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Stand growth and carbon stocks of community-based mangrove rehabilitation in Singkawang City, West Kalimantan, Indonesia

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Abstract. *Astiani D, Roslinda E, Widiastuti T, Ekamawanti HA, Ekyastuti W, Dwianto W, Alfikri F, Ngidu EY. 2024. Stand growth and carbon stocks of community-based mangrove rehabilitation in Singkawang City, West Kalimantan, Indonesia. Biodiversitas 25: 2799-2805.* The ability of tropical mangrove ecosystems to store carbon in the form of biomass is well-founded. The mangrove forest in Setapuk Besar Village, Singkawang City, West Kalimantan Province, Indonesia has been managed by community members in response to the development of alluvial sediment land in recent years. The community's efforts in Setapuk Besar Village to rehabilitate and manage mangrove forests illustrate how essential mangrove forests are to the local ecology and should be applauded for their success. This study aims to investigate the growth and development, carbon stored and sequestered in mangrove forests planted by community in Setapuk Besar between 2015 and 2020. Field survey was conducted from July to November 2022 by mapping the sediment land that had expanded since 2015 and continued with the measurement of density and diameter of mangrove stands that were systematically planted in each planting year using sampling plot method. In addition, site factors such as pH, carbon content, nitrogen, phosphorus, CEC, and soil solution salinity were investigated. Our findings indicate that due to alluvial sedimentation, the coastline in Setapuk village is expanding by 3.3 to 4.6 ha annually, accumulating 24 ha throughout a six-year period. The mangroves planted in 2015-2016 are now thriving on the new land. The six-year-old trees diameter achieved an average of 6.80±0.13 cm, averaged 5.1 m in height, and increased from 0.45 to 2.2 cm in diameter. The total biomass (above and below-ground) of plants aged 4, 5 and 6 years was 250, 303 and 430 tons ha^{-1}, with a potential to absorb carbon of 28-33 tons ha^{-1} year^{-1}, correspondingly. Given that this mangrove area plays a crucial role in CO_2 capture in nature and has a relatively high ability to absorb and store carbon, conservation efforts and best practices are necessary for this forest.

Keywords: Carbon sequestration, carbon stocks, planted mangrove, Setapuk Besar, tree biomass

INTRODUCTION

Mangrove forest is one of important ecosystems due to its unique location, biophysical characteristics, ecological functions, and socio-economic values. Mangrove forest has various ecosystem services including as barrier to protect coastal areas from winds, storms, cyclones, tsunamis, abrasion and sea intrusion (Friess and Webb 2014). Mangrove ecosystem also serves as habitat and breeding ground of a variety of aquatic biotas (Dehghani 2014; Aisyah et al. 2019; Carrasquilla-Henao et al. 2019). Recently, mangrove ecosystem is increasingly acknowledged as important carbon sink for climate change mitigation especially due to its high capacity to sequester carbon in its vegetation (Cameron et al. 2019; Wiarta et al. 2019). The capacity of mangrove ecosystem in the uptake and stocking of carbon from the atmosphere is higher than other ecosystem types including tropical forests (Astiani et al. 2017). More recent studies reveal the high capacity of mangrove ecosystem in storing organic carbon in the soil (Kida et al. 2017; Breithaupt et al. 2023). In term of socio-economic aspect, mangrove ecosystem provides the surrounding community with various fisheries and non-timber forest products as well as being developed for ecotourism.

Indonesia has the largest extent of mangrove forest in the world with 4.293 million ha, or equivalent to 75% of all mangroves in Southeast Asia and 27% of mangrove forests globally (Sidik et al. 2018). However, some extent of mangrove ecosystem in Indonesia are deforested or degraded due to various factors including mangrove tree cutting and conversion, settlements, industries, irrigated rice fields, and fish and shrimp ponds (Cahyaningsih et al. 2022). Therefore, the current state of mangrove forests in Indonesia, and in the tropics broadly, requires prudent management, particularly to minimize the deterioration of their environmental functions and to ensure their sustainability (Friess et al. 2022).

One of mangrove areas in Indonesia is located along the coastal area of Singkawang City, West Kalimantan Province. The mangrove in this area is managed by local community, being motivated by the concern of the fishermen and villagers to preserve mangrove forest and marine biota. There are various activities in managing the mangrove area, one of which is mangrove restoration by conducting planting activities along the entire new ocean-deposited lands in Setapuk Besar Village, Singkawang City. The deposits of mud have formed near river mouths, where the water slows down and deposits the mud it carries from upstream and in bays that are shielded from the wave impact.

Initially, the total mangrove area had an extent of 20.67 ha. Recently, the mangrove area has been extending to 26.1 ha because as many as 150,000 mangrove seedlings, most of them *Rhizophora apiculate* Blume, have been planted since 2016. The mangrove planting activities are continuously expanded with now already reach the nearby Village Setapuk Kecil. The planting of mangrove seedlings in Setapuk Besar actually began in 2007, but only in small spots, until 2015. Then, the scale of mangrove planting began to increase when the planting activities were supported by local government and NGO's and this collaboration continues until present. The mangrove planting is conducted annually to revegetate the deposited land which continuously formed and expanded toward the sea. Such efforts need to be acknowledged by stakeholders to maintain the sustainability of the mangrove forest that has been restored. Nowadays, this area is also developed as a tourist area in Singkawang City.

It is interesting to investigate the contribution of community-based mangrove restoration in Singkawang City in improving the extent of mangrove forest as well as the ecological benefits its deliver. Such information is important to serve as a tool of evaluation of existing management as well as for reference for similar programs and activities in other regions. Therefore, the information on the extent of mangroves, the stand's growth and the carbon sequestered as the result of land rehabilitation in Setapuk Besar Village, Singkawang City is crucial. This study aims to investigate the annual growth of mangroves planted in the newly formed land area, the growth of tree and their biomass and carbon as well estimation of carbon stocks in the area. The research findings are expected to add perspective on the importance and effectiveness of community-based mangrove rehabilitation in carbon sequestration for climate change mitigation. The success of this effort in Singkawang might be replicated elsewhere.

MATERIALS AND METHODS

Study area and period

The study was conducted in approximately 30 ha of community-mangrove rehabilitation area in Setapuk Besar Village, Singkawang City, West Kalimantan, Indonesia (Figure 1). The field assessment was carried out between June to December 2022.

Data collection procedure

This study was carried out in stages. The initial stage was to map annual expansion of newly formed land in the coastal areas originated from sedimentation and mangrove planting. The delineation of land expansion and mangrove planting was conducted in the year of 2015-2016, 2016-2017, 2017-2018, 2018-2019, and 2019-2020. Delineation was conducted by manually tracing the borders of mangrove planting by the community between 2015 and 2020 using GPS (Global Positioning System). Borders that were difficult to approach via tracking were estimated their coordinates. The collected field data was then projected into an annual land expansion map.

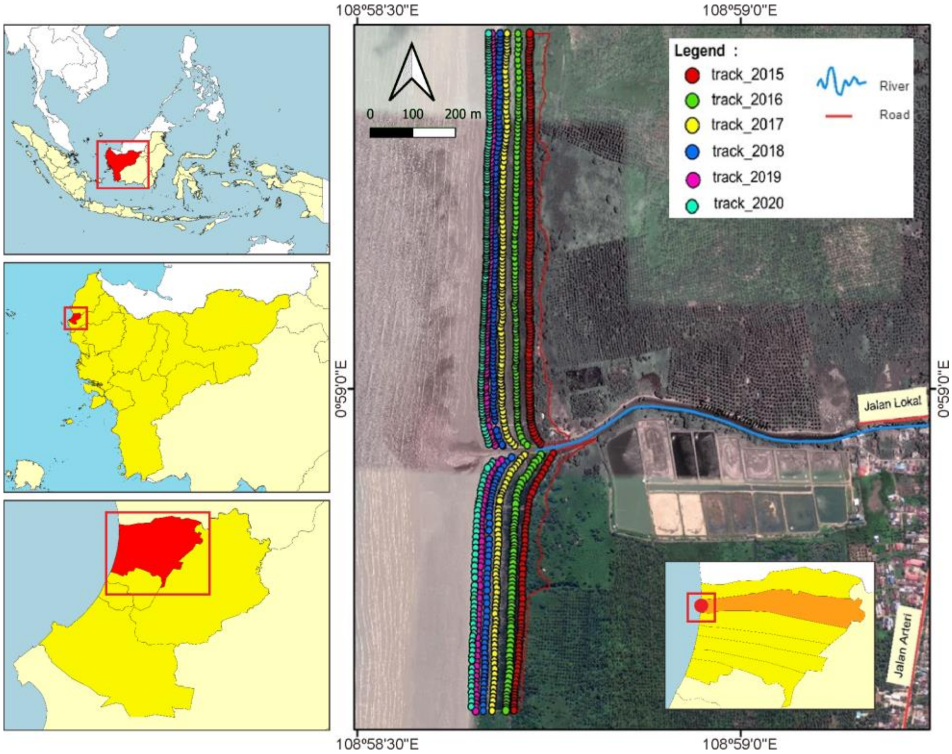


Figure 1. Annual expansion of deposited land in coastal area in Setapuk Besar Village, Singkawang City, West Kalimantan, Indonesia

The next stage was vegetation survey to record and measure planted mangroves by systematic sampling method using line plot technique. Sampling lines were purposefully designed by separating into six lines. Three lines representing planting year of 2015, 2016, and 2017, were used for carbon estimation by establishing observation plots measuring 5 × 5 m each with a distance between lines of 50 m, resulting in total of 60 plots. Tree diameter was measured at Diameter at Breast Height (DBH) or 1.3 m above the ground (Rusolono et al. 2015) or 30 cm above the most upper stilt root. For juvenile trees with stilt root, DBH was measured at normal position. There were a significant number of *Rhizophora* trees with more than one stem grew from the same base. For these multi branch trees, all stems were measured as individual tree as long as they meet the minimum DBH size requirement (larger than 5 cm). Measurements were carried out directly on the tree stem using phi-bands to obtain the DBH to be used for biomass estimation. Furthermore, tree height was measured to define the stand's average crown height, but it was not used as a variable to calculate tree biomass.

Data analysis

A non-destructive sampling method utilizing allometric equations was used to determine the aboveground and belowground biomass of *Rhizopora stylosa* Griffith. Mangrove stand biomass was determined using Komiyama's et al. (2007) allometric equation, which is B_{top} = 0.251 $DBH^{2.46}$. Below-ground biomass is calculated as B = DBH2,22 × 0,199 × p0,899, where B stand for Biomass, p is the wood-specific weight and DBH is the diameter at breast height (Komiyama et al. 2007). Following SNI 7724, 2011, the carbon value is transformed to represent 47% of the biomass. Combined above and below carbon levels equals the mangrove standing biomass.

RESULTS AND DISCUSSION

The results of land mapping of alluvial deposits in the Setapuk Besar Village, Singkawang City, show that the deposited lands were still being formed and increased until field assessment in 2022. However, area measurements can only be carried out for the land formed in 2021 because the land formed in 2022 was too muddy, making it difficult to access. The result of mapping indicates that new deposited land emerged relatively uniform throughout the year, ranging between 15 and 20 m in width (Figure 1). The extent of newly formed deposited land each year ranged from 3.3 to 4.9 ha, which is separated by the river that flows to the settlements of the Setapuk Village community (Table 1).

The deposited land planted with mangroves are still affected by tides although the frequency is decreasing as the planted location is further to the sea (i.e., the 5-year-old mangroves are less frequently affected than the 1 to 3-year-old plants). Tides in mangrove ecosystem have a significant impact on the zoning of plant and animal living there, particularly for young mangrove plants that are still very dependent on tides for survival (Krauss et al. 2008) since mineral nutrients will be supplied by the tides. As the plant grow larger, the litter is accumulated in the substrate to serve as organic carbon and nutrient sources to the plant although the ebb and flow occur only periodically throughout the lunar tide (Figure 2). Because it is only periodically flooded by tides, litter accumulation is more intensive and is not washed away, whereas litter accumulation has not occurred in more recently planted areas.

Cheong et al. (2013) stated that sea-level rise and coastal geomorphology influence the persistence of mangrove forests in the marine intertidal zone; vegetation also influences soil structure and surface elevation change - a shift in the location of the mangrove soil surface in the vertical direction. Thus, mangroves (and other vegetation) might have adaption mechanism to respond to the changes in environment, promote habitat resilience in nature, and serve as ecological engineers in coastal ecosystems.

Many mangrove forests are located in the transition zones between marine and terrestrial realms such as coastal plains, estuarine and deltaic formation. Kadaverugu et al. (2022) stated that mangroves are often restricted to a narrow elevation range inside the intertidal frame. The intertidal habitat is affected by depositional systems and geomorphological complexity.

Table 1. The annual extend of deposited land and planted mangrove area in Setapuk Besar Village, Singkawang City, West Kalimantan

Years	Direction from main river	Land area (Ha)	Total land area (Ha)
2015/2016	North	3	4.6
	South	1.6	
2016/2017	North	2.8	4.2
	South	1.4	
2017/2018	North	2.8	4.9
	South	2.1	
2018/2019	North	2.6	3.9
	South	1.3	
2019/2020	North	2.3	3.3
	South	0.99	
2020/2021	North	2.6	3.9
	South	1.3	


A B

Figure 2. Litterfall accumulation under planted mangrove stands with age of A. One to B. Six -years-old

In addition, the distribution of mangroves on the coastline dynamically changes over time, involving subtle balances between deposition and subsidence, erosion and vegetative stabilization, productivity and decomposition, and tidal flushing and drainage efficiency (Feng et al. 2020).

The growth of planted mangroves

Mangrove seedlings were planted each year in newly deposited muddy areas by the community with planting distance ~2m × 2 m or 2m × 1.5m, resulted in the density of approximately 2500-3000 trees per hectare. The seeds for planting came from mother trees that were planted several years before, both in Setapuk Village and natural mangrove forest surrounding the village. The seeds of *Rhizophora* spp. germinate whilst the fruit is still attached to the trees (vivipary). This allows them to be planted more easily in nurseries with a relatively high survival rate. Unlike typical seed development, viviparous seeds in mangroves have evolved with several unusual characteristics. Once planted in the fields, mangroves are untreated and dependent on their natural habitat. In addition, the accumulated sedimentary lands allow the mangroves to grow so that the species distribution is expanded.

The measurement of growth parameter of planted mangroves in term of diameter and height are presented in Figures 3 and 4. Even though no treatment was applied after planting, tree growth and development were relatively good. Figure 3 indicates that tree diameter growth is steady but fluctuates from year to year. The average diameter of mangrove planted from 2015 to 2021 (aged 6 to 1) was 6.8±0.13; 5.6±0.09; 5.5±0.06; 2.76±0.08; 2.05±0.14; and 1.5±0.11 cm, respectively with an increase in diameter ranging from 1.13-1.38 cm each year. Observations in the field showed that plants with age up to three years are still heavily affected by the tides. On the other hand, planting seedlings older than three years receive direct freshwater intake in the form of rainfall and groundwater, as well as nutritional input from litter that falls from trees.

Tree height growth exhibits a similar pattern. For the 6-year-old *Rhizophora* spp., the height reached 5.05±0.07 m, and at the age of 5 years, the crowns of the trees begin to meet and overlap. Rhizophora species are often grow to be a multi-stem tree. The multi-stem tree is unique character as response to the extreme environment. It is normally found only at specific areas (Suhardiman et al. 2016). In the study area, the multi stem tree in mangrove enhance crown cover as early as 5 years old plants. The appearance of planted *Rhizophora* with age of 1 year to 6 years old is illustrated in Figure 5.

Variations in the growth rate in young mangrove plants, despite of differences in fertility and soil pH, plants in mangroves are greatly influenced by mangrove salinity (Figure 6). As stated by Krauss et al. (2008) that there is a close relationship between water salinity and the growth of mangrove seedlings. Investigation on mangrove soil indicated that soil salinity ranged from 0-30 ppm, and it decreased along the year of mangrove plantation. Another factor is the availability of nutrients for plants. Total N increases with increasing plant age. Accumulation of litter occurs at older plant ages, in line with the increasing dimensions of the trees. Thus, when mangrove plants reached age of 4, 5, and 6 years, closed nutrient turnover occurred like other natural forest areas. However, the canopy structure of mangrove not as complicated as other forest types.

Biomass of the mangrove stand in Setapuk Besar Village

Mangrove forests have great capacity to absorb and retain carbon in the form of biomass. Nonetheless, such capacity is influenced by several factors including the species of mangrove which is determined by its physiological characteristics and environmental variables such as salinity, pH, nutrient availability and light. In the planted mangrove in Setapuk Besar Village we estimated the biomass for plants 3 years and older with an average tree diameter of 5 cm (Table 5). This is because the allometric equation used is only applicable to plant with a diameter of 5 cm or more.

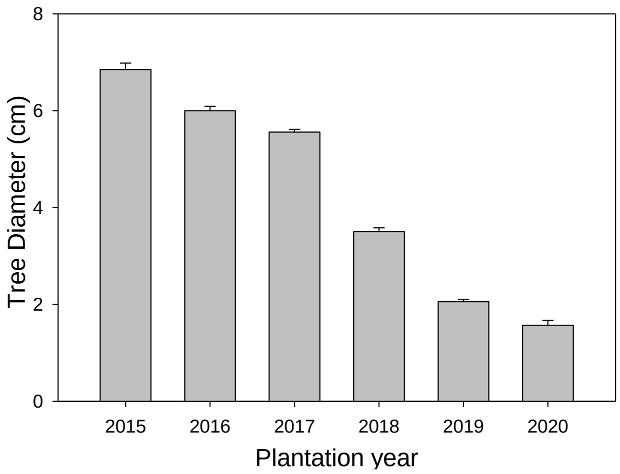


Figure 3. Diameter of planted mangroves at varying ages in Setapuk Besar Village, Singkawang City, West Kalimantan

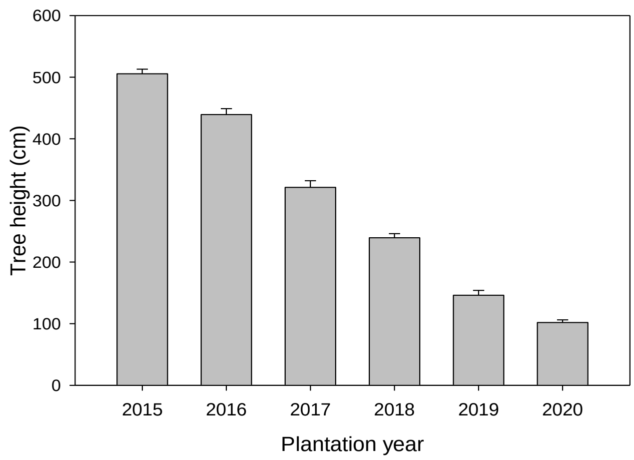
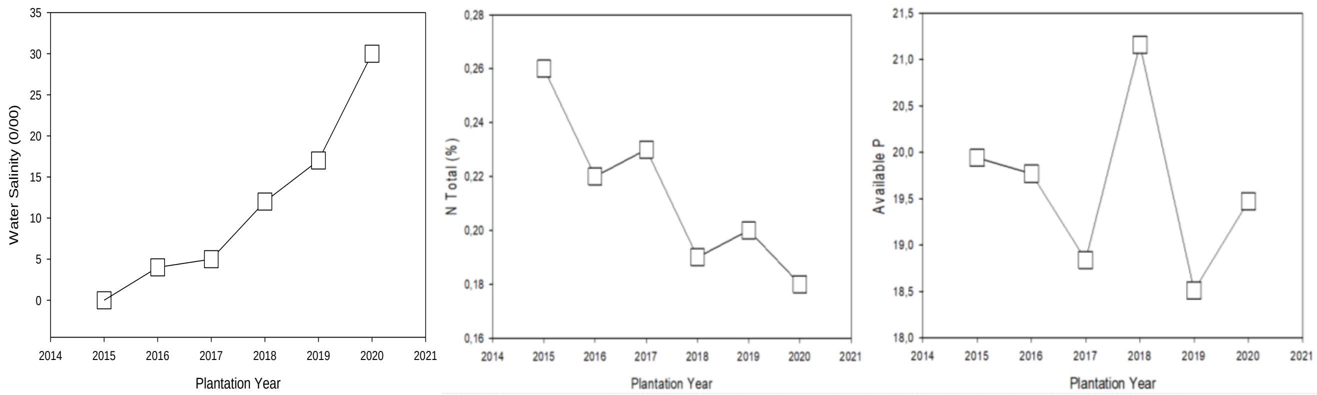


Figure 4. Diameter of planted mangroves at varying ages in Setapuk Besar Village, Singkawang City, West Kalimantan

Figure 5. Planted *Rhizophora* at age of: A. 1 year; B. 2 years; C. 3 years; D. 4 years; E. 5 years, and F. 6 years old consecutively



A B C

Figure 6. Environmental variables at varying mangrove ages: A. Salinity; B. N total; and C. P available

Table 5. Biomass of mangrove stands aged 4 to 6 years in Setapuk Besar Village, Singkawang City, West Kalimantan

Stand age	Above-Ground Biomass (AGB) (ton ha^{-1})	Below-Ground Biomass (BGB) (ton ha)	Total biomass (ton ha^{-1})	Proportion of BGB to total biomass (%)
6	294.24 ±0.32	135.38±0.18	429.62	31.51
5	205.38±0.17	97.82±0.12	303.20	32.26
4	168.72±0.11	82.00±0.09	250.72	32.27

Note: Number after the means shows Standard Error (SE)

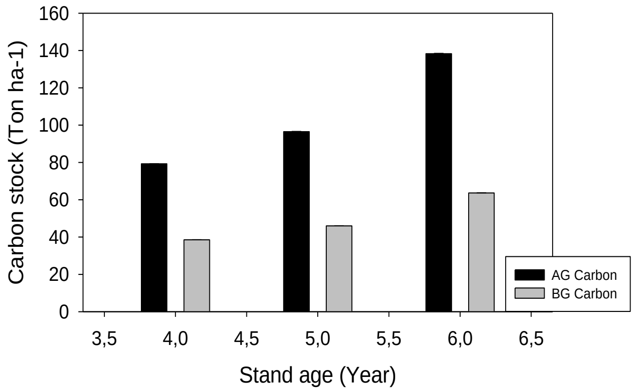


Figure 7. Carbon of mangrove stands aged 4 to 6 years in Setapuk Besar Village, Singkawang City, West Kalimantan

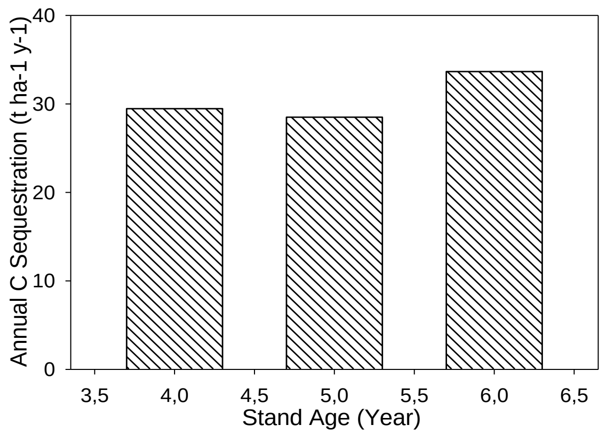


Figure 8. Mean annual carbon sequestration of mangrove stands aged 4 to 6 years in Setapuk Besar Village, Singkawang City, West Kalimantan

The findings show that mangrove planting has the potential to store carbon in the form of biomass, with a 4-year-old stand capable of storing 250 tons of biomass per ha. When the stand was 6 years old, it had a total biomass of 429.6 tons per ha, which was comparable to natural mangrove stands in Lampung (Windarni et al. 2018). In the future, this mangrove stand will continue to sequester and store even more carbon. In stands aged 4 to 6 years, annual biomass growth ranged from 60.6 to 71.6 tons per ha with the accumulation rate increased as the mangroves getting older.

Carbon stocks of mangrove stand in Setapuk Besar Village

The calculation on carbon stock showed the enormous capacity of planted mangrove to store carbon both above and below ground (Figure 7). The six-year-old mangrove stand can totally store 201.9±33.6 tons per ha, of which ~32% is below the soil surface. At the age of 4 and 5 years, these stands were able to store 117.8±29.4 and 142.5±28.5 tons of carbon per ha, respectively. These results indicate that the ability of this planted mangrove forest in storing carbon is much higher than other forest types. Compared to the standards stated by the IPCC (2006), the carbon stocks in planted mangroves aged 6 years have exceeded and are comparable to the carbon stored in other natural forest types.

The potential of carbon sequestered by mangrove stand in Setapuk Besar Village

Based on the average tree diameter growth and the calculation on biomass and carbon, the ability of mangrove stands aged 4 to 6 years to sequester carbon annually is relatively high (Figure 8).

During their growing phase, mangroves store and accumulate CO_2 from the atmosphere. Other investigations have shown and confirmed that mangroves have a high potential for CO_2 sequestration. Mangroves can capture more than 24 million metric tons of carbon per year globally (Twilley and Rovai 2019). Our study revealed that annually the planted mangroves in Setapuk Besar Village have the ability to absorb carbon 28-33 tons per ha annually or equivalent of absorbing 102.7 to 121 tons of CO_2 ha^{-1} $year^{-1}$, a huge ability when compared to other forest types. Astiani et al. (2017) for example calculated carbon stocks and uptake of peat swamp natural forests that have been formed for thousands of years, amounting to 12-16 tons per ha, only half to one third of the capabilities of this mangrove forest. Goldberg et al. (2020) reported that geomorphological and biophysical quality of mangrove sites are important in site selection for maximizing the mangrove carbon sequestration.

In conclusion, the results demonstrated that mangrove trees planted in this area are growing their diameter with range 1.13 to 1.32 cm annually. With relatively high in wood density, it shows the essential roles of mangrove forests to absorb and store carbon per unit time and area. Mangrove forests in Setapuk Besar Village store 117.8 to 201.9 tons of carbon per ha. Likewise with the ability to sequester carbon, these planted mangrove forests can absorb 28 to 33 tons of carbon per ha per year or the equivalent of sequestering 102.7 to 121 tons of CO_2 ha^{-1} $year^{-1}$. This study suggests that mangrove rehabilitation by planting mangrove should be considered as an option to sequester and store CO_2 as an effort to reduce GHG concentrations in the atmosphere. This study also provides evidence that mangrove rehabilitation by community can be effective and might be adopted to other areas in Indonesia.

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