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Blue Carbon Potential of Mangrove Ecosystem on the Coast of Negeri Waai, Central Maluku Regency

Potensi Karbon Biru Ekosistem Mangrove di Pesisir Negeri Waai, Kabupaten Maluku Tengah

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ABSTRACT

The mangrove ecosystem contributes to climate change mitigation by absorbing carbon dioxide gas. The shoreline of Negeri Waai, Central Maluku Regency (CMR), becomes one of Indonesia's promising mangrove ecosystem habitats for carbon absorption. Therefore, this research aimed to assess the blue carbon potential of mangroves on the coast of Negeri Waai, CMR. This research collected data using the quadrant transect method (10 x 10 m) and placed randomly in 65 quadrants. The analysis of blue carbon potential used an allometric approach to above and below-ground biomass (AGB and BGB). The results showed that the total blue carbon mangrove stock on the coast of Negeri Waai was 73.22 ton C/ha, consisting of 49.44 tons C/ha above-ground carbon (AGC) and 23.78 tons C/ha below-ground carbon (BGC). Sonneratia alba contributed the most extensive carbon stock, namely 70.69 ton C/ha, consisting of 47.53 tons C/ha AGC and 23.16 tons C/ha BGC. This result was relatively low compared to the global average of blue carbon in mangroves, 134 ton C/ha. Based on this result, efforts were needed to restore the mangrove ecosystem, increase the potential for carbon absorption, and mitigate climate change.

INTISARI

Ekosistem mangrove memiliki peranan dalam mitigasi perubahan iklim melalui penyerapan gas karbondioksida. Salah satu habitat ekosistem mangrove yang potensial dalam penyerapan karbon adalah pesisir Negeri Waai, Kabupaten Maluku Tengah. Penelitian bertujuan untuk menganalisis potensi blue carbon mangrove di pesisir Negeri Waai Kabupaten Maluku Tengah. Pengumpulan data dilakukan dengan metode transek kuadran (10 x 10 m) yang diletakkan secara random sebanyak 65 kuadran. Analisis potensi blue carbon dilakukan melaluipendekatan allometrik above-ground biomass (AGB) dan below ground biomass (BGB). Hasil penelitian menunjukkan bahwa total blue carbon stock di pesisir Negeri Waai sebesar 73,22 ton C/ha, terdiri dari 49,44 tons C/ha above-ground carbon (AGC) dan 23,78 tons C/ha below-ground carbon (BGC). Sonneratia alba memberikan kontribusi yang sangat signifikan yaitu 70,69 ton C/ha, terdiri dari 47,53 tons C/ha AGC dan 23,16 tons C/ha BGC. Potensi tersebut tergolong rendah bila dibandingkan dengan rata–rata global simpanan karbon pada mangrove yaitu 134 ton C/ha. Dengan demikian, perlu upaya restorasi ekosistem mangrove untuk meningkatkan potensi serapan karbon dan mitigasi perubahan iklim.

Introduction

Global warming is a natural occurrence that must be monitored globally, particularly in Indonesia. Currently, the most significant contributors to global warming are carbon dioxide and methane, resulting from different human activities, such as the combustion of fossil fuels, motorized vehicles, and industrial equipment (IPCC 2001). Optimizing the role of the ecosystem in absorbing carbon dioxide gas in the atmosphere could enhance climate change mitigation efforts (Murdiyarso et al. 2015). This optimization of carbon absorption occurs through terrestrial and coast ecosystems, such as mangroves.

Blue carbon is the total carbon equivalent (CO_2e) absorbed and stored by the ocean and coastal ecosystems, including mangroves. Research on the potential of blue carbon in mangrove ecosystems has been an exciting area of investigation due to the importance of climate change mitigation and its relationship to carbon trading regulations. Furthermore, blue carbon has become an emerging paradigm in managing mangrove ecosystem sustainably (Sidik et al. 2022). According to Rahman et al. (2017), mangrove carbon stores in the Makassar Tallo River area reached 296 ton C/ha, primarily contributed by *Sonneratia alba* and *Rhizophora mucronata* species. Rahman et al. (2020b) reported that Maluku hosts 34 types of mangroves, generally dominated by true mangroves. Therefore, research on mangrove ecosystems in eastern Indonesia, specifically Maluku, needs extension.

The coast of Negeri Waai, CMR, has become one of the areas in Maluku that hosts mangrove ecosystems. This area is in the northeastern region of Ambon Island and faces the Haruku Strait. The open coastal ecosystem of Negeri Waai exhibits different characteristics compared to the bay ecosystem type in the Ambon Island region. Open ecosystems experience organic matter leaching due to tidal variations, which hinders optimal biomass accumulation in mangrove sediments. Consequently, the potential blue carbon estimation occurs mainly on stands (above-ground biomass) and roots (below-ground biomass).

Previous research showed that *Sonneratia alba* was the dominant mangrove species. Rahman (2020) reported that *S. alba* had better carbon stock and absorption capabilities than other species. Therefore, this research aimed to analyze the potential of above and below-ground blue carbon in the mangrove ecosystems on the coast of Negeri Waai, Central Maluku Regency. The results offered scientific insights for the CMR government in managing mangrove ecosystems for climate change mitigations.

Methods

Time and Location

This research was conducted in Waai Coast, CMR, from November to December 2022 (Figure 1). Terlir (2022) reported that *S. alba* species dominated the

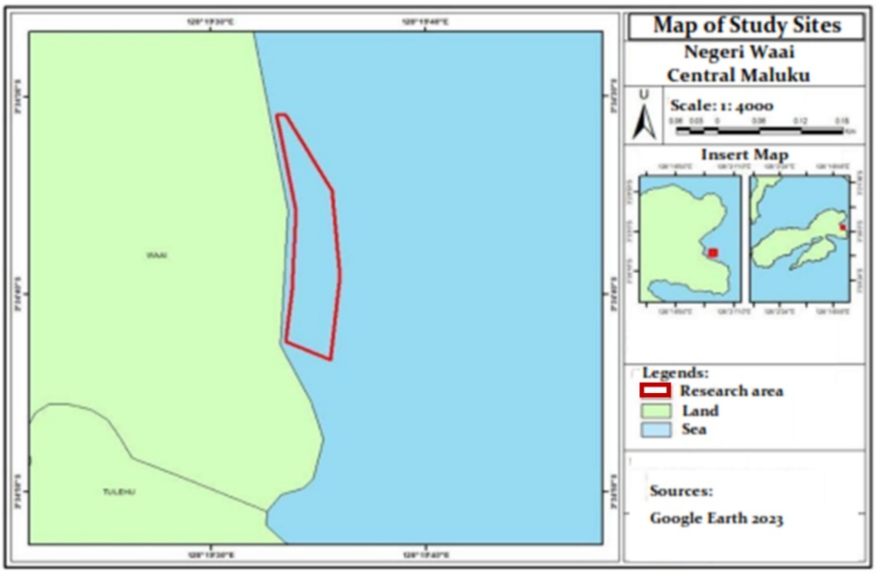

Figure 1. Map of the study site

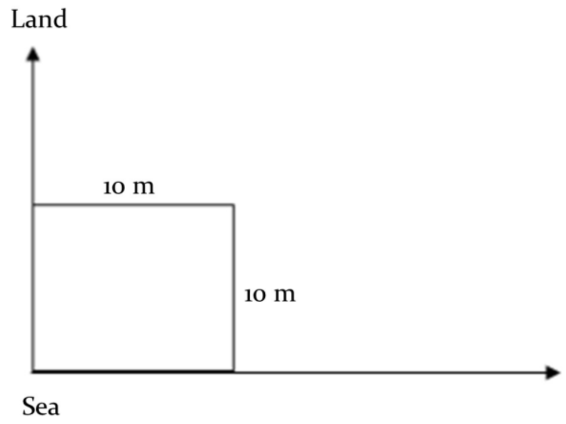

Figure 2. Plot or transect quadrant of mangrove stand density measurement

mangrove ecosystem on the coast of Negeri Waai with a diameter range of 15 – 140 cm. This species was prevalent in the open coast areas of Negeri Waai, predominantly occupying sandy habitats.

Data Collection

Data collection focused on the density and diameter of each mangrove species. Density measurements were made by randomly placing 65 plots or quadrant transact measuring 10 x 10 m (Figure 2). Mangrove species in the plot were identified based on morphological characteristics, such as roots, stems, leaves, and fruit (Noor et al. 2006). The methods for measuring mangrove tree diameter referred to the diameter at breast height measurement (DBH = 130 cm), as explained by Bengen et al. (2022).

$$D \text{ (trees/ha)} = \frac{\sum \text{number of trees (trees)}}{\text{Area (ha)}} \quad (1)$$

The classification of mangrove density referred to the criteria suggested by Rahman et al. (2019) in Table 1.

The analysis of the factors contributing to the degradation of the mangrove ecosystems in Negeri Waai used the Drive-Pressures-State-Impact-Responses (DPSIR) framework, as suggested by Baldwin et al. (2016) (Figure 3).

Table 1. Criteria of mangrove stand density according to Rahman et al. (2019)

No	Density (stands/ha)	Criteria
1	<500	Very rare
2	>500 – 1000	Rare
3	>1000 – 1500	Medium
4	>1500 – 2000	Dense
5	>2000	Very dense

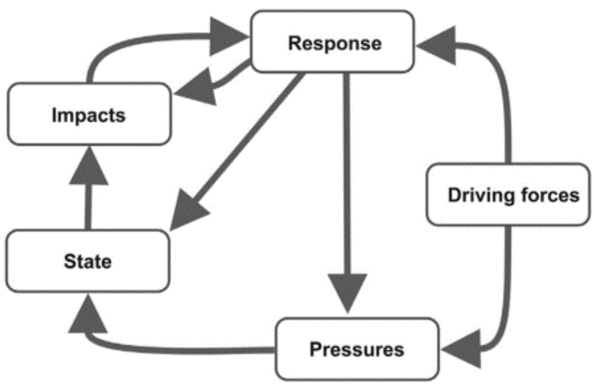

Figure 2. Plot or transect quadrant of mangrove stand density measurement

Table 2. Allometry models of biomass estimations on various mangrove species

No	Species	AGB	Sources	BGB	Sources
1	S. alba	$B = 0.258\ (D)^{2.287}$	Kusmana et al. (2018)	$B = 0.230\rho(D^2H)^{0.74}$	Kusmana et al. (2018)
2	R. apiculata	$B = 0.235(D)^{2.42}$	Ong et al. (2004)	$B = 0.0689\ (D)^{2.61}$	Ong et al. (2004)
3	R. mucronata	$B = 0.128(D)^{2.60}$	Fromard et al. (1998)	$^*B = 0.0974(D^2H)^{1.05}$	Tamai et al. (1986)
4	R. stylosa	$B = 0.178(D)^{2.59}$	Gevana & IM. (2016)	$B = 0.261\ (D)^{1.86}$	Comley & McGuinness (2005)
5	Common equations	$B = 0.251\ \rho(D)^{2.46}$	Komiyama et al. (2005)	$B = 0.199\ \rho^{0.899}D^{2.22}$	Komiyama et al. (2005)

Notes: B = Biomass, D = dbh (130 cm); ρ= wood density (mg/cm^3); *H (Height) = D/(0.02D + 0.678) (Tamai et al. 1986)

Biomass, Carbon Stock, and Carbon Absorption

The above and below-ground biomass analysis in each mangrove species used allometric equations developed in previous research (Table 2).

Multiplying the biomass by the carbon fraction (CF) resulted in carbon stock values. The CF for mangroves was 46.82% or 0.4682 (Rahman et al. 2023). Therefore, the carbon stock estimation used equations (2) and (3).

Standing Carbon Stock (kg C/stand) = Standing Biomass x 0.4682 (2)

Carbon Stock per hectare (ton C/ha) = C stock of stands x Density (3)

The value of carbon absorption was obtained through the equivalence of carbon stock to CO_2 based on the ratio of carbon atomic mass (Ar C) to the compound's molecular mass (Mr CO_2). The value of 3.67 was the ratio between Mr CO_2 (44 44 g/mol) and Ar C (12 44 g/mol).

Carbon Absorption = Carbon Stock x 3.67 (4)

Results and Discussions

Mangrove Density

The highest mangrove density in Negeri Waai was *S. alba*, constituting 208 trees/ha. The lowest densities were *Rhizophora mucronata*, *Rhizophora stylosa*, and *Sonneratia ceseolaris*, constituting 18, 20, and 22 trees/ha (Figure 4). The total mangrove density in Negeri Waai was 393 trees/ha. This study included the "very rare" density value category according to Rahman et al. (2019) or "rare" according to KepMen LH No. 201 of 2004. This mangrove density value in Negeri Waai was relatively low compared to the mangrove ecosystem of West Muna Regency, namely 752 trees/ha (Rahman et al. 2020b).

A low density signified an unhealthy condition of the mangrove ecosystem, necessitating restoration or rehabilitation efforts to improve the mangrove ecosystem's health. Various factors influenced this condition, such as logging and building settlement infrastructure (Figure 5). This result was consistent with the report of Ilman et al. (2016), Rahman et al. (2020a), and Arifanti et al. (2019; 2021) that suggested

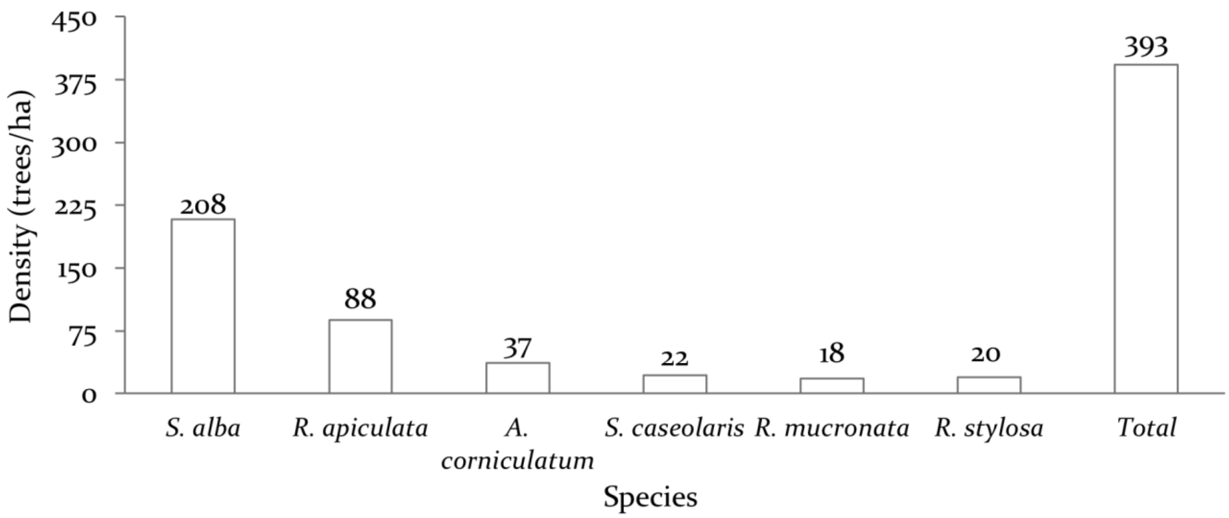

Figure 4. Mangrove density on the coast of Negeri Waai, CMR

Figure 5. Residential infrastructure in the mangrove ecosystem area of Negeri Waai, CMR

land conversion into cultivation areas, agriculture, settlements, infrastructure, and mining have led to the degradation of the mangrove ecosystem in Indonesia.

The results of the DPSIR analysis (Figure 6) showed that the causes of mangrove ecosystem degradation (Pressures) were settlements and infrastructure (Drivers). This degradation affected the mangrove density and increased CO_2 emission (State), directly and indirectly decreasing economic benefits, including blue carbon potential (Impact). Therefore, a response was required to restore the function of the mangrove ecosystem through various policies, particularly ecosystem restoration (Responses).

The CMR government needed to rehabilitate this low-density mangrove ecosystem with native species such as *R. mucronata* and *S. alba*. This rehabilitation needed collaboration with various stakeholders, specifically the community, which played a critical role in the success of mangrove ecosystem rehabilitation programs (Oni et al. 2019).

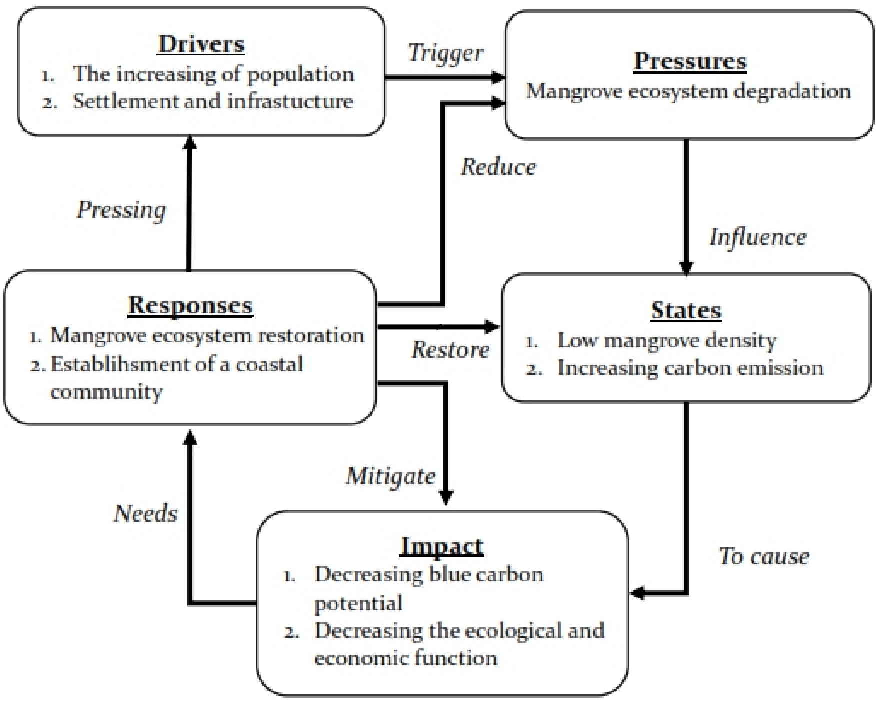

Figure 6. DPSIR framework of mangrove ecosystems on the coast of Negeri Waai, CMR

Biomass, Blue Carbon, and Carbon Absorption

Mangrove Biomass

The mangrove tree biomass values for each species on Negeri Waai's coast differed. The results showed the highest biomass in *S. alba*, with a value of 725.91 kg/tree, consisting of 488.04 kg and 237.87 kg of above and below-ground biomass, respectively. On the other hand, *R. mucronata had* the lowest tree biomass, with a biomass value of 21.32 kg/tree each, consisting of 16.83 kg and 4.49 kg, respectively. The *R. apiculata* had a total biomass of 23.61 kg/tree, consisting of 16.75 kg above and 6.86 kg below-ground biomass (Table 3).

The DBH size and the density of mangroves influenced the difference in biomass among species. A larger DBH size of mangroves resulted in a higher biomass value (Komiyama et al. 2005). Biomass values were affected by the density of each mangrove species (Rahman et al. 2020d). Therefore, mangrove species could have different biomass values at the same DBH size. The wood density (ρ) of mangrove species *S. alba* is 0.79 g/cm^3 (Kusmana et al. 2018). It was the largest compared to other species, such as *Rhizophora* (0.67 g/cm^3) and *Nypa* (0.39 g/cm^3) (Rahman et al. 2020c).

The total mangrove biomass on the coast of Negeri Waai was 156.39 tons/ha, consisting of 105.60 tons/ha above and 50.79 tons/ha below-ground biomass. The *S. alba* species contributed 150.99 tons/ha, consisting of 101.51 tons/ha AGB and 49.48 tons/ha BGB, equivalent to 96.54%. The lowest contributions were *R. mucronata* and *A. corniculatum* with respective values of 0.38 tons/ha (0.30 tons/ha AGB and 0.08/ha tonne BGB) or equivalent to 0.25%, and 0.95 tons/ha (0.75 tons/ha AGB and 0.20 tons/ha BGB) or the equivalent of 0.60% (Figure 7).

Mangroves Blue Carbon Stock

The *S. alba* species had the most significant potential blue carbon stock (339.87 kg C/tree), consisting of 228.50 kg C AGB and 111.37 kg C BGB, respectively. Meanwhile, *R. mucronata* species had the least potential blue carbon stock (9.98 kg C/tree), consisting of 7.88 kg C AGB and 2.10 kg C BGB (Table 4). The biomass, DBH, density, and carbon fraction values influenced the carbon stock value of each mangrove species.

The carbon content in mangrove consisted of 26.20 C carbohydrates, 2.97% C amino acids, 3.22% C tannins, 3.38% C lignin, 7.69% C fatty acids, 3.17% C triterpenoids, and 0.19% C n-alkane (Rahman et al. 2023). These carbon components were relatively similar for Rhizophora, Bruguiera, and Sonneratia mangroves, and the difference was only found in the n-alkane chain 26 – 31 n – alkane (C_nH_{2n+2}). However,

Table 3. Average of tree mangrove biomass on the coast of Negeri Waai, CMR

Species	Biomass (kg/trees)		
	Above-ground	Below-ground	Total
S. alba	488.04	237.87	725.91
R. apiculata	16.75	6.86	23.61
A. corniculatum	20.26	5.31	25.57
S. caseolaris	36.69	8.63	45.33
R. mucronata	16.83	4.49	21.32
R. stylosa	37.73	12.22	49.96

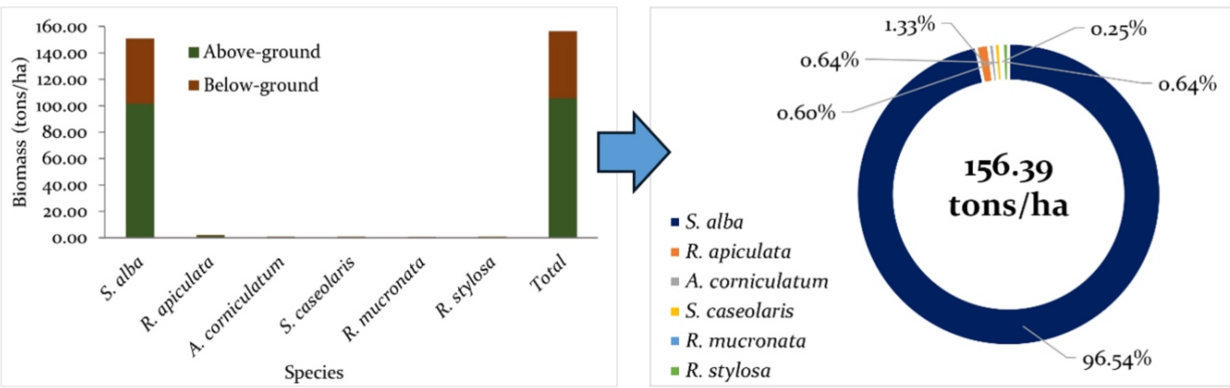

Table 3. Average of tree mangrove biomass on the coast of Negeri Waai, CMR

Table 4. Blue carbon stock in each mangrove trees on the coast of Negeri Waai, CMR

Species	Blue Carbon Stock (kg C/tree)		
	Above-ground	Below-ground	Total
S. alba	228.500	111.37	339.87
R. apiculata	7.842	3.21	11.06
A. corniculatum	9.484	2.49	11.97
S. caseolaris	17.180	4.04	21.22
R. mucronata	7.878	2.10	9.98
R. stylosa	17.666	5.72	23.39

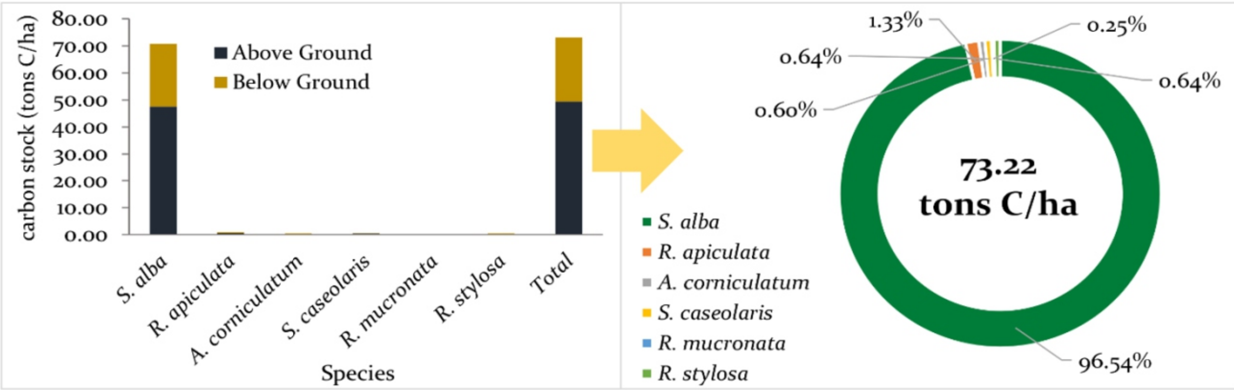

Figure 8. Total of blue carbon stock (ton C/ha) of mangrove ecosystems on the coast of Negeri Waai

this difference in the n-alkane chain was insignificant in determining the mangrove carbon fractions (Kristensen et al. 2008).

The total blue carbon stock on the coast of Negeri Waai was 73.22 ton C/ha, consisting of 49.44 tons C/ha above-ground carbon (AGC) and 23.78 tons C/ha below-ground carbon (BGC). *The S. alba* contributed the most extensive carbon stock, namely 70.69 ton C/ha, consisting of 47.53 tons C/ha AGC and 23.16 tons C/ha BGC, equivalent to 96.54%. In contrast, *R. mucronata* contributed the lowest carbon stock, namely 0.25% or 0.18 ton C/ha, consisting of 0.14 tons C/ha AGC and 0.04 tons C/ha BGC (Figure 8).

The total carbon stock in Negeri Waai was lower than the global average of mangrove carbon stock, with a value of 134 tons C/ha (Alongi 2014). The types and density of mangrove species influenced the differences in this value. An ecosystem dominated by *S. alba* with a high density tended to have an immense potential for carbon stocks, and those dominated by a low-density Nypa would have low-carbon stores. Nypa-type had high water content and stored merely 39% of carbon (Rahman et al. 2020c). The potential of carbon stocks could increase when the CMR government succeeds in mangrove rehabilitation. A well-restored or rehabilitated Rhizophora mangroves could absorb up to 16.67 ton C. Rhizophora mangroves exhibited a more significant survival rate in rehabilitation than other species (Bengen et al. 2022).

Carbon Absorption (CO_2e)

The total CO_2e potential in the mangrove ecosystem of Negeri Waai was 268.48 ton CO_2e/ha, consisting of 181.29 ton of CO_2e on the stand and 87.20 ton of CO_2e on the root. The *S. alba* type of mangrove contributed around 259.21 ton of CO_2e/ha, accounting for 174.27 ton of CO_2e/ha above-ground and 84.94 ton of CO_2e/ha below-ground (Figure 9). The *S. alba* had the most significant potential for standing blue carbon with a value of 1246.19 kgCO_2e/tree, consisting of 837.83 kgCO_2e above ground and 408.36 kgCO_2e on the root (below ground). Meanwhile, *R. mucronata* had the lowest value of 36.60 kgCO_2e, consisting of 28.89 kgCO_2e above ground and 7.71 kgCO_2e below ground (Table 5).

Mangroves exhibited a greater capacity for CO_2 absorption than other vegetation forms, including seagrasses, tropical rainforests, and peat swamps (Donato et al. 2012; Alongi 2014; Adame et al. 2015). Mangroves absorb CO_2 through two mechanisms, namely CO_2 absorption by leaves with stomata and

Table 5. CO_2 absorption of mangrove trees on the coast of Negeri Waai, CMR

Species	CO_2 absorption (kg CO_2-e/trees)		
	Above-ground	Below-ground	Total
S. alba	837.83	408.36	1246.19
R. apiculata	28.75	11.78	40.54
A. corniculatum	34.78	9.12	43.89
S. caseolaris	62.99	14.82	77.82
R. mucronata	28.89	7.71	36.60
R. stylosa	64.77	20.99	85.76

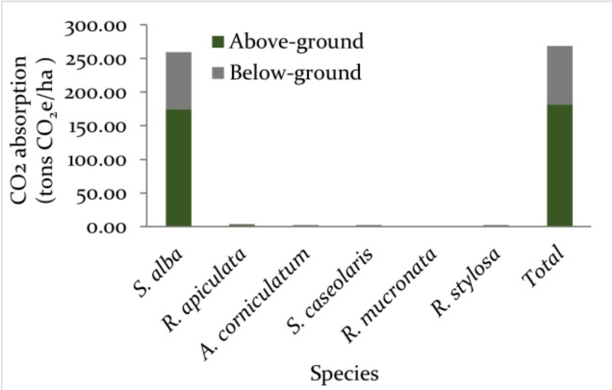

Figure 9. Total of CO_2 absorption (ton CO_2e/ha) on mangrove ecosystems on the coast of Negeri Waai

roots with pneumatophora (Rahman et al. 2020d). This potential of mangrove ecosystems to absorb carbon could contribute to achieving the Nationally Determined Contribution (NDC) target of 30% emission reduction by 2030, as proclaimed by the Indonesian government.

Conclusion

In conclusion, the potential for blue carbon mangroves on the coast of Negeri Waai, Central Maluku Regency, was low compared to the global average of blue carbon. The *S. alba* contributed significantly to the blue carbon potential, while *R. mucronata, S. caseolaris, A. corniculatum,* and *R. stylosa* species had the lowest contribution.

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