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Original Research Article

The Estimation Of Carbon Absorption In Mangrove Area Of PT PLN Nusantara Power UP Rembang

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Abstract

Mangrove areas serve as a nexus between sea and land regions. These mangroves thrive in areas with standing seawater and are influenced by tidal fluctuations. In addition to their physical function as erosion barriers, mangrove ecosystems possess the ability, akin to other plant types, to absorb carbon dioxide (CO_2). The carbon sequestration capacity of mangroves is deemed higher than that of terrestrial forests and tropical rainforests (Donato et al., 2011). This research aims to estimate carbon (C) absorption in the mangroves of the PT PLN Nusantara Power UP Rembang mangrove area and strategize mangrove area development to enhance carbon (C) absorption capacity based on emitted carbon. The study was conducted from November 2023 to January 2024 in the mangrove area of PT PLN Nusantara Power UP Rembang. Purposive Sampling Method was employed, determining three observation station points with one-time, non-repetitive sampling. Carbon uptake analysis (C) results reveal that Rhizophora stylosa exhibits the highest carbon absorption capacity (C) at 13.13 kg/tree, followed by Rhizophora mucronata at 10.76 kg/tree and Rhizophora apiculata at 8.93 kg/tree. Mangrove area development entails planting six mangrove types: Rhizophora mucronata, Rhizophora stylosa, Rhizophora apiculata, Avicennia marina, Sonneratia alba, and Bruguiera gymnorrhiza based on their carbon absorption capacity (C). The additional area covers 15.41 hectares, resulting in a carbon absorption capacity (C) increase of 24,462.29 tons of CO_2/year. Estimated carbon (C) uptake by mangroves is expected to increase with mangrove diameter growth.

Keywords: carbon absorption (C); Mangrove; carbon emissions (CO_2)

1. Introduction

Mangroves are a unique type of vegetation capable of thriving in intertidal areas, typically found in coastal regions with tropical to subtropical climates. These resilient plants exhibit the ability to survive in harsh environmental conditions, including high salinity levels, waterlogged soil, and soil instability. They achieve this by actively excluding salt from their tissues and developing a specialized root system known as pneumatophores to facilitate oxygen absorption in waterlogged soils (Kathiresan and Bingham, 2001; Alongi, 2012). In addition to their physiological adaptations, mangroves also contribute significantly to coastal protection by reducing wave energy and preventing shoreline erosion. Furthermore, they serve as vital habitats for a wide variety of marine and terrestrial species, supporting high biodiversity and complex food webs in coastal ecosystems (Alongi, 2012).

Mangrove forests play a crucial role in forest, water, and environmental ecosystems. In addition to serving as a natural barrier against erosion, mangroves function similarly to other tree species by absorbing carbon dioxide (CO_2) emissions from the atmosphere. The carbon sequestration capacity of mangroves is considered greater than that of terrestrial forests and tropical rainforests (Donato et al., 2011). The ability of mangroves to absorb carbon dioxide (CO_2) is closely linked to the carbon and biomass content within each vegetation. It is estimated that the mangrove ecosystem in Indonesia has the capacity to absorb up to 67.7 metric tons of CO_2/ hectare per year (Sadelie et al., 2012). The capacity of mangrove forests to sequester carbon is strongly influenced by their vegetation biomass and species-specific characteristics. Variations in the growth rate, stem diameter, height, wood density, and root structure among mangrove species result in different levels of biomass accumulation and carbon storage (Komiyama *et al.*, 2008). Biomass represents the total amount of organic matter contained within plant tissues and serves as the primary reservoir for stored carbon. It is generally assumed that approximately 45–50% of the total plant biomass consists of carbon, making biomass estimation a fundamental step in carbon stock assessment (Brown, 1997). Consequently, the accurate quantification of mangrove biomass is essential for evaluating the carbon sequestration potential and CO_2 absorption capacity.

PT PLN Nusantara Power UP Rembang is an electricity generation unit with a capacity of 2 x 315 MW, which employs coal as its primary fuel in the production process. The company also maintains a mangrove conservation area of approximately 1.6 hectares, hosting nine types of mangroves. Variations in the physical characteristics of each mangrove type result in differing carbon capacities for each variety. This conservation area not only supports local biodiversity, but also plays an important role in carbon sequestration, thereby helping to offset a portion of the emissions produced by coal-based power generation. Differences in growth rate, biomass accumulation, and root structure among the mangrove species further influence their ability to store carbon, making species-specific assessments essential for accurately estimating the total carbon stock within the conservation area.

Collecting sample tests from various mangrove species aims to ascertain their biomass and carbon content, facilitating the calculation of carbon dioxide (CO_2) absorption by each type of mangrove. This process also helps in identifying suitable mangrove species for the development of the mangrove area. In addition, the results can be used as scientific evidence to support conservation strategies and climate change mitigation efforts at the local level. Through this approach, decision-makers are better equipped to prioritize the cultivation of mangrove species that demonstrate higher carbon sequestration potential and greater adaptability to site-specific environmental conditions. Biomass is a renewable resource derived from plants, either directly or indirectly, and can be utilized as energy in significant quantities. According to Brown (1997), biomass is defined as the total organic matter living above the ground in plants, including twigs, branches, leaves, main stems, and bark, measured in tons of dry weight per unit area. Carbon (C) comprises the primary component, constituting 45-50% of the biomass of plant materials (Brown, 1997). Biomass serves as a storage location for carbon, also known as carbon sinks. Measuring the biomass content of vegetation aims to determine the nutrients and quantity of carbon available, both overall and in specific parts of the tree structure.

This study aimed to estimate the carbon sequestration capacity of the dominant mangrove species within the conservation area of PT PLN Nusantara Power UP Rembang by analyzing biomass, carbon content, and CO_2 sequestration at various stages of growth. In addition, this study evaluated the potential of mangrove area development scenarios to increase carbon sequestration capacity in relation to carbon emissions. The findings are expected to provide scientific evidence to support mangrove conservation strategies, contribute to blue carbon initiatives, and strengthen the role of mangrove ecosystems in climate change mitigation efforts at corporate and regional levels.

2. Methods

The research was conducted in the mangrove area of PT PLN Nusantara Power UP Rembang, situated between Leran Village and Trahan Village, Sluke, Rembang Regency (see Figure 1). The method employed was purposive sampling, selecting representative mangrove vegetation based on the dominant mangrove type and their height/diameter. This approach ensures that the sampled trees adequately reflect the structural composition and growth characteristics of the mangrove stand. Furthermore, the selected samples provide a reliable basis for estimating biomass and carbon stock across the wider mangrove area.

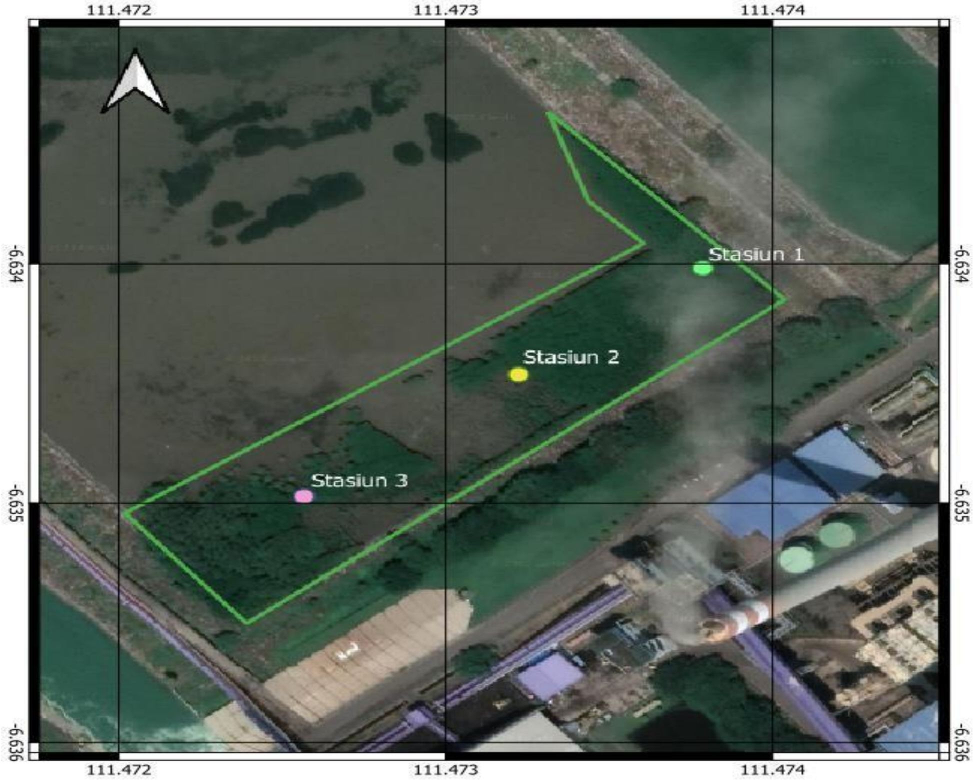

Figure 1. Research Location

2.1 Biomass Estimation

Biomass estimation was carried out by oven-drying mangrove samples for 2 × 24 hours at a temperature of 70°C, then weighing them until a constant weight was obtained. This procedure ensures that the water content is removed so that the measured biomass represents the dry weight of the sample. Biomass can be calculated with the following equation:

$$\text{Biomass (BKT)} = \frac{BKS \times BB}{BBS} \quad (1)$$

Information :

BKT : Biomass$BKS \times BB$

BKS : sample dry weight (gr)

BBS : sample wet weight (gr)

BB : total wet weight (kg)

2.2 Carbon

Carbon (C) in plants was calculated using the formulas developed by Brown (1997) and the IPCC (2003), which estimate carbon content based on the measured biomass values of the mangrove samples. Calculation of carbon (C) in plants using the Brown (1997) and IPCC (2003) formulas :

$$C = BKT \times 50\% \quad (2)$$

Information :

C : carbon (C) (gr)

BKT : biomass

2.3 Uptake of Carbon Dioxide (CO_2)

Estimation of carbon dioxide (CO_2) for each tree is determined using the equation proposed by Heriyanti and Subiandono (2011) as follows: this equation converts the carbon content stored in tree biomass into its equivalent CO_2 value using an appropriate conversion factor, allowing the contribution of each tree to carbon sequestration to be quantitatively assessed. Estimation of carbon dioxide (CO_2) each tree is determinated using the equation (Heriyanti dan Subiandono, 2011) as follow:

$$CO_2 = \frac{MrCO_2}{ArCO_2} \quad (3)$$

atau,

$$CO_2 = 3{,}67 \times C \quad (4)$$

Keterangan :

CO_2 : uptake of carbon dioxide(CO_2)

Mr CO_2 : relative molecules of CO_2

Ar CO_2 : relative atoms of CO_2

3. Result and Discussion

3.1 Mangrove Carbon Absorption

Based on the results of a survey of existing conditions and analysis of mangrove vegetation in the PT PLN Nusantara Power UP Rembang mangrove area, three dominant types of mangroves have been identified. The mangroves selected for carbon uptake measurement are the three dominant types: Rhizophora mucronata, Rhizophora stylosa, and Rhizophora apiculata, which represent the distribution of mangroves in the area. The mangrove sample size that will be taken has an average diameter of more than 5 cm and a height exceeding 1.5 m. These criteria are applied to ensure that the sampled trees have reached a sufficient growth stage, thereby providing more accurate estimates of biomass and carbon storage. In addition, only healthy trees without visible physical damage or disease symptoms are selected, so that the measured carbon uptake reflects the optimal growth conditions of each mangrove species.

The ability of mangroves to absorb carbon dioxide (CO_2) is directly proportional to their biomass and carbon content. Determining biomass is the initial step in calculating CO_2 uptake in mangroves. This process involves weighing the wet weight of the mangrove sample and then oven-drying the sample at 70°C for 2 days (48 hours) until a constant weight is achieved. This procedure was conducted at the Chemical Laboratory of PT PLN Nusantara Power UP Rembang. The biomass value obtained represents the actual biomass after subtracting the water content. According to Brown (1997), the carbon content in vegetation biomass can range from 45% to 50%. Thus, determining the biomass allows us to ascertain the carbon content in mangroves. Once the carbon content is known, it can be converted into its CO_2-equivalent by multiplying it by a factor of 44/12, which represents the ratio of the molecular weight of CO_2 to elemental carbon. The resulting CO_2-equivalent values provide a quantitative basis for assessing the role of mangrove stands in mitigating greenhouse gas emissions. Moreover, variations in biomass and carbon content among different mangrove species and size classes can inform management strategies aimed at maximizing carbon sequestration in the study area.

Table 1 shows that Rhizophora stylosa has the highest carbon absorption capacity, at 13.13 kg/tree. Rhizophora mucronata and Rhizophora apiculata have carbon absorption capacities of 10.76 kg/tree and 8.93 kg/tree, respectively. Differences in carbon absorption capacity are influenced by the total wet weight and height of each sample. The calculation results also indicate that the highest carbon absorption is on the tree trunk. This pattern reflects the dominance of woody tissues in the above-ground biomass, where most structural carbon is stored in lignified cell walls. In contrast, branches and leaves contribute relatively less to the total carbon stock due to their lower mass and faster turnover rates. Consequently, species with greater stem diameter and height, such as Rhizophora stylosa in this study, tend to exhibit higher per-tree carbon absorption and play a key role in carbon-oriented mangrove management strategies.

At the same total wet weight, the biomass in the stem of Rhizophora mucronata is 2% higher than that in the stem of Rhizophora stylosa and 4% higher than that in the stem of Rhizophora apiculata. Therefore, the comparison of biomass content in Rhizophora mucronata, Rhizophora stylosa, and Rhizophora apiculata respectively is 4:2:1. This ratio indicates that Rhizophora mucronata has the greatest concentration of stem biomass, followed by Rhizophora stylosa, while Rhizophora apiculata has the lowest. The higher stem biomass in Rhizophora mucronata suggests a greater potential for carbon storage in its trunk compared to the other two species. In practical terms, this makes Rhizophora mucronata a particularly important species for carbon-oriented mangrove conservation and restoration programs. Nonetheless, the presence of all three species still contributes collectively to the overall carbon stock and ecological stability of the mangrove ecosystem.

Table 1 Biomass Value, Carbon (C), and CO_2 Absorption

Type Mangroves	Part	Biomass (kg/tree)	Carbon (C) (kg/tree)	CO_2 Absorption (kg CO_2/tree)
Rhizophora mucronata	Root	0,81	0,40	1,48
	Stem	3,16	1,58	5,80
	Twig	1,41	0,70	2,58
	Leaf	0,49	0,24	0,89
Total		5,86	2,93	10,76
Rhizophora stylosa	Root	0,98	0,49	1,80
	Stem	3,51	1,76	6,45
	Twig	2,04	1,02	3,75
	Leaf	0,62	0,31	1,13
Total		7,15	3,58	13,13
Rhizophora apiculata	Root	0,69	0,34	1,26
	Stem	2,09	1,05	3,84
	Twig	1,69	0,85	3,10
	Leaf	0,39	0,20	0,72
Total		4,86	2,43	8,93

The research results from Crisna Akbar (2019) indicate that the stem plays an important role in absorbing CO_2. In the height class > 100 cm, a portion of the mangrove stem of the Rhizophora apiculata type can absorb CO_2 amounting to 398.16 gr/tree. Additionally, other research by Heriyanto and Subandono (2011) demonstrates that the mangrove type Rhizophora sp. has the highest biomass content and carbon absorption capacity, with biomass reaching 217.22 tonnes per hectare and carbon absorption amounting to 398.60 tons of CO_2/ha. These findings support the conclusion that the stem is the main component contributing to carbon storage in mangrove vegetation. The high biomass and CO_2 absorption values recorded for Rhizophora species also reinforce their strategic role in climate change mitigation efforts through blue carbon initiatives. Furthermore, these studies provide a useful reference for selecting priority mangrove species in rehabilitation and conservation programs aimed at maximizing carbon sequestration potential.

The mangroves in the PT PLN Nusantara Power UP Rembang mangrove area consist of three levels: seedling, sapling, and mature tree levels. The seedling level represents young mangrove plants that have recently established and are still vulnerable to environmental disturbances. The sapling level includes mangroves that have grown taller and sturdier, serving as a transitional phase before reaching full maturity. The mature tree level is characterized by well-developed mangroves with larger diameters and heights, which contribute most significantly to biomass and carbon storage. The presence of these three structural levels indicates that the mangrove ecosystem in the area is undergoing continuous regeneration and has good potential for long-term sustainability.

The estimated carbon absorption capacity (CO_2) in mangrove species Avicennia marina and Bruguiera gymnorrhiza, using research data from Choridina & Insafitri (2020), indicates that the carbon absorption capacity (CO_2) for Avicennia marina and Bruguiera gymnorrhiza are 7.14 kg/tree and 7.01 kg/tree, respectively. Meanwhile, the estimation of carbon uptake (CO_2) by mangrove species Sonneratia alba, based on research results from Inggrit Solissa (2022), is 7.44 kg/tree. The aim of utilizing this research data is to achieve a more accurate estimation of the carbon absorption capacity (CO_2). As for the mangrove types

Lumnitzera racemose and Excoecaria agallocha, it is assumed that their carbon absorption capacity (CO_2) is the same as that of Rhizophora apiculata. This assumption is made due to the scarcity of research on the carbon absorption capacity (CO_2) of these two mangrove types, thus employing the carbon absorption capacity (CO_2) of Rhizophora apiculata as the closest available approximation.

Table 2 Total Carbon Absorption By Mangrove

No	Mangrove levels	Total Carbon Absorption
1.	Seedling	339,43
2.	Stake	97,22
3.	Tree	186,78
Total Carbon Absorption		**623,44**

In calculating carbon absorption capacity (CO_2), different results are obtained for the seedling, sapling, and tree levels. This discrepancy arises from variations in diameters and sizes between seedlings and trees. According to research by Fajar et al. (2014), carbon uptake (CO_2) at the seedling stage is 12% lower compared to carbon uptake (CO_2) at the sapling level. As mangroves grow from seedlings into saplings and eventually mature trees, their biomass increases, leading to higher carbon storage and CO_2 absorption. This pattern shows that stand structure and age composition strongly influence the total carbon sequestration potential of a mangrove area. Therefore, evaluating carbon absorption must take into account the proportion of individuals at each growth level within the stand. Such information is crucial for designing effective mangrove management and rehabilitation strategies that maximize carbon sequestration over time.

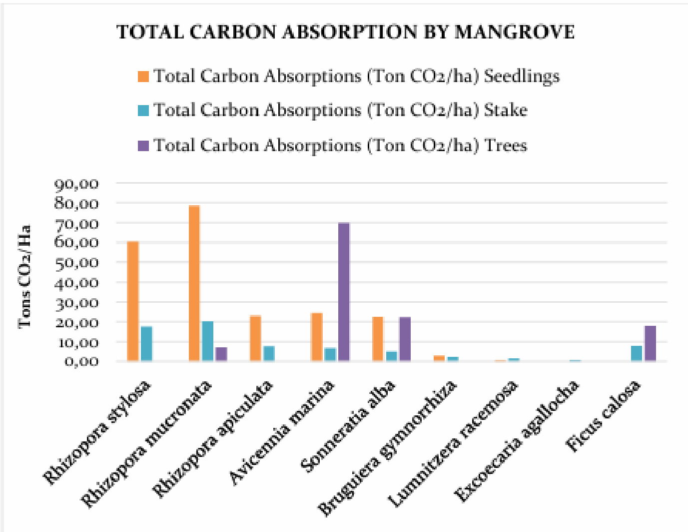

Figure 2 Carbon Absorption (CO_2) in Mangrove

The estimate of carbon absorption will continue to increase as the mangrove diameter expands. According to research by Ardani et al. (2018), mangroves exhibit a height growth rate of 2.54 cm/month, while the diameter increases at a rate of 1.33 mm/month or 1.56 cm/year. Another study indicates that the diameter growth rate of the Rhizophora sp mangrove type is 0.75 cm/year (Herlina, 2021). These growth rates show that even relatively small annual increases in diameter can significantly enhance biomass and carbon storage over time. When projected over several years, incremental changes in stem size translate into substantial additional carbon sequestration at the stand scale. Therefore, monitoring diameter growth is an effective way to estimate future changes in the carbon absorption capacity of mangrove ecosystems.

This variation occurs due to several influencing factors in mangrove growth, as explained by Herdiana et al. (2008), including nutrient content in the growth environment, light intensity, and the development of plant meristematic tissue. Differences in site conditions, such as salinity gradients and tidal inundation frequency, can also affect the growth performance of individual trees. In areas with optimal environmental conditions, mangroves tend to grow faster, resulting in higher biomass accumulation and carbon uptake. Conversely, stressful conditions may slow growth, reduce biomass production, and limit the potential for CO_2 sequestration. Understanding these controlling factors is essential for interpreting variations in growth rates reported by different studies and locations. Such knowledge can be applied to select suitable planting sites and management practices that support maximum growth and carbon sequestration in mangrove restoration programs.

Based on the current existing conditions, the mangrove area at PT PLN Nusantara Power UP Rembang is primarily populated by mangroves with a trunk diameter of 5–10 cm. This suggests that it will take approximately 10–15 years for these mangroves to reach a diameter of 30–50 cm. This time frame reflects the relatively slow growth rate of mangrove species, which is influenced by site-specific environmental factors such as salinity, tidal inundation, and nutrient availability. The projected growth period also indicates that long-term commitment is required to fully realize the carbon sequestration potential of the mangrove stand. Consequently, consistent protection, monitoring, and maintenance efforts are essential to ensure that the mangroves can grow undisturbed to larger diameter classes. In addition, the growth projection can serve as a useful reference for planning future carbon stock assessments and evaluating the effectiveness of conservation and restoration programs in the area. Therefore, the estimated carbon (CO_2) uptake when the mangroves reach a diameter of 30 cm, assuming the current data on mangroves with diameters measuring 5-10 cm, is as follows:

Table 3 Increased Carbon Absorption (CO_2) in Mangroves

Year	Diameter Increase (cm)	Total Carbon Absorption (Ton CO_2/ha/year)
2023 (existing)	5 - 10 cm	623,44
2028	16,67	48.190,26
2033	23,33	114.811,61
2038	30,00	219.876,65

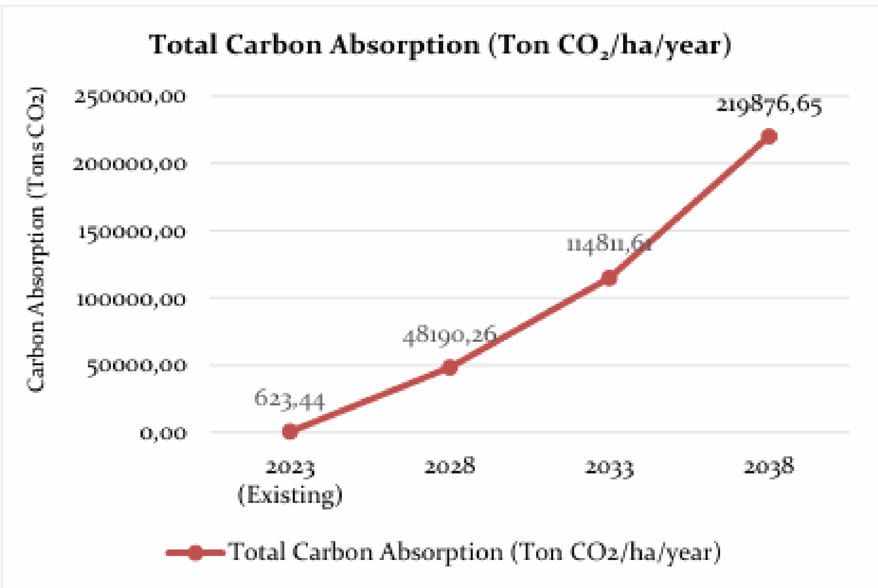

Figure 3 Graph of Increase in Carbon Absorption (CO_2) In Mangrove

Table 3 shows that the diameter of mangroves under existing conditions will increase by around 7 cm within 5 years. When the mangrove reach a diameter of 30 cm, the PT PLN Nusantara Power UP Rembang mangrove area in its current condition will be capable of absorbing 219.876,65 tons of CO_2. This projection indicates a substantial enhancement in the carbon sequestration potential of the site as the mangrove stand matures. The estimated increase in CO_2 absorption also highlights the long-term benefits of maintaining and protecting existing mangrove vegetation. These results can be used as a baseline scenario for planning future conservation, rehabilitation, and corporate climate mitigation programs. Furthermore, the projected carbon absorption capacity strengthens the role of the PT PLN Nusantara Power UP Rembang mangrove area as an important component of the company's environmental management and sustainability strategy.

4. Conclusion

The highest carbon absorption by Rhizophora stylosa is 13.13 kg/tree. This value indicates that Rhizophora stylosa has a greater ability to store carbon per individual tree compared to the other mangrove species observed in the study. Overall, the estimated carbon absorption by mangroves is 339.43 tonnes of CO_2 at the seedling stage, 97.22 tonnes of CO_2 at the sapling stage, and 186.78 tonnes of CO_2 at the tree stage. These differences between growth stages illustrate that even at the seedling level, mangroves already contribute significantly to carbon sequestration when considered at the stand or area scale. The distribution of carbon absorption across the three growth levels also reflects the structural complexity and ongoing regeneration of the mangrove ecosystem in the PT PLN Nusantara Power UP Rembang area. This information is important for understanding the role of each growth stage in supporting the total carbon stock of the mangrove forest.

The carbon absorption capacity of mangroves will increase along with the growth of their diameter. As mangrove trees become larger in diameter and height, their biomass also increases, which directly enhances their ability to store carbon. The carbon absorption capacity of mangroves is directly proportional to their biomass, meaning that higher biomass results in greater amounts of carbon being stored in plant tissues. This relationship emphasizes the importance of allowing mangrove stands to reach more advanced growth stages to maximize their function as natural carbon sinks. Consequently, conservation and rehabilitation efforts should not only focus on planting new seedlings but also on maintaining and protecting existing mature trees. By managing mangrove growth and structure effectively, the overall carbon sequestration potential of the ecosystem can be optimized over the long term.

Further research is needed to estimate biomass and carbon absorption by taking samples from each type of mangrove and at each growth stage. This will ensure more accurate estimates of carbon absorption by mangroves in the PT PLN Nusantara Power UP Rembang mangrove area. In addition, expanding the number of sampling plots and replicating measurements over time will help capture spatial and temporal variability in mangrove growth. It is also important to include below-ground components, such as roots and soil organic carbon, to obtain a more comprehensive estimate of total carbon stocks. Integrating field measurements with remote sensing or GIS-based analysis could further improve the accuracy and scalability of carbon assessment. The results of such studies would provide stronger scientific support for blue carbon initiatives and climate-related reporting by the company. Ultimately, more detailed and long-term research will enhance the effectiveness of mangrove management strategies in maximizing carbon sequestration and ecosystem resilience.

5. References

Akbar, Crisna dkk. 2019. Dugaan Serapan Karbon pada Vegetasi Mangrove, di Kawasan Mangrove Desa Beureunut, Kecamatan Seulimum, Kabupaten Aceh Besar. Available online at: Jurnal Laot Ilmu Kelautan (utu.ac.id)

Alongi, D.M. 2012. Carbon sequestration in mangrove forests. *Carbon Management*, 3(3), pp. 313–322.

Ardani, dkk. 2018. Pertumbuhan Rhizophora Apiculata dengan Dua Teknik Persemaian Hidroponik NFT

(Nutrient Film Technique) dan Tradisional. Universitas Sriwijaya, Indralaya, Indonesia

Brown, S. 1997. *Estimating biomass and biomass change of tropical forests: A primer*. FAO Forestry Paper No. 134. Rome: Food and Agriculture Organization of the United Nations.

Darwati, Herlina dkk. 2021. Pertumbuhan Tanaman Bakau (Rhizophora spp.) di Kawasan Mangrove Kelurahan Setupak Besar Kota Singkawang. Universitas Tanjungpura. Jurnal Hutan Lestari. Vol.9 (4): 686 – 694

Donato, C. D., Kauffman, J., Murdiyarso, B., Kurnianto, S., Stidham, M dan Kanninen, M. 2011. Mangroves among the most carbon-rich forests in the tropics. Nature Geoscience. 4: 293 – 297

FAO. 2007. Mangroves of Asia 1980-2005 : Country Reports. Working Paper 137. FAO Forestry Department. Rome

Herdiana, N., Lukman, A. H. & Mulyadi, K., 2008. Pengaruh Dosis dan Frekuensi Aplikasi Pemupukan NPK Terhadap Pertumbuhan Bibit Shorea ovalis Korth. Jurnal Penelitian Hutan dan Konservasi Alam, 5(3), pp. 289-296

Heriyanto N.M., Subiandono, E. 2012. Komposisi dan struktur tegakan, biomasa, dan potensi kandungan karbon hutan mangrove di Taman Nasional Alas Purwo. Jurnal Penelitian dan Konservasi Alam Vol. 9 No.1: 023-032. Pusat Penelitian dan Pengembangan Konservasi dan Rehabilitasi. Bogor.

IPCC. 2003. IPPC guidelines for nation greenhouse inventories. Reference manual IPCC

Kareninsekar, C. & Insafitri. 2020. Stok dan Serapan Karbon pada Jenis Mangrove yang Berbeda (Rhizophora stylosa, Avicennia marina dan Bruguierra gymnorrhiza) di Perairan Tuban. Available online at: Juvenil:Jurnal Ilmiah Kelautan dan Perikanan (trunojoyo.ac.id)

Komiyama, A., Ong, J.E. and Poungparn, S. 2008. Allometry, biomass, and productivity of mangrove forests: A review. *Aquatic Botany*, 89(2), pp. 128–137. https://doi.org/10.1016/j.aquabot.2007.12.006

Rahmah, Fajar dkk. 2015. Potensi Karbon Tersimpan pada Lahan Mangrove dan Tambak di Kawasan Pesisir Kota Banda Aceh. Jurnal Manajemen Sumberdaya Lahan. Unsyiah, Darussalam Banda Aceh

Sadelie, A., Kusumastanto, T., Kusmana, C., Hardjomidjojo, H. 2012. Kebijakan pengelolaan sumberdaya pesisir berbasis perdagangan karbon. Jurnal Hutan dan Masyarakat, 6(1), 1-1

Solissa, Marget Inggrit. 2022. Estimasi Karbon pada Tegakan Sonneratia Alba di Pesisir Kampung Waroki, Distrik Nabire Barat, Kabupaten Nabire. TABURA: Jurnal Perikanan dan Kelautan