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COMPARISON OF THE POTENTIAL OF MANGROVE FORESTS AS AN ESTIMATE OF CARBON STOCKS : A REVIEW

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ABSTRACT: Global warming is an increase in carbon dioxide gas (CO_2) and other gases in the earth's atmosphere, which will make the earth's atmosphere retain more heat coming from the sun. This study aimed to determine the highest carbon stock ratio from various areas with mangrove forest areas. This research was conducted using the grid route method by collecting data from a literature study from different locations in the mangrove forest. The research results obtained that the highest average carbon stock in various regions of Indonesia which has the highest mangrove forest conservation is the Mangrove Area in Pasar Banggi Rembang Village of 737.2 tons/ha with three stations whose species names consist of *Rhizophora apiculata*, *Rhizophora stylosa*, and *Rhizophora mucronata*. High and low carbon content, density, and mangrove species in mangrove leaf litter were influenced by the rate of litter production. This production rate will later affect the high low carbon content in mangrove leaf litter.

Keywords: Carbon, Global Warming, Mangrove Forest.

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INTRODUCTION

Global warming is a form of imbalance in the earth's ecosystem due to increasing temperatures in the atmosphere, sea, and land. In the last 100 years, the average temperature on the earth's surface has risen by 0.74 ± 0.18°C. The cause of this increase in average temperature is greenhouse gas emissions, including carbon dioxide (CO_2), methane (CH_4), carbon dioxide, methane, nitrous oxide, hydrofluorocarbons (HFC), perfluorocarbons (PFC), and sulfur hexafluoride (SF6) in the atmosphere. These emissions are produced through the combustion process of fuels, which include petroleum and coal, due to deforestation and the burning of forests (Fitria, 2021). Global warming is caused by increased emissions of greenhouse gases such as carbon dioxide (CO_2) and methane (CH_4), which can be produced from various aspects such as industry, transportation, agricultural, and livestock activities. The steps used to reduce the concentration of carbon dioxide in the atmosphere are by using the blue carbon concept, which has three main ecosystems and plays a vital role in storing carbon either in tissues or

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in sediments, for example, salt marshes, lamin grassland ecosystems, and mangroves (Dinilhuda et al., 2018).

The implications of global warming can be called climate change. Factors that cause global warming include greenhouse gases, such as carbon dioxide (CO_2) and methane (CH_4). Climate change will be impacted by melting ice at the South Pole, increasing sea levels, and shifting seasons (Trissanti et al., 2022). Coastal waters have an essential role in the global carbon budget, receiving carbon and nutrient flows from land and wetland ecosystems, even though they have a smaller total area than the open sea. This ability is supported by the presence of materials and energy transport by the open sea via the continental slope, making the area with active biogeochemical processes. 0.25–0.4 x 105 grams of dissolved organic carbon is released into the sea from rivers to coastal waters almost yearly (Wicaksono, 2017). The exchange of carbon dioxide (CO_2) between the atmosphere and coastal waters occurs intensively and is influenced by CO_2 fluxes on a regional or global scale (Nedhisa & Tjahjaningrum, 2020).

The coastal ecosystem that has the highest ability to absorb CO_2 is the mangrove forest. The mangrove forest is a tropical ecosystem with a lot of potential and benefits for the environment and humans. The functions of mangrove forests include absorbing and storing carbon (C), which can be linked to their role in preventing the effects of global warming (Nuraini et al., 2021). Mangroves can store more carbon than almost all forests on earth. Mangrove ecosystems play an important role in reducing the greenhouse gas effect as a mitigation of climate change because they can reduce CO_2 through the "sequestration" mechanism, namely the absorption of carbon from the atmosphere and its storage in the form of biomass (Rahman et al., 2017). The optimal function of mangroves in carbon absorption reaches 77.9% (Heriyanto & Subiandono, 2016). Biomass from carbon absorption is a forest service used to restore the environment by reducing CO_2 in the air. The loss or degradation of mangrove ecosystems will be a source of large amounts of carbon for the greenhouse effect (Dinilhuda et al., 2018; Sondak et al., 2015). Estimates of carbon stores in mangrove forests provide exciting opportunities for forest conservation measures that are currently difficult to implement. Conservation will provide three aspects, namely preservation, protection, and utilization. So, it can be used as a strategy for managing mangrove forests in Indonesia to carry out conservation efforts by estimating the value of a forest, namely estimating the carbon stored. This research aims to compare the potential of mangrove forests as an estimate of carbon stocks in various regions of Indonesia.

METHOD

The research objects were obtained from case studies of mangrove forests in various regions of Indonesia that have mangrove forest conservation. This study used a descriptive qualitative method. The results of this research are explained from a descriptive study of the information obtained. Data presented in qualitative form with scientific sources can be called a scientific study based on the formation of an idea. Writing analysis and information collection is required to function as data support and analysis of writing related to the Mangrove Area in

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Mojo Village, Pemalang Regency, Mangrove Area in Genuk Village, Semarang Regency, Mangrove Area in Bedono Village, Demak, Mangrove Area in Pasar Banggi Rembang Village, and Forest Area Mangroves at the mouth of the Batang Apar River. One of the steps that will be taken as forest management is a crucial problem in this research. The information obtained is based on various trusted sources, namely scientific journals with researched objects and community sources in the Mangrove Area in Mojo Village, Pemalang Regency, Mangrove Area in Genuk Village, Semarang Regency, Mangrove Area in Bedono Village, Demak, Mangrove Area in Pasar Banggi Village, Rembang, and Mangrove Forest Area at the Batang Apar River Estuary.

RESULTS AND DISCUSSION

Table 1 presents the estimated carbon stocks accumulated in mangrove stands in Central Java. This data provides a clearer picture of the carbon storage potential of mangrove forests in the region and serves as a basis for further discussion on the ecological and strategic implications of managing and conserving mangrove forests.

Table 1. Estimated Carbon Stocks in Mangrove Stands in Central Java.

Mangrove Area in Mojo Village, Pemalang Regency				
Station/ Species Name	**K (Ind/ha)**	**Biomass**	**C (ton/ha)**	**CO_2 Uptake (ton/ha)**
Station 1/ *Avicennia marina*	652	77.65	55.98	205.44
Station 2/ *Avicennia alba*	38	9.46	117.05	429.56
Station 2/ *Rhizophora mucronata*	314	36.28	54.31	119.32
Average	334.6	41.13	75.78	251.44
Mangrove Area in Genuk Village, Semarang Regency				
Station/ Species Name	**K (Ind/ha)**	**Biomass**	**C (ton/ha)**	**CO_2 Uptake (ton/ha)**
Station 1/ *Avicennia marina*	1917.77	178.35	83.82	307.64
Station 2/ *Avicennia marina*	11651.112	163.27	76.73	281.62
Station 3/ *Avicennia marina*	1366.94	173.21	81.41	298.77
Rhizophora mucronata	251.95	155.51	73.09	268.24
Station 4/ *Avicennia marina*	2290.61	156.13	73.38	269.30
Rhizophora mucronata	467.157	110.87	52.11	191.24
Average/ *Avicennia marina*	1806.611	167.73	78.83	289.33
Average/ *Rhizophora mucronata*	485.532	133.19	62.60	229.74
Mangrove Area in Bedono Village, Demak Regency				
Station/ Species Name	**K (Ind/ha)**	**Biomass**	**C (ton/ha)**	**CO_2 Uptake (ton/ha)**
Station 1/ *Avicennia marina*	5533.333	126.373	59.395	217.783
Station 2/ *Avicennia marina*	4366.667	104.196	48.972	179.562
Station 3/ *Avicennia marina*	4100	60.494	28.432	104.252
Station 4/ *Rhizophora mucronata* and *Avicennia marina*	200 and 5500	113.737	53.457	196.007
Average	3158.8	134.3	47	174
Mangrove Area in Pasar Banggi Rembang Village				
Station/ Species Name	**K (Ind/ha)**	**Biomass**	**C (ton/ha)**	**CO_2 Uptake (ton/ha)**
Station 1/ *Rhizophora stylosa*	1500	647.66	297.92	297.92
Station 2/ *Rhizophora mucronata*	5300	472.96	217.56	217.56

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Station 3/ *Rhizophora apiculata*	3000	373.47	221.72	171.79
Average	3266.7	498.03	737.2	687.27

Mangrove Forest Area in the Batang Apar River Estuary, North Pariaman District, Pariaman City, West Sumatra Province

Station/ Species Name	K (Ind/ha)	Biomass	C (ton/ha)	CO_2 Uptake (ton/ha)
Station 1/ *Nypa fruticans*	1055.56	496.26 ± 19.65	233.24 ± 9.23	855.19 ± 33.85
Station 2/ *Rhizophora mucronata*	1311.11	703.97 ± 95.49	331.01 ± 44.95	1213.69 ± 164.81
Station 3/ *Sonneratia caseolaris*	1855.56	800.67 ± 19.27	376.30 ± 9.05	1379.79 ± 33.19
Average	1407.41	666.97	313.52	1149.56

Notes:
K = Mangrove stand density;
C = Carbon; and
CO_2 = Carbon dioxide.

Based on Table 1, the average stand density in the Mangrove Area in Mojo Village, Pemalang Regency is 334.6 ind/ha, the Mangrove Area in Genuk Village, Semarang Regency is 1132.5715 ind/ha, the Mangrove Area in Bedono Village, Demak is 3158.8 ind/ha, the Mangrove Area in Pasar Banggi Rembang Village is 3266.7 ind/ha, and the Mangrove Forest Area in Muara Sungai Batang Apar, North Pariaman District, Pariaman City, West Sumatra Province is 1407.41 ind/ha. So, the highest stand density in the mangrove area is the Mangrove Area in Pasar Banggi Rembang Village, amounting to 3266.7 ind/ha. Gunawan et al. (2019) stated that the low density of mangroves in an area is due to the sizeable anthropogenic influence which changes the mangrove habitat for other purposes, such as clearing land for settlements and fish farms, as well as cutting down trees for building materials and charcoal so that the mangrove ecosystem experiences pressure and his condition has decreased. Mangrove stands can produce greater biomass than other aquatic ecosystems, including wetlands (Safnowandi, 2021). However, significant vegetation biomass content can produce large conversions of carbon content. An area can obtain the amount of biomass from production and density. Furthermore, this comes from estimating the diameter, specific gravity, plant height or density of each species or type of tree, soil quality, and fertility (Rifandi & Abdillah, 2020).

Table 1 shows the average biomass in the Mangrove Area in Mojo Village, Pemalang Regency is 41.13 tons/ha, the mangrove area in Genuk Village, Semarang Regency 150.46 tons/ha, the mangrove Area in Bedono Demak Village is 134.3 tons/ha, the Mangrove Area in Pasar Banggi Rembang Village is 498.03 tons/ha, and the Mangrove Forest Area in Muara Sungai Batang Apar, North Pariaman District, Pariaman City, West Sumatra Province is 666.97 tons/ha. So, the highest biomass in the mangrove area is the Mangrove Forest Area in Muara Sungai Batang Apar, North Pariaman District, Pariaman City, West Sumatra Province, amounting to 666.97 tons/ha. The biomass content of large trees means that the carbon stored in tree stands is also more significant. The value of tree biomass greatly influences the diameter and height of the vegetation itself. Taller vegetation will receive more sunlight than other trees covered by the canopy of

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other trees. Therefore, the most significant biomass values were found in mangrove types that were larger and taller (Nugraha et al., 2020). One of the existing solutions to global warming is to utilize forests. The ability of forests to absorb carbon dioxide in the air is essential in controlling carbon in the atmosphere. According to Ibrahim & Muhsoni (2020), biomass and carbon sinks in mangroves are one of the benefits of mangroves as a carbon absorber and store to reduce CO_2 levels in the air through a sequestration mechanism, namely absorbing carbon from the atmosphere and storing it in the form of biomass.

Based on Table 1, the average carbon content in the Mangrove Area in Mojo Village, Pemalang Regency is 75.78 tons/ha, the Mangrove area in Genuk Village, Semarang Regency 70.715 tons/ha, the Mangrove Area in Bedono Demak Village is 47 tons/ha, the Mangrove Area in Pasar Banggi Rembang Village is 737.2 tons/ha, and the Mangrove Forest Area in Muara Sungai Batang Apar, North Pariaman District, Pariaman City, West Sumatra Province is 313.52 tons/ha. So, the area with the highest carbon content is the Mangrove Area in Pasar Banggi Rembang Village, amounting to 737.2 tons/ha. The production rate of the litter influences the high and low carbon content in mangrove leaf litter. Apart from that, the density and type of mangrove will also influence the production rate of mangrove leaf litter, where the production rate will influence the high and low levels of carbon stored in mangrove leaf litter. The same type of mangrove with different ages will have different litter production rates, mangroves with the *Rhizophora* type have more leaf litter than older or optimum mangrove types. If the age of the mangrove exceeds the optimum point, the litter that falls will decrease because, in old mangrove trunks, the inside begins to become porous so that the tree canopy begins to narrow. The carbon stock in mangrove vegetation is influenced by the large biomass produced by trees, where large vegetation biomass will result in relatively high carbon conversion. This shows that CO_2 absorption is closely related to biomass in standing vegetation at the research location (Sari et al., 2022).

Based on Table 1, the average carbon dioxide content in the Mangrove Area in Mojo Village, Pemalang Regency is 251.44 tons/ha, the Mangrove Area in Genuk Village, Semarang Regency is 259.535 tons/ha, the Mangrove Area in Bedono Village, Demak is 174 tons/ha. Mangrove Area in Pasar Banggi Rembang Village amounted to 687.27 tons/ha, and Mangrove Forest Area in Muara Sungai Batang Apar, North Pariaman District, Pariaman City, West Sumatra Province amounted to 1149.56 tons/ha. So, the highest carbon dioxide content is in the Mangrove Forest area at Muara Sungai Batang Apar, North Pariaman District, Pariaman City, West Sumatra Province, as much as 1149.56 tons/ha. The results of the analysis of the carbon dioxide content are classified as high when compared with the Bahowo Mangrove Forest, Tongkaina Village, Bunaken District, namely 748.07 tons/ha and research which is also classified as high when compared with the carbon dioxide uptake in the mangrove forest of the Lepar Pongok Islands, South Bangka Regency, namely 658.07 tons/ha (Lestariningsih et al., 2018).

Based on these results, point 13 has the highest AGC value (175.77 tons/ha) among other sampling points, while point 23 has the lowest AGC value (29.77 tons/ha). The AGC estimation model was built assuming that AGB is

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closely related to tree diameter (DBH) and wood density. AGB affects the amount of AGC stored in each tree, so an increase in biomass is positively correlated with an increase in carbon (Purnamasari et al., 2021). The species that dominated all sampling points was *Sonneratia alba*, but the highest AGC value was found at sample points dominated by *Rhizophora mucronata* species. These results are by Iksan et al. (2019) and Purnamasari et al. (2021), where *Rhizophora* sp. has higher biomass and carbon than other species. The amount of carbon stock in mangrove stands is influenced by DBH, biomass density, and canopy cover (Suwa et al., 2021). Based on observations at the study site, canopy cover at the sample point of *Rhizophora mucronata* dominance was higher than at the sample point of *Sonneratia alba* dominance (Suardana et al., 2023).

The low carbon stock and sequestration values in Segarjaya Village are in line with data showing that Segarjaya Village is a village that has the smallest village area and mangrove area compared to other locations (Trissanti et al., 2022). It is different with Sedari Village, this village is not a village that has the largest village area and mangrove area among other villages. However, stock, biomass and carbon sequestration showed the greatest value among other villages. This proves that the carbon stock in an area is not related to the area of an administration but the main factor that can increase the carbon value in an administrative area other than its area is the quality, such as growing conditions, and the quantity, such as diameter and density, of the mangrove area itself. Additionally, the success of Sedari Village in carbon sequestration highlights the importance of targeted conservation efforts and habitat management. The presence of well-preserved mangrove forests with optimal growing conditions suggests that effective protection measures, such as limiting human encroachment and maintaining water quality. The ability of plants to absorb CO_2 is influenced by several factors such as temperature, sunlight, water availability, total leaf area, age, and growth phase (Sinaga et al., 2023).

CONCLUSION

Based on the results of the discussion of this research, the conclusion obtained is that the mangrove area which has the highest average carbon stock in various regions of Indonesia which, has the highest mangrove forest conservation is the Mangrove Area in Pasar Banggi Rembang Village amounting to 737.2 tons/ha with 3 the species name station consists of *Rhizophora stylosa*, *Rhizophora mucronata*, and *Rhizophora apiculata*.

RECOMMENDATION

Researchers can then conduct research on the highest carbon stocks in various other regions of Indonesia based on differences in planting years mangrove rehabilitation and potential environmental service species from mangrove ecosystem as storage carbon also has an impact on economic aspects.

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