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Potential Carbon Stock and Absorption in Mangroves in Penempul Village, Sungai Sembilan District, Dumai City, Riau Province

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ABSTRACT

Global warming is caused by increased greenhouse gas emissions, particularly CO_2, and can be controlled through carbon sequestration by vegetation, including mangrove forests. The study was conducted in January and February 2025 in the mangrove area of Penempul Village, Sungai Sembilan District, Dumai City, Riau Province, to determine the density in relation to biomass, carbon stock, and CO_2 absorption, as well as to investigate the relationship between density and biomass, carbon stock, and CO_2 absorption. The method used in this study was a survey method with a purposive sampling technique, which involved measuring the diameter of mangrove tree trunks at chest height (DBH). Mangrove biomass calculations were performed using allometric equations, and biomass was converted into carbon stock and CO_2 absorption. The study results indicated the presence of 11 mangrove species, with average estimated biomass, carbon stock, and CO_2 absorption values of 521.84 tons/ha, 245.25 tons/ha, and 899.35 tons/ha, respectively. The ANOVA results showed significant differences ($p > 0.05$) between the three stations regarding biomass, carbon stock, and CO_2 absorption. Mangrove density had a weak correlation with biomass, carbon stock, and CO_2 absorption, with a correlation coefficient of 0.299.

Keywords: Penempul Village, Mangroves, Biomass, Carbon Stock, CO_2 Absorption

1. INTRODUCTION

Global warming, characterized by an increase in the average temperature of the Earth's atmosphere, oceans, and land, hurts global ecosystems. Tangible effects have already been observed, including rising sea levels, extreme weather events (such as heatwaves), and changes in rainfall patterns and intensity. Global warming is closely linked to the increasing concentration of greenhouse gases in the atmosphere, such as carbon dioxide (CO_2). One of the steps to mitigate greenhouse gas emissions is to enhance absorption by mangrove forest vegetation in coastal areas (blue ecosystems), which must be preserved and developed (Efriyeldi et al., 2023).

Mangroves are a type of vegetation that is highly susceptible to deforestation. The area of mangrove forests has decreased by 30–50% in the last 50 years due to coastal development, expansion of aquaculture ponds, and excessive logging (Syafruddin et al., 2018). It is estimated that emissions caused by deforestation and forest degradation account for approximately 20% of total annual greenhouse gas (GHG) emissions. This can lead to the biomass stored in trees decomposing or breaking down, releasing carbon dioxide (CO_2), and thereby increasing the concentration of greenhouse gases in the atmosphere (CIFOR, 2010).

Plants absorb carbon from the atmosphere through photosynthesis and store it as biomass (Istomo & Farida, 2017). Tree biomass is divided into aboveground and belowground biomass, which store aboveground carbon (Cag) and belowground carbon (Cbg). The most significant proportion of biomass carbon storage is above ground (Irawan & Purwanto, 2020). Several factors influence the extent of carbon storage in aboveground biomass. Spatially, the factors affecting carbon absorption include species composition, stand diameter, stand height, density, and canopy cover (Heriyanto & Subiandono, 2016).

Atmospheric CO_2 is absorbed (carbon sequestration) by vegetation and stored in biomass. Measurements of vegetation biomass describe the amount of CO_2 absorbed by plants, referred to as carbon reserves above and below ground. Mangroves have high potential for carbon sequestration, accounting for 1% of global carbon sequestration and 14% in coastal areas (Alongi, 2014). Mangroves can capture more CO_2 from the atmosphere than secondary tropical vegetation (Cui et al., 2018).

Penempul Village, Dumai City, is one of the areas where mangroves grow naturally, making it an ideal location for research on carbon stocks and sequestration. The community has long been aware of the ecological, physical, and economic benefits of mangroves. However, they are unaware that mangroves also help reduce carbon emissions into the atmosphere, mitigating the greenhouse effect. Therefore, it is crucial to conduct the proposed research.

2. RESEARCH METHOD

Time and Place

The research was conducted from January to February 2025 in Penempul Village, Sungai Sembilan District, Dumai City, Riau Province (Figure 1).

Figure 1. Research location

Method

The research location was determined using purposive sampling. This non-probability sampling technique aims to produce a sample that is considered representative of the population based on its characteristics and the research objectives (Lavrakas, 2008).

Procedures

Determining Research Locations

The stations were determined based on NDVI (Normalized Difference Vegetation Index) analysis, which shows areas with different vegetation densities (Figure 2). Based on NDVI analysis, which identified areas with the highest density, the research station locations were determined as follows: Station 1 is situated in the mangrove forest area of Muara Sungai Santa Hulu, Penempul Village. This area is far from residential areas. Station 2 is located in the mangrove forest area of Kampung Nelayan, Penempul Village, near residential areas. Station 3 is located in the mangrove forest area of Muara Sungai Geniot, Penempul Village. This area is close to brackish water cultivation, where residents utilize the land by clearing it for this purpose.

Each research station has nine plots, each measuring 10 × 10 m², arranged linearly and perpendicular to the coastline or mangrove ecotone.

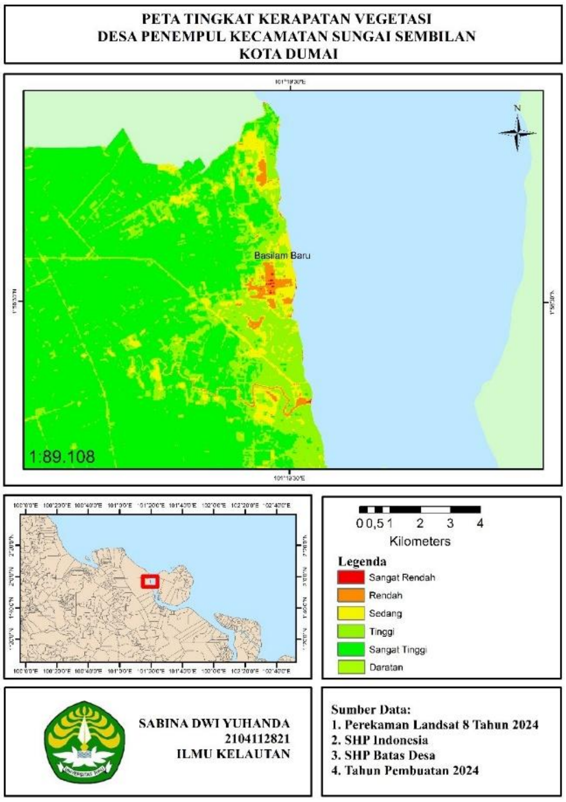

Figure 2. NDVI Map

Mangrove Density

Mangrove density is defined by SNI (2011) as follows.

$$K = \frac{ni}{A}$$

Description:

K = Density of individuals (ind/m^2)

ni = Number of individuals

A = Total area of plot (m^2)

Mangrove Biomass

The diameter of tree trunks in the plot, measured on a single transect, was taken at breast height (DBH), as per the SNI (2011). The measurement of aboveground biomass (AGB) of the stand was carried out using the allometric equation method. The allometric equations used are as follows (Table 1).

Table 1. Allometric equations for mangrove biomass

Species Name	Formula	Source
Rhizophora apiculata	$B = 0{,}043\ DBH^{2{,}63}$	Kauffman & Donato (2012)
R. mucronata	$B = 0{,}1466\ DBH^{2{,}3236}$	Dharmawan & Samsoedin (2012)
Xylocarpus granatum	$B = 0{,}1832\ DBH^{2{,}21}$	Tarlan (2008)
Avicennia marina	$B = 0{,}1848\ DBH^{2{,}3624}$	Dharmawan & Siregar (2008)
A. alba	$B = 0{,}079211\ DBH^{2{,}470895}$	Tue et al. (2014)
Lumnitzera racemosa	$B = 0{,}184\ DBH^{2{,}384}$	Kauffman & Donato (2012)
Scyphiphora hydrophyllacea	B = 0,825DBH0,89 ρ	Khairijon et al. (2013)
Ceriops tagal	$B = 0{,}251\ DBH^{2{,}46}\ \rho$	Komiyama et al. (2005)
Sonneratia alba	$B = 0{,}128\ DBH^{2}$	Kauffman & Donato (2012)
Excoecaria agallocha	$B = 1{,}0996\ DBH^{0{,}8572}$	Hossain et al. (2015)
Bruguiera gymnorhiza	$B = 0{,}0754\ DBH^{2{,}505}\ \rho$	Kauffman & Donato (2012)

Note: B : Biomass (Kg/m^2); DBH : Diameter at breast height (cm); ρ : Wood density (g/cm^2)

Table 3. Specific gravity of mangroves

Species Type	Wood Density (g/m^2)
B. gymnorhiza	0,699
S. hydrophyllacea	0,685
C. tagal	0,97

Carbon Stock

Carbon stock calculations for mangroves are based on the SNI (2011) as follows.

$$Cb = B \times \%C\ Organic$$

Description:

Cb = Carbon stocks from biomass (kg)

B = Total biomass (kg)

%C Organik = Carbon reserve percentage value of 0,47

$$Cbh = \frac{Cx}{1000} \times \frac{10000}{L\ plot}$$

Description:

Cbh = Carbon stock per hectare of biomass (ton/ha)

Cx = Carbon stocks in each carbon pool in each plot (kg)

Lplot = Area of each carbon pool (m^2)

Carbon dioxide Absorption (CO_2)

The calculation of carbon dioxide (CO_2) absorption refers to Bismark et al. (2008) as follows:

$$S\ CO_2 = \frac{Mr\ CO2}{Ar\ C} \times Kc$$

Explanation:

$S\ CO_2$ = Carbon dioxide absorption

$Mr\ CO_2$ = The relative molecular mass of carbon atoms is 44

Ar C = The relative atomic mass of carbon is 12

Kc = Carbon content

$$Sn = \frac{S\ CO2}{1000} \times \frac{10000}{Lplot}$$

Explanation:

Sn : Carbon dioxide (CO_2) absorption per hectare in each plot

$S\ CO_2$: Carbon dioxide absorption (CO_2)

Lplot : Area of each carbon pool

Data Analysis

The data analysis used in this study was ANOVA, LSD, and linear regression tests. The ANOVA test was used to compare biomass, carbon stock, and CO_2 absorption between stations. The LSD test was used to determine which parts were significantly different. The linear regression test was used to determine the level of relationship between mangrove stand density and other variables (biomass, carbon stock, and carbon dioxide absorption), with reference to Sugiyono (2016), as follows.

0.00 – 0.20: Very weak relationship
0.21 – 0.40: Weak relationship
0.41 – 0.70: Moderate relationship
0.71 – 0.90: Strong relationship
0.91 – 1.00: Very strong relationship

3. RESULT AND DISCUSSION

Mangrove Density

The mangrove vegetation found at the three research stations consisted of 11 species, namely: *Rhizophora apiculata, R. mucronata, Scyphiphora littorea, Ceriops tagal, Xylocarpus granatum, Sonneratia alba, Bruguiera gymnorrhiza, Excoecaria agallocha, Avicennia alba, A.marina, and Lumnitzera racemosa*. The results of the mangrove density calculations at each station are presented in Figure 3.

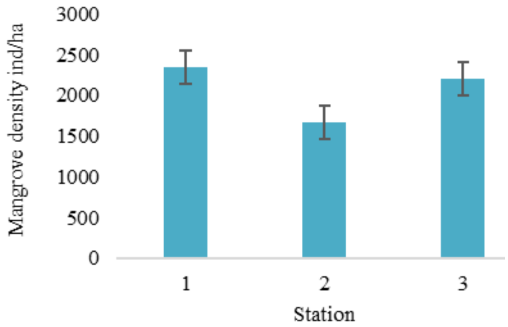

Figure 3. Mangrove density

Based on the density calculations performed at the three stations, it was found that the highest mangrove density was at Station 1, with 2355.5 ind/ha, while the lowest mangrove density was at Station 2, with 1677.75 ind/ha. The mangrove stand density at station 1 is higher than at stations 2 and 3 due to the different characteristics of the three areas. Station 1 is a mangrove forest area located far from residential areas, resulting in minimal forest utilization in that area. In contrast, the other stations are mangrove forest areas that are more heavily impacted by human use, such as Station 2, which is located near residential areas, where the community uses wood and land for settlement construction, and Station 3, which is located near brackish water cultivation areas, where the local community utilizes the land by clearing it for brackish water farming.

The ANOVA results indicate a significant difference in mangrove stand density between stations ($p = 0.001$), suggesting a statistically significant difference ($p < 0.05$). Therefore, the analysis proceeded with the LSD (Least Significant Difference) test. There was a significant difference in density between Station 1 and Station 2 ($p = 0.000$), while there was no significant difference between Station 1 and Station 3 ($p = 0.364$). The density at station 2 compared to station 1 and station 3 showed significant differences, namely ($p = 0.000$) and ($p = 0.005$). There was no significant difference in density between station 3 and station 1 ($p = 0.364$), but there was a significant difference between station 3 and station 2 ($p = 0.005$).

Based on the standard criteria for mangrove damage established by the Minister of Environment (2004), namely dense density > 1500 ind/ha, moderate > 1000 - < 1500 ind/ha, and sparse < 1000 ind/ha, it can be concluded that the three research stations have mangrove stand densities in the dense category.

Mangrove Biomass

Based on the biomass calculations at the three research stations, it was found that the highest total biomass was at station 1, namely 643.04 tons/ha, while the lowest total mangrove biomass was at station 3, namely 361.85 tons/ha. The difference in biomass levels is attributed to the higher mangrove density at Station 1 compared to Stations 2 and 3, as well as the larger diameter of trees at Station 1 compared to those at Station 3. This is consistent with the statement by Mandari et al. (2016), which states that biomass values are influenced not only by tree density but also by the diameter of the trees themselves, as larger tree diameters result in higher biomass values.

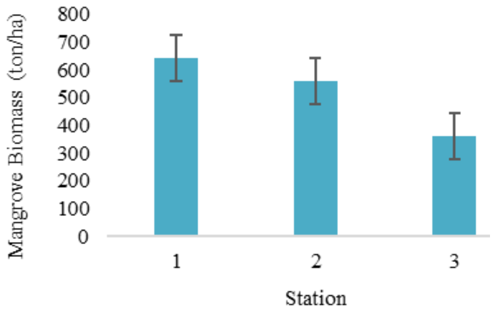

Figure 4. Mangrove biomass

The differences in biomass are due to the density and diameter of the trees in a stand. The larger the diameter of a stand, the greater the biomass present in that stand. The influence of trunk diameter on the biomass value of a tree stand is significant, consistent with the statement by Ihsan et al. (2016) that there is a strong relationship between tree dimensions (diameter and height) and biomass, particularly with tree diameter.

Based on the research conducted, the average biomass of mangroves in the mangrove forest of Penempul Village, Sungai Sembilan District, Dumai City, Riau Province, was found to be 521.53 tons/ha. The biomass in this area is higher than that found in the study conducted by Rifandi (2021) in the mangrove forest of Mojo Village, Ulujami District, Pemalang Regency, Central Java, with an average biomass of 123.40 tons/ha. However, the biomass in the study by Handoyono et al. (2020) in the Sungai Sembilan District, specifically in Dumai City's mangrove forest, was higher, with an average biomass of 621.46 tons/ha. The results of biomass research in other ecosystems (terrestrial forests) conducted by Sribianti et al. (2022) in Abdul Latief Forest Park, South Sulawesi, showed an average biomass of 192.10 tons/ha. This aligns with the statement by Heriyanto et al. (2011) that mangrove stands can produce greater biomass than other aquatic ecosystems, including wetlands. However, high vegetation biomass content can also result in significant carbon conversion.

Mangrove Carbon Stock

Based on the results of mangrove carbon stock calculations at the three research stations, it was found that the highest mangrove carbon stock was at station 1, namely 302.23 tons/ha, while the lowest mangrove carbon stock was at station 3, namely 170.05 tons/ha. This difference in mangrove carbon stocks is due to the higher density of mangrove stands at Station 1 compared to the other stations. The low potential for carbon storage in mangrove stands at the research site does not indicate a low ability of mangroves to absorb and store carbon; this is, of course, influenced by the biomass content of the mangroves. One of the determining factors is the age of the mangroves and the diameter of the trunk (DBH), as each mangrove ecosystem has distinct mangrove characteristics (Hafli et al., 2024).

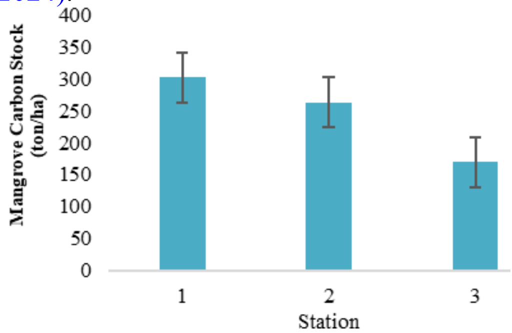

Figure 5. Mangrove carbon stock

Carbon storage in mangrove vegetation reflects the extent to which the vegetation can absorb and store carbon in the form of biomass. The biomass and tree size are predicted to influence carbon storage capacity (Analuddin et al., 2020). Based on the research findings, mangroves with larger stem diameters have greater biomass and carbon stocks. The biomass values can indicate the amount of carbon stock available or stored in a stand. The amount of tree carbon stock is directly proportional to the size of the tree biomass. This is because the carbon content of an organic material accounts for approximately 47% of its total biomass (SNI, 2011).

Based on the research conducted, the average carbon stock of mangroves in the mangrove forest of Penempul Village, Sungai Sembilan District, Dumai City, Riau Province, was found to be 245.27 tons/ha. The biomass in this area is higher than that found in the study conducted by Rifandi (2021) in the mangrove forest of Mojo Village, Ulujami District, Pemalang Regency, Central Java, with an average biomass of 57.99 tons/ha. However, the carbon stock in the study by Handoyono et al. (2020) in the mangrove forest of Sungai Sembilan District, Dumai City, was higher, with an average carbon stock of 289.22 tons/ha. The carbon research results in other ecosystems (terrestrial forests) conducted by Sribianti et al. (2022) in Abdul Latief Forest Park, South Sulawesi, were 90.28 tons/ha. This is consistent with the statement by Daniel et al. (2012) that mangrove ecosystems have the highest carbon absorption capacity due to their high density of roots. Each hectare of mangrove ecosystem can store four times more carbon than other ecosystems.

Carbon Dioxide Absorption (CO_2)

The research results showed that the highest CO2 absorption was at station 1, with a value of 1108.16 tons/ha, while the lowest total carbon dioxide (CO2) absorption was at station 3, at 623.59 tons/ha. This difference in CO_2 absorption is due to the higher biomass and carbon stock values at Station 1 compared to Stations 2 and 3. Station 1 is far from settlements, so there is minimal forest utilization. In contrast, stations 2 and 3 are mangrove forest areas where the local community uses wood and land to build settlements and open land for brackish water cultivation. Land utilization has a direct impact on the forest's function as a carbon sink. A decrease in mangrove forest area indicates a decline in the forest's ability to absorb carbon, leading to increased atmospheric carbon concentrations.

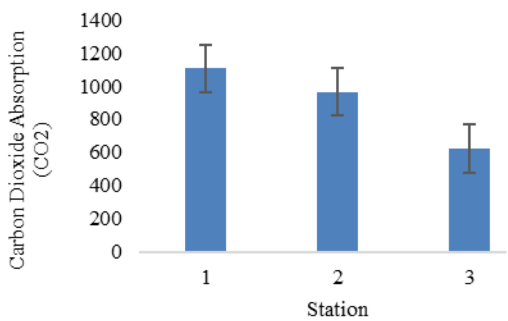

Figure 6. Carbon dioxide absorption

CO_2 or carbon dioxide absorption results from mangroves' ability to absorb CO_2 from the atmosphere, which is used as a material for photosynthesis. Thus, mangroves directly affect the concentration of CO_2 in the atmosphere. These CO_2 calculations directly correlate with the carbon storage in mangrove vegetation. According to Afdal (2014), mangroves can absorb CO_2 from the atmosphere, which is used for photosynthesis. This photosynthesis process is carried out by mangrove leaves, influencing the amount of CO_2 absorbed in a particular area of mangrove vegetation.

Based on the research conducted, it was found that the average CO_2 absorption of mangroves in the mangrove forest of Penempul Village, Sungai Sembilan District, Dumai City, Riau Province, is 899.35 tons/ha. The CO_2 absorption rate in this area is higher than that reported by Rifandi (2021) in the mangrove forest of Mojo Village, Ulujami Subdistrict, Pemalang Regency, Central Java, with an average CO_2 absorption rate of 175.90 tons/ha. However, the CO_2 absorption rate in the study by Handoyono et al. (2020) in the mangrove forest of Sungai Sembilan District, Dumai City, was higher, with an average CO_2 absorption rate of 1,074.99 tons/ha. The results of carbon absorption studies in other ecosystems (terrestrial forests) conducted by Sribianti et al. (2022) in Abdul Latief Forest Park, South Sulawesi, were 281.75 tons/ha. This aligns with Susetyo's (2022) statement that mangrove carbon absorption is 3-5 times greater than that of the densest terrestrial forests.

The Relationship Between Mangrove Density and Carbon Dioxide (CO_2) Stock and Absorption (CO_2)

The correlation coefficient values for the relationships between mangrove density and biomass, mangrove carbon stock, and CO_2 absorption show a correlation value of 0.299, indicating that the relationships between density and biomass, carbon stock, and CO_2 absorption are weak. One factor that influences the variation in biomass, mangrove carbon stock, and CO_2 absorption is the diameter of the trees. The larger the tree diameter, the greater the biomass, mangrove carbon stock, and CO_2 absorption. This shows that the density of mangrove stands and other factors, such as tree diameter, influence the variation in these three aspects.

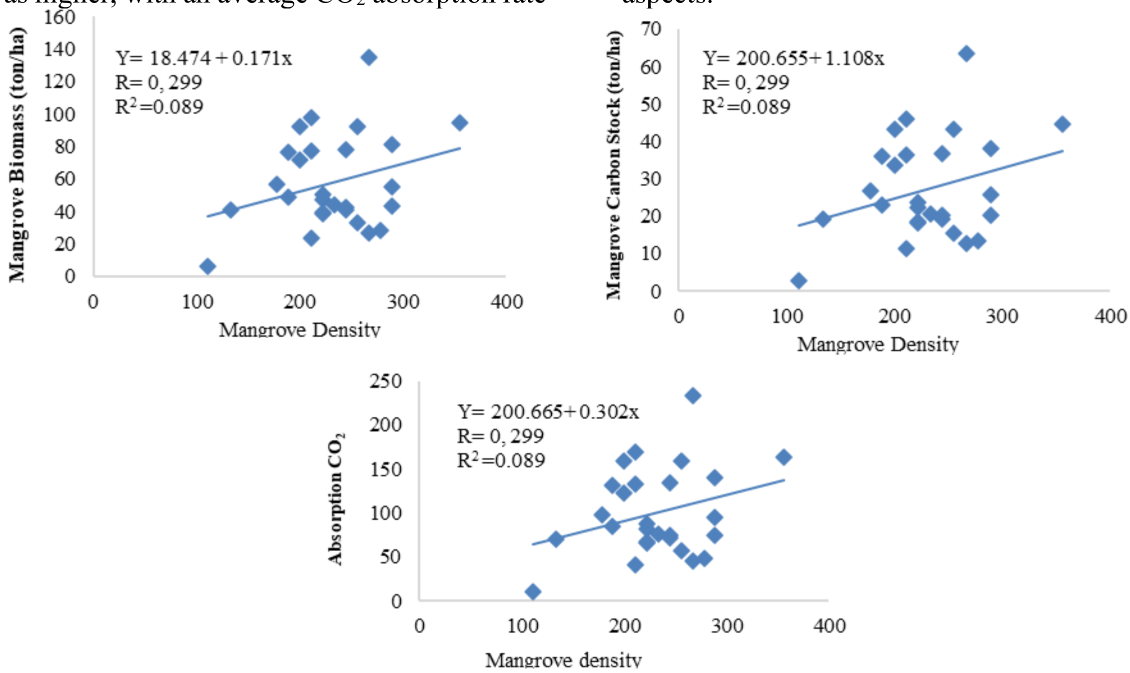

Figure 7. Relationship between density and biomass, carbon stock, and CO_2 absorption

4. CONCLUSION

Based on the research results, the density of mangroves at the three research stations was categorized as good. Station 1 had the highest density value, at 2355.5 ind/ha, followed by Station 3, at 2199.96 ind/ha, and Station 2, at 1677.75 ind/ha. The average estimated mangrove biomass in the Penempul Village mangrove forest area was recorded at 521.84 tons/ha, with an average carbon stock of 245.25 tons/ha and a CO_2 absorption potential of 899.35 tons/ha.

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