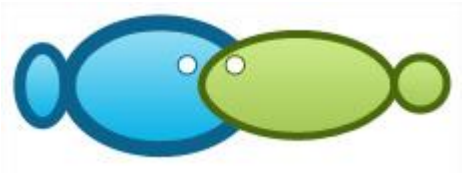

Species composition, diversity and biomass of mangroves forest in Pulau Bai-Pantai Panjang Natural Conservation Park of Bengkulu, Indonesia

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Abstract. In Indonesia, coastal development has rapidly reduced the mangrove covers, however some mangrove forests still exist in Bengkulu. The study was conducted to identify the species composition and to estimate the biomass of the mangrove forest in Pulau Bai-Pantai Panjang Natural Conservation Park (NCP), Bengkulu, Indonesia. Three representative stations were selected using the quadrat sampling technique. Twenty seven plots were established to facilitate the inventory and measurement of the trees. The Shannon-Wiener index and the allometric equations were used to determine the species diversity and biomass. The results showed that the mangrove could be categorized as in high density (>2,500 trees ha^{-1}), however the species diversity (H'<0.46) was very low, with only three mangrove species recorded, *Rhizophora apiculata*, *Sonneratia alba* and *Avicennia marina*. *R. apiculata* dominated at all stations, with importance values of 148-181, 129-192 and 103-140%, with threes with diameter larger than 10 cm, between 5 to 10 cm and less than 5 cm, respectively. The biomass was also dominated by *R apiculata*, especially for trees with larger diameters. Among stations, the greatest total biomass was accounted at the station one, corresponding to 25.8 ton ha^{-1}, while to the stations three and two there were credited 19.3 and 12.0 ton ha^{-1}, respectively. The low species diversity of the mangrove investigated in this study suggested that a higher awareness regarding the protection and conservation was required to maintain the mangrove in the region.
Key Words*:* density, dominance, station, distribution, index.

Introduction. One of the ecotone ecosystems that are widely distributed along the tropical coastal areas is the mangrove forest (Ardiansyah et al 2019; Asadi et al 2018; Kauffman & Donato 2012). It is a unique ecosystem that only covers 0.5% of the earth's coastal areas but contributes significantly to the provision of ecosystem services (Alongi 2014; Kauffman & Donato 2012). Being dominated by trees, shrubs, and other vegetations, which are tolerant to salt, the mangroves spread over the inter-tidal areas, an area near the coasts, bays and around the river mouths (FAO 2007; Naidoo 2009; Zhou et al 2010). In time, these plants had adapted and developed special features allowing them to better live in a difficult environment (Masstaler 1977).

The primary producer of the coastal environment was the mangrove ecosystem, dominated by trees interacting with the associated aquatic fauna. This ecosystem sustains the diversity and biomass of mangrove forest within the Baluran National Park, Indonesia (Asadi & Pambudi 2020), but also the livelihoods of the coastal communities, and provides an essential support to the fishery resources and to the other marine organisms (Garcia et al 2014; Hoque et al 2015). Mangrove provides nursery, refuge, and feeding grounds for marine species and protects human communities from storms, waves and floods, also preventing the soil erosion and preserving the water quality (Lovelock et al 2015; Garcia et al 2014; Valiela et al 2001). Mangrove is also known for its high capacity in sequestering CO_2. It stores up to three times more organic carbon than the typical terrestrial forests and is known as the most important form of blue carbon (Kauffman et al 2016; Alongi 2014). However, there is still a lack of study on the biomass or carbon storage of the mangrove ecosystem in many areas (Donato et al 2011; Brander et al 2012).

Mangroves are a priceless part of our biodiversity, with enormous ecological and economic value (Hema & Devi 2015). This ecosystem is an income source for the community, but it is also a source of nutrients, such as proteins and carbohydrate for foods, or raw materials like timber for housing, firewood and charcoal.

Indonesia has the biggest mangrove forest in the world. It is about 27% (16.9 million ha) of the world mangrove area and it has been considered as the center of biodiversity of mangrove species and of mangrove ecosystems (Spalding et al 2010), However, Indonesia is facing a fast degradation of its mangrove forest (Setyawan et al 2003). It was estimated that a total of 40% of the mangrove cover had been lost in the last three decades (Murdiyarso et al 2015). Mangroves are also threatened by increases in the sea surface temperature and by the sea-level rise due to the global climate change (Kauffman et al 2016; Lovelock et al 2015). Therefore, we need to preserve and evaluate mangrove forests (Oktawati & Sulistianto 2015).

Several studies on mangrove identification and diversity had been conducted from several parts of Indonesia, such as: in Balikpapan Bay, East Kalimantan (Warsidi & Endayani 2017), Merauke Regency coastal areas (Widyastuti et al 2018), Baluran National Park (Asadi et al 2018), Benoa Pemogan Village, South Denpasar District, Denpasar Municipality, Bali Province (Darmadi & Ardhana 2010) and the village of Kumu, Tombariri, Minahasa Regency (Nauw 2012). However, there is a lack of information on mangroves from Bengkulu. Bengkulu is located in south-west Sumatera where almost 75% of the mangrove forests are sparsely spread within the conservation forest area (Senoaji & Hidayat 2016). In Bengkulu, the coastal development has also rapidly reduced the mangrove cover. Some mangrove forests still exist, including in Pulau Bai-Pantai Panjang Nature Conservation Park (NCP). The aim of this study was to identify the species composition and to estimate the biomass of the mangrove forest of Pulau Bai-Pantai Panjang NCP.

Material and Method

Description of the study sites. This study was conducted in the natural mangrove forest of Pulau Bai-Pantai Panjang NCP, located in the south-west of Sumatera Island of Indonesia. The mangrove locations are between 7°29'10'' S and 7°55'55'' S latitude, and between 114°29'10'' E and 114°39'10'' E longitude. The research location map is presented in Figure 1.

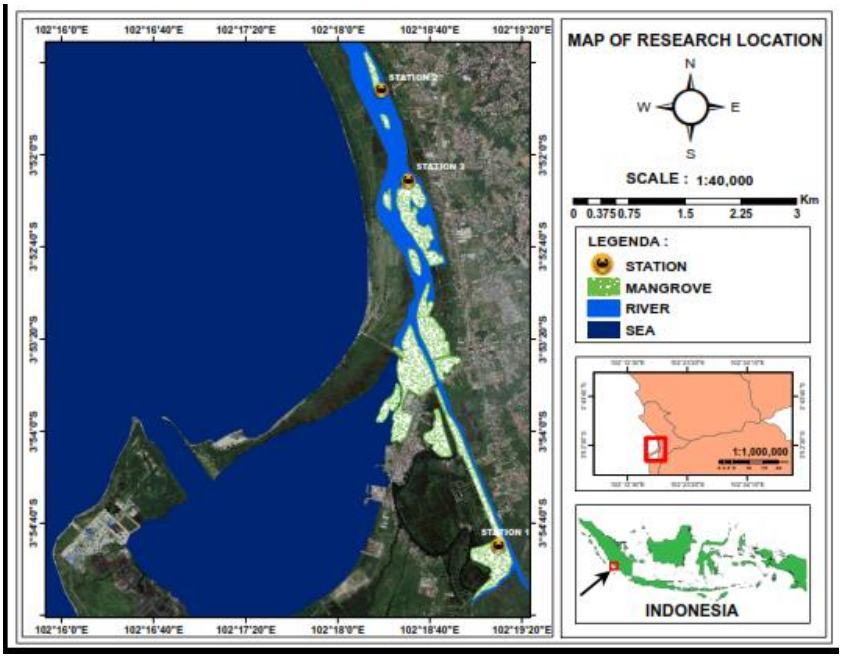

Figure 1. Map of the study area showing the sampling locations along the mangrove forest of Pulau Bai-Pantai Panjang NCP, Bengkulu, Indonesia.

Three stations were selected for the study. The coordinate and physical characteristics of each station are described in Table 1. The salinity and soil pH of the research stations ranged from 14.2 to 31.3‰ and from 6.6 to 6.7, respectively. The temperature ranged from 29.0 to 31.3°C and the high tide fluctuated from 49 to 145 cm.

Table 1

Geographic coordinates and the characteristics of each sampling station

Station	*Geographic coordinate*	*Temperature (°C)*	*Salinity (°/₀₀)*	*pH*	*High tide (cm)*
1	$3^0$51″17.4″S -$102^0$18″13.2″E	29.0±0.3	14.2±0.6	6.7±0.1	49±12.6
2	$3^0$51′01.0″S -$102^0$18″04.5″E	30.3±0.6	14.2±0.3	6.6±0.2	133±28.4
3	$3^0$53″50.8″S- $102^0$18″21.1″E	31.3±0.6	25.5±1.2	6.6±0.3	145±30.6

Sampling design and species identification. The inventories were conducted in September and October 2020. Nine sample plots were established at each station. The plots were assigned to 3 lines-transects parallel to the shoreline, with a distance of 50 m between transects. On each line-transect, three sample plots were arranged with a distance of 20 m between plots. The species composition, structure and biomass were observed using a non-destructive quadrant technique. Plots of 20 x 20 m, 10 x 10 m, and 5 x 5 m were used for trees with a diameter larger than 10 cm (T), between 5 to 10 cm (P) and of less than 5 cm (S), respectively. The field guide of mangrove species (Noor et al 2006) was used to identify the species. To confirm the identification, pictures of fruits, flowers, leaves, stems and roots of each mangrove species were taken. The number and stem diameter of mangrove trees at each station were counted and recorded. The diameters were measured at the breast height.

Structure analysis and biomass assessment. The species diversity was determined using the Shannon–Wiener diversity index (H'), which is commonly used to compare the diversity in mangrove forests (Abino et al 2014; Tang et al 2012). The diversity index was calculated for each station using the following formula (Shanon 1948):

$$H' = -\Sigma\ pi * \ln(pi)$$

Where:
H' - the diversity index;
pi - the number of a species as a proportion of all species.

Relative density (RD), relative dominance (RD), relative frequency (RF) and Importance Value Index (IVI) of each species were also accessed. Estimation of the biomass of mangrove stands was made using the allometric equations by species, with the appropriate coefficients and exponents (Kauffman & Donato 2012). These allometric equations for *Avicennia marina*, *Rhizophora apiculata* and *Sonneratia alba* were $B=0.1848D^{2.3524}$, $B=0.1709D^{2.516}$ and $B=0.3841D^{2.101}*p$, respectively, where B is the biomass (kg), D is the diameter at breast height (cm) and p is the wood density (0.078).

Results and Discussion

Species diversity and compositions. Species richness measures the amount of the various sorts of organisms present within a particular area. The species composition of the mangrove forest at Pulau Bai-Pantai Panjang NCP is shown in Table 2. The results showed that there were only three species of mangrove subsisting in the area of study, *R. apiculata*, *S. alba* and *A. marina*. The highest mean diameter of the mangrove was 18.5 cm and the lowest mean diameter was 2.8 cm. The study also showed that all of the stations had similarly low values of the Shanon Diversity Index. Station 2 had the highest value (0.46) followed by station one (0.44) and the lowest occurred at the station three (0.32).

The species richness in Pulau Bai-Pantai Panjang NCP Bengkulu was lower than in mangroves from most areas of Indonesia. The number of mangrove species was about 20 species in Balikpapan Bay, East Kalimantan (Warsidi & Endayani 2017), 12 species in in Mentawir, East Kalimantan (Kristiningrum 2019), 14 species in the Segara Anakan Central Java (Widyastuti et al 2018), 9 species Lamongan, East Java (Asadi et al 2018) and 7 species in Benoa Bali (Darmadi & Ardhana 2010). However, the studied mangrove's diversity is similar to the mangrove in Minahasa, Celebes, with 3 species (Nauw 2012).

The number of species in this study decreased, compared to the the same location, but two years earlier (Oktamalia 2018), when besides *R. apiculata*, *S. alba,* and *A. marina,* there were also found *Bruguera* spp. and a small number of *Xylocarpus granatum* König, *Kandelia candel* (L) Druce and *Lumnitzera littore* Voigt*.* The decreasing number of species in this area is likely caused by the intervention of sandy sediments in the substrate and the illegal conversion of the area into some ponds and new settlements.

Table 2

Species diversity, abundance, diameter and Shanon Diversity Index at three stations of mangrove at Pulau Bai-Pantai Panjang NCP, Bengkulu, Indonesia

Station	*Species*	*Density (trees ha^{-1})*				*Diameter (cm)*			*Diversity index (H')*
		T	*P*	*S*	*Total*	*T*	*P*	*S*	
1	*R. apiculata*	224	185	933	1342	12.4	6.9	3.2	0.44
	A. marina	77	46	222	346	16.1	6.3	3.2	
	S. alba	15	46	800	862	18.5	7.1	3.5	
	Total	316	278	1956	2550	15.7	6.8	3.3	
2	*R. apiculata*	97	53	1067	1217	15.1	6.9	3.2	0.46
	A. marina	58	36	667	761	15.2	6.8	2.8	
	S. alba	33	28	667	728	13.1	6.7	3.3	
	Total	189	117	2400	2706	14.5	6.8	3.1	
3	*R. apiculata*	81	47	578	706	15.8	7.4	3.2	0.32
	A. marina	44	25	1244	1314	15.1	7.0	3.9	
	S. alba	6	0	44	50	13.8	-	4.0	
	Total	131	72	1867	2069	14.9	7.2	3.7	

T-Tree; P-Pole; S-Seedling.

The density of mangroves in all stations was relatively similar: 2,550, 2,706 and 2,069 trees ha^{-1} at the stations one, two and three, respectively. According to the Indonesian Forest Service, these figures correspond to a high density of mangrove (Ministry of Environment Republic of Indonesia 2004).

At all stations, especially for trees with a larger diameter, *R. apiculata* dominated the composition of the mangrove. The distribution of mangrove forests depends upon their environmental factors (Bengen 2001). The area closest to the ocean, with less sandy soil and rich in organic matter, is usually dominated by *Avicennia* spp. and *Sonneratia* spp. Near the land, mangrove forests are usually dominated by *Rhizophora* spp. The abundance of *R. apiculata* at most stations is likely caused by the condition of the sandy substrate (Oktamalia 2018). Mangrove species of *Rhizophora* spp. prefer to grow on sandy soil (Noor et al 2006) and has a higher adaptability than other genera (Sulistiyowati 2009).

Table 2 also shows that the composition of the smallest mangrove trees, with a diameter inferior to 5 cm, at stations one and two was dominated by *R apiculata*, with about 933 and 1,067 trees ha^{-1}, respectively. However, the highest number of the mangrove trees with a diameter of less than 5 cm at station three was of *A. marina*, with about 1,244 trees ha^{-1}. It indicated that the regeneration of mangrove stands at stations one and two was still dominated by *R. apiculata*, while at station three, the regeneration shifted and became dominated by *A. marina*. The shift could be due to frequent higher intertidal and muddier land at the station three.

The relative density (RD), relative frequency (RF), relative dominance (RD), and importance value index (IVI) of the species found in the study area are shown in Table 3. At all stations and for most stem diameters, *R. apiculata* had the highest RD, RF and RD, resulting in the highest IVI. The IVI of *R. apiculata* at stations one, two, and three were 172.3, 148.6 and 181.0 (for trees with diameter of more than 10 cm), 171.7, 129.9 and 192.9 (for trees with diameter of 5-10 cm), and 140.6, 124.0 and 103.54 (for trees with diameter of less than 5 cm), respectively. It indicated that *R apiculata* was the most ecologically important species for the mangrove forest at Pulau Bai-Pantai Panjang NCP, Bengkulu. As in most mangrove forests, *R. apiculata* is commonly found as the major component (Asadi et al 2020).

Table 3

Relative density, frequency, dominance and importance value index of tree species in three stations of mangrove forest at Pulau Bai-Pantai Panjang NCP, Bengkulu, Indonesia

Station	*Species*	*Relative density*			*Relative frequency*			*Relative dominance*			*IVI*		
		T	*P*	*S*	*T*	*P*	*S*	*T*	*P*	*S*	*T*	*P*	*S*
1	*R. apiculata*	70.7	66.7	47.7	56.3	50.0	50.0	45.3	55.1	42.8	172.3	171.7	140.6
	A. marina	24.4	17.9	11.4	31.3	22.2	16.7	47.2	14.3	10.9	102.8	54.5	38.9
	S. alba	4.9	15.4	40.9	12.5	27.8	33.3	7.5	30.6	46.3	24.9	73.7	120.5
2	*R. apiculata*	51.5	45.2	44.4	42.9	39.1	32.0	54.3	45.6	47,6	148.6	129.9	124.0
	A. marina	30.9	31.0	27.8	38.1	30.4	32.0	31.9	31.7	22.2	100.9	93.1	82.0
	S. marina	17.6	23.8	27.8	19.0	30.4	36.0	13.8	22.7	30.2	50.5	77.0	94.0
3	*R. apiculata*	61.7	65.4	33.3	53.8	60.0	40.0	65.5	67.5	30.0	181.0	192.9	103.4
	A. marina	34.0	34.6	54.8	30.8	40.0	46.7	31.3	32.5	66.7	96.1	107.1	168.2
	S. alba	4.3	0	11.9	15.4	0	13.3	3.3	0	3.3	22.9	0	28.5

T-Tree; P-Pole; S-Seedling.

In contrast to the stations 1 and 2, where the highest IVI of the smallest trees (trees with diameter of less than 5 cm) were also dominated by *R. apiculata*, the highest IVI of the smallest trees at the station 3, which have a higher inter tidal and are muddier, was recorded for *A. marina*. The results indicated that, in the future, *A. marina* may become an important species for the area, replacing *R apiculata*.

Biomass of mangroves. The total biomass densities of the mangrove stands, at the stations one, two and three, were about 42.4, 26.0 and 30.4 ton ha^{-1}, respectively. The difference of total biomass among the three stations was due to the species composition of the mangrove stands and to the size of the tree species. The mangrove biomass at the station one was the highest, compared to the other stations (Figure 2).

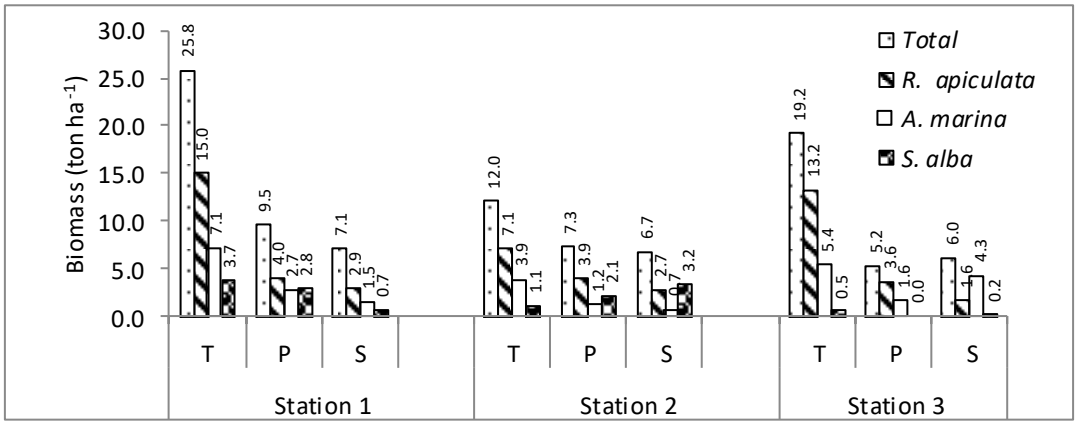

Figure 2. The mangrove biomass, corresponding to trees with different diameters, at the stations one, two and three, at Pupau Bai-Pantai Panjang NCP, Bengkulu, Indonesia (T-Tree; P-Pole; S-Seedling).

Three species, *R. apiculata*, *A. marina* and *S. alba* were found at the station one and contributed to the total biomass with about 21.9, 11.3 and 7.2 t ha^{-1}, respectively. According to the size categories, the biomass of *R. apiculata* tree was about 21.9 t ha^{-1}: 15.0 t ha^{-1} for diameters >10 cm, 4.0 t ha^{-1} for diameters between 5 and 10 cm and 2.9 t ha^{-1} for diameters under 5 cm. The biomass of the *A. marina* trees was about 11.3 t ha^{-1}, consisting of 7.1 t ha^{-1}, 2.7 t ha^{-1} and 1.5 t ha^{-1}, for the trees with a diameter >10 cm , between 5 and 10 cm and <5 cm , respectively . The biomass of the *S. alba* trees was about 7.2 t ha^{-1} consisting of 3.7 t ha^{-1}, 2.8 t ha^{-1} and 0.7 t ha^{-1}, for the trees with a diameter >10 cm, between 5 and 10 cm and <5 cm, respectively. The biomass at the station one was the highest compared to the other stations, possibly due to the number and diameters differences.

At station 2, the mangrove biomass was of 12.0 t ha^{-1}, 7.3 t ha^{-1} and 6.7 t ha^{-1} for the trees with a diameter >10 cm, between 5 and 10 cm and <5 cm, respectively. The biomass of mangrove trees with a diameter >10 cm was less than at the stations one and three, because the average diameter of the trees at this station was smaller than at the stations one or three. The mangrove biomass of the trees with a diameter between 5 and 10 cm (7.3 t ha^{-1}) consisted of 3.9, 1.2 and 2.1 t ha^{-1} of *R. apiculata*, *A. Marina* and *S. alba*, respectively. The mangrove trees with a diameter between 5 and 10 cm contributed to the total biomass with 2.7, 0.7 and 3.2 t ha^{-1}, for the *R. apiculata*, *A. marina* and *S. alba* species, respectively.

The total biomass of the mangrove stand at station three was about 30.4 t ha^{-1}, consisting of 19.2, 5.2 and 6.0 t ha^{-1}, for the trees with a diameter >10 cm, between 5-10 cm and <5 cm, respectively. In trees category with a diameter >10 cm, the three species, *R. apiculata*, *A. marina* and *S. alba* contributed to the biomass with about 13.2, 5.4 and 0.5 t ha^{-1}, respectively. Trees with a diameter between 5 and 10 cm were represented only by *A. marina* and *S. alba*, that contributed to the biomass with about 3.6 and 1.6 t ha^{-1}, respectively. In the smallest tree category found at the station three, *R. apiculata*, *A. marina* and *S. alba* contributed to the biomass with about 1.6, 4.3 and 0.2 t ha^{-1}, respectively.

The distribution (in percentage) of biomass among the trees with different diameters, at each station, is shown in Figure 3. The biomass distribution of the trees with a diameter >10 cm and between 5 and 10 cm, at stations one, two and three, was in line with the distribution and the abundance of each species at the observation stations, being also dominated by *R apiculata*, with approximately 58.1-69.0% and 42.1-68.8%, respectively.

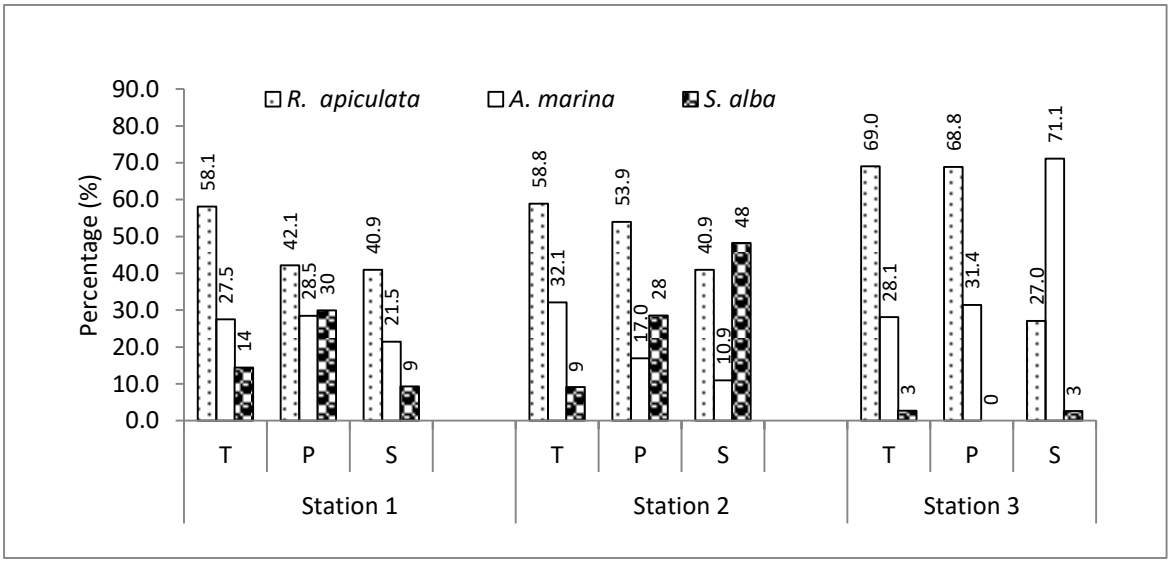

Figure 3. Percentage distribution of biomass among trees with a different diameter at station one, two, and three of mangrove at Pulau Bai-Pantai Panjang NCP, Bengkulu, Indonesia (T-Tree; P-Pole; S-Seedling).

At station 2, the distribution of the biomass of the smallest trees (diameter <5 cm) was dominated by *S alba*, with 48.2%. The highest percentage of biomass of the smallest tree at the station one was found in *R apiculata*, with 41.1%. But, unlike stations 1 and 2, the biomass of the smallest trees at the station 3 was dominated by *A. marina*, with 71.1%.

Conclusions. Low values of the Shanon Diversity Index were observed in the mangrove forest at Pulau Bai-Pantai Panjang NCP, Bengkulu, Indonesia. The mangrove forest was composed of three types of mangrove plants, *R. apiculata*, *A. marina* and *S. alba*. *R. apiculata* had the highest important value index and biomass production at the tree, pole and seedling levels that attributed the play an importance role in controlling the dynamic of the mangrove forest.

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Conflict of interest. The authors declare no conflict of interest.

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