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Short Communication: Carbon stock of mangrove forest in Pantai Sederhana, Bekasi District, West Java, Indonesia

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Abstract. *Erniasari I, Hernawan E, Mulyaningrum. 2024. Short Communication: Carbon stock of mangrove forest in Pantai Sederhana, Bekasi District, West Java, Indonesia. Biodiversitas 25: 2974-2980.* Mangrove forests play an important role in the carbon cycle because this forest can store greater amounts of carbon than other ecosystems including tropical rainforests. Mangrove forests in Bekasi District, West Java, Indonesia have enormous potential to absorb carbon in this industrial area. In this research, we estimate the aboveground carbon (AGC), belowground carbon (BGC), and soil organic carbon (SOC) of mangrove forest in Pantai Sederhana, Muaragembong Subdistrict, Bekasi District. Carbon estimation of AGC and BGC was carried out using the allometric method, while SOC at four depth intervals (0-15, 15-30, 30-50, and 50-100 cm) was estimated using the LOI (Loss of Ignition) method. There were four mangrove species in Pantai Sederhana, namely *Avicennia marina*, *Avicennia alba*, *Rhizophora apiculata*, and *Rhizophora mucronata*. The total carbon stock was 329.54 $Mg.C.ha^{-1}$, which was composed by aboveground carbon (114.51 $Mg.C.ha^{-1}$), belowground carbon (61.46 $Mg.C.ha^{-1}$) and soil carbon (153.56 $Mg.C.ha^{-1}$). The largest carbon pool was contributed from soils with 47% of the total carbon stock. The result of this study can be used as the initial information of the importance of the mangrove ecosystem in Bekasi District.

Keywords: Aboveground carbon, allometric method, belowground carbon, carbon reserves, soil organic carbon

INTRODUCTION

Climate change has become a global issue in the last century which is largely driven by the increase in greenhouse gases (GHG), such as CO_2. Since the revolution of industry, which was dated back in the 1900s, combustion generated from fossil fuels has resulted in a high concentration of CO_2 in the atmosphere. According to the Indonesian Ministry of Industry, in 2023, the industrial sector contributes 15-20% of national GHG emissions, 60% of which comes from energy use. The continuing increase of CO_2 concentrations can be halted or reduced through carbon sequestration and storage. This can be achieved by increasing the area serving as carbon sinks, one of which is mangrove forests. Mangrove forests serve as significant carbon sinks, possessing carbon reserves up to 50% greater than other forest types (Maku et al. 2020).

Indonesia is an archipelagic country with an area of 3 million hectares of mangrove forest, making it as the country with the largest mangrove forest area in the world. Indonesia contributes to 24% of the world's total mangroves (Arifanti et al. 2022), spreading from the east coast of Sumatra, the north coast of Java, the west and east coasts of Kalimantan, small islands in Maluku, and the south coast of Papua (Rahadian et al. 2019). This mangrove forest includes tree communities in tidal areas that grow naturally or are planted. Beside serving as carbon sinks (Chatting et al. 2022), mangrove forests have various functions, including protection against storms, tsunamis and sea level rise (Barbier et al. 2011), regulation of water systems that prevent seawater intrusion in coastal areas and estuaries (Aurilia and Saputra 2020), and habitat for various flora and fauna. For example, mangrove ecosystems in Indonesia consist of 122 species of invertebrates, 45 species of fish, and 148 species of terrestrial fauna (Basyuni et al. 2022).

Carbon storage in mangrove forests originates from aboveground biomass (AGB), below-ground biomass (BGB), and soil organic carbon (SOC). Key factors influencing carbon stocks in mangrove ecosystems include geomorphological characteristics, soil and hydrological properties, mangrove species, stand density, average height and diameter of trees and land uses (Swangjang and Paniskhan 2021). Rahmah et al. (2015) found that the largest carbon storage in mangrove forests is in the soil, accounting for 50-90% of total carbon stock, and five times greater than that in other tropical forests (Zaman et al. 2023). Variations in soil organic carbon are strongly influenced by species composition (Gao et al. 2019) and the age of the trees in the mangrove forest (Zaman et al. 2023). Soil deposits affected by tidal amplitude and temperature accumulate rich organic materials several meters below the surface, where they can be stored for centuries if undisturbed (Elwin et al. 2019).

Bekasi District, West Java Province, Indonesia is one of the largest industrial areas in Southeast Asia. It faces challenges in controlling GHG emissions due to its industrial activities. As reported by Bekasi District Industry

Service, there were 2,680 industrial companies in the district consisting of 213 industry types and occupying no less than 11,000 hectares of land in 2022. The industry sector provides labor force of 624,587 people and serves as important sources of state income. The rapid growth of industrialization and population in this region has caused GHG emissions from various sources, such as industrial processes, transportation, waste, and land use changes (Wadanambi et al. 2020; Pratama 2022). This is exacerbated by the reduction in the area of carbon sink due to the large number of vegetated lands being converted into industrial buildings and residential zones.

The mangrove forests in the northern part of Bekasi District have the potential to absorb the GHG emissions in this area. However, the carbon absorption potential has not been calculated, leading to suboptimal management of these mangrove forests. Based on previous research data conducted by Mahingsa (2018) and data collected from the Bekasi District Environmental Service (2022), mangrove forests in the Muaragembong area, Bekasi experienced degradation from 1.380 ha in 2009 to only 985.84 ha in 2022. Initial observations indicated the damage on the mangrove forests was caused by conversion into pond areas and sea waves abrasion occurred along the coastline. The accumulation of wastes originating from rivers that flow into the northern part of the Bekasi District also causes mangrove degradation. Therefore, this research aims to estimate carbon stock in the Pantai Sederhana mangrove forest located in Muaragembong subdistrict, Bekasi District. The information on carbon stock obtained from this research is expected to serve as a guideline for supporting the long-term conservation of these fragile ecosystems, which are threatened by natural and anthropogenic activities.

MATERIALS AND METHODS

Study period and area

The research was conducted during September-October 2023 in mangrove forest in Pantai Sederhana Village, Muaragembong Sub-district, Bekasi District, West Java Province, Indonesia (Figure 1). This mangrove forest has an area of 985.84 ha and is designated as a protected forest. In terms of forestry administration, the Muaragembong mangrove forest area is included in the Ujung Krawang (Muaragembong) Protected Forest and Production Forest Area, which consists of the Muaragembong Forest Management Unit Resort (RPH) covering an area of 2,439.75 ha (23.28%), the Singkil RPH covering an area of 3,318.50 ha (31.66%) and Pondok Tengah RPH covering an area of 4,722.90 ha (45.06%), Ujung Krawang Forest Management Unit (BKPH), Bogor Forest Management Unit (KPH), Perum Perhutani Unit III West Java and Banten.

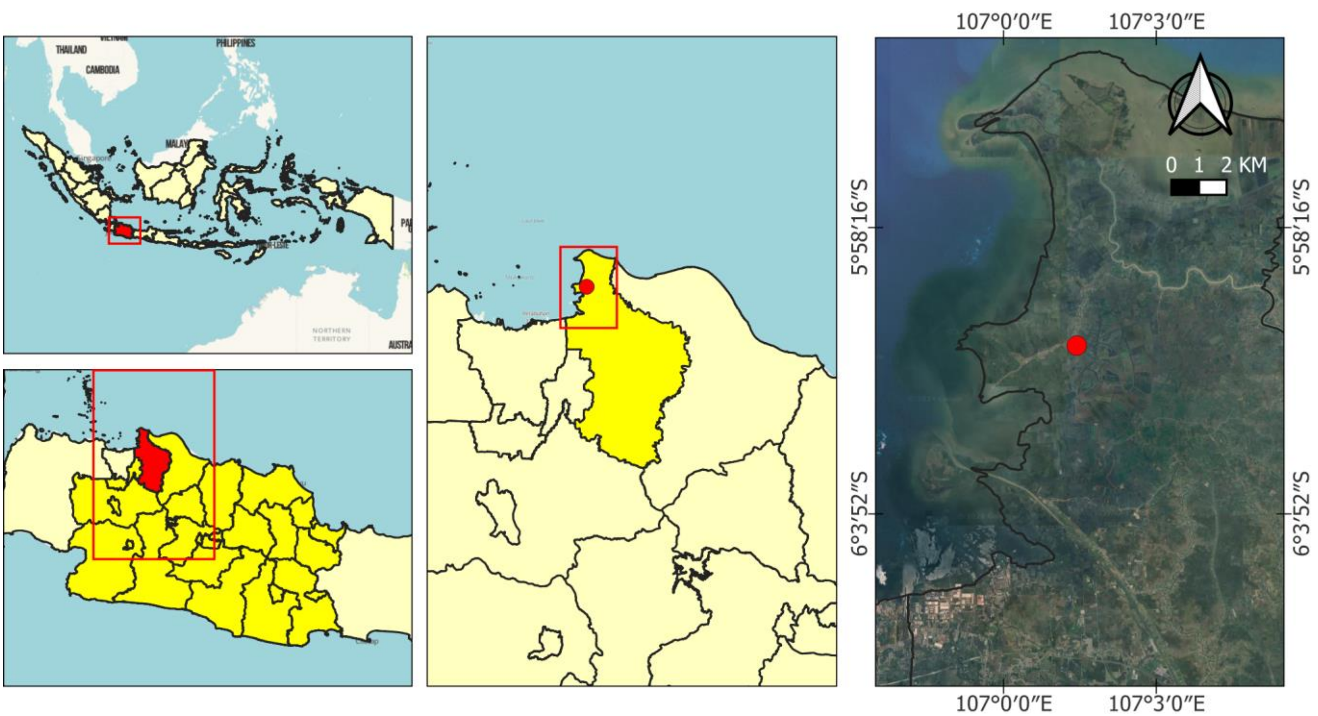

Figure 1. Map of study area in mangrove forest of Pantai Sederhana, Muaragembong Sub-district, Bekasi District, West Java, Indonesia

Table 1. The allometric equations used in this study to determine the biomass of mangrove vegetation

Species	Allometric equation	References	Wood Density (ρ)*
Aboveground Biomass (AGB)			
Avicennia marina	$B=0.1848*D^{2.3524}$	Dharmawan and Siregar (2008)	0.65
Avicennia alba	$B=0.308*D^{2.11}$	Komiyama et al. (2008)	0.67
Rhizophora apiculata	$B=0.043*D^{2.63}$	Amira (2008)	0.85
Rhizophora mucronata	$B=0.1466*D^{2.3136}$	Komiyama et al. (2008)	0.82
Belowground Biomass (BGB)			
General equation	$B=0.199*(\rho^{0.899})*(D^{2.22})$	Komiyama et al. (2008); Kauffman and Donato (2012)	

Note: Biomass in kg, ρ is wood density in $g.cm^{-3}$, DBH is the Breast Height Diameter in cm

Data collection

The sampling location included 6 stations which consist 3 plots per station, randomly placed inside the Pantai Sederhana mangrove forest to collect biophysical information of the forest. The shape and size of the sample plots were determined according to SNI 7724:2011 standards for measuring and calculating carbon storage. The sample plots measured 10×10 m for tree stage and 5×5 m for pole stage. Data was collected to estimate aboveground biomass (AGB), below-ground biomass (BGB), and soil samples. The data to estimate AGB and BGB included species names, the number of individual species, and the tree diameter of breast high (DBH) (SNI 7724:2011). Soil samples were taken from a depth of 1 meter at four different intervals: 0-15, 15-30, 30-50, and 50-100 cm, using a modified soil core sampler in each observation plot, resulting in a total of 24 soil samples. The environmental variables, such as pH, air temperature, air humidity, soil humidity, and light intensity, were also measured at each station using pH meter, thermometer, sling psychrometer, soil tester, and lux meters.

Data analysis

AGB and BGB carbon measurement

Carbon stock of each mangrove species was calculated using allometric equation (Table 1). The estimation of tree biomass was carried out using a non-harvesting method or without damaging vegetation (non-destructive). Carbon storage estimation involved multiplying the biomass amount ($Mg.ha^{-1}$) by 0.47. This calculation is based on the IPCC 2006 equation, which states that 47% of biomass vegetation is composed of carbon thus the equation or conversion factor used was

$$C = B\times 0.47$$

Where: C: Carbon Storage ($Mg.ha^{-1}$), B: Expansion tree biomass ($Mg.ha^{-1}$) is the result of conversion from kg/m^2, 0.47= Conversion factor for carbon estimation according to IPCC 2006.

Soil carbon measurement

Soil samples were analyzed to estimate carbon content at the Research Laboratory of Bandung Institute of Technology (ITB) using the Loss on Ignition (LOI) method. LOI analysis is utilized to determine the organic matter content (%OM) of a soil sample. This method is relatively simple compared to other procedures for determining %OM as it only requires the samples to be placed in a muffle furnace at 450°C (Sternberg-Rodríguez et al. 2023) for 4 hours, without involving any chemicals. The subsample's weight before and after the ashing process in the furnace was measured, and the carbon content was calculated using equation below:

$$OM= \frac{\text{subsample dry weight (g)} - \text{ash weight (g)}}{\text{subsample dry weight (g)}} \times 100\%$$

$$SOC = BD \times d \times \%C \times 100$$

Where: OM: Organic matter (%), SOC: Soil Organic Carbon ($Mg.ha^{-1}$), BD: Bulk Density ($gr.cm^{-3}$) is the result of the dry weight of soil divided by the volume of the core sampler, d: depth of soil sample of each interval (cm), %C: carbon concentration which is 58% OM.

Carbon sequestration (CS) value was calculated by multiplying total carbon content (C) by the value of the ratio of atomic carbon dioxide to carbon (44/12) (IPCC 2006).

$$CS = 3.67 \times C$$

RESULTS AND DISCUSSION

Species diversity and density

Based on the research results, four mangrove species were identified across all stations ($6x100\ m^2 = 600\ m^2$) in the Pantai Sederhana mangrove forest, namely *Avicennia marina*, *A. alba*, *Rhizophora apiculata*, and *R. mucronata*, with 93, 59, 51, and 58 individuals, respectively, totaling 261 individuals. Station 2 had the highest number of individuals with 66, followed by station 6 with 53, station 3 with 44, station 1 with 39, station 5 with 35, and station 4 with 24, as shown in Figure 2. *Avicennia marina* exhibited the highest density among the mangrove species, largely due to reforestation programs through industrial Corporate Social Responsibility (CSR) initiatives in Bekasi District. The abundance of *A. marina* is also attributed to its classification as a major mangrove species, which naturally grows only in mangrove ecosystems and not in terrestrial environments. This species plays a crucial role in the structure of mangrove vegetation communities and can form pure stands. It is a pioneer and opportunist species, capable of rapid regeneration, which aids in the quick recovery of damaged areas. Its crypto-vivipary reproduction method ensures a good growth rate, with seeds thriving in muddy soil with high salinity (Aluri 2022). The respiratory roots of *A. marina* further facilitate its growth in muddy soil conditions. The genera *Avicennia* is prevalent in most mangrove ecosystems across Indonesia, as reported by Halidah (2014), Widyastuti et al. (2018) in Cilacap Central Java, Dinilhuda et al. (2020) in West Kalimantan, and Fatonah et al. (2023) in Siak, Riau.

Environmental factors

Environmental factors recorded at the location included pH, air temperature, air humidity, soil humidity, light intensity, and substrate type, with a maximum depth of 100 cm (Table 2). The environmental conditions outlined in Table 2 were found to be relatively suitable for the growth of mangrove trees. The different condition was noted for light intensity at stations 5 and 6 which was quite low due to their location tended to be closer to the sea, resulting in a lower individual density at these stations.

Biomass and carbon content

Biomass is defined as the total amount of organic material contained in vegetation, representing the matter and energy accumulated through photosynthesis (Poley et al. 2020). The AGB was derived from the main trunk of the tree measured at DBH, while the BGB measured from the roots and was calculated using the general equation in Table 1. The highest amount of biomass was recorded at station 2, with a total of 79.18 Mg.ha^{-1}, followed by stations 3, 1, 4, 6, and 5, with total biomass of 76.19 Mg.ha^{-1}, 67.82 Mg.ha^{-1}, 59.56 Mg.ha^{-1}, 53.30 Mg.ha^{-1}, and 23.88 Mg.ha^{-1}, respectively. Station 2 had the highest biomass content because it had more individuals for each species than the other locations. This finding highlights that both the diameter of the main stem and the number of individuals influence the amount of carbon stored in the Pantai Sederhana mangrove ecosystem. This aligns with previous research by Perera and Amarasinghe (2013) which stated that there's a statistically significant relationship between DBH and total organic carbon of trees. Bai et al. (2021) also reported that mangrove diversity positively affects biomass production and soil carbon storage. Mangrove forests with greater diversity have higher carbon storage capacities and conservation potential. Similar results were reported by Fichtner et al. (2018) and Li et al. (2019), who stated that biomass productivity is significantly influenced by diversity, depending on species composition and environmental factors. They observed that species richness within a community is associated with increased biomass, which can be attributed to the niche effect. This effect occurs when species occupy specific niches that enable more efficient resource utilization, thereby boosting biomass production and subsequently increasing mangrove carbon (Wang et al. 2019). Therefore, planting multiple mixed species in the same restoration area is recommended over planting a single species.

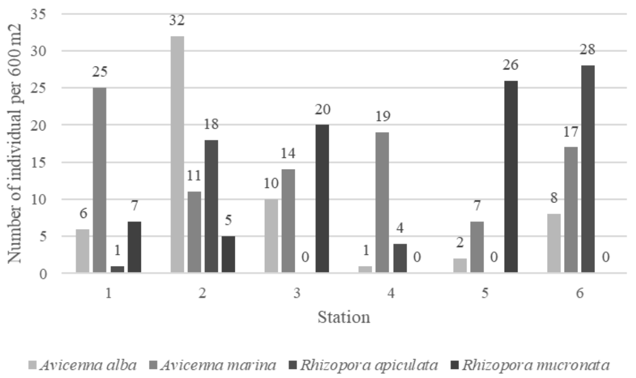

Figure 2. Individual number of each mangrove species at each station in Pantai Sederhana, Bekasi District, West Java, Indonesia

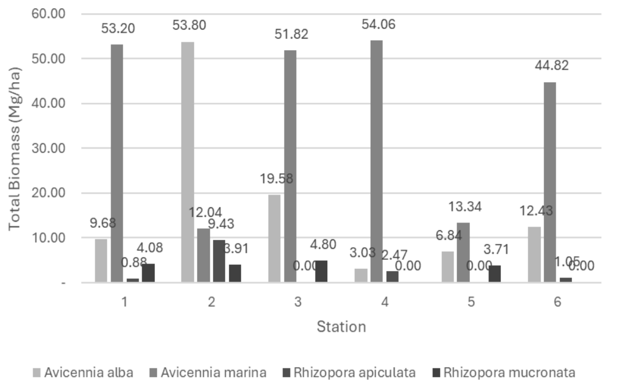

Figure 3. Total biomass of species at each station in Pantai Sederhana mangrove forest, Bekasi District, West Java, Indonesia

Table 2. Environmental factors at each station in Pantai Sederhana mangrove forest, Bekasi District, West Java, Indonesia

Environmental factors	Average condition of environmental factors						
	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Quality Standards*
pH	6	5	5.5	5	5.5	5.5	7-8.5
Air temperature (°C)	30	32	34	33	33	33	28-32
Air humidity (%)	89	88	86.5	79	82.5	77.5	-
Soil humidity (%)	80	80	80	90	90	90	-
Light intensity (lux)	7580	16450	10200	7335	4000	3600	-
Substrate	mud	mud	mud	mud	mud	mud	-
Bulk density (g/cm^3)	0.345	0.347	0.153	0.186	0.140	0.231	-

Note: * Decree of the Ministry of Environment and Forestry No.51/2021

As shown in Figure 3, the genera *Avicennia* dominated the total biomass across all stations. *A. marina* had the highest total biomass among the mangrove species because it is predominant in five stations. The total biomass of plants influences the amount of carbon they contain; thus, greater plant biomass corresponds to higher carbon stock. The carbon stored in plant biomass results from photosynthesis, where CO_2 and H_2O serves as substrates. With the aid of sunlight, the reaction between CO_2 and H_2O produces carbohydrates, which are stored in various parts of the plant (Abdullah et al. 2021). Therefore, measuring the carbon stored in living plant biomass can indicate the amount of CO_2 in the atmosphere (Hariana et al. 2020).

Based on the calculation using conversion factor for carbon estimation according to IPCC 2006, the total amount of the aboveground carbon (AGC) of the Pantai Sederhana was 114.51 MgC.ha^{-1}. This value of carbon storage similar to the mangrove forest in Angke Kapuk, Jakarta (111.6 MgC.ha$^{-1)}$ which is located close to the Pantai Sederhana, Muaragembong, Bekasi District, and restored mangrove ecosystem in Sungai Apit, Siak, Riau with 128 Mg.C.ha^{-1} (Fatonah et al. 2023). Compared to the amount of AGC storage in other sites of mangrove ecosystems in Indonesia such as Paliat Island, Sumenep, East Java (10.80 Mg.C.ha^{-1}), South Sulawesi (100.66 MgC.ha^{-1}), Karimunting Bay, West Kalimantan (99.23 MgC.ha^{-1}), and Nusa Lembongan Bali (56.41 MgC.ha^{-1}), the Pantai Sederhana relatively had the high carbon stocks (Hidayah and Andriyani 2019; Malik et al. 2023; Dinilhuda et al. 2020; Pricillia et al. 2020). The high carbon storage capacity of the mangrove ecosystems in the study area confirms that the mangrove ecosystem has an important contribution to mitigating climate change by absorbing CO_2 from the atmosphere. In addition to their ability to effectively capture and store carbon in aboveground biomass, mangrove trees also have extensive and complex root systems that often extend both vertically and horizontally, which provide extensive space for carbon storage (Sumarga et al. 2023).

Soil Organic Carbon (SOC)

We also calculated soil organic carbon (SOC) at four depth intervals. Figure 4 illustrates the SOC content at each soil depth interval, analyzed using the Loss on Ignition (LOI) method. The highest carbon content was found in the 50-100 cm depth interval with 61.25 MgC.ha^{-1}, followed by the 30-50 cm interval (40.63 MgC.ha^{-1}), the 15-30 cm interval (31.70 MgC.ha$_{-1}$), and the 0-15 cm interval (19.97 MgC.ha^{-1}). The total carbon content across the three carbon pools in the Pantai Sederhana mangrove forest revealed that soil carbon had a greater amount than carbon stored in the aboveground and belowground biomass, as shown in Table 3. This finding aligns with Alongi (2020), who reported that soil in mangrove forests accounts for 76.5% of the total carbon in the ecosystem to a depth of 1 meter, underscoring the significant role of soil soils in carbon storage within mangrove ecosystems.

Carbon sequestration in soils is more complex than in biomass because carbon sources include vegetation-associated biota and external systems like seagrass and coral reef ecosystems (Howard et al. 2014; Saderne et al. 2019). This research indicates that the amount of carbon stored in soil soil increases with the depth of the soil interval sampled. At 50-100 cm depth, soil soil samples showed the lowest unit weight values. There is an inverse relationship between SOC (%C) and bulk density (Bhomia et al. 2016); higher organic carbon content corresponds to lower bulk density due to increased porosity, which prevents carbon depositions in soils. Soil depth and carbon stock have a positive relationship. The deeper the soil, the greater the value of the carbon reserves in the soil as shown in Figure 4. The low carbon content at shallower depths is likely due to the influx of sand soil from sea waves impacting the mangrove area. In contrast, the high value of carbon content in deeper soils is likely influenced by the complete decomposition processes. This aligns with Eid et al. (2019), who found that soil bulk density in mangrove soils decreases with higher SOC concentrations on Farasan Island, Saudi Arabia. Similarly, Gao et al. (2019) reported that soil pH, salinity, and bulk density were negatively correlated with SOC contents in Chinese mangrove forests.

Compared to the SOC in mangrove forest in the estuary of the Batang River West Sumatra (2,561.9 MgC.ha^{-1}), restored mangrove forest of Lubuk Kertang North Sumatra (461.85-506.89 MgC.ha^{-1}), Mahakam Delta East Kalimantan (1,120 MgC.ha^{-1}), and Ambon Bay (320.03 MgC.ha^{-1}), Pantai Sederhana has lower value (153.55 MgC.h^{-1}) but higher than that in Benoa Bay, Bali (104 MgC.ha^{-1}) (Amanda et al. 2021; Amelia et al. 2023; Diana et al. 2023; Kaimuddin et al. 2023; Sugiana et al. 2024). This is because the mangrove ecosystems in Java generally experience higher level of degradation due to anthropogenic activities and natural events rather than the mangrove ecosystem in Sumatra, Kalimantan, and Maluku islands.

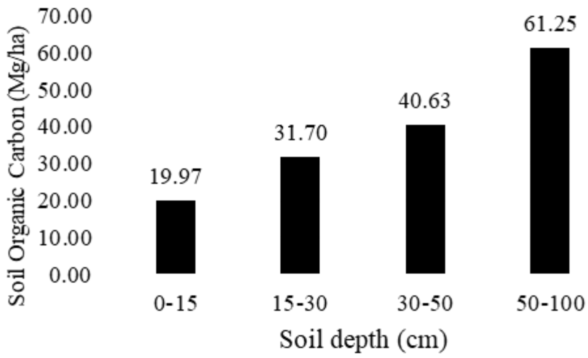

Figure 4. Soil organic carbon at different depth intervals in Pantai Sederhana mangrove forest, Bekasi District, West Java, Indonesia

Table 3. Carbon content of varying pool in Pantai Sederhana mangrove forest, Bekasi District, West Java, Indonesia

Carbon pool	Carbon content (Mg.C.ha^{-1})
AGB	114.51
BGB	61.46
Soil Carbon	153.55
Total	**332.52**

In conclusion, there were four species of mangrove in Pantai Sederhana, Muaragembong, Bekasi District: *Rhizophora mucronata*, *Rhizophora apiculata*, *Avicennia marina*, and *Avicennia alba* with *Avicennia marina* was the most dominant species. The total carbon stock of the mangrove ecosystem at the study site was estimated to be 332.52 $MgC.ha^{-1}$, equating to the absorption of approximately 1,220.34 $MgC.ha^{-1}$ CO_2. The research showed significant differences in carbon stock among the three carbon pools: aboveground biomass (AGB), below-ground biomass (BGB), and soil organic carbon (SOC) with the highest was found in the SOC, accounted for 46% of the total carbon. However, compared to other mangrove forests in Indonesia, the SOC value in Pantai Sederhana was relatively lower. Given the critical role of mangrove ecosystems in carbon storage, it is essential to protect these forests from degradation and deforestation caused by anthropogenic activities.

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