store carbon. Mangroves absorb
494 CO₂ during the photosynthesis process and then change it into carbohydrate by storing
495 it in form of biomass in roots, stems, branches, and leaves. According to Kauffman *et al.*,
496 (2012), carbon stocks in mangrove forests are higher than that in any other forests,
497 where the biggest carbon stocks are contained in mangrove sediments. When
498 compared to the biomass estimation from other studies the biomass of mangrove forest
499 stands in research location was much lower. It may be affected by the difference of the
500 number of trees ha⁻¹, the size of stem diameter, height as well as the wood density of
501 types of mangroves making up of stands. Rachmawati *et al.*, (2014) revealed that the
502 biomass of mangrove stands in Wilayah Pesisir Muara Gembong, Bekasi Region was
503 108.6 ton ha⁻¹. Meanwhile according to Kristiningrum *et al.*, (2019) the average value of
504 mangrove forest carbon at the studied area in Mentawir Village is 50.73 tons C ha⁻¹. In
505 addition, Bachmid *et al.*, (2018) found that the biomass of mangrove stands in
506 Kuburaya Region, West Kalimantan, was 189.2 ton ha⁻¹. Kristiningrum *et al.*, 2019
507 informed the biomass of mangrove forests in Mentawir which is part of the Balikpapan
508 Bay Area is one and a half times higher than that in Siberut Island, West Sumatra, which
509 is 49.13 tons ha⁻¹ (Bismark 2008). Kusmana *et al.*, (2003) stated that muddy sediments
510 are generally richer in organic matter compared to sandy sediments.

511
512 The relation between organic carbon and total volume of *R. apiculata* and *S. alba* can be
513 seen at Fig 4 and Fig. 5.

514
515 **Fig 4. The relation between organic C and total volume of *S. alba***

516
517 **Fig 5. The relation between organic C and total volume of *R. apiculata***

518
519 Fig. 4 shows that in *S. alba* the organic C content was decreasing from plot A (closest to
520 land) to plot C (closest to sea), and so did the total volume of the trees. It can be
521 concluded that *S. alba* really needs organic C to increase its total volume. On the
522 contrary, Fig. 5 shows that in *R. apiculata* the organic C value decreased, however, the

523 tree total volume was increasing. It proves that *R. apiculata* is able survive in the areas
524 with lower organic C.

525
526 The average value of water pH was 7.03% in plot A, 4.99% in plot B, and 7.49% in plot
527 C. Furthermore, the organic C value was 2.1% in plot A, 2.6% in plot B, and 0.81% in
528 plot C. On the other hand, the total N value was 0.07% in plot A, 0.07% in plot B, and
529 0.04% in plot C. The CEC value was 30.0 me 100g⁻¹ in plot A, 25 me 100g⁻¹ in plot B,
530 and 25.4 me 100g⁻¹ in plot C. The basal area of *R. apiculata* was 0.006 m² tree⁻¹ in plot
531 A, 0.006 m² tree⁻¹ in plot B, and 0.007 m² tree⁻¹, whereas the basal area of *S. alba* was
532 0.009 m² tree⁻¹ in plot A, 0.008 m² tree⁻¹ in plot B, and 0.006 m² tree⁻¹ in plot C. The
533 biomass value per ha for *R. apiculata* was 36.12 ton ha⁻¹ in plot A, 38.60 ton ha⁻¹ in plot
534 B, and 36.25 ton ha⁻¹ in plot C, meanwhile the biomass value of *S. alba* was 56.27 ton
535 ha⁻¹ in plot A, 38.60 ton ha⁻¹ in plot B, and 36.25 ton ha⁻¹ in plot C. The value of carbon
536 stock per ha for *R. apiculata* was 18.06 ton ha⁻¹ in plot A, 19.20 ton ha⁻¹ in plot B, and
537 22.97 ton ha⁻¹ in plot C. On the other hand, the value carbon stock per ha for *S. alba*
538 was 28.13 ton ha⁻¹ in plot A, 24.47 ton ha⁻¹ in plot B, and 22.97 ton ha⁻¹ in plot C.

539

540 **CONCLUSIONS**

541 The results showed that the diameter of *R. apiculata* type in plot A, B, and C was
542 8.3±2.3 cm, 8.4±2.8 cm, and 8.9±3.3 cm respectively, and that of *Rhizophora alba* type
543 in plot A, B, and C was 10.4±1.8 cm, 9.0±3.8 cm, and 8.5±1.5 cm respectively. The
544 biomass value of *R. apiculata* in plot A was 36.12 ton ha⁻¹, B= 38.60 ton ha⁻¹, and C=
545 45.94 ton ha⁻¹, and the biomass value of *S. alba* in plot A, B, and C was 56.27 ton ha⁻¹,
546 48. Ton ha⁻¹, and 36.25 ton ha⁻¹ respectively. The value of carbon contents in *R.*
547 *apiculata* in plot A, B, and C was 18.06 ton ha⁻¹, 19.30 ton ha⁻¹, and 22.97 ton ha⁻¹
548 ¹successively. In addition, the value of carbon content in *S. alba* was 28.13 ton ha⁻¹ in
549 plot A, 24.47 ton ha⁻¹ in plot B, and 18.12 ton ha⁻¹ in plot C.

550

551

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556

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Table 1. Test result data pH H₂O and of the soil in sample plots

No	Parameter	Methode	Unit	Data Analisis								
				Plot A			Plot B			Plot C		
				0-30	30-60	Average	0-30	30-60	Average	0-30	30-60	Average
1	pH H ₂ O	Electrode	-	6.74	7.32	7.03	5.38	4.59	4.99	7.57	7.40	7.49
2	Ca ⁺⁺	AAS	meq100gr ⁻¹	8.59	9.93	9.26	2.22	2.35	2.29	10.80	1.89	6.35
3	Mg ⁺⁺	AAS	meq100gr ⁻¹	4.56	4.28	4.42	4.49	4.56	4.53	8.13	5.83	6.98
4	Na ⁺	AAS	meq100gr ⁻¹	13.38	13.23	13.305	13.44	13.44	13.44	10.18	9.39	9.79
5	K ⁺	AAS	meq100gr ⁻¹	2.89	2.24	2.565	3.70	4.12	3.91	1.89	1.66	1.78
6	KTK	Hitung	meq100gr ⁻¹	30.00	30.10	30.05	24.51	25.97	25.24	31.58	19.27	25.43
9	Total N	Kjeldahl	%	0.10	0.04	0.07	0.08	0.06	0.07	0.04	0.04	0.04
10	C. Organic	Walkley and Black	%	2.29	1.92	2.105	2.71	2.49	2.60	0.84	0.77	0.81

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741 **Table 2.** Biomass and carbon content of each species of mangrove at Plot A, Plot B
742 and Plot C.

No	Plot	Biomass (ton ha ⁻¹)		Carbon (ton ha ⁻¹)	
		<i>R.</i>	<i>S.</i>	<i>R.</i>	<i>S.</i>
		<i>apiculata</i>	<i>alba</i>	<i>R. apiculata</i>	<i>alba</i>
1	Plot A	36.12	56.27	18.06	28.13
2	Plot B	38.60	48.95	19.30	24.47
3	Plot C	45.94	36.25	22.97	18.12
	Total	120.66	141.47	60.33	70.72
	Average	40.22	47.16	20.11	23.57
	Average total	87.38		43.68	

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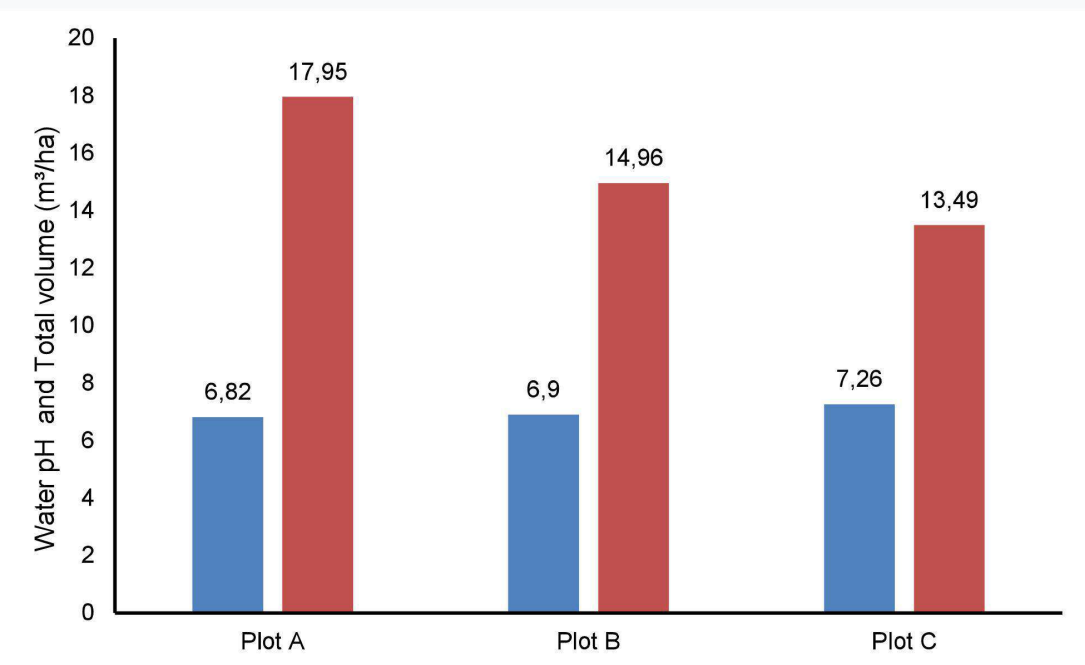
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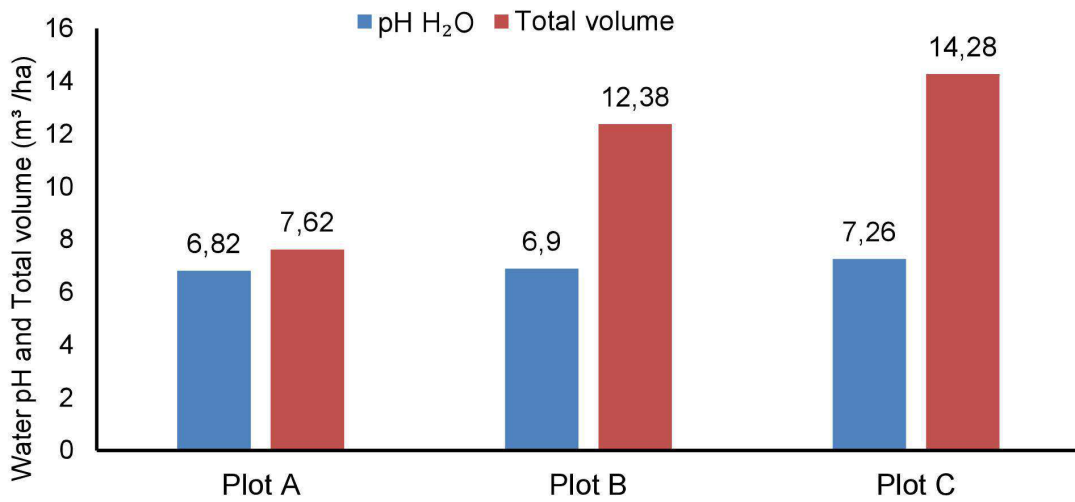
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Fig 2. The correlation of seawater pH and total volume of *Rhizophora alba* tree



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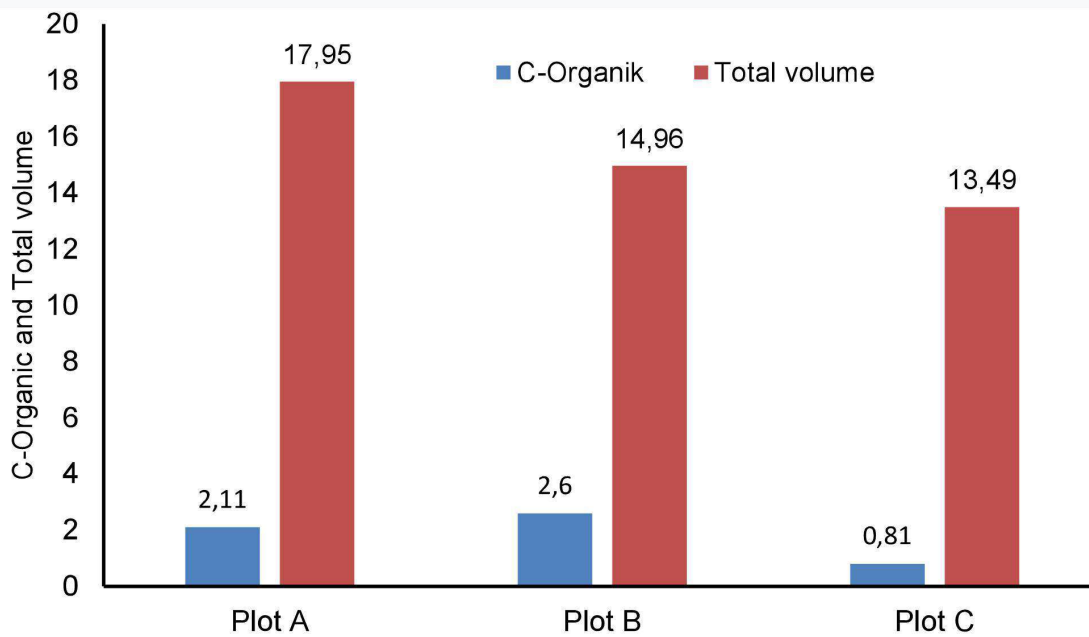
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768 **Fig 3.** The correlation of seawater pH and total volume of *R. apiculata* tree

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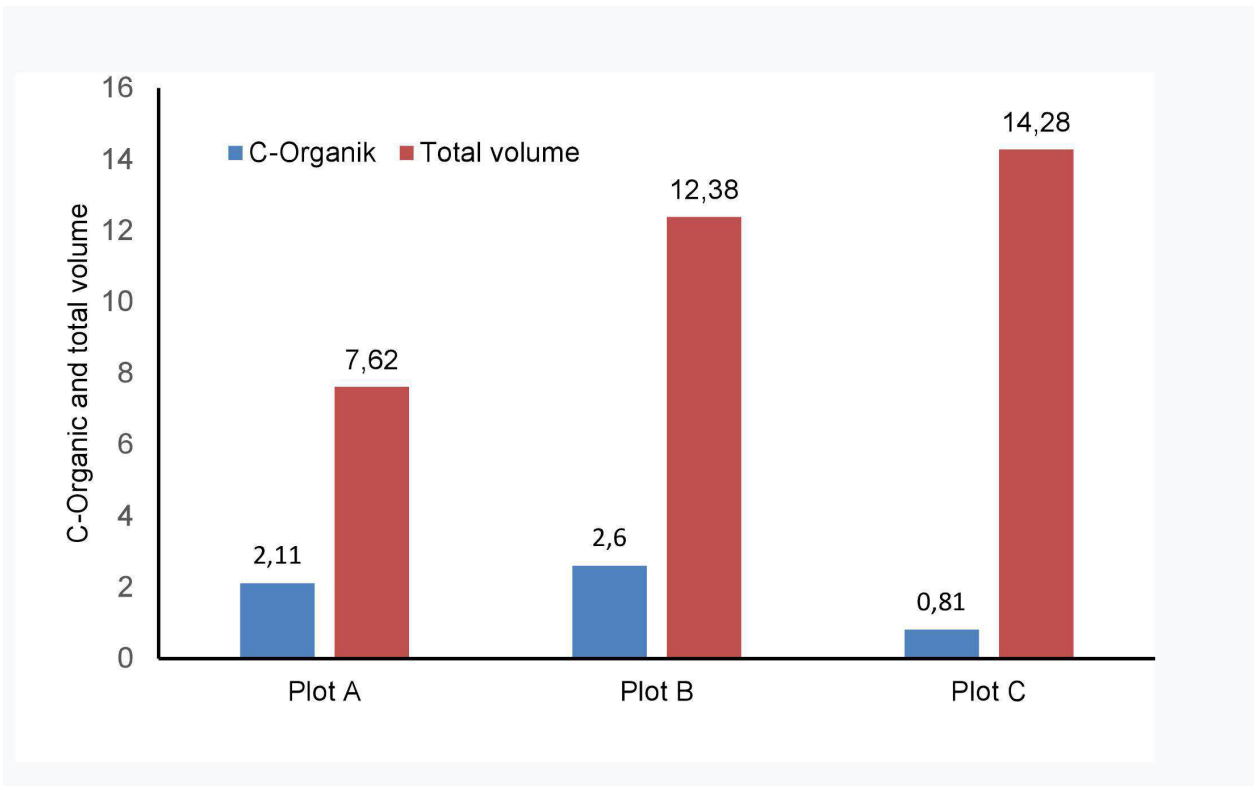


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773 **Fig 4.** The relation between organic C and total volume of *S. alba*

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Fig 5. The relation between organic C and total volume of *R. apiculata*

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Carbon stocks of *Rhizophora apiculata* and *Sonneratia alba* of mangrove forest in Ngurah Rai Forest Park, Bali Province, Indonesia

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Key words: carbon growth and stocks, edaphic, salinity.

Abstract

Mangrove forest is a typical tropical and subtropical forest, which is affected by sea tides. This study aimed to investigate the effect of pH, seawater salinity, and edaphic factors on carbon growth and stocks. The research plots were developed by employing transect method with a size of 20m x 50m for three plots along the beach. The pH value of plot A= 6.82, plot B= 6.90, and plot C= 7.26. The analysis of CEC elements found that plot A= 30.0, plot B= 25.2, and plot C= 25.4. The value of N-Total showed that plot A= 0.07, plot B= 0,07, and plot C= 0.04. The value of organic carbon was plot A= 2.1, plot B= 2.6, and plot C= 0.81. The results showed that the diameter of *Rhizophora apiculata* type in plot A, B, and C was 8.3±2.3cm, 8.4±2.8cm, and 8.9±3.3cm respectively, and that of *Sonneratia alba* type in plot A, B, and C was 10.4±1.8cm, 9.0±3.8cm, and 8.5±1.5cm respectively. The biomass value of *R. apiculata* in plot A was 36.12ton ha⁻¹, B= 38.60ton ha⁻¹, and C= 45.94ton ha⁻¹, and the biomass value of *S. alba* in plot A, B, and C was 56.27ton ha⁻¹, 48.ton ha⁻¹, and 36.25ton ha⁻¹ respectively. The value of carbon contents in *R. apiculata* in plot A, B, and C was 18.06ton ha⁻¹, 19.30ton ha⁻¹, and 22.97ton ha⁻¹ successively. In addition, the value of carbon content in *S. alba* was 28.13ton ha⁻¹ in plot A, 24.47ton ha⁻¹ in plot B, and 18.12ton ha⁻¹ in plot C.

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Introduction

Indonesia has the biggest mangrove ecosystems in the world, consisting of 27% (16.9 million ha) from the total mangrove forests in the world, and becomes the center of the distribution of species biodiversity and mangrove ecosystems (Spalding *et al.*, 2014), however, it experienced rapid and dramatic destruction (Setyawan *et al.*, 2003). Mangrove is a valuable treasure for Indonesian biodiversity with huge ecological and economical significances (Hema and Devi, 2015). Mangrove ecosystems also have a high economic value, either directly or indirectly, because the ecosystems have become one of meaningful income sources for the society and the country.

Mangrove forest is a typical tropical and subtropical forest type, growing along the beach and estuary affected by sea tides. Mangroves are generally found around coastal areas protected from the onslaught of waves and gently sloping terrain. Mangroves optimally grow in coastal areas with large estuary and in deltas whose water flow contains a lot of mud. On the contrary, mangroves do not optimally grow in coastal areas with no estuary. Mangrove is a valuable treasure for its biodiversity, ecologically and economically (Hema and Devi, 2015). Thus, services, approaches, and improvements to nearby society needs to be done in order to understand the mangrove ecosystems (Mukherjee *et al.*, 2014; Nguyen *et al.*, 2019). The role of mangroves the natural hazards and it is difficult for mangroves to grow in steep, choppy coasts with strong tidal currents because it does not allow the deposition of mud that is needed as a substrate for its growth (Spalding *et al.*, 2014). Reduced-impact logging method can directly decrease emissions because using mono-cable winch on forest floors induced by logs skidding on top soil and injured with bark broken intensity for remaining stands (Ruslim 2011; Ruslim *et al.*, 2016; Chien, 2019).

The land of mangrove forests in terms of the habitat and the ecosystems is a diffused environment that is formed by the encounter between marine

environment and land environment which have a big impact on human life or even for their ecosystem balance. Since mangrove forest is always affected by excessive water throughout the year and is sometimes interspersed with drying in some parts in a short time, it may involve a chemical reaction of soil oxidation radicals. Since mangrove forest growing in inhospitable environment in tropics and sub-tropics are equipped with very efficient free radical foraging system to withstand the variation of stress conditions (Thathoi *et al.*, 2013). Mangrove plants may grow in different types of soil; therefore, their vegetation, species composition and structure may vary considerably at the global, regional, local region (Sherman *et al.*, 2003)

The height and time of seawater flooding in particular locations during the high tide can also determine the salinity. The salinity is of factors determining the spread of mangroves. In addition, the salinity also becomes the limiting factor for particular species. Even though some mangrove species have a high mechanism adaptation towards salinity, however, if fresh water supply is not available, this will make soil and water salinity reach an extreme condition which is potential to threaten its life (Chen and Ye, 2014; Nyangon *et al.*, 2019).

Mangrove forests as any other forests have a significant role as a carbon dioxide (CO₂) sink in the air. Carbon dioxide sink has a significant relation to tree biomass. Trees during photosynthesis process absorb CO₂ and convert it into organic carbon (carbohydrate) which is merged into the body of the trees. Mangrove can also provide food and shelter for various organisms, either in land or in water (Ekka and Pandit, 2012).

Essentially, the atmosphere receives more carbon than it ejects, as a result of burning fossil fuels, motor vehicles, and industrial machines which make carbon accumulated (IPCC, 2003). On the other hand, tropical forest deforestation also contributes in supplying carbon to the atmosphere (Defries *et al.*,

2002). This function is a part of ecosystem service which is not traded in the market but highly contributes to the human welfares (Barbier *et al.*, 2011; Liquete *et al.*, 2013; Ezebilo, 2016). Carbon stock was estimated from mangrove biomass referred as 50% of the value of biomass (Komiya *et al.*, 2005). Measurement of biomass was done in a non-destructive way. It was determined based on data from measurements of tree volume Bismark, 2008).

On the other hand, the amount of CO₂ absorption decreases as a result of deforestation, the change of land use, and residential development. The carbon accumulation in the atmosphere provokes greenhouse effects as sunlight shortwave trapped in the atmosphere that increases the temperature of the earth atmosphere. One of the forest ecosystems that is able to reduce the greenhouse effect and functions as climate change mitigation is mangrove forest (Komiya *et al.*, 2008). For the sake of human beings, the result of our observation showed that the stretch of mangroves and corals is the ecosystem that is most often rated, meanwhile the stretch of seaweed is not really taken into account (Mehvar *et al.*, 2018).

During the high tide, the seawater often goes further to the inland. At this time the soil absorbs various nutrients from underground water. Enrichment of the soil on the surface can also occur through the movement of water. Therefore, the nature of the soil under the mangrove vegetation is also related to the chemical components under the groundwater. On the other hand, mangrove roots are essential for the coastal environment due to its function that can retain the soil under the mangrove forest from the seawater, so it can strengthen the coastline and maintain the land around the roots as an environment that is suitable for marine life breed.

The height and time of seawater-flooding in Ngurah Rai Forest Park during the high tide can determine salinity. The salinity is one of the determining factors of the mangroves spread. In addition, the salinity also becomes the limiting factor for particular species.

Even though some mangrove species have a high mechanism adaptation towards salinity, however, if freshwater supply is not available, this will make soil and water salinity reach an extreme condition which is potential to threaten its life.

Based on the above descriptions, it can be stated that the spread of mangrove species is mainly affected by the condition of the waters where it grows while the growth of mangrove stands is influenced by edaphic conditions which cover physical characteristics and soil fertility where it grows. Mangrove forests like any other forests have a significant role including absorbing carbon dioxide (CO₂) in the air so that its existence contributes to controlling climate change. The ability of mangrove forests in absorbing CO₂ is depending on the amount of stands biomass and carbon content of the soil where the forest grows. In order to support the function of Ngurah Rai Forest Park, especially as a means of developing science and educational facilities supporting cultivation, tourism, and recreation, a study that can reveal the relationship between mangrove stands and their habitats is important to be conducted. From the above background this study aims to: (i) How is the physical condition and soil fertility of the mangrove forests in Ngurah Rai Forest Park and how many edaphic factors that affect the growth of mangrove stands. (ii) To measure the physical characteristics, chemical characteristics (pH, cation exchange capacity (CEC) and soil fertility (organic material components, total Nitrogen) of the mangrove forest habitat in Ngurah Rai Forest Park (iii) To evaluate the growth conditions of the mangrove forest habitat in Ngurah Rai Forest Park, including the number of trees, tree height, tree diameter, basal area, stand volume, stand biomass, and the content of carbon stands.

Materials and methods

Time and Location

The present study was conducted in mangrove forest located in the area of Kuta Municipality forest park, Bali Province (Fig 1).



Fig. 1. Research location (■), Kuta Municipality forest park, Bali Province, Indonesia.

Procedures

As adjusted to the research goals and objectives, this study consisted of 1) the making of transect lines from the seashore to the shore for the zoning of mangrove forest; 2) the making of sample plots along the transect lines; 3) the determination of tree species in the sample plots 4) measuring the tree diameter and height in the sample plots 5) testing the edaphic nature (soil physic/chemistry) in the sample plots and 6) testing the parameters of mangrove forest water such as subtracts, salinity, water pH, and carbon stock estimation. The sample plots were made by employing transect method with a size of 20m x 50m for three plots along the beach. The measurement was conducted based on commonly used criteria, which was the diameter of chest-tall tree trunks (130cm) or the topmost roots of the soil surface.

Data analysis

Productivity of mangrove stand

Data of mangrove species identification results were tabulated in Microsoft Excel to calculate the potentials of mangrove species at the studied area. Analysis of mangrove wood was done by calculating the total volume of standing stock (including height, diameter, basal area, and volume).

Basal area calculation

The conversion of the diameter obtained by using a diameter measuring tool was done by applying the following formula:

$$g = \frac{1}{4} \pi d^2$$

With g = basal area (m^2); and d = diameter breast height (cm);

Volume calculation

The tree volume was measured by using Ruchaemi formula (2006) as follow:

$$V = \frac{1}{4} \pi d^2 \times h \times f$$

With V = Tree volume (m^3); d = diameter breast height (cm); h = tree height (m) and f = form factor

Physical and chemical testing of the soil

The method used for parameter analysis of physical and chemical properties of the soil was based on Bogor soil research center and Wenworth scale. The place for soil analysis was in the soil laboratory of the Forest Rehabilitation Center Mulawarman University, Samarinda East Kalimantan.

Result and discussions

Soil Reaction (pH H₂O)

The pH value of particular water and soil reflects the balance between acid and base concentration in the

water. The pH value of water is affected by some factors, such as photosynthesis activity, biology activity, temperature, oxygen content, and the existence of

cations and anions in the water (Aksornkoae, 1993). The results of soil pH measurement in sample plots are presented on the Table 1.

Table 1. Test result data pH H₂O and of the soil in sample plots.

No	Parameter	Method	Unit	Data Analisis								
				Plot A			Plot B			Plot C		
				0-30	30-60	Average	0-30	30-60	Average	0-30	30-60	Average
1	pH H ₂ O	Electrode	-	6.74	7.32	7.03	5.38	4.59	4.99	7.57	7.40	7.49
2	Ca ⁺⁺	AAS	meq100gr ⁻¹	8.59	9.93	9.26	2.22	2.35	2.29	10.80	1.89	6.35
3	Mg ⁺⁺	AAS	meq100gr ⁻¹	4.56	4.28	4.42	4.49	4.56	4.53	8.13	5.83	6.98
4	Na ⁺	AAS	meq100gr ⁻¹	13.38	13.23	13.305	13.44	13.44	13.44	10.18	9.39	9.79
5	K ⁺	AAS	meq100gr ⁻¹	2.89	2.24	2.565	3.70	4.12	3.91	1.89	1.66	1.78
6	KTK	Hitung	meq100gr ⁻¹	30.00	30.10	30.05	24.51	25.97	25.24	31.58	19.27	25.43
9	Total N	Kjeldahl	%	0.10	0.04	0.07	0.08	0.06	0.07	0.04	0.04	0.04
10	C. Organic	Walkley and Black	%	2.29	1.92	2.105	2.71	2.49	2.60	0.84	0.77	0.81

The Table 1 shows that the mangrove forest soil inspected had a varying pH value. Plot C which was located closest to the beach had a neutral pH with highest average (7.49), while plot B which was located between plot A and plot C had an acidic pH with much lower value (4.99). On the other hand, plot A which was located furthest from the beach also had a neutral pH with average value of 7.03. The low pH value of the soil in plot B was because the mangrove stands in that plot produced more litter than in plot A and C. Through the decomposition process, besides producing minerals, the litter also secreted organic acid that made the soil pH become sour. The more litter produced in plot C than in the other plots was also indicated by the more organic carbon contents available (plot B= 2.60%; plot A= 2.10%; plot C= 0.81%).

The influence of frequency and time and the duration of water logging towards the pH value of mangrove forest soil was also reported by Nursin *et al.* (2014) through their study in Balinggi sub-district, Parigi Moutong region, Central Sulawesi. The other studies that revealed the same phenomenon were Ragil *et al.* (2017) through their study in mangrove forest in Mempawah Region, West Kalimantan. The result of this study about mangrove soil pH was compared to the other related studies such as 7) found that the mangrove soil pH in Muara Resort, Selangor, was 7.7, whereas Kamariah (2014) found that the mangrove forest in Mamuju Region, West Sulawesi had a pH

value of 5.98-6.12. Onrizal and Kusmana (2008) informed soil and water quality take effect on mangrove growth in mangrove rehabilitation activities at east coast of North Sumatera.

Regarding soil pH values in mangrove forests, Hasrun *et al.* (2013) stated that the water with pH value of < 4 is categorized as highly sour and potentially threaten the life of organisms. On the other hand, the water with pH value of > 9.5 is classified as highly alkaline and could also result in death for organisms and reduce productivity. On the contrary, plants can easily absorb carbon when the soil has a neutral pH (Setiawan *et al.*, 2013).

The correlation of seawater pH and total volume is shown in details through the following Fig 2 and Fig 3.

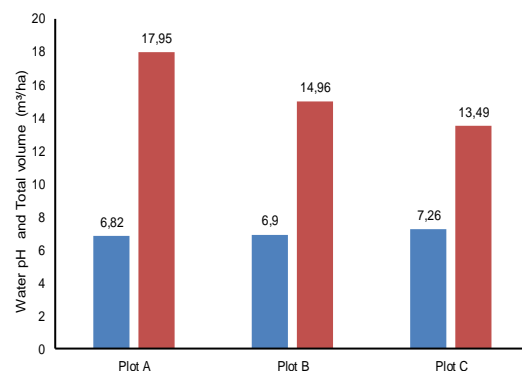


Fig. 2. The correlation of seawater pH and total volume of *Rhizophora alba* tree.

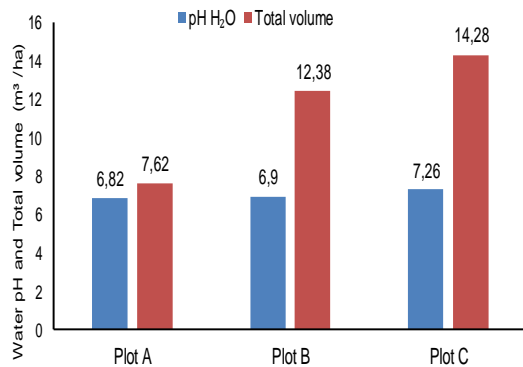


Fig. 3. The correlation of seawater pH and total volume of *R. apiculata* tree.

As shown on Fig. 2, the seawater pH was increasing from the direction of plot A (closest to land) to plot c (closest to sea), and it affected the decreasing of the tree total volume. From this phenomena, it can concluded that *S. alba* mangrove had a less tolerant nature towards seawater pH on particular limits. On the contrary, Fig. 3 shows that the volume of *R. apiculata* tree increased as the seawater pH increased. It proved that this type of mangrove was tolerant to the seawater pH.

Organic Carbon (C)

Soil organic matter is of soil components derived from the rest of dead animals and plants, both in the form of original and weathered tissues. The main resources of soil organic matter in the sample plots were the litters of mangrove stands such as the components of leaves, twigs, branches, stems and roots. According to Lee *et al.* (2014), organic matter has a productive function to support plant biomass production and a protective function to keep the soil fertility and soil biotic stability.

Generally, the soil C concentration of the sample plots had a status of very low to moderate with values between 0.81 to 2.60%. the lowest C concentration was found in plot C which was located closest to the beach. The higher frequency and duration of the waterlogging in plot C do not only limit the chance of piles of dropping organic matter on the forest floor,

but also limit the rate of decomposition of organic matter on the forest floor. Ferreira *et al.* (2007) stated that the decomposition of soil organic matter under mangrove stands is highly affected by frequency, duration of waterlogging, and distribution of its substract particle size.

The estimation of soil carbon concentration in mangrove forests in the study areas was in line with that reported by Handoko *et al.* (2017) who conducted a study in Balinggi sub-district, Parigi Region, Central Sulawesi. She found that soil carbon concentration in that area was 0.34-2.34%. A higher figure was reported from a study by Ragil *et al.* (2017) stating that the soil C concentration was 3.99-5.05% (high to very high), based on their study conducted in mangrove forest in Mempawah Region, West Kalimantan.

Total Nitrogen

Nitrogen is an essential element for plants, functioning to improve vegetative growth. The main resource of N in forest mangrove soil is the litters produced by mangrove stands as well as other dead organic material components that have been accumulated on the forest floor. The decomposition of the organic matter to be minerals, including N, is highly affected by inundation periodization. The anaerobic conditions when the floor flooded causes litter decomposing microorganisms restricted, otherwise, in aerobic conditions when the floor is not flooded, the microorganism activity increases. The total N concentration in mangrove forest soil in the sample plots is presented on Table 1.

Table 1 shows that soil N concentration in the depth of 0-60cm in the sample plots was very low, only about 0.04-0.10%. In plot A and B, the soil N concentration in the depth of 0-30cm was higher than that in the depth of 30-60cm. However, in plot C, the soil N concentration in both layers was similar. The impact of the flood on organic material mineralization process to be N could be seen from the lower N concentration in the depth of 0-30cm in plot C which was bordering with the beach compared to plot A and B respectively. Plot was located

the furthest from the beach, whereas plot C was located in between plot C and A.

The estimations of soil N concentration value as reported by the researchers are as follows: 0.27-0.45% (status: moderate) in mangrove forest in Mangunharjo, Semarang Region (Chrisyariati *et al.*, 2014); and 0.29-0.43% (status: moderate) in mangrove forest in Mamuju Region, West Sulawesi (Malik *et al.*, 2019).

Cation Exchange Capacity (CEC)

Overall, the average value of CEC for the mangrove soil studied in the depth of 0-60cm, categorized as high, was 25.2 – 30.0 me 100g⁻¹. In plot A and B, the CEC value of topsoil and subsoil was relatively similar, while in plot C there was a significant difference. As mentioned before, there are two factors affecting the high and low of soil CEC, namely organic matter content and its mineral clay content. The result shows that the highest CEC value for mangrove forest soil in this study was in the depth of 0-30cm in plot C (31,6 me 100g⁻¹). Since the soil organic matter content was lower than that in the other plots (see Table 4), the factor causing the high CEC value of the soil in the depth of 0-30cm was the clay content which was higher than in plot B or plot A (Table 1). In the layer of 30-60cm, the CEC value of the soil in plot C significantly decreased to 19.3 me 100g⁻¹ even though the clay content was not really different from that in the layer of 0-30cm (11.5%). This is interesting because despite its lower clay content, 10.6%, the soil in the depth of 30-60cm in plot A had a higher CEC value (30.1 me 100g⁻¹) than in plot C. I may be because the soil in plot A had higher organic matter content (2.10%) than in plot C (0.77%).

Cation Exchange Capacity (CEC) is the soil chemical nature highly related to the soil fertility. The soil with higher CEC is able to absorb and provide nutrients better than the soil with lower CEC. The soils with organic matter content or with higher clay content consisted of higher CEC compared to the soils with lower or sandy organic matter content (Soewandita,

2008). The CEC value of soil is influenced by the soil weathering level, organic matter content and the number of alkali cations in the soil. The soil with higher organic matter content had higher CEC, so did young soil with newly started weathering level, and soils with further weathering levels had low CEC value.

The Condition of Mangrove Forest Stands In Ngurah Rai Forest Park

The mangrove in plot A (Distal zone or the furthest zone from sea), plot B (Middle zone or middle zone), and plot C (Proximal zone, the closest zone from sea) was carried out an inventory covering number of trees, diameter at breast height (DBH), the height of free trunk (TBC), the total height (TTL), the width of basal area (LBD), and the total volume (VT). Besides, the calculation was also done towards the amount of biomass and the content of carbon stands in each of those researches. The types of mangrove available in the research plots only consisted of *R. apiculata* and *S. alba*.

The Density and Types of Tree Stands

The number of trees in a research plot was not the same. Plot B had the most number of trees, including 272 trees, each of 162 trees of *R. apiculata* type and 110 trees of *S. alba*. Plot C had 220 trees, each of 110 trees of *R. apiculata* and *S. alba*. In the hectare unit, the numbers of trees in each plot were: plot A 1.950trees, plot C 2.200 trees and plot B 2.720trees, the total of trees 438ha⁻¹ and 517ha⁻¹ reached the study result in Mentawir Village Balikpapan, Kalimantan Timur of 2,300ha⁻¹, Lahjie *et al.*, 2019; Kristiningrum *et al.* (2019). The stand density of mangrove forests in eastern coast of North Sumatera varied from 1,692ind ha⁻¹ to 2,990ind ha⁻¹ (Onrizal *et al.*, 2019a).

The density of mangrove tree stands in each plot tended to be influenced by each clay content. Plot B with the highest tree density (2720 trees ha⁻¹), also had the highest clay content (11,40-14,30%). Followed by plot C with the number of 2.200 trees ha⁻¹ and clay content 11, 50-12,70%, and plot A with the number of 1950 trees ha⁻¹ and clay content 6,50-10,60%. As described by Hossain and Nuruddin (2016), clay

fragment is a supporting factor of the regeneration process, where the clay particle in the form of mud will catch the mangrove fruit that falls when it is ripe. This process determined whether a zone was dense or not.

Comparing the study results from Tolangara and Ahmad (2017) in Bacan mangrove forest, Halmahera Selatan Regency which resulted in the density of the tree of 1.500 ha^{-1} so the number of trees per hectare in Mangrove Forest in Tahura Ngurah Rai for the three observing plots were considered denser. But if compare with the study result of Handoko *et al.* (2017) at 12 research plots of mangrove forest in the area of South Rupa Island, Pekanbaru, with the density value ranges between $2.592 \text{ trees ha}^{-1}$ until $8.148 \text{ trees ha}^{-1}$, therefore the tree stands of mangrove forest in Tahura Ngurah Rai was much lower.

The types of *R. apiculata* and *S. alba* were the two types of mangroves that were available in all research plots lying from the seashore (plot C) to the land (plot B and plot A). Generally outermost zone of mangrove with high salinity occupied by *Avicennia* associated with *Sonneratia* spp., while *Rhizophora* was located in the middle zone and *Bruguiera* grew in the furthest zone of the beach with much lower salinity. Onrizal *et al.* (2019b) said in muddy areas with high salinity levels which can grow *R. apiculata* species. The phenomenon of *Rhizophora* domination in the research area was suspected to be related to the low salinity of its water ecosystem. The typical water salinity in the research area of 14,8 -19,6% in reality was much lower than those reported by other researcher. The factors that influence high and low water salinity were evaporation and rainfall. The higher the level of evaporation of seawater, the higher the salinity would be. The higher rainfall, then the lower salinity would be.

Trunk Diameter

Based on attachment 1-6, it was known that trunk diameter of tree type *R. apiculata* in each research plot was : plot A = $8,3 \pm 3,8\text{cm}$, plot B = $8,4 \pm 2,8\text{cm}$ and plot C $8,9 \pm 3,3\text{cm}$ then the average value of

trunk diameter for the whole plots was $8,56\text{cm}$. in terms of the diversity of trunk diameter of each plot, it can be concluded that the growth of trunk diameter in plot A stands was more identical than other plots. Meanwhile, in plot C the growth of trunk diameter was largely diverse.

S. alba type tended to have a bigger trunk diameter. In plot A, its value was = $10,4 \pm 1,8\text{cm}$, plot b = $9,0 \pm 3,8\text{cm}$, plot C = $8,5 \pm 1,5\text{cm}$ so the average value for all plots was $9,3\text{cm}$. Trunk diameter of *R. apiculata* was bigger in plot A and even smaller in plot B and plot C which located further from the beach. Meanwhile, type *S. alba* showed the opposite. The closer to the land, the bigger the diameter was. Due to that matter, it was suspected that the growth of *R.apiculata* was better that the salinity in higher waters.

Climate affected the development of mangrove and the physical factor of its growing place was substrate and waters. Further, Alwikado (2014) reported that climate also affected the growth of mangrove through the light element, rainfall, temperature, and wind. The diameter growth and mangrove diameter increment growth were also influenced by many factors of its growing place including the substrate. The substrate in this study referred to a substrate containing soft mud. Furthermoe, Hastuti and Budhihastuti (2016) added that growth was the result of the interaction of various physiological processes. The physiological process referred to as photosynthesis, respiration, and transpiration. While the results that were reported by Kusmana *et al.* (2003) in mangrove Center Lampung were obtained from the diameter value of $7,5 - 9,7\text{cm}$. Moreover, Pattipeilohy (2014) in Minahasa Utara Sub-district obtained the diameter value of 11cm .

Tree Height

As shown by its diameter growth, the average of total height growth of trees type *S. alba* ($15,99\text{m}$) was bigger than tree type *R. apiculata* ($12,19\text{m}$). Hence, it can be concluded that as a whole that the condition of mangrove habitats in the research area is more suitable for *S. alba* than for *R. apiculata*.

The results of the total height growth of trees type *R. apiculata* in each plot was: plot A = 13,08 ± 2,34m, plot B = 10,57 ± 2,91m, plot C = 12,91 ± 2,68m while for type *R. alba* plot A = 15,58 ± 5,99m, plot B = 16,28 ± 5,88m, plot C = 16,11 ± 1,9m. For type *R. apiculata*, plot A resulted in a bigger height growth with a smaller coefficient of variation than those grew in other plots. The height growth and diameter of tree is not only depending on the space and surface canopy, relative humidity as well as root system, but also influenced by climate and soil fertility. Cuenca *et al.* (2015) stated the factors were complex and affected towards the distribution and mangrove growth including salinity, tidal drying, disturbance, warming, and predation. Meanwhile, Toknok (2006) in Donggala obtained the value of 13-20m.

The Width of Basal Area

According to the estimation conducted in the research location, Ngurah Rai Forest Park, Denpasar, it was revealed that the widths of the basal area of *A. apiculata* in plot A, B, and C were 0.006m² tree⁻¹, 0.006m² tree⁻¹, and 0.007m² tree⁻¹ respectively. The average width of the basal area was 0.006m² tree⁻¹. On the other hand, the widths of the basal area of *S. alba* were 0.009m² tree⁻¹ in plot A, 0.008m² tree⁻¹ in plot B, 0.006m² tree⁻¹ in plot C, and 0.008m² tree⁻¹ on average. Meanwhile, Aswita and Syahputra (2012) on their study in Seuruy sub-district, Aceh Taming Region, Aceh Province, reported that the width of the basal area of mangrove stands was 0.004m² tree⁻¹.

Stand Biomass and Carbon Content

The result showed that the average biomass of mangrove forest stands in the research location was 87.38ton ha⁻¹, consisting of *R. apiculata* biomass of 40.22ton ha⁻¹ (46%) and *S. alba* biomass of 47.16ton ha⁻¹ (54%). *S. alba* in plot A (located the furthest from the beach) and plot B (located in the middle) were higher than in plot C (located closest to the beach). The accumulation of the three plots was higher (12.7ton ha⁻¹) compared to the finding of the research conducted by Bindu *et al.* (2018). As shown on Table 2, in terms of the average number of trees in the three

plots, actually, *S. alba* had a fewer number (107 trees) than *R. apiculata* (131 trees), however, in terms of tree average diameter and height (D=9.30cm; T=15.99 m), *S. alba* had a bigger size than *R. apiculata* (D=8.56cm; T= 12.19 m).

Table 2. Biomass and carbon content of each species of mangrove at Plot A, Plot B and Plot C.

No	Plot	Biomass (ton ha ⁻¹)		Carbon (ton ha ⁻¹)	
		<i>R. apiculata</i>	<i>S. alba</i>	<i>R. apiculata</i>	<i>S. alba</i>
1	Plot A	36.12	56.27	18.06	28.13
2	Plot B	38.60	48.95	19.30	24.47
3	Plot C	45.94	36.25	22.97	18.12
	Total	120.66	141.47	60.33	70.72
	Average	40.22	47.16	20.11	23.57
	Average total	87.38		43.68	

Biomass is defined as the total number of organisms on the surface of a tree and is measured by using the ton unit of dry weight per area (Brown, 2004). The amount of biomass in particular mangrove forest is obtained from measuring the diameter, height, and wood density of each type of mangroves (Rachmawati *et al.*, 2014). Mangrove ecosystem has an ecological function to absorb and store carbon. Mangroves absorb CO₂ during the photosynthesis process and then change it into carbohydrate by storing it in form of biomass in roots, stems, branches, and leaves. According to Kauffman *et al.* (2012), carbon stocks in mangrove forests are higher than that in any other forests, where the biggest carbon stocks are contained in mangrove sediments. When compared to the biomass estimation from other studies the biomass of mangrove forest stands in research location was much lower. It may be affected by the difference of the number of trees ha⁻¹, the size of stem diameter, height as well as the wood density of types of mangroves making up of stands. Rachmawati *et al.* (2014) revealed that the biomass of mangrove stands in Wilayah Pesisir Muara Gembong, Bekasi Region was 108.6ton ha⁻¹. Meanwhile according to Kristiningrum *et al.* (2019) the average value of mangrove forest carbon at the studied area in Mentawir Village is 50.73tons C ha⁻¹. In addition, Bachmid *et al.* (2018) found that the biomass of

mangrove stands in Kuburaya Region, West Kalimantan, was 189.2ton ha⁻¹. Kristiningrum *et al.*, 2019 informed the biomass of mangrove forests in Mentawir which is part of the Balikpapan Bay Area is one and a half times higher than that in Siberut Island, West Sumatra, which is 49.13tons ha⁻¹ (Bismark 2008). Kusmana *et al.* (2003) stated that muddy sediments are generally richer in organic matter compared to sandy sediments.

The relation between organic carbon and total volume of *R. apiculata* and *S. alba* can be seen at Fig 4 and Fig. 5.

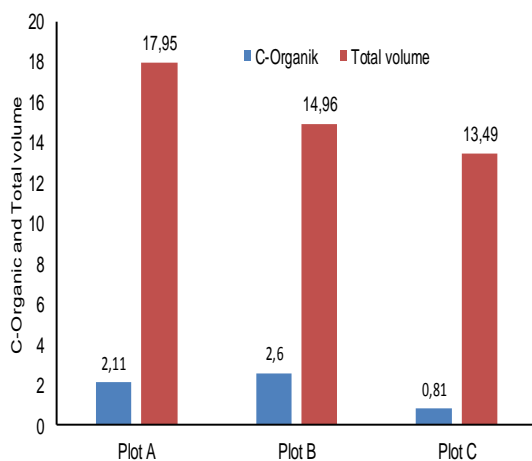


Fig. 4. The relation between organic C and total volume of *S. Alba*.

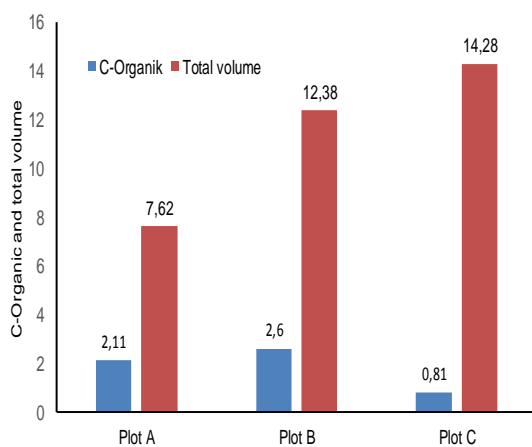


Fig. 5. The relation between organic C and total volume of *R. apiculata*.

Fig. 4 shows that in *S. alba* the organic C content was decreasing from plot A (closest to land) to plot C (closest to sea), and so did the total volume of the trees. It can be concluded that *S. alba* really needs organic C to increase its total volume. On the contrary, Fig. 5 shows that in *R. apiculata* the organic C value decreased, however, the tree total volume was increasing. It proves that *R. apiculata* is able survive in the areas with lower organic C.

The average value of water pH was 7.03% in plot A, 4.99% in plot B, and 7.49% in plot C. Furthermore, the organic C value was 2.1% in plot A, 2.6% in plot B, and 0.81% in plot C. On the other hand, the total N value was 0.07% in plot A, 0.07% in plot B, and 0.04% in plot C. The CEC value was 30.0 me 100g⁻¹ in plot A, 25 me 100g⁻¹ in plot B, and 25.4 me 100g⁻¹ in plot C. The basal area of *R. apiculata* was 0.006 m² tree⁻¹ in plot A, 0.006 m² tree⁻¹ in plot B, and 0.007 m² tree⁻¹, whereas the basal area of *S. alba* was 0.009 m² tree⁻¹ in plot A, 0.008 m² tree⁻¹ in plot B, and 0.006 m² tree⁻¹ in plot C. The biomass value per ha for *R. apiculata* was 36.12ton ha⁻¹ in plot A, 38.60ton ha⁻¹ in plot B, and 36.25ton ha⁻¹ in plot C, meanwhile the biomass value of *S. alba* was 56.27ton ha⁻¹ in plot A, 38.60ton ha⁻¹ in plot B, and 36.25ton ha⁻¹ in plot C. The value of carbon stock per ha for *R. apiculata* was 18.06ton ha⁻¹ in plot A, 19.20ton ha⁻¹ in plot B, and 22.97ton ha⁻¹ in plot C. On the other hand, the value carbon stock per ha for *S. alba* was 28.13ton ha⁻¹ in plot A, 24.47ton ha⁻¹ in plot B, and 22.97ton ha⁻¹ in plot C.

Conclusions

The results showed that the diameter of *R. apiculata* type in plot A, B, and C was 8.3±2.3cm, 8.4±2.8cm, and 8.9±3.3cm respectively, and that of *Rhizophora alba* type in plot A, B, and C was 10.4±1.8cm, 9.0±3.8cm, and 8.5±1.5cm respectively. The biomass value of *R. apiculata* in plot A was 36.12ton ha⁻¹, B= 38.60ton ha⁻¹, and C= 45.94ton ha⁻¹, and the biomass value of *S. alba* in plot A, B, and C was 56.27ton ha⁻¹, 48.ton ha⁻¹, and 36.25ton ha⁻¹ respectively. The value of carbon contents in *R. apiculata* in plot A, B, and C was 18.06ton ha⁻¹, 19.30ton ha⁻¹, and 22.97ton ha⁻¹

successively. In addition, the value of carbon content in *S. alba* was 28.13ton ha⁻¹ in plot A, 24.47ton ha⁻¹ in plot B, and 18.12ton ha⁻¹ in plot C.

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RESEARCH PAPER

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Carbon stocks of *Rhizophora apiculata* and *Sonneratia alba* of mangrove forest in Ngurah Rai Forest Park, Bali Province, Indonesia

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Key words: Carbon growth and stocks, Edaphic, Salinity

Abstract

Mangrove forest is a typical tropical and subtropical forest, which is affected by sea tides. This study aimed to investigate the effect of pH, seawater salinity, and edaphic factors on carbon growth and stocks. The research plots were developed by employing transect method with a size of 20m x 50m for three plots along the beach. The pH value of plot A= 6.82, plot B= 6.90, and plot C= 7.26. The analysis of CEC elements found that plot A= 30.0, plot B= 25.2, and plot C= 25.4. The value of N-Total showed that plot A= 0.07, plot B= 0.07, and plot C= 0.04. The value of organic carbon was plot A= 2.1, plot B= 2.6, and plot C= 0.81. The results showed that the diameter of *Rhizophora apiculata* type in plot A, B, and C was 8.3±2.3cm, 8.4±2.8cm, and 8.9±3.3cm respectively, and that of *Sonneratia alba* type in plot A, B, and C was 10.4±1.8cm, 9.0±3.8cm, and 8.5±1.5cm respectively. The biomass value of *R. apiculata* in plot A was 36.12ton ha⁻¹, B= 38.60ton ha⁻¹, and C= 45.94ton ha⁻¹, and the biomass value of *S. alba* in plot A, B, and C was 56.27ton ha⁻¹, 48.ton ha⁻¹, and 36.25ton ha⁻¹ respectively. The value of carbon contents in *R. apiculata* in plot A, B, and C was 18.06ton ha⁻¹, 19.30ton ha⁻¹, and 22.97ton ha⁻¹ successively. In addition, the value of carbon content in *S. alba* was 28.13ton ha⁻¹ in plot A, 24.47ton ha⁻¹ in plot B, and 18.12ton ha⁻¹ in plot C.

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Introduction

Indonesia has the biggest mangrove ecosystems in the world, consisting of 27% (16.9 million ha) from the total mangrove forests in the world, and becomes the center of the distribution of species biodiversity and mangrove ecosystems (Spalding *et al.*, 2014), however, it experienced rapid and dramatic destruction (Setyawan *et al.*, 2003). Mangrove is a valuable treasure for Indonesian biodiversity with huge ecological and economical significances (Hema and Devi, 2015). Mangrove ecosystems also have a high economic value, either directly or indirectly, because the ecosystems have become one of meaningful income sources for the society and the country.

Mangrove forest is a typical tropical and subtropical forest type, growing along the beach and estuary affected by sea tides. Mangroves are generally found around coastal areas protected from the onslaught of waves and gently sloping terrain. Mangroves optimally grow in coastal areas with large estuary and in deltas whose water flow contains a lot of mud. On the contrary, mangroves do not optimally grow in coastal areas with no estuary. Mangrove is a valuable treasure for its biodiversity, ecologically and economically (Hema and Devi, 2015). Thus, services, approaches, and improvements to nearby society needs to be done in order to understand the mangrove ecosystems (Mukherjee *et al.*, 2014; Nguyen *et al.*, 2019). The role of mangroves the natural hazards and it is difficult for mangroves to grow in steep, choppy coasts with strong tidal currents because it does not allow the deposition of mud that is needed as a substrate for its growth (Spalding *et al.*, 2014). Reduced-impact logging method can directly decrease emissions because using mono-cable winch on forest floors induced by logs skidding on top soil and injured with bark broken intensity for remaining stands (Ruslim 2011; Ruslim *et al.*, 2016; Chien, 2019).

The land of mangrove forests in terms of the habitat and the ecosystems is a diffused environment that is formed by the encounter between marine environment and land environment which have a big

impact on human life or even for their ecosystem balance. Since mangrove forest is always affected by excessive water throughout the year and is sometimes interspersed with drying in some parts in a short time, it may involve a chemical reaction of soil oxidation radicals. Since mangrove forest growing in inhospitable environment in tropics and sub-tropics are equipped with very efficient free radical foraging system to withstand the variation of stress conditions (Thathoi *et al.*, 2013). Mangrove plants may grow in different types of soil; therefore, their vegetation, species composition and structure may vary considerably at the global, regional, local region (Sherman *et al.*, 2003).

The height and time of seawater flooding in particular locations during the high tide can also determine the salinity. The salinity is of factors determining the spread of mangroves. In addition, the salinity also becomes the limiting factor for particular species. Even though some mangrove species have a high mechanism adaptation towards salinity, however, if fresh water supply is not available, this will make soil and water salinity reach an extreme condition which is potential to threaten its life (Chen and Ye, 2014; Nyangon *et al.*, 2019).

Mangrove forests as any other forests have a significant role as a carbon dioxide (CO₂) sink in the air. Carbon dioxide sink has a significant relation to tree biomass. Trees during photosynthesis process absorb CO₂ and convert it into organic carbon (carbohydrate) which is merged into the body of the trees. Mangrove can also provide food and shelter for various organisms, either in land or in water (Ekka and Pandit, 2012).

Essentially, the atmosphere receives more carbon than it ejects, as a result of burning fossil fuels, motor vehicles, and industrial machines which make carbon accumulated (IPCC, 2003). On the other hand, tropical forest deforestation also contributes in supplying carbon to the atmosphere (Defries *et al.*, 2002). This function is a part of ecosystem service which is not traded in the market but highly

contributes to the human welfares (Barbier *et al.*, 2011; Liqueete *et al.*, 2013; Ezebilo, 2016). Carbon stock was estimated from mangrove biomass referred as 50% of the value of biomass (Komiya *et al.*, 2005). Measurement of biomass was done in a non-destructive way. It was determined based on data from measurements of tree volume Bismark, 2008).

On the other hand, the amount of CO₂ absorption decreases as a result of deforestation, the change of land use, and residential development. The carbon accumulation in the atmosphere provokes greenhouse effects as sunlight shortwave trapped in the atmosphere that increases the temperature of the earth atmosphere. One of the forest ecosystems that is able to reduce the greenhouse effect and functions as climate change mitigation is mangrove forest (Komiya *et al.*, 2008). For the sake of human beings, the result of our observation showed that the stretch of mangroves and corals is the ecosystem that is most often rated, meanwhile the stretch of seaweed is not really taken into account (Mehvar *et al.*, 2018).

During the high tide, the seawater often goes further to the inland. At this time the soil absorbs various nutrients from underground water. Enrichment of the soil on the surface can also occur through the movement of water. Therefore, the nature of the soil under the mangrove vegetation is also related to the chemical components under the groundwater. On the other hand, mangrove roots are essential for the coastal environment due to its function that can retain the soil under the mangrove forest from the seawater, so it can strengthen the coastline and maintain the land around the roots as an environment that is suitable for marine life breed.

The height and time of seawater-flooding in Ngurah Rai Forest Park during the high tide can determine salinity. The salinity is one of the determining factors of the mangroves spread. In addition, the salinity also becomes the limiting factor for particular species. Even though some mangrove species have a high mechanism adaptation towards salinity, however, if freshwater supply is not available, this will make soil

and water salinity reach an extreme condition which is potential to threaten its life.

Based on the above descriptions, it can be stated that the spread of mangrove species is mainly affected by the condition of the waters where it grows while the growth of mangrove stands is influenced by edaphic conditions which cover physical characteristics and soil fertility where it grows. Mangrove forests like any other forests have a significant role including absorbing carbon dioxide (CO₂) in the air so that its existence contributes to controlling climate change.

The ability of mangrove forests in absorbing CO₂ is depending on the amount of stands biomass and carbon content of the soil where the forest grows. In order to support the function of Ngurah Rai Forest Park, especially as a means of developing science and educational facilities supporting cultivation, tourism and recreation, a study that can reveal the relationship between mangrove stands and their habitats is important to be conducted. From the above background this study aims to: (i) How is the physical condition and soil fertility of the mangrove forests in Ngurah Rai Forest Park and how many edaphic factors that affect the growth of mangrove stands. (ii) To measure the physical characteristics, chemical characteristics (pH, cation exchange capacity (CEC) and soil fertility (organic material components, total Nitrogen) of the mangrove forest habitat in Ngurah Rai Forest Park (iii) To evaluate the growth conditions of the mangrove forest habitat in Ngurah Rai Forest Park, including the number of trees, tree height, tree diameter, basal area, stand volume, stand biomass, and the content of carbon stands.

Materials and methods

Time and Location

The present study was conducted in mangrove forest located in the area of Kuta Municipality forest park, Bali Province (Fig 1).

Procedures

As adjusted to the research goals and objectives, this study consisted of 1) the making of transect lines from

the seashore to the shore for the zoning of mangrove forest; 2) the making of sample plots along the transect lines; 3) the determination of tree species in the sample plots 4) measuring the tree diameter and height in the sample plots 5) testing the edaphic nature (soil physic/chemistry) in the sample plots and 6) testing the parameters of mangrove forest water such as

subtracts, salinity, water pH, and carbon stock estimation. The sample plots were made by employing transect method with a size of 20m x 50m for three plots along the beach. The measurement was conducted based on commonly used criteria, which was the diameter of chest-tall tree trunks (130cm) or the topmost roots of the soil surface.



Fig. 1. Research location (■), Kuta Municipality forest park, Bali Province, Indonesia.

Data analysis

Productivity of mangrove stand

Data of mangrove species identification results were tabulated in Microsoft Excel to calculate the potentials of mangrove species at the studied area. Analysis of mangrove wood was done by calculating the total volume of standing stock (including height, diameter, basal area, and volume).

Basal area calculation

The conversion of the diameter obtained by using a diameter measuring tool was done by applying the following formula:

$$g = \frac{1}{4} \pi d^2$$

With g = basal area (m²); and d = diameter breast height (cm);

Volume calculation

The tree volume was measured by using Ruchaemi formula (2006) as follow:

$$v = \frac{1}{4} \pi d^2 \times h \times f$$

With V = Tree volume (m³); d = diameter breast height (cm); h = tree height (m) and f = form factor

Physical and chemical testing of the soil

The method used for parameter analysis of physical and chemical properties of the soil was based on Bogor soil research center and Wenworth scale. The place for soil analysis was in the soil laboratory of the Forest Rehabilitation Center Mulawarman University, Samarinda East Kalimantan.

Result and discussions

Soil Reaction (pH H₂O)

The pH value of particular water and soil reflects the balance between acid and base concentration in the water. The pH value of water is affected by some factors, such as photosynthesis activity, biology activity, temperature, oxygen content, and the existence of cations and anions in the water (Aksornkoae, 1993). The results of soil pH measurement in sample plots are presented on the Table 1.

Table 1. Test result data pH H₂O and of the soil in sample plots.

No	Parameter	Methods	Unit	Data Analysis								
				Plot A			Plot B			Plot C		
				0-30	30-60	Average	0-30	30-60	Average	0-30	30-60	Average
1	pH H ₂ O	Electrode	-	6.74	7.32	7.03	5.38	4.59	4.99	7.57	7.40	7.49
2	Ca ⁺⁺	AAS	meq100gr ⁻¹	8.59	9.93	9.26	2.22	2.35	2.29	10.80	1.89	6.35
3	Mg ⁺⁺	AAS	meq100gr ⁻¹	4.56	4.28	4.42	4.49	4.56	4.53	8.13	5.83	6.98
4	Na ⁺	AAS	meq100gr ⁻¹	13.38	13.23	13.305	13.44	13.44	13.44	10.18	9.39	9.79
5	K ⁺	AAS	meq100gr ⁻¹	2.89	2.24	2.565	3.70	4.12	3.91	1.89	1.66	1.78
6	KTK	Hitung	meq100gr ⁻¹	30.00	30.10	30.05	24.51	25.97	25.24	31.58	19.27	25.43
9	Total N	Kjeldahl	%	0.10	0.04	0.07	0.08	0.06	0.07	0.04	0.04	0.04
10	C. Organic	Walkley and Black	%	2.29	1.92	2.105	2.71	2.49	2.60	0.84	0.77	0.81

The Table 1 shows that the mangrove forest soil inspected had a varying pH value. Plot C which was located closest to the beach had a neutral pH with highest average (7.49), while plot B which was located between plot A and plot C had an acidic pH with much lower value (4.99). On the other hand, plot A which was located furthest from the beach also had a neutral pH with average value of 7.03. The low pH value of the soil in plot B was because the mangrove stands in that plot produced more litter than in plot A and C. Through the decomposition process, besides producing minerals, the litter also secreted organic acid that made the soil pH become sour. The more litter produced in plot C than in the other plots was also indicated by the more organic carbon contents available (plot B= 2.60%; plot A= 2.10%; plot C= 0.81%).

The influence of frequency and time and the duration of water logging towards the pH value of mangrove forest soil was also reported by Nursin *et al.* (2014) through their study in Balinggi sub-district, Parigi Moutong region, Central Sulawesi. The other studies that revealed the same phenomenon were Ragil *et al.* (2017) through their study in mangrove forest in Mempawah Region, West Kalimantan. The result of this study about mangrove soil pH was compared to the other related studies such as 7) found that the mangrove soil pH in Muara Resort, Selangor, was 7.7, whereas Kamariah (2014) found that the mangrove forest in Mamuju Region, West Sulawesi had a pH value of 5.98-6.12. Onrizal and Kusmana (2008) informed soil and water quality take effect on mangrove growth in mangrove rehabilitation activities at east coast of North Sumatera. Regarding soil pH values in mangrove forests, Hasrun *et al.*

(2013) stated that the water with pH value of < 4 is categorized as highly sour and potentially threaten the life of organisms. On the other hand, the water with pH value of > 9.5 is classified as highly alkaline and could also result in death for organisms and reduce productivity. On the contrary, plants can easily absorb carbon when the soil has a neutral pH (Setiawan *et al.*, 2013).

The correlation of seawater pH and total volume is shown in details through the following Fig 2 and Fig 3.

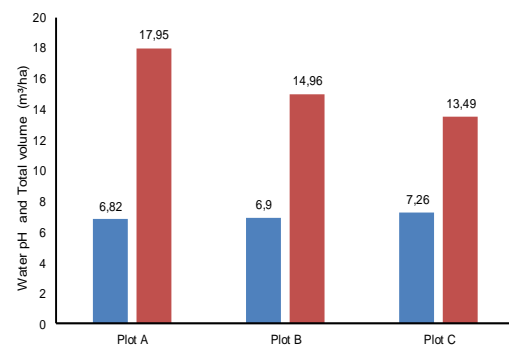


Fig. 2. The correlation of seawater pH and total volume of *Rhizophora alba* tree.

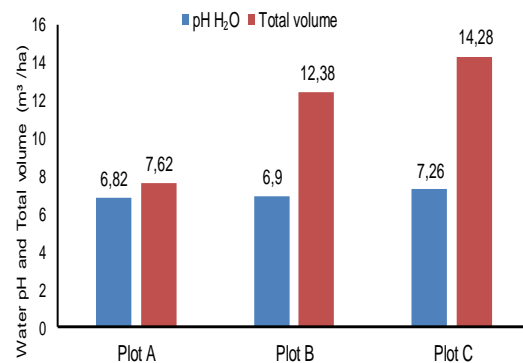


Fig. 3. The correlation of seawater pH and total volume of *R. apiculata* tree.

As shown on Fig. 2, the seawater pH was increasing from the direction of plot A (closest to land) to plot c (closest to sea), and it affected the decreasing of the tree total volume. From this phenomena, it can concluded that *S. alba* mangrove had a less tolerant nature towards seawater pH on particular limits. On the contrary, Fig. 3 shows that the volume of *R apiculata* tree increased as the seawater pH increased. It proved that this type of mangrove was tolerant to the seawater pH.

Organic Carbon (C)

Soil organic matter is of soil components derived from the rest of dead animals and plants, both in the form of original and weathered tissues. The main resources of soil organic matter in the sample plots were the litters of mangrove stands such as the components of leaves, twigs, branches, stems and roots. According to Lee *et al.* (2014), organic matter has a productive function to support plant biomass production and a protective function to keep the soil fertility and soil biotic stability.

Generally, the soil C concentration of the sample plots had a status of very low to moderate with values between 0.81 to 2.60%. the lowest C concentration was found in plot C which was located closest to the beach. The higher frequency and duration of the waterlogging in plot C do not only limit the chance of piles of dropping organic matter on the forest floor, but also limit the rate of decomposition of organic matter on the forest floor. Ferreira *et al.* (2007) stated that the decomposition of soil organic matter under mangrove stands is highly affected by frequency, duration of waterlogging, and distribution of its subtract particle size. The estimation of soil carbon concentration in mangrove forests in the study areas was in line with that reported by Handoko *et al.* (2017) who conducted a study in Balinggi sub-district, Parigi Region, Central Sulawesi. She found that soil carbon concentration in that area was 0.34-2.34%. A higher figure was reported from a study by Ragil *et al.* (2017) stating that the soil C concentration was 3.99-5.05% (high to very high), based on their study conducted in mangrove forest in Mempawah Region, West Kalimantan.

Total Nitrogen

Nitrogen is an essential element for plants, functioning to improve vegetative growth. The main resource of N in forest mangrove soil is the litters produced by mangrove stands as well as other dead organic material components that have been accumulated on the forest floor. The decomposition of the organic matter to be minerals, including N, is highly affected by inundation periodization. The anaerobic conditions when the floor flooded causes litter decomposing microorganisms restricted, otherwise, in aerobic conditions when the floor is not flooded, the microorganism activity increases. The total N concentration in mangrove forest soil in the sample plots is presented on Table 1.

Table 1 shows that soil N concentration in the depth of 0-60cm in the sample plots was very low, only about 0.04-0.10%. In plot A and B, the soil N concentration in the depth of 0-30cm was higher than that in the depth of 30-60cm. However, in plot C, the soil N concentration in both layers was similar. The impact of the flood on organic material mineralization process to be N could be seen from the lower N concentration in the depth of 0-30cm in plot C which was bordering with the beach compared to plot A and B respectively. Plot was located the furthest from the beach, whereas plot C was located in between plot C and A.

The estimations of soil N concentration value as reported by the researchers are as follows: 0.27-0.45% (status: moderate) in mangrove forest in Mangunharjo, Semarang Region (Chrisyariati *et al.*, 2014); and 0.29-0.43% (status: moderate) in mangrove forest in Mamuju Region, West Sulawesi (Malik *et al.*, 2019).

Cation Exchange Capacity (CEC)

Overall, the average value of CEC for the mangrove soil studied in the depth of 0-60cm, categorized as high, was 25.2 – 30.0 me 100g⁻¹. In plot A and B, the CEC value of topsoil and subsoil was relatively similar, while in plot C there was a significant difference. As mentioned before, there are two factors affecting the high and low of soil CEC, namely organic matter content and its mineral clay content.

The result shows that the highest CEC value for mangrove forest soil in this study was in the depth of 0-30cm in plot C (31,6 me 100g⁻¹). Since the soil organic matter content was lower than that in the other plots (see Table 4), the factor causing the high CEC value of the soil in the depth of 0-30cm was the clay content which was higher than in plot B or plot A (Table 1).

In the layer of 30-60cm, the CEC value of the soil in plot C significantly decreased to 19.3 me 100g⁻¹ even though the clay content was not really different from that in the layer of 0-30cm (11.5%). This is interesting because despite its lower clay content, 10.6%, the soil in the depth of 30-60cm in plot A had a higher CEC value (30.1 me 100g⁻¹) than in plot C. I may be because the soil in plot A had higher organic matter content (2.10%) than in plot C (0.77%).

Cation Exchange Capacity (CEC) is the soil chemical nature highly related to the soil fertility. The soil with higher CEC is able to absorb and provide nutrients better than the soil with lower CEC. The soils with organic matter content or with higher clay content consisted of higher CEC compared to the soils with lower or sandy organic matter content (Soewandita, 2008). The CEC value of soil is influenced by the soil weathering level, organic matter content and the number of alkali cations in the soil. The soil with higher organic matter content had higher CEC, so did young soil with newly started weathering level, and soils with further weathering levels had low CEC value.

The Condition of Mangrove Forest Stands In Ngurah Rai Forest Park

The mangrove in plot A (Distal zone or the furthest zone from sea), plot B (Middle zone or middle zone), and plot C (Proximal zone, the closest zone from sea) was carried out an inventory covering number of trees, diameter at breast height (DBH), the height of free trunk (TBC), the total height (TTL), the width of basal area (LBD), and the total volume (VT). Besides, the calculation was also done towards the amount of biomass and the content of carbon stands in each of those researches. The types of mangrove available in the research plots only consisted of *R. apiculata* and *S. alba*.

The Density and Types of Tree Stands

The number of trees in a research plot was not the same. Plot B had the most number of trees, including 272 trees, each of 162 trees of *R. apiculata* type and 110 trees of *S. alba*. Plot C had 220 trees, each of 110 trees of *R. apiculata* and *S. alba*. In the hectare unit, the numbers of trees in each plot were: plot A 1.950trees, plot C 2.200 trees and plot B 2.720trees, the total of trees 438ha⁻¹ and 517ha⁻¹ reached the study result in Mentawir Village Balikpapan, Kalimantan Timur of 2,300ha⁻¹, Lahjie *et al.*, 2019; Kristiningrum *et al.* (2019). The stand density of mangrove forests in eastern coast of North Sumatera varied from 1,692ind ha⁻¹ to 2,990ind ha⁻¹ (Onrizal *et al.*, 2019a).

The density of mangrove tree stands in each plot tended to be influenced by each clay content. Plot B with the highest tree density (2720 trees ha⁻¹), also had the highest clay content (11,40-14,30%). Followed by plot C with the number of 2.200 trees ha⁻¹ and clay content 11, 50-12,70%, and plot A with the number of 1950 trees ha⁻¹ and clay content 6,50-10,60%. As described by Hossain and Nuruddin (2016), clay fragment is a supporting factor of the regeneration process, where the clay particle in the form of mud will catch the mangrove fruit that falls when it is ripe. This process determined whether a zone was dense or not.

Comparing the study results from Tolangara and Ahmad (2017) in Bacan mangrove forest, Halmahera Selatan Regency which resulted in the density of the tree of 1.500 ha⁻¹ so the number of trees per hectare in Mangrove Forest in Tahura Ngurah Rai for the three observing plots were considered denser. But if compare with the study result of Handoko *et al.* (2017) at 12 research plots of mangrove forest in the area of South Rupa Island, Pekanbaru, with the density value ranges between 2.592 trees ha⁻¹ until 8.148 trees ha⁻¹, therefore the tree stands of mangrove forest in Tahura Ngurah Rai was much lower.

The types of *R. apiculata* and *S. alba* were the two types of mangroves that were available in all research plots lying from the seashore (plot C) to the land (plot B and plot A). Generally outermost zone of mangrove with high salinity occupied by *Avicennia* associated

with *Sonneratia* spp., while *Rhizophora* was located in the middle zone and *Bruguiera* grew in the furthest zone of the beach with much lower salinity. Onrizal *et al.* (2019b) said in muddy areas with high salinity levels which can grow *R. apiculata* species. The phenomenon of *Rhizophora* domination in the research area was suspected to be related to the low salinity of its water ecosystem. The typical water salinity in the research area of 14,8 -19,6‰ in reality was much lower than those reported by other researcher. The factors that influence high and low water salinity were evaporation and rainfall. The higher the level of evaporation of seawater, the higher the salinity would be. The higher rainfall, then the lower salinity would be.

Trunk Diameter

Based on attachment 1-6, it was known that trunk diameter of tree type *R. apiculata* in each research plot was : plot A = $8,3 \pm 3,8$ cm, plot B = $8,4 \pm 2,8$ cm and plot C $8,9 \pm 3,3$ cm then the average value of trunk diameter for the whole plots was 8,56cm. in terms of the diversity of trunk diameter of each plot, it can be concluded that the growth of trunk diameter in plot A stands was more identical than other plots. Meanwhile, in plot C the growth of trunk diameter was largely diverse.

S. alba type tended to have a bigger trunk diameter. In plot A, its value was = $10,4 \pm 1,8$ cm, plot b = $9,0 \pm 3,8$ cm, plot C = $8,5 \pm 1,5$ cm so the average value for all plots was 9,3cm. Trunk diameter of *R. apiculata* was bigger in plot A and even smaller in plot B and plot C which located further from the beach. Meanwhile, type *S. alba* showed the opposite. The closer to the land, the bigger the diameter was. Due to that matter, it was suspected that the growth of *R.apiculata* was better that the salinity in higher waters.

Climate affected the development of mangrove and the physical factor of its growing place was substrate and waters. Further, Alwikado (2014) reported that climate also affected the growth of mangrove through the light element, rainfall, temperature, and wind. The diameter growth and mangrove diameter

increment growth were also influenced by many factors of its growing place including the substrate. The substrate in this study referred to a substrate containing soft mud. Furthermoe, Hastuti and Budhihastuti (2016) added that growth was the result of the interaction of various physiological processes. The physiological process referred to as photosynthesis, respiration, and transpiration. While the results that were reported by Kusmana *et al.* (2003) in mangrove Center Lampung were obtained from the diameter value of 7,5 – 9,7cm. Moreover, Pattipeilohy (2014) in Minahasa Utara Sub-district obtained the diameter value of 11cm.

Tree Height

As shown by its diameter growth, the average of total height growth of trees type *S. alba* (15,99m) was bigger than tree type *R. apiculata* (12, 19m). Hence, it can be concluded that as a whole that the condition of mangrove habitats in the research area is more suitable for *S. alba* than for *R. apiculata*. The results of the total height growth of trees type *R. apiculata* in each plot was: plot A = $13,08 \pm 2,34$ m, plot B = $10,57 \pm 2,91$ m, plot C = $12,91 \pm 2,68$ m while for type *R. alba* plot A = $15, 58 \pm 5,99$ m, plot B = $16,28 \pm 5,88$ m, plot C = $16,11 \pm 1,9$ m. For type *R. apiculata*, plot A resulted in a bigger height growth with a smaller coefficient of variation than those grew in other plots. The height growth and diameter of tree is not only depending on the space and surface canopy, relative humidity as well as root system, but also influenced by climate and soil fertility. Cuenca *et al.* (2015) stated the factors were complex and affected towards the distribution and mangrove growth including salinity, tidal drying, disturbance, warming, and predation. Meanwhile, Toknok (2006) in Donggala obtained the value of 13-20m.

The Width of Basal Area

According to the estimation conducted in the research location, Ngurah Rai Forest Park, Denpasar, it was revealed that the widths of the basal area of *A. apiculata* in plot A, B, and C were $0.006\text{m}^2 \text{ tree}^{-1}$, $0.006\text{m}^2 \text{ tree}^{-1}$, and $0.007\text{m}^2 \text{ tree}^{-1}$ respectively. The average width of the basal area was $0.006\text{m}^2 \text{ tree}^{-1}$.

On the other hand, the widths of the basal area of *S. alba* were 0.009m² tree⁻¹ in plot A, 0.008m² tree⁻¹ in plot B, 0.006m² tree⁻¹ in plot C, and 0.008m² tree⁻¹ on average. Meanwhile, Aswita and Syahputra (2012) on their study in Seurway sub-district, Aceh Taming Region, Aceh Province, reported that the width of the basal area of mangrove stands was 0.004m² tree⁻¹.

Stand Biomass and Carbon Content

The result showed that the average biomass of mangrove forest stands in the research location was 87.38ton ha⁻¹, consisting of *R. apiculata* biomass of 40.22ton ha⁻¹ (46%) and *S. alba* biomass of 47.16ton ha⁻¹ (54%). *S. alba* in plot A (located the furthest from the beach) and plot B (located in the middle) were higher than in plot C (located closest to the beach). The accumulation of the three plots was higher (12.7ton ha⁻¹) compared to the finding of the research conducted by Bindu *et al.* (2018). As shown on Table 2, in terms of the average number of trees in the three plots, actually, *S. alba* had a fewer number (107 trees) than *R. apiculata* (131 trees), however, in terms of tree average diameter and height (D=9.30cm; T=15.99 m), *S. alba* had a bigger size than *R. apiculata* (D=8.56cm; T= 12.19 m).

Table 2. Biomass and carbon content of each species of mangrove at Plot A, Plot B and Plot C.

No	Plot	Biomass (ton ha ⁻¹)		Carbon (ton ha ⁻¹)	
		<i>R. apiculata</i>	<i>S. alba</i>	<i>R. apiculata</i>	<i>S. alba</i>
1	Plot A	36.12	56.27	18.06	28.13
2	Plot B	38.60	48.95	19.30	24.47
3	Plot C	45.94	36.25	22.97	18.12
	Total	120.66	141.47	60.33	70.72
	Average	40.22	47.16	20.11	23.57
	Average total	87.38		43.68	

Biomass is defined as the total number of organisms on the surface of a tree and is measured by using the ton unit of dry weight per area (Brown, 2004). The amount of biomass in particular mangrove forest is obtained from measuring the diameter, height, and wood density of each type of mangroves (Rachmawati *et al.*, 2014). Mangrove ecosystem has an ecological function to absorb and store carbon. Mangroves absorb CO₂ during the photosynthesis process and

then change it into carbohydrate by storing it in form of biomass in roots, stems, branches, and leaves. According to Kauffman *et al.* (2012), carbon stocks in mangrove forests are higher than that in any other forests, where the biggest carbon stocks are contained in mangrove sediments. When compared to the biomass estimation from other studies the biomass of mangrove forest stands in research location was much lower. It may be affected by the difference of the number of trees ha⁻¹, the size of stem diameter, height as well as the wood density of types of mangroves making up of stands. Rachmawati *et al.* (2014) revealed that the biomass of mangrove stands in Wilayah Pesisir Muara Gembong, Bekasi Region was 108.6ton ha⁻¹. Meanwhile according to Kristiningrum *et al.* (2019) the average value of mangrove forest carbon at the studied area in Mentawir Village is 50.73tons C ha⁻¹. In addition, Bachmid *et al.* (2018) found that the biomass of mangrove stands in Kuburaya Region, West Kalimantan, was 189.2ton ha⁻¹. Kristiningrum *et al.*, 2019 informed the biomass of mangrove forests in Mentawir which is part of the Balikpapan Bay Area is one and a half times higher than that in Siberut Island, West Sumatra, which is 49.13tons ha⁻¹ (Bismark 2008). Kusmana *et al.* (2003) stated that muddy sediments are generally richer in organic matter compared to sandy sediments.

The relation between organic carbon and total volume of *R. apiculata* and *S. alba* can be seen at Fig 4 and Fig 5.

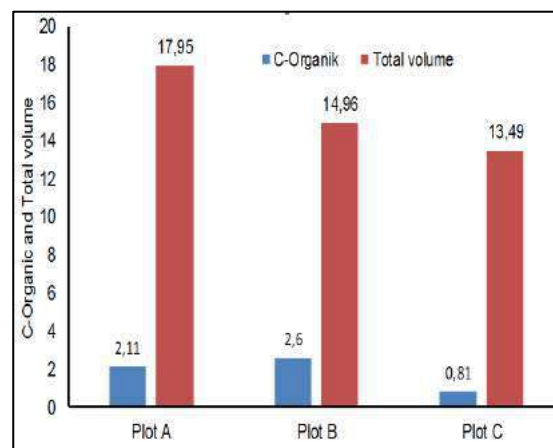


Fig. 4. The relation between organic C and total volume of *S. Alba*.

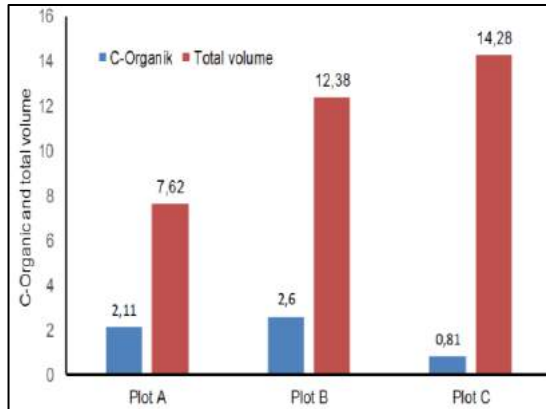


Fig. 5. The relation between organic C and total volume of *R. apiculata*.

Fig. 4 shows that in *S. alba* the organic C content was decreasing from plot A (closest to land) to plot C (closest to sea), and so did the total volume of the trees. It can be concluded that *S. alba* really needs organic C to increase its total volume. On the contrary, Fig. 5 shows that in *R. apiculata* the organic C value decreased, however, the tree total volume was increasing. It proves that *R. apiculata* is able survive in the areas with lower organic C.

The average value of water pH was 7.03% in plot A, 4.99% in plot B, and 7.49% in plot C. Furthermore, the organic C value was 2.1% in plot A, 2.6% in plot B, and 0.81% in plot C. On the other hand, the total N value was 0.07% in plot A, 0.07% in plot B, and 0.04% in plot C. The CEC value was 30.0 me 100g⁻¹ in plot A, 25 me 100g⁻¹ in plot B, and 25.4 me 100g⁻¹ in plot C. The basal area of *R. apiculata* was 0.006 m² tree⁻¹ in plot A, 0.006 m² tree⁻¹ in plot B, and 0.007 m² tree⁻¹, whereas the basal area of *S. alba* was 0.009 m² tree⁻¹ in plot A, 0.008 m² tree⁻¹ in plot B, and 0.006 m² tree⁻¹ in plot C. The biomass value per ha for *R. apiculata* was 36.12ton ha⁻¹ in plot A, 38.60ton ha⁻¹ in plot B, and 36.25ton ha⁻¹ in plot C, meanwhile the biomass value of *S. alba* was 56.27ton ha⁻¹ in plot A, 38.60ton ha⁻¹ in plot B, and 36.25ton ha⁻¹ in plot C.

The value of carbon stock per ha for *R. apiculata* was 18.06ton ha⁻¹ in plot A, 19.20ton ha⁻¹ in plot B, and 22.97ton ha⁻¹ in plot C. On the other hand, the value carbon stock per ha for *S. alba* was 28.13ton ha⁻¹ in plot A, 24.47ton ha⁻¹ in plot B, and 22.97ton ha⁻¹ in plot C.

Conclusions

The results showed that the diameter of *R. apiculata* type in plot A, B, and C was 8.3±2.3cm, 8.4±2.8cm, and 8.9±3.3cm respectively, and that of *Rhizophora alba* type in plot A, B, and C was 10.4±1.8cm, 9.0±3.8cm, and 8.5±1.5cm respectively.

The biomass value of *R. apiculata* in plot A was 36.12ton ha⁻¹, B= 38.60ton ha⁻¹, and C= 45.94ton ha⁻¹, and the biomass value of *S. alba* in plot A, B, and C was 56.27ton ha⁻¹, 48.ton ha⁻¹, and 36.25ton ha⁻¹ respectively. The value of carbon contents in *R. apiculata* in plot A, B, and C was 18.06ton ha⁻¹, 19.30ton ha⁻¹, and 22.97ton ha⁻¹ successively. In addition, the value of carbon content in *S. alba* was 28.13ton ha⁻¹ in plot A, 24.47ton ha⁻¹ in plot B, and 18.12ton ha⁻¹ in plot C.

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