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Estimation of existing and contribution of mangrove restoration by REMAJA PHE ONWJ Program to carbon stocks in coastal Karawang Regency, Indonesia

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Abstract---*One of the efforts to mitigate climate change is the preservation of mangrove ecosystems because of their function as carbon storage and absorbers. The coast of Karawang Regency is a potential area for mangrove ecosystems, but information on existing carbon stocks and sequestration is not yet known, let alone the contribution of mangrove rejuvenation, including from rehabilitation seedlings. The study results show that the total carbon stock on the coast of Karawang Regency ranges from 13.75 – 56.89 MgC ha–1 or 5,799.88 – 24,003.58 MgC. This value*

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is obtained from the contribution of three main species, namely A. marina of 4.38 – 15.38 MgC ha^{-1}, R. apiculata of 5.80 – 24.63 MgC $ha^{-1,}$ and R. mucronata of 3.57 – 16.88 MgC ha^{-1}. The carbon sequestration value (CO_2-equivalent) on the coast of Karawang Regency ranges from 50.40 – 208.58 $MgCO_2$-eq ha^{-1} or an overall of 21,266.23 – 88,013.14 MgCO2-eq. This value was obtained from the contribution of three main species, namely A. marina of 16.07 – 56.41 $MgCO_2$-eq ha^{-1}, R. apiculata of 21.25 – 90.29 $MgCO_2$-eq ha^{-1}, and R. mucronata of 13.08 – 61.88 $MgCO_2$-eq ha^{-1}. The total contribution value of stock and carbon sequestration from mangrove rejuvenation in the simulation up to 10 years of diameter growth reached 24.58 MgC $year^{-1}$ and 90.14 $MgCO_2$-eq $year^{-1}$. These values are an accumulation of three categories of youth, namely the existing sapling category (7.86 MgC $year^{-1}$ and 28.82 $MgCO_2$-eq $year^{-1}$), the existing seedling category (4.72 MgC $year^{-1}$ and 17.32 $MgCO_2$-eq $year^{-1}$), and the seedling category (3.64 MgC $year^{-1}$ and 13.33 $MgCO_2$-eq $year^{-1}$).
Keywords---*carbon stock, mangrove regeneration, mangrove rehabilitation, REMAJA PHE ONWJ program.*

Introduction

The occurrence of climate change has now caught the world's attention. Because climate change can impact various sectors of life, it is necessary to anticipate various mitigation efforts. Badjeck et al. (2010), stated that climate change could impact aspects characterized by increasing water temperature, sedimentation, pH, salinity, wind speed, waves, and sea level rise. The changing conditions of aquatic ecology as a result of climate change have reduced ecosystem services in both marine and freshwater waters (Cheung et al., 2009; Drinkwater et al., 2010; Brander, 2010; Jones, 2002; Wang et al., 2016).

One of the greenhouse gases that causes climate change is carbon dioxide (CO_2) gas. CO_2 gas is produced from various anthropogenic activities such as burning fossil fuels, motor vehicles, and industrial machinery that cause CO_2 gas to accumulate (IPCC, 2001).

One of the efforts to reduce CO_2 gas emissions in the atmosphere is to maintain ecosystems on land and coast and to rehabilitate potential lands for plant vegetation. Coastal ecosystems that can absorb CO_2 gas are mangrove ecosystems (Hairiyah & Rahayu, 2007). According to Donato et al. (2012), Alongi (2014), and Adame et al. (2015), mangrove ecosystems can absorb and store carbon gas up to four times more than other ecosystems.

Research on estimating carbon stocks and sequestration in mangroves has been carried out in various places using various approaches. However, these studies are still focused on biomass estimation models, estimation of existing carbon stocks both on stands (above-ground biomass) and substrates (below-ground biomass), and have not analyzed the contribution of carbon sequestration to mangroves in the categories of seedlings, seedlings, and rehabilitated mangroves (Chen et al., 2003; Van Breugel et al., 2011).

The coast of Karawang Regency has a potential area of mangrove ecosystem of 421.59 hectares (Nopiana et al., 2020). The coastal area is overgrown with mangrove vegetation, including various tree stands, saplings, and seedlings. Additionally, the coastal area of Karawang Regency holds significant potential for mangrove rehabilitation. Therefore, PT Pertamina Hulu Energi Offshore North West Java (PT PHE ONWJ) implemented a mangrove restoration program on the north coast of Java (REMAJA), with the coast of Karawang Regency being one of its operational areas. Based on this, this study aims to estimate the carbon stock in existing mangrove stands and assess the potential contribution of saplings and seedlings in both natural and rehabilitated mangrove areas in the coastal region of Karawang Regency, Indonesia (Otero et al., 2020; Agaton & Collera, 2022).

Material and Methods

Description of the research location

The coast of Karawang Regency is one of the habitats of mangrove ecosystems, which are generally dominated by the species *Avicennia marina, Rhizophora apiculata, and Rhizophora mucronata* with a vegetated land area of 421.59 ha (Nopiana et al., 2020). This research was conducted from October 2020 – February 2021 at six observation stations, namely Segarjaya Village, Tambaksari, Sedari, North Pusakajaya, Mekarpohaci, and Sukajaya (Figure 1). At each station, mangrove rehabilitation was carried out with the number of plantings each, namely 2000 seedlings in Segarjaya village (0.0144 ha), 5000 seedlings in Tambaksari village (0.279 ha), 5000 seedlings in Sedari village (0.18 ha), 32,000 seedlings in North Pusakajaya village (12.97 ha), 2000 seedlings in Mekarpohaci village (0.099 ha), and 7000 seedlings in Sukajaya village (0.212 ha). Rehabilitation seedlings consist of *Avicennia marina* (1%), *Avicennia oficinalis* (4%), *Rhizophora stylosa* (23%), and *Rhizophora mucronata* (72%).

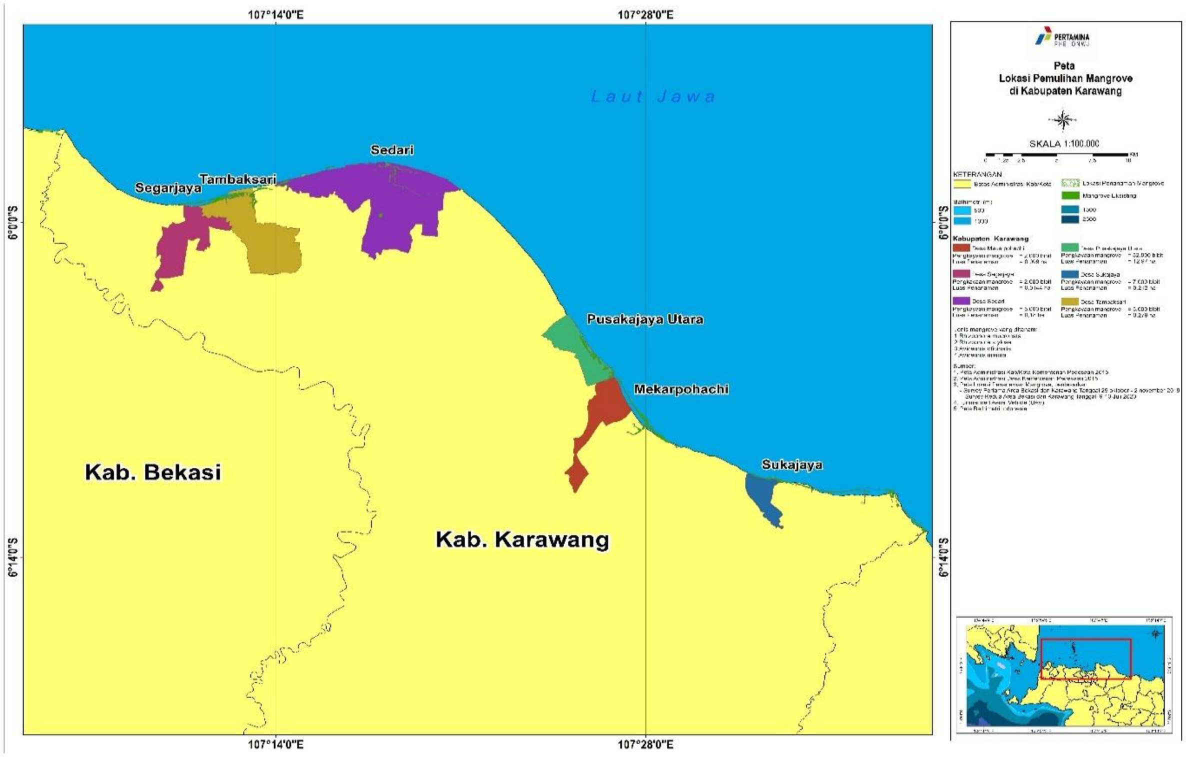

Figure 1. The location of mangrove ecosystems and rehabilitation area on the coast of Karawang, Indonesia

Data collection procedures

The data collected consisted of primary data and secondary data. Primary data include the life rate of rehabilitated mangroves in each area (number of healthy and dead mangroves) and the ecological condition of the rehabilitation area. Primary data was obtained through direct observation during the study with an interval of 15 – 30 days per observation in the rehabilitation area of REMAJA PHE ONWJ program. Secondary data include data on the structure of existing mangrove communities (density, dbh = 130 cm, species type, and area of mangrove ecosystems). Secondary data was obtained by reviewing the latest literature relevant to the needs of research data (Barrientos & Gómez, 2020).

Data analysis

Existing carbon stocks and sequestration. The existing carbon stock is calculated by multiplying the biomass of the allometric equation (Table 1) against the value of the carbon fraction, which is 0.4682 (Rahman, 2020). Meanwhile, the absorption of existing carbon (CO_2-equivalent) is calculated by multiplying the value of carbon stock with the value of the comparison of the relative molecular mass of CO_2 (Mr. CO_2 = 44 gr mol^{-1}) to the relative atomic mass of carbon (Ar C = 12 gr mol^{-1}). The value of existing carbon stocks and sequestration is calculated based on dominant species, according to Nopiana et al. (2020).

Table 1
Allometric model of mangrove biomass estimation

Species	Models	Sources
A. marina	$B = 0.308(D)^{2.10}$	Comley & McGuinness (2005)
R. apiculata	$B = 0.235(D)^{2.42}$	Ong et al. (2004)
R. mucronata	$B = 0.128(D)^{2.60}$	Fromard et al. (1998)

Notes: B = Biomass, D = dbh (130 cm)

Contribution of stock and carbon sequestration of mangrove rehabilitation

The analysis of stock and carbon sequestration in mangrove youth was calculated based on the density of existing mangroves in the sapling and seedling categories and the rehabilitation of mangrove seedlings that were affected by the life rate of mangroves. The estimate of stock contribution and carbon sequestration will be simulated according to the growth of diameter up to 10 years, namely 2031. The equation for estimating biomass from the rejuvenation of mangroves, both saplings and seedlings, refers to Rahman (2020) (Table 2).

Table 2
Mangrove biomass estimation growth models (Rahman, 2020)

Species	Biomass growth estimation models	
	Sapling	Seedling
A. marina	$Bt = 0.186 (D_0 + (0.0387t + 0.6083))^{2.46}$	$Bt = 0.186 (0.0387t + 0.6083)^{2.46}$
R. apiculata	$Bt = 0.230 (D_0 + (0.0515t + 0.5804))^{2.38}$	$Bt = 0.235 (0.0515t + 0.5804)^{2.38}$
R. mucronata	$Bt = 0.128 (D_0 + (0.0449t + 0.6252))^{2.60}$	$Bt = 0.128 (0.0449t + 0.6252)^{2.60}$
R. stylosa	$Bt = 0.178 (D_0 + (0.0416t + 0.6152))^{2.59}$	$Bt = 0.178 (0.0416t + 0.6152)^{2.59}$

Notes: Bt is the mangrove biomass at certain times, t is the time in years to be converted to months, D_0 is the initial diameter of the sapling.

Result

Dominant mangrove density

According to Nopiana et al. (2020), there are three dominant mangrove species on Karawang Regency's coast: *A. marina*, *R. apiculata,* and *R. mucronata.* The total density of the three dominant species was 474 stands ha^{-1} for the tree category, 2072 stands ha^{-1} for the seedling category, and 4153 stands ha^{-1} for the seedling category. The average relative density of *A. marina* was 198 stands ha^{-1} in the tree category, 1809 stands ha^{-1} in the seedling category, and 1250 stands ha^{-1} in the seedling category. The average relative density of *R. apiculata* was 159 stands ha^{-1} in the tree category, 263 stands ha^{-1} in the seedling category, and 2242 stands ha^{-1} in the seedling category, while the average relative density of *R. mucronata* was 117 stands ha^{-1} in the tree category and 661 stands ha^{-1} in the seedling category (Figure 2)

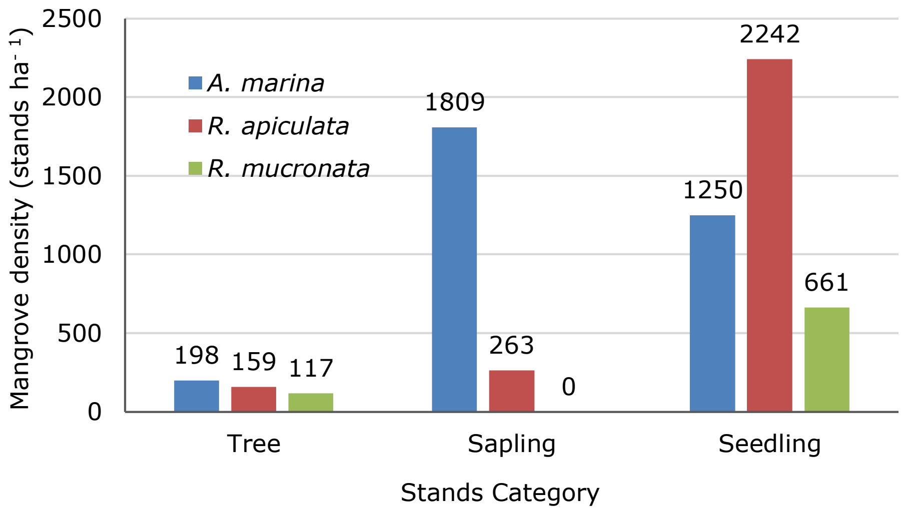

Figure 2. Average of dominant mangrove density on the coast of Karawang Regency

Existing carbon stocks and sequestration

The total carbon stock value was obtained through the approach of dominant species density and total area of the mangrove ecosystem referred to in Nopiana et al. (2020), as well as the average range of diameter (dbh = 130 cm).

The observation results show that the diameter range of mangroves in the tree category is 11 – 20 cm. Based on this, the total carbon stock on the coast of Karawang Regency ranges from 13.75 – 56.89 MgC ha^{-1} or overall of 5,799.88 – 24,003.58 MgC. This value is obtained from the contribution of three main species, namely *A. marina* of 4.38 – 15.38 MgC ha–1 or 1,849.74 – 6,491.57 MgC (31.86%), *R. apiculata* of 5.80 – 24.63 MgC ha^{-1} or 2,445.33 – 10,391.07 MgC (42.18%), and *R. mucronata* of 3.57 – 16.88 MgC ha^{-1} or 1,504.81 – 7,120.94 MgC (25.96%) (Table 3).

Table 3
Total of mangrove carbon stock on the coast of Karawang Regency

Species	Carbon stock per hectare ($MgC\ ha^{-1}$)		Total of carbon stock (MgC)	
	minimum	maximum	minimum	maximum
A. marina	4.38	15.38	1,849.74	6,491.57
R. apiculata	5.80	24.63	2,445.33	10,391.07
R. mucronata	3.57	16.88	1,504.81	7,120.94
Total	**13.75**	**56.89**	**5,799.88**	**24,003.58**

The total carbon stock is an accumulation of carbon stock distribution in each sub-district with mangrove vegetation on the coast of Karawang Regency. Based on the mangrove vegetation area in each sub-district, It was found that Tirtajaya, Cibuaya, and Tempuran Districts have the largest carbon stocks, namely 1,571.06 – 6,502.06 MgC, 1,148.40 – 4,752.82 MgC, respectively. and 894.81 – 3703.27 MgC. At the same time, the lowest ones are found in Pakisjaya, Cilamaya Kulon, and Batujaya Districts with total carbon stocks of 107.76 – 445.99 MgC, respectively, 230.51 – 953.98 MgC and 261.16 – 1,080.83 MgC (Figure 3).

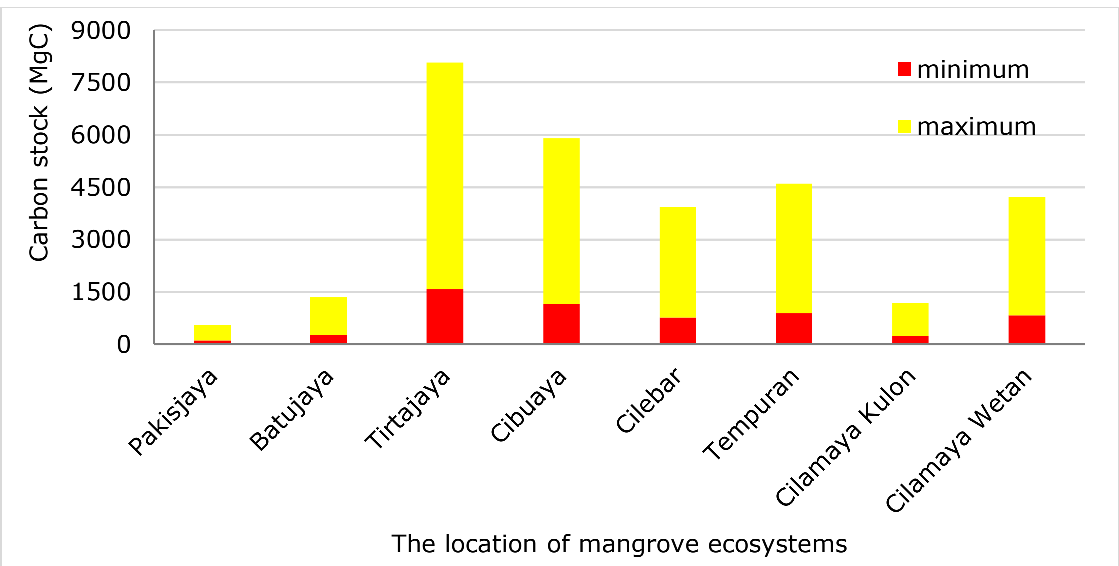

Figure 3. The total carbon stock range is based on the mangrove vegetation area in each sub-district on the coast of Karawang Regency

Based on the value of carbon stocks, the carbon sequestration value (CO_2-equivalent) on the coast of Karawang Regency ranges from 50.40 – 208.58 $MgCO_2$-eq ha^{-1} or regularly of 21,266.23 – 88,013.14 $MgCO_2$-eq. This value was obtained from the contribution of three main species, namely *A. marina* of 16.07 – 56.41 $MgCO_2$-eq ha^{-1} or 6,782.39 – 23,802.43 $MgCO_2$-eq, *R. apiculata* of 21.25 – 90.29 $MgCO_2$-eq ha^{-1} or 8,966.22 – 38,100.59 $MgCO_2$-eq, and *R. mucronata* of 13.08 – 61.88 $MgCO_2$-eq ha^{-1} or 5,517.62 – 26,110.12 $MgCO_2$-eq (Table 4).

Table 4
The total mangrove carbon absorption on the coast of Karawang Regency

Species	Carbon absorption per hectare ($MgCO_2$-eq ha^{-1})		Total of carbon absorption ($MgCO_2$-eq)	
	minimum	maximum	minimum	Maximum
A. marina	16.07	56.41	6,782.38	23,802.43
R. apiculata	21.25	90.29	8,966.22	38,100.59
R. mucronata	13.08	61.88	5.517.62	26,110.12
Total	**50.40**	**208,58**	**21,266.23**	**88013.14**

As is the case with carbon stocks, the largest carbon sequestration values were also found in three sub-districts, namely Tirtajaya, Cibuaya, and Tempuran Districts, with carbon sequestration values of 5,760.57 – 23,840.89 $MgCO_2$-eq, 4,210.81 – 17,427 $MgCO_2$-eq, and 3,280.96 – 13,578.67 $MgCO_2$-eq, while the lowest were found in Pakisjaya, Cilamaya Kulon, and Batujaya Districts with a total carbon sequestration of 395.13 – 1,635.28 $MgCO_2$-eq respectively, 845.19 – 3,497.92 $MgCO_2$-eq, and 957.58 – 3,963.05 $MgCO_2$-eq (Figure 4)

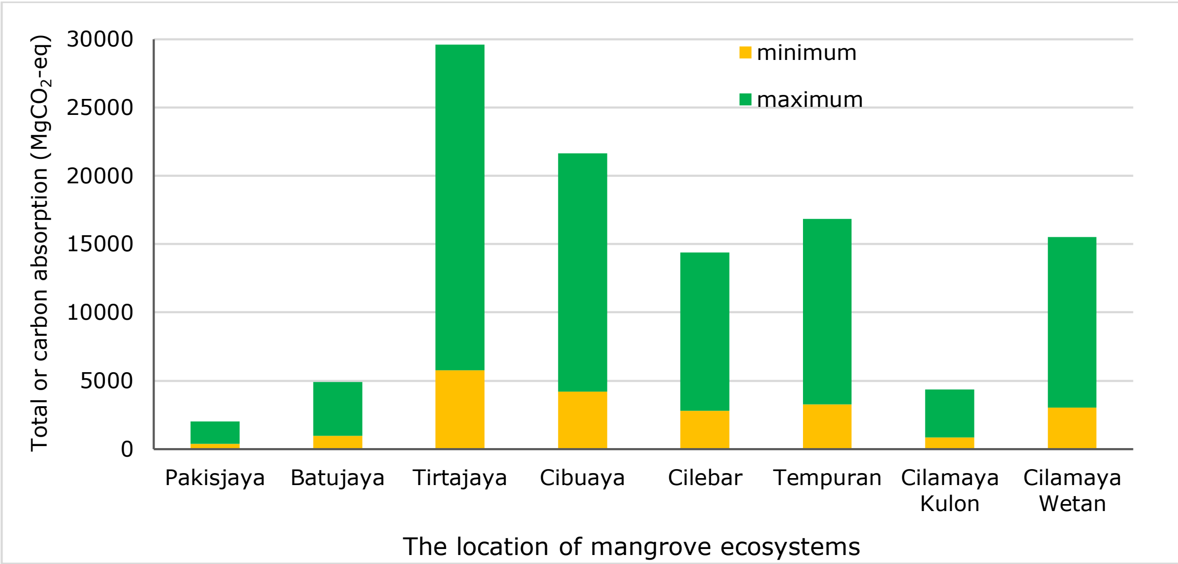

Figure 4. The range of total carbon absorption is based on the area of mangrove vegetation in each sub-district on the coast of Karawang Regency

Survival rate of mangrove rehabilitation

During observations, the life of rehabilitated mangroves tends to vary at each planting location. The best health levels were found in Segarjaya Village and Tambaksari mangroves, with an average mangrove life rate of 99.55% and 92.04%, respectively. Meanwhile, the worst mangrove life rate is found in North Pusakajaya Village, with an average life rate of 46.55% or a mortality rate of 53.45% (Table 5).

Table 5
The live level of mangrove seedlings in the rehabilitation area on the coast of Karawang Regency

Locations	Σseeds	% live at the month of observation					average (%)	
		1	2	3	4	5	live seeds	dead seeds
Segarjaya	2000	99.75	99.5	99.5	99.5	99.5	99.55	0.45
Tambaksari	5000	100	97.4	90	90	82.8	92.04	7.96
Sedari	5000	100	97	94	94	70	91.00	9.00
Mekarpohaci	2000	100	90	87.5	82.3	80	87.96	12.04
Sukajaya	7000	100	98.57	98.57	78.57	78.57	90.86	9.14
Pusakajaya Utara	32000	69.80	59.16	59.16	22.30	22.30	46.55	53.45
Total	53000	Average					84.66	15.34

Contribution of mangrove rejuvenation stock and carbon sequestration

The total contribution value of stock and carbon sequestration from mangrove rejuvenation in the simulation up to 10 years of diameter growth reached 24.58 MgC year^{-1} and 90.14 MgCO_2-eq year^{-1}. These values are the accumulation of three categories of youth, namely the existing seedling category with an average stock and carbon sequestration of 7.86 MgC year^{-1} and 28.82 MgCO_2-eq year^{-1}, respectively, the existing seedling category with an average stock and carbon sequestration of 4.72 MgCO_2-eq year^{-1}and 17.32 MgCO_2-eq year^{-1}, respectively, as well as the rehabilitation seedling category with an average stock and carbon sequestration of 3.64 MgC per year^{-1} and 13.33 MgCO_2-eq year^{-1}, respectively (Figure 5).

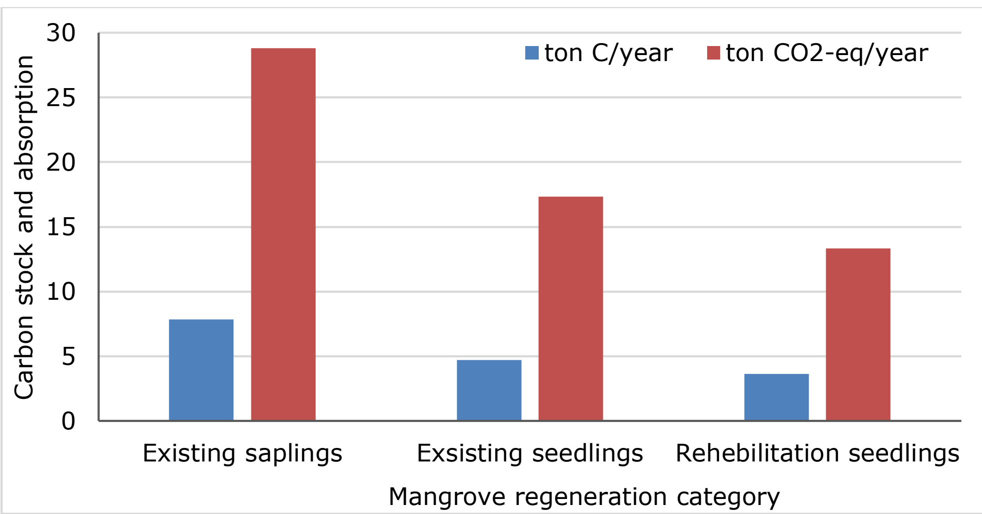

Figure 5. The contribution of stock and carbon absorption to mangrove regeneration in the simulation up to 10 years of diameter growth (2021-2030)

The types of mangrove species that contribute the most to carbon stocks and sequestration are relatively different in each rejuvenation category. In the rejuvenation of mangroves, the sapling category that contributes the most is A. marina with an average stock and carbon sequestration of 6.09 MgC year^{-1} and 22.32 MgCO_2-eq year^{-1}. In the rejuvenation category of existing seedlings, the most contributing species is *R. apiculata*, with an average stock and carbon sequestration of 3.68 MgC year^{-1} and 13.51 MgCO_2-eq year^{-1}. Meanwhile, in the rejuvenation category of seedling rehabilitation, the most contributing species is *R. mucronata*, with an average stock and carbon sequestration of 2.62 MgC year^{-1} and 9.60 MgCO_2-eq year^{-1} (Table 6).

Table 6
The contribution of carbon stocks and uptake of mangrove species in each regeneration category in the simulation up to 10 years of diameter growth (2021 – 2030)

Regeneration category	Species	Carbon stock ($MgC\ year^{-1}$)	Carbon absorption ($MgCO_2$-eq $year^{-1}$)
Existing saplings	*A. marina*	6.09	22.32
	R. apiculata	1.77	6.50
	Total	**7.86**	**28.82**
Existing seedlings	*A. marina*	0.41	1.49
	R. apiculata	3.68	13.51
	R. mucronata	0.63	2.32
	Total	**4.72**	**17.32**
Rehabilitation seedlings	*A. marina*	0.04	0.13
	A. oficinalis	0.15	0.53
	R. mucronata	2.62	9.60
	R. stylosa	0.84	3.07
	Total	**3.64**	**13.33**

Discussion

The mangrove ecosystem on the Karawang Regency coast is a potential climate change mitigation area. It is because the total carbon stock of mangroves is very large, which reaches 13.75 – 56.89 MgC ha^{-1} or an overall of 5,799.88 – 24,003.58 MgC, and carbon sequestration (CO_2-equivalent) ranges from 50.40 – 208.58 $MgCO_2$-eq ha^{-1} or an overall of 21,266.23 – 88,013.14 $MgCO_2$-eq. The value of carbon stock and sequestration per hectare in this location is greater than that of carbon stock and sequestration in Muara Gembong, Bekasi, with a carbon stock value of 17.6 MgC ha^{-1} and carbon sequestration of 64.53 $MgCO_2$-eq ha^{-1} (Rachmawati et al., 2014). In addition, the carbon stock and sequestration in the Karawang coast is smaller when compared to the carbon stock and sequestration in the mangrove area of the Tallo River, Makassar, with a carbon stock value of 113.74 MgC ha^{-1} and carbon sequestration of 417.05 $MgCO_2$-eq ha^{-1} (Rahman et al., 2017). The difference in stock value and carbon sequestration in mangroves is influenced by the density, diameter, and type of mangrove species (Rahman et al. 2020d). However, the total carbon stock on the coast of Karawang Regency is very large because of the large land area of the mangrove ecosystem, which is 421.59 ha.

Wardiatno et al. (2020), stated that under dynamic conditions, the species that contribute the most to carbon storage are from the Rhizophora (*R. stylosa*, *R. apiculata,* and *R. mucronata*), while the lowest is from the Nypa (*N. fruticans).* In addition, the species *R. apiculata* and *R. mucronata* have a larger diameter growth rate than other species, so the seedling production rate is faster (Yulianda et al., 2019). It causes a difference in the tree density to seedling density, ultimately affecting each mangrove species' stock composition and carbon absorption.

In the rehabilitation activities carried out on the coast of Karawang Regency, it can be seen that the mangrove seedlings with the largest living rate are found in the villages of Segarjaya, Tambaksari, and Sedari, which are 99.55%, 92.04%, and 91%, respectively, which are classified as very good. In contrast, the lowest is found in North Pusakajaya village, with a living rate of 44.55%, and is classified as poor. In general, the high mortality rate of mangroves is caused by accretion events that cause sand accumulation on the beach, inhibiting mangrove life. In addition, the cause of mangrove death is also due to the presence of garbage related to mangrove seedlings, which causes mangrove seedlings to break and die.

Nopiana et al. (2020) reported that on the coast of Karawang Regency, there is an area of 18,717.58 ha, which is a potential area for mangrove life. The land is spread along the coast of Karawang Regency, starting from Pakisjaya District and moving to Cilamaya Wetan. Based on this, to increase the contribution of mangrove stock and carbon absorption through rehabilitation, the areas that must become the main areas for mangrove rehabilitation are the villages of Segarjaya, Tambaksari, and Sedari, with potential land areas of 847.59 ha, 2,701.02 ha, and 4,154.10 ha, respectively. In contrast, the main species that must be planted are *R. apiculata* and *R. mucronata*. Bengen (2004), stated that Rhizophora's mangrove species are highly adapted to the aquatic environment, making them easy to use as rehabilitation seeds.

Furthermore, Wardiatno et al. (2020), reported that *R. apiculata* and *R. mucronata* have a faster diameter growth rate than other species, such as *R. stylosa* and *S. alba.* The difference in diameter growth rate occurs due to habitat differences, especially substrates. Bengen (2004) and Rahman et al. (2014), stated that *R. apiculata* and *R.*

mucronata live in muddy or sandy mud substrate habitats so that they have faster growth ability than *R. stylosa* and *S. alba* species, which predominantly live in muddy sandy substrate habitats and even sand substrates.

In addition to the carbon potential in mangrove stands, according to Donato et al. (2012) and Alongi (2014), mangrove ecosystems also store carbon in three times larger substrates than those found in tree stands. The accumulation of carbon storage in the substrate is influenced by the production rate of mangrove litter, which reaches 3.45 – 56.01 mg m^{-2} $days^{-1}$ 0.01 – 0.2 Mg ha^{-1} $year^{-1}$ (Aida et al., 2016; Watumlawar et al. 2019). The largest contribution to the litter production rate came from the species *R. apiculata, R. mucronata,* and *R. stylosa* (Rahman et al., 2020a).

The accumulation of carbon stocks both in stands (above-ground biomass) and in mangrove substrates (soil carbon/below-ground biomass) is much greater than the potential for carbon emissions emitted into the atmosphere through litter degradation, which only reaches 0.06 – 0.14 MgC ha^{-1} $year^{-1}$ year (Rahman et al. 2018; 2020b; 2020c).

Conclusion

The total carbon stock on the coast of Karawang Regency ranges from 13.75 – 56.89 MgC ha^{-1} or an overall of 5,799.88 – 24,003.58 MgC. This value is obtained from the contribution of three main species, namely *A. marina* of 4.38 – 15.38 MgC ha^{-1}, *R. apiculata* of 5.80 – 24.63 MgC $ha^{-1,}$ and *R. mucronata* of 3.57 – 16.88 MgC ha^{-1}. The carbon sequestration value (CO_2-equivalent) on the coast of Karawang Regency ranges from 50.40 – 208.58 $MgCO_2$-eq ha^{-1} or an overall of 21,266.23 – 88,013.14 $MgCO_2$-eq. This value was obtained from the contribution of three main species, namely *A. marina* of 16.07 – 56.41 $MgCO_2$-eq ha^{-1}, *R. apiculata* of 21.25 – 90.29 $MgCO_2$-eq ha^{-1}, and *R. mucronata* of 13.08 – 61.88 $MgCO_2$-eq ha^{-1}. The total contribution value of stock and carbon sequestration from mangrove rejuvenation in the simulation up to 10 years of diameter growth reached 24.58 MgC $year^{-1}$ and 90.14 $MgCO_2$-eq $year^{-1}$. These values are the accumulation of three categories of youth, namely the existing sapling category (7.86 MgC $year^{-1}$ and 28.82 $MgCO_2$-eq $year^{-1}$), the existing seedling category (4.72 MgC $year^{-1}$ and 17.32 $MgCO_2$-eq $year^{-1}$), and the seedling category (3.64 tons C $year^{-1}$ and 13.33 tons CO2-eq $year^{-1}$). The total carbon stock of mangroves on the coast of Karawang Regency has great potential for management based on climate change mitigation. This is because there is much potential land for mangrove life that has not been utilized, so it is necessary to rehabilitate, especially for the species *A. marina, R. apiculata,* and *R. mucronata.*

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