# Productivity and CNP availability in *Rhizophora apiculata* Blume and *Avicennia marina* (Forssk.) Vierh. at Banggi Coast, Central Java - Indonesia

[1]Dafit Ariyanto, [2]Dietriech G. Bengen, [2]Tri Prartono, [3,4]Yusli Wardiatno

[1] Department of Aquaculture, Faculty of Agriculture, Asahan University, Kisaran, North Sumatera, Indonesia; [2] Department of Marine Science and Technology, Bogor Agricultural University, Dramaga, West Java, Indonesia; [3] Department of Aquatic Resources Management, Bogor Agricultural University, Dramaga, West Java, Indonesia; [4] Center for Coastal and Marine Resources Studies, Bogor Agricultural University, Dramaga, West Java, Indonesia. Corresponding author: D. Ariyanto, dafitariyanto676@gmail.com

**Abstract**. Mangrove productivity is a source of nutrients for the organisms within the mangrove ecosystem. This study aimed to determine the relationship between mangrove productivity and the carbon, nitrogen, phosphor (CNP) availability in the sediment. This study was conducted between September 2016 and August 2017. Productivity was measured using 1 m x 1 m nets placed beneath the mangrove canopy. The results of this study revealed that the productivity of *R. apiculata* was 1.07 kg $m^{-2}$ $yr^{-1}$. The mangrove litter production contribution was *R. apiculata* leaves (74%) and *A. marina* leaves (83%). Mangrove productivity is influenced by diameter at breast height (DBH), density, season, and mangrove type. The maximum content was C: 3.97%, N: 3.12%, P: 2.08%. High productivity resulted in a high CNP in the mangrove sediment.

**Key Words**: litter fall, mangrove, soil sediment, Banggi coast.

**Introduction**. The Banggi Coast is located in Rembang, Central Java and has various mangrove species such as *Rhizophora mucronata* Lam., *Rhizophora apiculata* Blume, *Rhizophora stylosa* Griff., *Avicennia marina* (Forssk.) Vierh., and *Sonneratia alba* Sm (Ariyanto et al 2018a). Mangroves have complex habitats and high productivity. Mangroves often experience nutrient deficiency (Bayen 2012; Flessner et al 2015). Mangroves control microbes and the vegetation cycle process in supporting the need for nutrients (Holguin et al 2001; Feller et al 2002). In addition, mangrove productivity also provides a source of food and other resources for humans. The mangrove ecosystem is tightly woven between the organisms, the air flow, and the atmosphere. Mazda (2013) stated that physical processes such as sea tides could support the existence of a mangrove ecosystem.

Mangrove litter that falls to the sediment undergoes a decomposition process signified by simple physical and chemical changes by organisms (Imgraben & Dittmann 2008), and influences the nutrient cycle in the mangrove ecosystem (Holguin et al 2001; Norris et al 2012; Hossain et al 2014). The productivity process is influenced by the mangrove leaf decomposition level factor. The decomposition rate could be fast or slow depending on three main factors: environmental conditions, the decomposition community, and the substrate quality (Castanho & de Oliveira 2008). Nutrients such as nitrogen and phosphorous are available for primary producers and higher trophic levels through decomposition and the trophic level transfer activity (Wardle et al 2004).

Nutrients in the sediment are an important factor in controlling the ecological and physiological processes in the mangrove ecosystem (Alongi 2002; Feller et al 2002). Anthropogenic activities in the coastal area could affect the availability of mangrove nutrients, thus resulting in a negative change in mangrove development and the sediment's geochemical properties (Reef et al 2010). Mangrove forests could also import carbon content by association with suspended sediments and organic waste matter (Adame et al 2010). Therefore, the mangrove has the ability to maintain its stability and health through nutrient availability (Valiela & Cole 2002). The aim of this study was to determine the relationship between mangrove productivity and the availability of C, N, and P content in the sediment.

## Material and Method

***Description of the study sites***. This study was conducted between September 2016 and July 2017 in the Banggi Beach, Rembang, Central Java, Indonesia (Figure 1). The research site consisted of two stations. Each station was divided into a number of observation zones: the sea zone, the middle zone, and land zone.

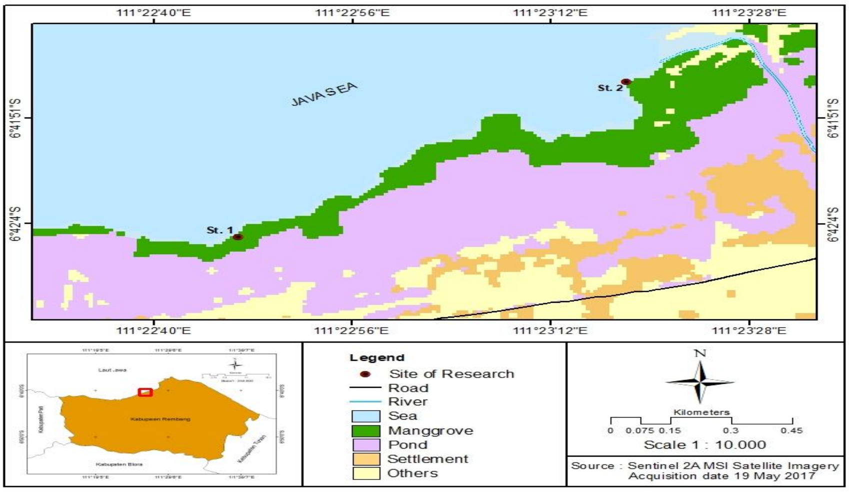


Figure 1. The location of research in Banggi Coast, Central Java - Indonesia.

***Mangrove vegetation***. This study employed 10 x 10 $m^2$ mangrove transects. Line transects were placed in each station based on the mangrove vegetation type. Each station had three sub-transects that were perpendicular to the coastline, placed 50 m away for each transect. Diameter at breast height (DBH) data for *R. apiculata* were collected by Ariyanto et al (2018b) while *A. marina* mangroves were measured on site. Tree measurements were taken based on DBH > 4 cm and height 1.3 m (Kathiresan & Bingham 2001; Ong et al 2004). The mangroves were then classified based on DBH measurements into small (< 5 cm), medium (5-15 cm), and and large trees (> 15 cm) (Day et al 1987; Comley & McGuinness 2005).

***Mangrove productivity***. Fallen litter was trapped using litter traps and this procedure was repeated three times for each station. The traps were placed beneath the tree canopy with the consideration that observations were made 1.5 m above the ground to avoid tides. The litter traps were made from nylon and were 1 m x 1 m in size. The fallen litter was collected and retrieved every month. The litter was dried, sorted, and weighed based on the type of mangrove and the components such as leaves, twigs, fruits, and flowers.

***Physico-chemical parameters***. The water quality parameters measured in each zone were the temperature, salinity, pH, and dissolved oxygen (DO) using a water quality meter (IP67 Combo in 8603 type). Each zone was assessed six times, in September and November 2016, January, March, May, and July 2017. Sediment samples were collected at a depth of 10 cm using a pipe. Sediment samples were collected from each transect in September 2016, January 2017, and July 2017. The sediment samples were analyzed in the Productivity and Aquatic Environment Laboratory, Bogor Agricultural University, for organic materials and sediment texture. The organic compound assessment was conducted using the Walkey-Black method, while assessment of the soil texture was conducted using the pipette method and the total nitrogen and phosphorous was assessed using spectrophotometry (Pansu & Gautheyrou 2003; APHA 2012).

***Data analysis***. The Principal Component Analysis (PCA) was employed to determine the relationship between mangrove productivity and environmental conditions. The PCA presented data in the form of a graph and data matrix consisting of the study zones as productivity (lines) and environmental variables (columns). The analysis used the Xlstat 2017 program.

**Results**. Leaf litter was produced monthly by *A. marina* and *R. apiculata* (Figure 2). Twigs produced in this study were relatively few. The leaf litter production of *A. marina* reached its peak in December 2016 and May 2017 (Figure 2). The increase in leaf litter production was followed by a decrease in twig production in December. Leaf production increased as a result of the rainy season. The production of flowers and fruit reached a peak in November (9.19 and 3.38 g $m^{-2}$ respectively). This demonstrated that a higher flower production could increase fruit production. Not the entire flower production would become fruit production due to factors such as wind. For *R. apiculata,* the leaf litter production reached its peak in November 2016, February 2017, and August 2017. The flower production peaked in January 2017 and August 2017. The fruit production reached its peak in November 2017 and May 2017. In general, the mangrove litter which fell during this study was influenced by the season, time, and mangrove species.

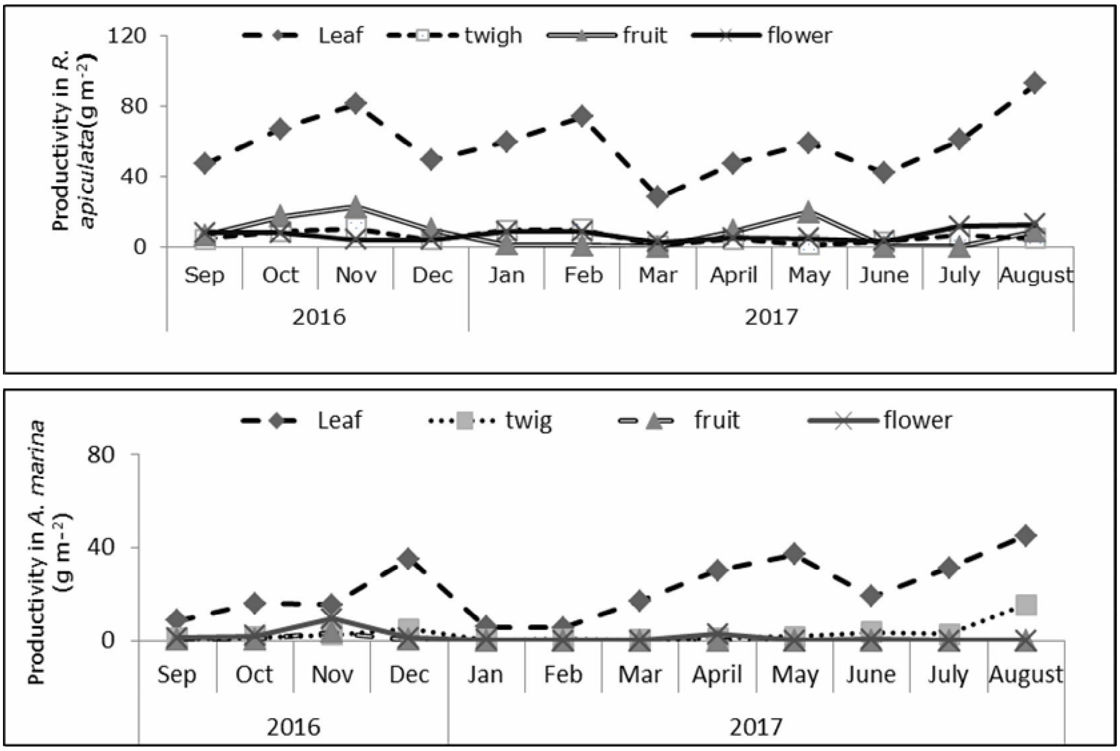


Figure 2. Productivity of mangroves *A. marina* and *R. apiculata* in Banggi Coast, Central Java - Indonesia.

The mangrove productivity contribution revealed a difference in mangrove parts (leaves, twigs, flowers, and fruits) in the mangroves *R. apiculata* and *A. marina*. The mangrove part with the highest contribution in both mangroves was the leaves. The mangrove-parts contribution from highest to lowest was leaves > fruits > flowers > twigs for *R. apiculata*, while for the mangrove *A. marina* it was leaves > twigs > flowers > fruits. This demonstrated that the highest mangrove productivity was contributed by the leaves.

*R. apiculata* has 74% and *A. marina* has 83% in leaves (Figure 3). Table 1 presents the density, tree-trunk diameter (DBH), and mangrove productivity. The medium-sized DBH was found in *R. apiculata,* while the *A. marina* mangroves were classified as small. The difference in DBH size shows different mangrove productivity in this research. The productivity of *R. apiculata* was higher than that of *A. marina.* The mangrove productivity tended to be influenced by DBH, mangrove density, and the mangrove age.

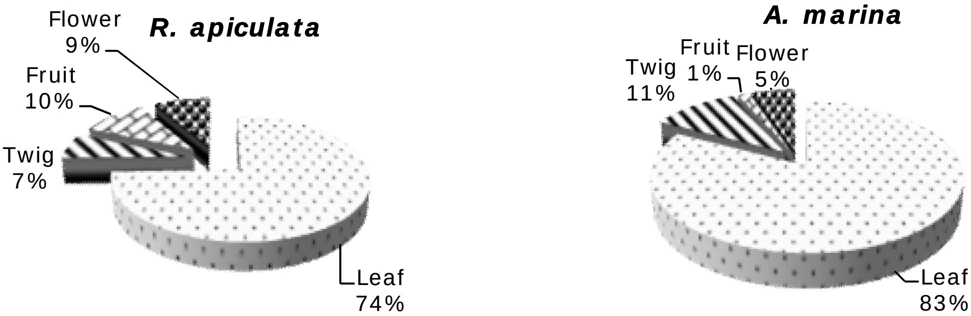


Figure 3. Contribution of mangroves productivity in Banggi Coast, Central Java – Indonesia.

Table 1

Density (tree/100 $m^2$), DBH (cm) and mangrove productivity (kg $m^{-2}$ $th^{-1}$) in Banggi Coast, Central Java – Indonesia

| *Mangrove* | *Tree density* | *DBH (cm)* | | | *Present study (kg $m^{-2}$ $th^{-1}$)* | *Comparing study (kg $m^{-2}$ $th^{-1}$)* | *Source* |
|---|---|---|---|---|---|---|---|
| | | *Small (4-4.9)* | *Medium (5-14.9)* | *Big (> 15)* | | | |
| *R. apiculata* | 44±15 | 8±6 | 38±8 | 0 | 1.07 | 8.86 | Nga et al (2005) |
| *A. marina* | 21±7 | 21±7 | 0 | 0 | 0.3 | 3.24 | Oñate-Pacalioga (2005) |

***Nutrient content***. Figure 4 shows the total phosphorous, nitrogen, and organic content in mangrove sediment. The three nutrient contents had various mangrove sediment values in each station and time. The overall total nitrogen (TN) content ranged between 0.43 and 3.12%. The TN content in both *R. apiculata* and *A. marina* fluctuated seasonally.During the rainy season (January 2017), the TN content was the highest. The highest TN was demonstrated by *R. apiculat*a. This was probably because there was a supply from inland. *R. apiculata* had a higher total phosphorous (TP) content than *A. marina*. The TP content in this study ranged between 0.4 and 2.08%. The highest TP was demonstrated by *R. apiculata* (2.08%). Carbon compounds are organic matter compounds. Organic compounds influence the fertility of the mangrove ecosystem. The organic compounds content in this study ranged between 0.7 and 3.96%. The organic C content in this study were caused by the season. Based on the season, the contribution from high to low was the dry season, (July 2107) < rainy season (Jan 2017) < transition season (Sep 2017). *R. apiculata* had a higher organic C content than *A. marina*.

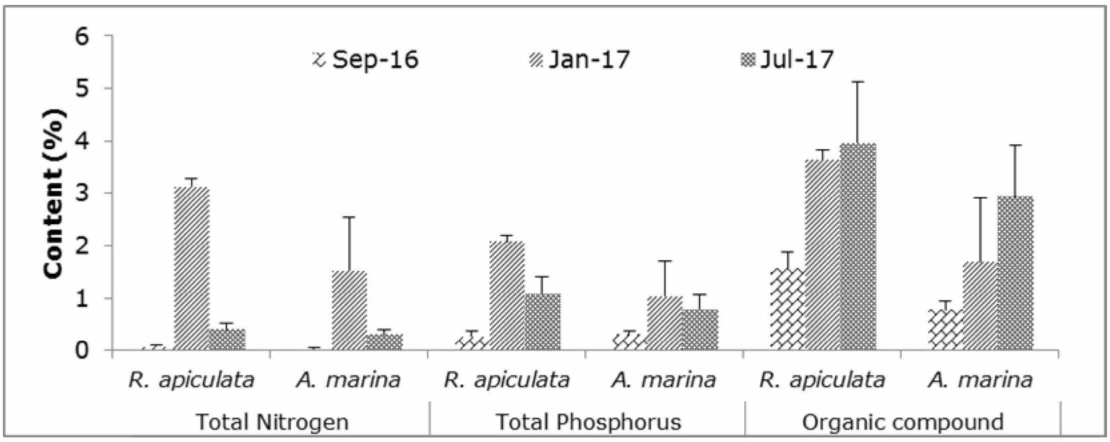


Figure 4. Content of TN, TP, and C in Banggi Coast, Central Java – Indonesia.

***Environmental parameters***. Table 2 shows the variations in water quality conditions. The DO ranged between 4.09 and 7.91 mg $L^{-1}$, which is the normal standard quality for the environment and biota conditions, the salinity ranged between 28.5 and 33.20 psu, and the pH ranged between 5.26 and 8.15. The temperature ranged between 26.17 and 30.7$^o$C. Silt was the more dominant sediment texture compared to sand and clay. The sediment texture (sand, silt, and clay) fluctuated in value based on the season (Table 3).

Table 2
Environmental parameters of Banggi Coast, Central Java - Indonesia

| *Mangrove* | *Date* | *DO (mg $L^{-1}$)* | *Salinity (psu)* | *pH* | *Temperature ($^o$C)* |
|---|---|---|---|---|---|
| *R. apiculata* | Sep 2016 | 5.23±0.35 | 28.5±1.5 | 7.17±0.47 | 28.05±0.7 |
| | Nov 2016 | 4.09±0.52 | 29.33±1.15 | 7.68±0.2 | 27.53±0.55 |
| | Jan 2017 | 7.91±0.51 | 31.33±1.15 | 7.76 ±0.38 | 30.1±4.2 |
| | Mar 2017 | 5.29±2.36 | 30.53±4.64 | 5.26±2.71 | 28.33±0.89 |
| | May 2017 | 5.71±0.45 | 31.1±0.17 | 8.09±0.07 | 27.17±0.12 |
| | Jul 2017 | 4.54±0.36 | 30.87±1.64 | 7.92±0.02 | 26.17±0.4 |
| *A. marina* | Sep 2016 | 7.37±1.96 | 32.9±0.34 | 8.37±0.38 | 27.73±1.10 |
| | Nov 2016 | 5.71±0.45 | 33.2±0.17 | 8.09±0.07 | 27.17±0.11 |
| | Jan 2017 | 7.42±0.52 | 32.9±0.57 | 8.09±0.11 | 27.3±0.17 |
| | Mar 2017 | 6.19±1.32 | 32.93±0.25 | 8.02±0.30 | 26.87±0.41 |
| | May 2017 | 7.24±2.31 | 32.93±0.51 | 6.59±2.2 | 30.7±0.3 |
| | Jul 2017 | 4.86 ±0.36 | 31.73±0.79 | 8.15±0.13 | 30.2±2.3 |

Table 3
The percentage of mangrove sediment texture in Banggi Coast, Central Java – Indonesia

| *Species* | *Date* | *Sand (%)* | *Silt (%)* | *Clay (%)* |
|---|---|---|---|---|
| *R. apiculata* | Jan 2017 | 0.05±0.02 | 94.87±1.1 | 5.11±1.1 |
| | Jul 2017 | 0.2±0.08 | 93.55±0.47 | 6.24±0.4 |
| | Sep 2016 | 1.93±1.14 | 94.13±6.03 | 3.94±1.61 |
| *A. marina* | Jan 2017 | 3.46±2.65 | 94.67±3.25 | 2.57±0.29 |
| | Jul 2017 | 0.02±0.01 | 96.38±0.73 | 3.60±0.73 |
| | Sep 2016 | 0.34±0.28 | 94.61±1.77 | 5.05±1.49 |

***The relationship of productivity and physico-chemical conditions***. The relationship between productivity and environmental conditions was analyzed using PCA (Figure 5). The result had 3 eigenvalues. The first PCA had an eigenvalue of 4.39 (39.92% variant), the second 3.52 (32.349% variant), and the third 1.15 (10.54% variant). The three eigenvalues described the data variation at 82.46% (cumulative %/total variant). The relationship between original variables and new variables formed by the PCA is called the loading value. The loading value selected was greater than 0.5 which was considered able to explain the variables of mangrove productivity. This demonstrates that high mangrove productivity was observed in high organic matter substrate, sand substrate, and clay substrate, and was supported by salinity. The second principal component affected TN, silt substrate, and temperature, whereas the third principal component was the pH condition.

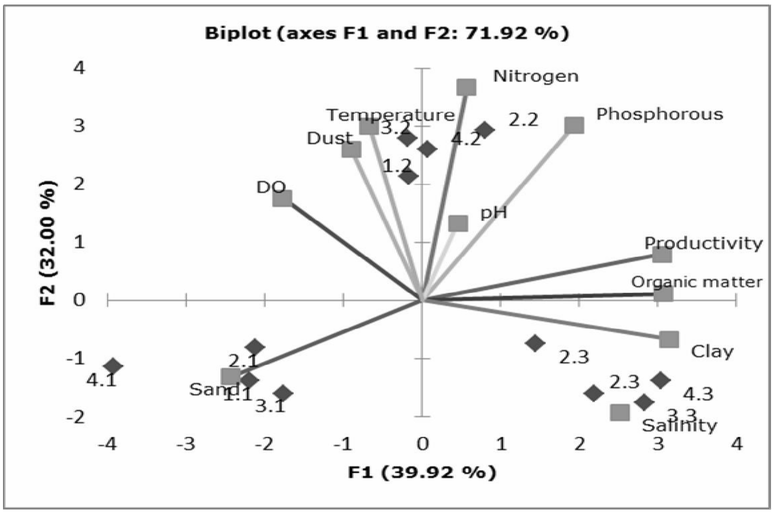


Figure 5. The relationship between productivity and physico-chemical parameters in Banggi Coast, Central Java - Indonesia with Principal Component Analysis (PCA).

**Discussion**. The leaf litter contribution of *A. marina* in the present study was 83% which was higher than the 73.3% leaf litter contribution reported by Steinke & Ward (1988). The productivity in this study was influenced by DBH, density, and season. Hookham et al (2014) stated that DBH size could reflect the mangrove condition whether it is healthy or disturbed. Chen et al (2009) disclosed that varying litter productivity could be affected by differences in DBH, tree age, and density or mangrove stands.

Fallen mangrove litter has the significance as the largest donor of nutrients and a source of energy in the mangrove ecosystem (Wafar et al 1997). Differences in the amount of fallen litter could be due to a number of environmental factors such as soil fertility, density, season, and mangrove species. Twilley & Day (1999) reported the litter fall mangrove showed seasonal variations that was influenced by a number of factors such as geographical location, precipitation rate, temperature, wind, nutrient concentration, substrate type, and freshwater flow. Mangrove leaves, twigs, fruits, and flowers are defined as vegetative reproduction caused by aging, rain, and wind.

Alongi et al (2005) estimated that fallen litter is 30% of the net primary productivity in the mangrove ecosystem. The 30% prediction could consistently be used for environmental stability in the mangrove ecosystem. Fallen litter production is accepted as the main route for enriching the ecosystem with nutrients (Tam et al 1998) but is related to the geographical location (Woodroffe et al 1988) and season (Bosire et al 2005). Generally, tropical mangroves located on the lower latitudes demonstrate higher litter productions than those found in higher latitudes (Komiyama et al 2008; Bernini & Rezende 2010).

In this study, *R. apiculata* had a higher TP than *A. marina*. Li (1997) found TP compounds in *Kandelia candel* (0.14%). Phosphorous is an important nutrient for biological productivity in aquatic environments. The TP level of mangrove sediment in our study was 0.27-2.08% in *R. apiculata* and 0.32-1.03% in *A. marina*, which was in the global range (0.1-16%) (Alongi et al 1992). The phosphorous level in the ecosystem is controlled by the drainage area, agricultural land, and NPK fertilizer application (Ramanathan et al 1999). TP in the mangrove sediment can be utilized through organisms and has an important implication in growth, especially in environments where nutrients are limited (Reef et al 2010).

This study revealed that the highest TN was found in *R. apiculata* (3.12%). This percentage was higher than that reported by Li (1997) (1.79%) and Kamimura & Tsuchiya (2006) (0.02%). The high TN content on the surface was influenced by nitrate compound input from external sources, especially cultivation waste, agricultural runoff, and domestic waste (Purvaja & Ramesh 2000). The low TN content might be due to the decrease in nitrification and degradation of N compounds into an inorganic form. The TN in the coastal sediment usually ranges between 0.2 and 0.4% of the sediment's dry weight (Alongi et al 1992). The TN content is strongly influenced by the intensity and duration of the rainy season (Jagtap 1987; Alongi 1988). The availability of TN in the mangrove ecosystem depends on the complex pattern of bacterial activity and mangrove mud anoxic zone. TN was found to limit the growth of *A. marina* in South Africa (Naidoo 2009) and New Zealand (Feller et al 2005). The organic content in this study ranged between 0.7 and 5.14%. *R. apiculata* had a higher organic compound content than *A. marina*. Kamimura & Thuchiya (2006) reported an organic compound content of 0.26%, but the organic carbon content in the mangrove sediment was found to be varying, nearly twice the aforementioned percentage at 0.6-31.7% (Bouillon et al 2003). Mangroves can act as an accumulation of organic matter absorbent or it is capable of enriching the adjacent coastal area through the export of organic and inorganic nutrients (Jennerjahn & Ittekkot 2002; Dittmar et al 2006). The organic content on the surface of the sediment depends on a number of factors such as the sediment's characteristics, microbial degradation rate, productivity, and input from the soil.

The effect of nutrient input, geomorphology, and sediment texture could influence the mangrove litter produced in a limited area (Coronado-Molina et al 2012). The maximum mangrove litter rate occurred during the rainy season (Arreola-Lizárraga et al 2004; Sanchez-Andres et al 2010). Ariyanto et al (2018c) reported salinity is a more dominant factor compared to the temperature and precipitation rate. The mangrove litter rate increased with an increase in the salinity and decreased with the decrease in the salinity (Rani et al 2016).

**Conclusions**. Productivity had a strong relationship with the availability of C, N, P in the sediment. The TN content ranged from 0.43 to 3.12%, TP between 0.4 and 2.08%, and C compounds between 0.7 and 3.96%. *R. apiculata* had a higher C, N, and P compound content than *A. marina* in all seasons. In general, the mangrove *R. apiculata* had a high litter production and also produced a high C, N, and P content in the mangrove sediment.

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Authors:
Dafit Ariyanto, Asahan University, Agricultural Faculty, Department of Aquaculture, Indonesia, North Sumatera, Kisaran, 21224, e-mail: dafitariyanto676@gmail.com
Dietriech Geoffrey Bengen, Bogor Agricultural University, Fisheries and Marine Science, Department of Marine Science and Technology, Faculty, Indonesia, Bogor, 16680, e-mail: dieter@indo.net.id
Tri Prartono, Bogor Agricultural University, Fisheries and Marine Science, Department of Marine Science and Technology, Faculty, Indonesia, Bogor, 16680, e-mail: triprartono@yahoo.com
Yusli Wardiatno, Department of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, Bogor Aqricultural University, Kampus IPB Darmaga, Bogor 16680, West Java, Indonesia; Center for Coastal and Marine Resources Studies, Bogor Agricultural University, Kampus IPB Baranangsiang, Jl. Raya Pajajaran, Bogor 16143, West Java, Indonesia, e-mail: yusli@ipb.ac.id

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