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Existing and Future Carbon Stock of Mangrove Restoration of the REMAJA PHE ONWJ Program in Mekarpohaci Village, Karawang Regency, Indonesia

Rahman[1], Luisa Febrina Amalo[2*], Marfian Dwidima Putra[2], Luluk Dwi Wulan Handayani[2], Muhammad Isnan Zuhri[2], Hadi Supardi[3], L. M. Alfin Agushara Bena[3], Arif Rahman[3]

[1]Department of Marine Science, Faculty of Fisheries and Marine Science, Pattimura University; Indonesia
[2]The Central for Environment Research, IPB University, West Java, Bogor, Indonesia
[3]Environmental Department, HSSE Division, PT. Pertamina Hulu Energi Offshore North West Java, Jakarta, Indonesia

***Corresponding author: luisafebrina@gmail.com**

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ABSTRACT

This study aimed to analyze the existing conditions and prediction of future carbon stocks in the planting of mangroves of the REMAJA PHE ONWJ program in Mekarpohaci Village, Karawang Regency, Indonesia. The observation began with the planting of 1200 seedlings of *R. mucronata* and *A. marina*, respectively. Furthermore, the monitoring of life graduation and diameter growth in the 2021-2023 period was carried out. Existing carbon stocks were analyzed by an allometric equation approach and carbon fraction values. Meanwhile, the prediction of future carbon stocks was modeled using Stella v.9.0.2 software concerning the growth rate of seedling stand diameter. The results of the study showed that carbon stocks reached 0.275 tons C in 2021, 3.66 tons C in 2022, and 5,765 tons C in 2023. Meanwhile, future carbon stock predictions indicate that the largest carbon stock in the 10-year growth projection is found in *R. mucronata*, with a value of 107.79kg C/tree, which includes 5.80kg AGC and 31.99kg BGC. In contrast, *A. marina* has the lowest carbon stock at 75.54kg C/tree (52.54kg AGC and 22.99kg BGC). The total contribution of carbon sequestration by 2033 is projected to reach 807.36 tons of CO2e, comprised of 474.69 tons of CO2e from *R. mucronata* and 332.67 tons of CO2e from *A. marina*.The carbon sequestration indicates that mangrove planting in the REMAJA PHE ONWJ program contributes to the reduction of CO_2 gas concentrations in the atmosphere and climate change mitigation and can realize the principles of sustainable development (SDGs).

INTRODUCTION

Mangrove ecosystems have an important role in supporting marine life through ecological benefits such as feeding ground, spawning ground, and nursery ground **(Rahman *et al.*, 2020a; Bengen *et al.*, 2022)**. Mangroves also provide ecosystem services that can support the welfare of coastal communities through direct benefits such as fishing grounds, timbers, and fruit providers for food and beverages **(Rahman *et al.*, 2022)**.

In addition to these functions, mangroves play a role in mitigating climate change through carbon sequestration **(Murdiyarso *et al.*, 2015)**. The carbon storage capacity of mangrove ecosystems reaches 956 tons of C/ha **(Alongi, 2014)** to 1200 tons of C/ha **(Adame *et al.*, 2015)**. These deposits are three or four times larger than other plant vegetation **(Donato *et al.*, 2011, 2012)**.

Unfortunately, all these benefits are not utilized properly and sustainably, thus triggering deforestation of the mangrove ecosystem. Deforestation occurs due to various human activities such as timber and land conversion into aquaculture, local residence, agriculture, and mining areas **(Rahman *et al.*, 2020b, 2024)**. **Carugati *et al*. (2018)** reported that deforestation of the mangrove ecosystem resulted in a 20% reduction in the biodiversity of benthic organisms and 80% of the biodiversity of decomposer microbes. Deforestation also increases CO_2 gas emissions, which can trigger climate change **(Arifanti *et al.*, 2021)** and can reduce the potential for blue carbon **(Chatting *et al.*, 2022)**.

Deforestation of mangrove ecosystems occurs in almost all coastal areas of Indonesia, including the coast of Mekarpohaci Village Karawang Regency. PT Pertamina Hulu Energi Offshore North West Java (PHE ONWJ), as a company engaged in the exploration and production of offshore oil and gas with environmentally friendly principles, has a role in restoring coastal ecosystems within the work area, namely the north coast of Jawa.

Mangrove restoration activities conducted by PHE ONWJ are part of the North Java Coast Mangrove Restoration (REMAJA) program, which includes efforts in Mekarpohaci Village, Karawang Regency. Mangrove restoration on the coast of Mekarpohaci Village was carried out by planting 2400 mangrove seedlings consisting of 1200 *Rhizophora mucronata* and 1200 *Avicennia marina* which was carried out in 2021. According to **Arifanti *et al.* (2022)**, mangrove restoration can play a role in storing carbon up to 16 tons of C/ha. This is certainly influenced by the type of species and the growth rate of mangrove diameter. Therefore, this study was conducted to analyze the potential of existing carbon stocks and predictions of future storage from mangrove planting in the REMAJA program conducted by PHE ONWJ in the coastal area of Mekarpohaci Village, Karawang Regency, Indonesia. The results of the research are expected to be a scientific basis for managing mangroves based on change mitigation and realizing sustainable development.

MATERIALS AND METHODS

1. Description of the study sites

Mekarpohaci Village is part of the administrative area of Karawang Regency which is one of the work areas of PHE ONWJ. This village has a mangrove area of 28.91 ha with a potential land for restoration of 1.97 ha. Mekarpohaci Village is located between North Pusakajaya and Sukajaya Villages which is also a mangrove ecosystem area (Fig.

1). The habitat characteristics of the restoration area are generally dominated by mud substrates with little tidal influence, allowing the area to be always wet and waterlogged with a height of less than 10cm.

Fig. 1. The location of mangrove planting of REMAJA program by PHE ONWJ on the coast of Mekarpohaci Villages, Karawang Regency, Indonesia

2. Procedures of data collection

This research began by planting 2400 mangrove seedlings in 2021 in the REMAJA PHE ONWJ program. The mangroves planted consisted of 1200 *R. mucronata* and 1200 *A. marina*, each with an initial diameter of 0.85cm. Mangroves are planted at a distance of 1 x 1m. Furthermore, the diameter growth rate was yearly measured until 2023 to obtain diameter values, namely D_{2021}, D_{2022}, and D_{2023}. Measurements were randomly carried out on ±100 seedlings, estimated to represent the entire growth rate of the planted seedlings.

3. Data analysis

3.1. Analysis of survival rate

The survival rate of mangrove seedlings planted through the REMAJA program was analyzed by comparing the number of living mangroves to the total number of seedlings planted for each species.

3.2. Analysis of biomass potential and carbon stock

The potential of mangrove biomass and carbon stock was analyzed using the allometric model (above-ground biomass and below-ground biomass) referred to by **Komiyama *et al.* (2005)**, which was then multiplied by the carbon fraction value, namely 0.4682 **(Rahman *et al.*, 2023)**. The biomass and carbon stock estimation equation is as follows:

$$\text{Above-ground biomass (kg)} = 0.251\rho D^{2.46} \quad (1)$$

$$\text{Below-ground biomass (kg)} = 0.199\rho^{0.899}D^{2.22} \quad (2)$$

$$\text{Carbon stocks} = \text{Biomass (kg)} \times 0.4682 \quad (3)$$

Notes: ρ is mangrove wood density; *R. mucronata* is 0.8483, and *A. marina* is 0.7316 based on data from the **World Agroforestry Center (2024)**.

3.3. Prediction of future carbon stock

Future carbon stock predictions were analyzed using a model based on Stella v.9.0.2 software. The prediction was based on the growth rate of diameter and coefficients in the allometric equation of mangrove biomass estimation. The framework of the carbon stock prediction model is presented in Fig. (2):

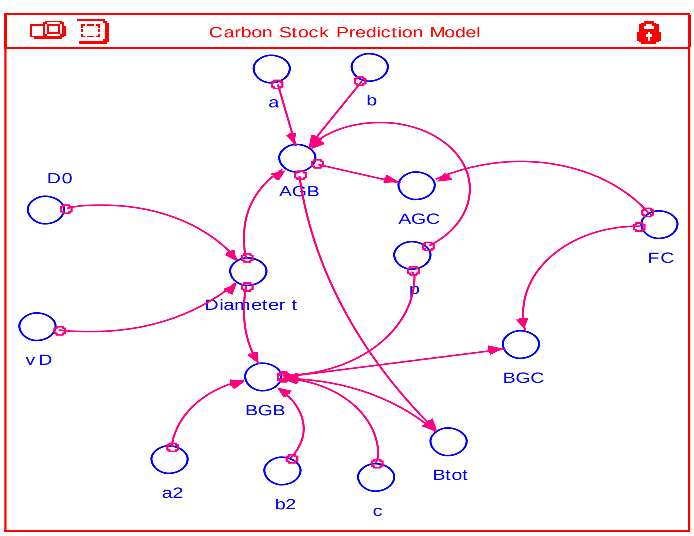

Fig. 2. Model of carbon estimation prediction in mangrove stands based on seedling diameter growth rate

The equation of carbon estimation prediction for each mangrove species based on the model can be described as follows:

- Diameter t = diameter growth model selected based on the initial diameter value (D0) and diameter growth rate (vD) estimated until the mangrove is 10 years old.
- vD is the average diameter growth rate in cm/years
- Biomass is the stand biomass value (kg) obtained from the allometric model (eq. 1)
- a and b is constant in the above-ground biomass allometric equation (eq. 1)
- a2, b2, and c is constanta in below-ground biomass allometric equation (eq. 2)

RESULTS

1. The survival rate

The results of observations on the growth of mangrove seedlings planted in the REMAJA PHE ONWJ program show that the total of all seedlings planted is alive and growing well even until 2023. Thus, the percentage of mangrove survival is 100% for each species of *R. mucronata* and *A. marina* (Table 1). An overview of mangrove conditions at the beginning of planting in 2020 to 2023 is presented in Fig. (3).

Table 1. The survival rate of mangrove planting REMAJA Program on the coast of Mekarpohaci Villages, Karawang Regency, Indonesia

	Survival rate (%)			
Species	2021	2022	2023	Average
Rhizophora mucronata	100	100	100	100
Avicennia marina	100	100	100	100

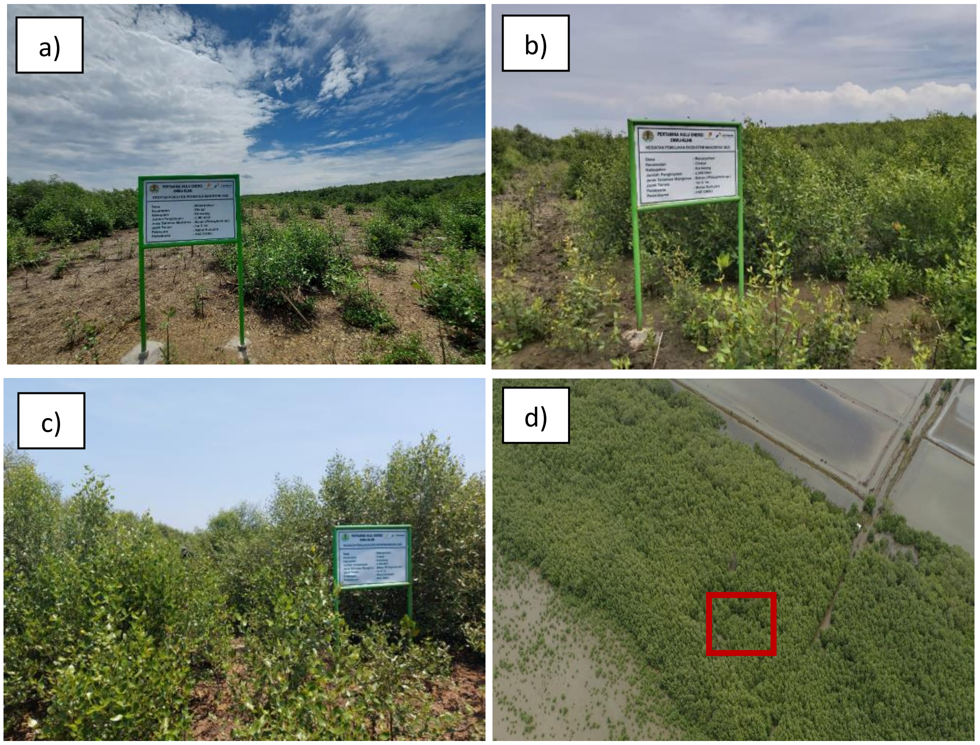

Fig. 3. Conditions of mangroves planted in 2020 – 2023: a) Initial conditions in 2020; b) Mangrove conditions in 2021; c) Mangrove conditions in 2022; and d) Mangrove conditions in 2023 - The red box is the same location as Fig. (3a, b, c)

The survival rate of mangrove seedlings for the REMAJA program shows very high results when compared to the standard of living potential for rehabilitated mangroves according to **Bengen *et al*. (2022)**, which only ranges from 60 to 80%. It is supported by environmental conditions, especially planting habitats dominated by muddy substrates and without pressure from wind or waves. The percentage of survival of mangrove seedlings in the REMAJA program is also more significant than the percentage of survival of *R. apiculata* seedlings in Sembilang National Park, Banyuasin, which only ranges between 61.5 & 75% **(Rahmat *et al*., 2015)**. The difference is that mangrove planting in Banyuasin uses propagules, while the REMAJA program uses seedlings from nurseries.

The success of the REMAJA Program is not only seen in the survival rate level but also in the significant growth in mangrove diameter, which ranges from 0.58-1.75cm per year for the *R. mucronata* species and 0.49-1.63cm per year for the *A. marina* species (Fig. 4). The highest growth rates occurred in the 2021 – 2022 range, 1.75 and 1.63cm, respectively, for *R. mucronata* and *A. marina* seedlings. This rate is greater than that reported by **Rahmat *et al*. (2015)** regarding the growth rate of *R. apiculata* seedling diameter, which only reached 1cm per year.

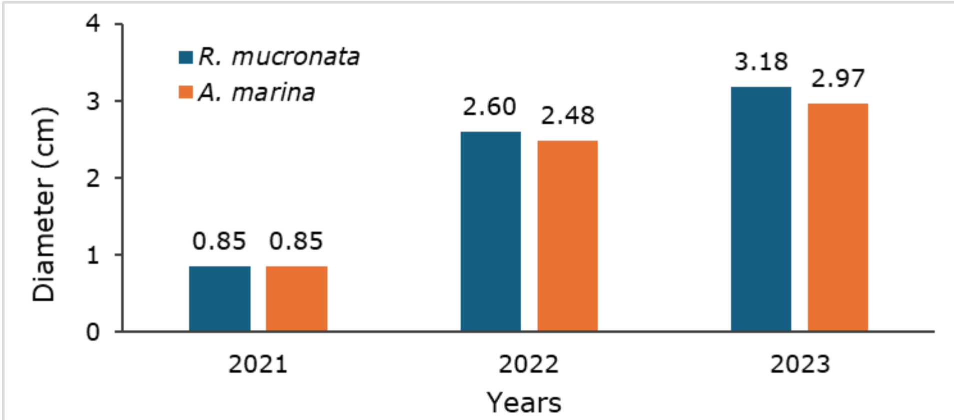

Fig. 4. Growth of mangrove diameter (cm) in the REMAJA program by PHE ONWJ in Mekarpohaci Village, Karawang Regency, Indonesia

2. The potential of biomass and mangrove carbon

The potential of mangrove biomass at the beginning of planting is 0.31 tons for *R. mucronata* (0.17 tons AGB and 0.14 tons BGB) and 0.27 tons for *A. marina* (0.15 tons AGB and 0.12 tons BGB). The potential of biomass is increasing in line with the growth in diameter that occurred in the 2021-2022 and 2022-2023 ranges. In the species *R. mucronata*, the total biomass increased by 4.08 tons in 2022 and 2.69 tons in 2023 (Fig. 5a). At the same time, *A. marina* also experienced an increase in biomass by 3.14 tons in 2022 and 1.82 tons in 2023 (Fig. 5b).

The increase in biomass of *R. mucronata* was faster than that of *A. marina* because differences influenced its diameter growth rate and wood density (*P*) values. Fig. (2) shows that the diameter growth rate of *R. mucronata* is greater than that of *A. marina*. Similarly, the density was 0.8483 vs 0.7316g/ cm^3 **(World Agroforestry Center 2024)**.

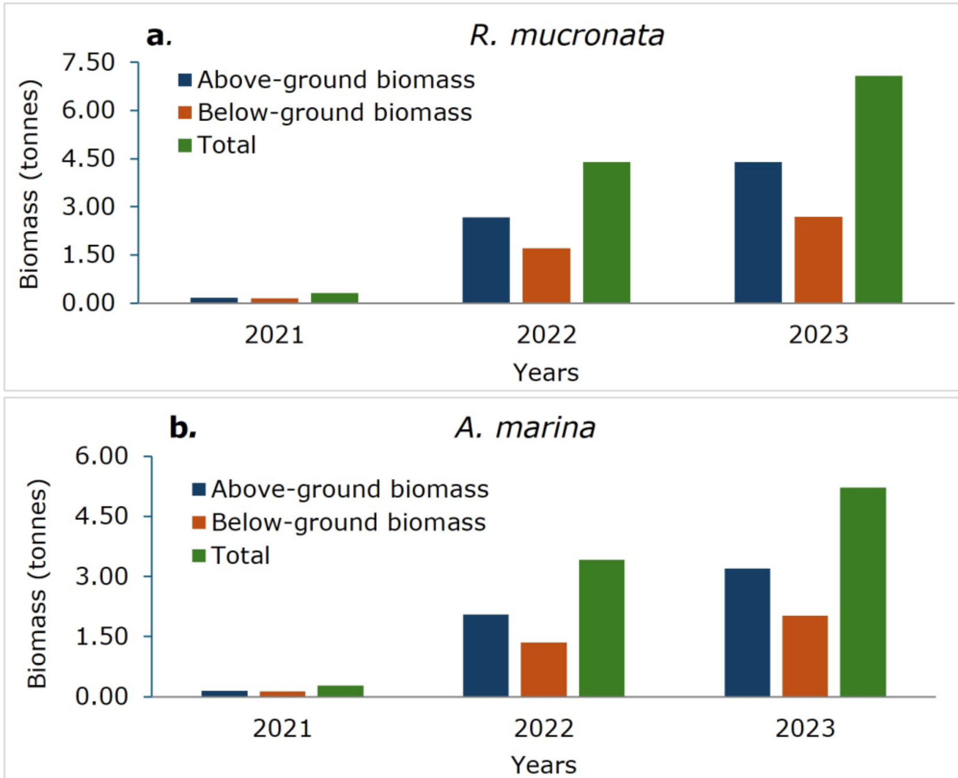

Fig. 5. Biomass potential in mangrove planting of REMAJA program by PHE ONWJ in Mekarpohaci Village, Karawang Regency, Indonesia: **a)** *R. mucronata*; **b)** *A. marina*

Based on this biomass potential, carbon stocks from the REMAJA program's mangrove planting were assumed to 0.275 tonnes C in 2021 (0.147 tonnes C for *R. mucronata* and 0.128 tonnes C for *A. marina*), 3.66 tonnes C in 2022 (2.06 tonnes C for *R. mucronata* and 1.60 tons C for *A. marina*), and 5.765 tons C in 2023 (3.317 tons C for *R. mucronata* and 2.447 tons for *A marina*) (Fig. 6). The average increase in potential carbon storage in the *R. mucronata* species compared to the area of mangrove planting is 0.792 tonnes C/ha, consisting of 0.495 tonnes C/ha AGC and 0.297 tonnes C/ha BGC. The most significant deposit rate occurred in the 2021-2022 range, namely 0.956 tons C/ha (0.587 tons C/ha AGC and 0.369 tons C/ha BGC) (Table 2). Likewise, the *A. marina* species' total carbon storage rate is 0.580 tons C/ha, consisting of 0.358 tons C/ha AGC and 0.222 tons C/ha BGC. The most considerable absorption rate occurred in the 2021-2022 range, namely 0.735 tonnes C/ha, consisting of 0.447 tonnes C/ha AGC and 0.288 tonnes C/ha BGC (Table 2).

Table 2. The rate of mangrove carbon storage REMAJA program by PHE ONWJ in Mekarpohaci Village, Karawang Regency, Indonesia

Species	Periods	Rate of carbon stocks (tones C/ha)		
		AGC	BGC	Total
R. mucronata	2021-2022	0.587	0.369	0.956
	2022-2023	0.402	0.227	0.629
	Average	0.495	0.297	0.792
A. marina	2021-2022	0.447	0.288	0.735
	2022-2023	0.269	0.156	0.425
	Average	0.358	0.222	0.580

Notes: AGC = Above-ground carbon; BGC = Below-ground carbon

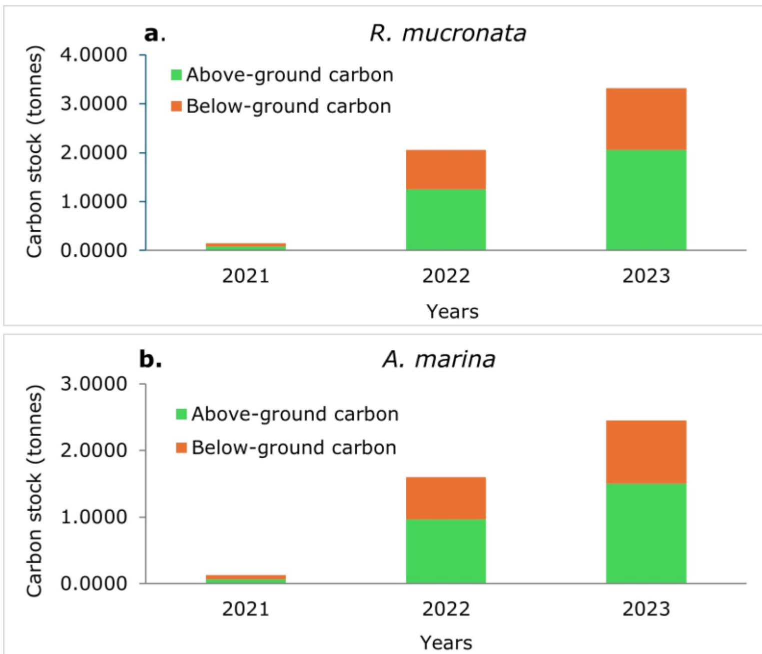

Fig. 6. Potential of mangrove carbon stock REMAJA program by PHE ONWJ in Mekarpohaci Village, Karawang Regency, Indonesia: **a)** *R. mucronata*; **b)** *A. marina*

Future carbon stock

Predictions of future carbon stock show that the largest carbon stock in the 10-year growth projection is in *R. mucronata* with a value of 107.79kg C/tree consisting of 75.80kg C at above-ground or AGC and 31.99kg C at below-ground or BGC (Fig. 7a). The lowest is *A. marina*, which is 75.54kg C/tree consisting of 52.54kg AGC and 22.99kg BGC (Fig. 7b).

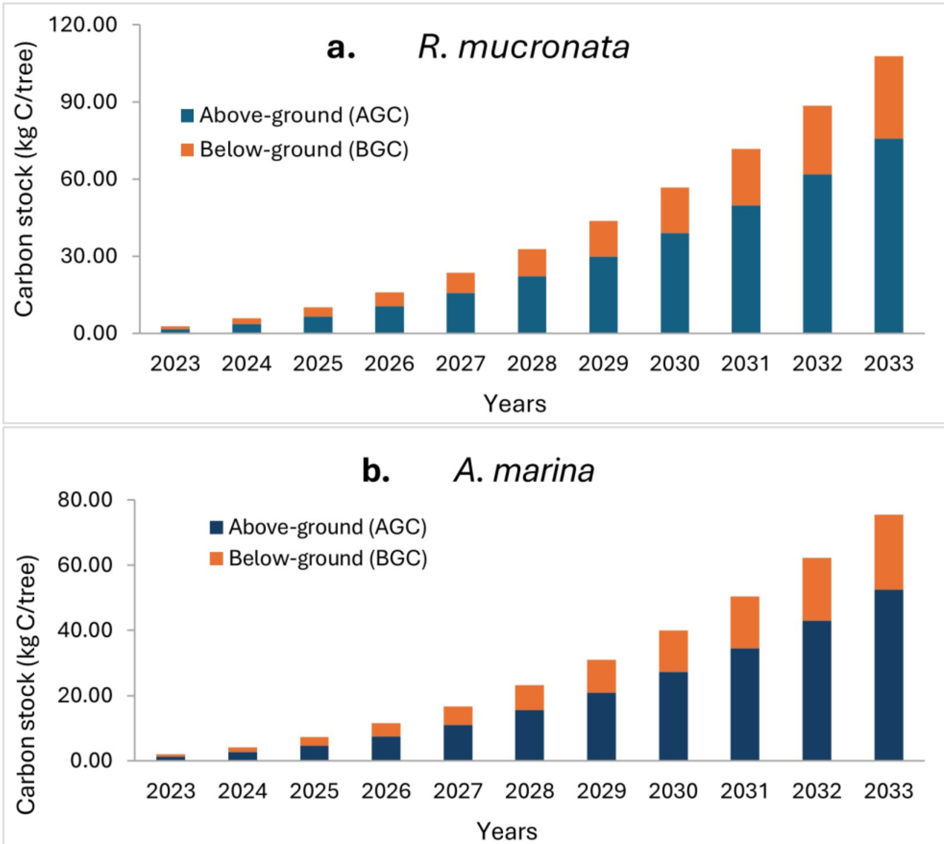

Fig. 7. Prediction of future carbon stock in **(a)** *R. mucronata* and **(b)** *A. marina*

DISCUSSION

Referring to the potential carbon stock, the total carbon sequestration potential (CO_2e) from mangrove planting in the REMAJA PHE ONWJ program in 2021 is 0.54 tons of CO_2e for the species *R. mucronata* and 0.47 tons of CO_2e for the species *A. marina*. The total carbon sequestration increased to 7.56 tons of CO_2e in 2022 and 12.18 tons of CO_2e in 2023 for the species *R. mucronata*. Meanwhile, the total absorption of *A. marina* increased to 5.86 tons of CO_2e in 2022 and 8.98 tons of CO_2e in 2023. The absorption of CO_2e is a representation of the reduction of CO_2 concentration in the atmosphere through the mechanism of photosynthesis carried out by plants **(Hairiah & Rahayu, 2007)**. In other words, carbon sequestration is the potential of mangroves to mitigate climate change by reducing greenhouse gas concentrations.

Rahman *et al.* (2020c) stated that carbon sequestration (CO_2e) is equivalent to 0.72 oxygen supply. Thus, the planting of mangroves under the REMAJA PHE ONWJ program provides oxygen supply (O_2e) of 0.393 tons of O2e in 2021, 5.497 tons of O_2e in 2022, and 8.855 tons of O_2e in 2023 for the species *R. mucronata*. Meanwhile, the total oxygen supply from *A. marina* is 0.34 tons of O_2e in 2021, 4.26 tons of O_2e in 2022, and 6.53 tons of O_2e in 2023.

Furthermore, based on the prediction of carbon storage in the 10-year growth simulation (Fig. 6), it was found that the carbon sequestration (CO_{2e}) by *R. mucronata* and *A. marina* would be 395.57 and 277.22kg CO_2e/tree, respectively. This indicates that mangrove restoration by PHE ONWJ contributes to carbon sequestration and climate change mitigation efforts. The total contribution of carbon sequestration up to 10 years of growth (in 2033) is projected to reach 807.36 tons of CO_2e, consisting of 474.69 tons of CO_2e *R. mucronata* and 332.67 tons of CO_2e *A. marina*.

The findings of this study are in line with the report of **Arifanti *et al.* (2022)**, who found a significant contribution from mangrove restoration to carbon sequestration and climate change mitigation. Thus, mangrove restoration efforts in various potential areas as reported by **Rahman *et al.* (2024)** need to be optimized, so that a total restoration value of 153.3 Mt CO_2e can be realized in 2030.

Syahid *et al.* (2023) reported that mangrove planting with a projected 100-year growth in the Southeast Asian region in 75% of potential restoration areas can reduce CO_2 emissions by up to 1800 TgCO_2e/ha/year. The reduction potential is influenced by the type of mangrove to be planted, but in general, it is contributed to the mangrove types of *Avicennia*, *Bruguiera*, and *Rhizophora*. Similarly, **Bourgeois et *al.* (2024)** postulated that four decades of planted mangrove growth store 75% of carbon on the above ground, especially on intact mature stands.

The potential carbon stock from mangrove planting is stored not only in AGB and BGB but also in sediment in the form of soil organic carbon (SOC). A study conducted by **Jimenez et *al.* (2021)** showed that the accumulation of SOC in restored mangroves was significant at seven years of growth and was influenced by organo-mineral interactions. **Gu and Wu (2023)** reported that the restored *K. obovata* mangroves with >5-year growth stored a 15.8% greater SOC compared to mudflats. These findings indicate that mangrove restoration carried out in the REMAJA PHE ONWJ program in the coastal Mekarpohaci villages will have great carbon potential in the future, both in AGB, BGB, and SOC.

CONCLUSION

Mangrove restoration by PHE ONWJ with the planting of *R. mucronata* and *A. marina* has a high survival rate and a fast growth rate. The restoration is significant in carbon storage and sequestration thus it contributes to climate change mitigation. Both species can be recommended in mangrove restoration efforts in other locations with a high potential score of 75-90%.

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REFERENCES

Adame, M.F.; Santini, N.S.; Tovilla, C.; Lule, A.V.; Castro, L. and Guevara, M. (2015). Carbon stock and soil sequestration rates of tropical riverine wetlands. Biogeosci 12: 3805-3818. https://doi.org/10.5194/bg-12-3805-2015

Alongi, D.M. (2014). Carbon cycling and storage in mangrove forests. Ann. Rev. of Mar. Sci 195 – 219. DOI: 10.1146/annurev-marine-010213-135020

Arifanti, V.B.; Novita, N.; Subarno. and Tosiani, A. (2021). Mangrove deforestation and CO_2 emissions in Indonesia. IOP Conf. Series. Earth and Environm. Scie 874, 012006. https://doi.org/10.1088/1755-1315/874/1/012006

Arifanti, V.B.; Kauffman, J.B.; Subarno.; Ilman, M.; Tosiani, A. and Novita, N. (2022). Contribution of mangrove conservation and restoration to climate change mitigation in Indonesia. Global Change Biology 28: 4523 – 4538. https://doi.org/10.1111/gcb.16216

Bengen, D.G.; Yonvitner. and Rahman. (2022). Pedoman Teknis Pengenalan dan Pengelolaan Ekosistem Mangrove. Bogor (ID): IPB Press. 88p. [in indonesian]

Bourgeois, C.F.; MacKenzie, R.A.; Sharma, S.; Bhomia, R.K. and Johnson, N.G. et al. (2024). Four decades of data indicate that planted mangroves stored up to 75% of the carbon stocks found in intact mature stands. Science Advanves. 10: 1-12. https://doi.org/10.1126/sciadv.adk5430

Carugati, L.; Gatto, B.; Rastelli, E.; Lo Martire, M.; Coral, C.; Greco, S. and Danovaro, R. (2008). Impact of mangrove forests degradation on biodiversity and ecosystem functioning. Science Report 8, 13298. https://doi.org/10.1038/s41598-018-31683-0

Chatting, M.; Al-Maslamani, I.; Walton, M.; Skov, M.W.; Kennedy, H.; Husrevoglu, Y.S. and Vay, L.L. (2022). Future mangrove carbon storage under climate change and deforestation. Frontiers in Marine Science 9: 1-14. https://doi.org/10.3389/fmars.2022.781876

Donato, D.C.; Kauffman, J.B.; Murdiyarso, D.; Kurnianto, S.; Stidham, M. and Kannien, M. (2011). Mangroves among the most carbon-rich forests in the tropics. Nature Geoscience 4: 293–297. https://doi.org/10.1038/ngeo1123

Donato, D.C.; Kauffman, J.B.; Mackenzie, R.A.; Ainsworth, A. and Pfleeger, A.Z. (2012). Whole-island carbon stock in the tropical pacific: Implications for mangrove conservation and upland restoration. Journal of Environmental Management 97: 89 – 96. https://doi:10.1016/j.jenvman.2011.12.004

Gu, J.; and Wu, J. (2023). Blue carbon effects of mangrove restoration in subtropics where *Spartina alterniflora* invaded. Ecological Engineering. 186, 106822. https://doi.org/10.1016/j.ecoleng.2022.106822

Hairiah, K.; and Rahayu, S. (2007). Pengukuran Karbon Tersimpan di Berbagai Macam Penggunaan Lahan. Malang (ID): World Agroforestry Centre. [in indonesian]

Jimenez, L.C.Z.; Queiroz, H.M.; Otero, X.L.; Nobrega, G.N. and Ferreira, T.O. (2021). Soil organic matter responses to mangrove restoration: A replanting experience in Northeast Brazil. International Journal of Environmental Research and Public Health. 18: 1 – 11. https://doi.org/10.3390/ijerph18178981

Komiyama, A.; Poungparn, S. and Kato, S. (2005). Common allometric equation for estimating the tree weight of mangroves. J. of Tropical Ecology 21:471-477. https://doi.org/10.1017/S0266467405002476

Murdiyarso, D.; Purbopuspito, J.; Kauffman, J. and et al. (2015). The potential of Indonesian mangrove forests for global climate change mitigation. Nature Climate Change 5: 1089–1092. https://doi.org/10.1038/nclimate2734

Rahman.; Wardiatno, Y.; Yulianda, F.; Rusmana, I. and Bengen, D.G. (2020a). Metode dan Analisis Studi Ekosistem Mangrove. Bogor (ID): IPB Press. 124p. [in Indonesian]

Rahman.; Wardiatno, Y.; Yulianda, F. and Rusmana, I. (2020b). Socio-ecological system of carbon-based mangrove forests on the coast of West Muna Regency, Southeast Sulawesi, Indonesia. AACL Bioflux 13(2): 518-528.

Rahman.; Wardiatno, Y.; Yulianda, F. and Rusmana, I. (2020c). Pengelolaan ruang terbuka hijau berbasis ekosistem mangrove sebagai mitigasi gas rumah kaca di Kawasan Sungai Tallo Kota Makassar. JPSL 10(2): 320-328. https://doi.org/10.29244/jpsl.10.2.320-328 [in Indonesian]

Rahman.; Maryono. and Ali, M. (2022). Analisis supply – demand jasa ekosistem mangrove pesisir Kecamatan Maginti, Kabupaten Muna Barat. Grouper 13(2): 1-9. [in indonesian]

Rahman.; Maryono. and Sigiro O.N. (2023). What is the true carbon fraction of mangrove biomass? Malaysian Journal of Science. 42(2): 1 – 6. https://doi.org/10.22452/mjs.vol42no2.10

Rahman.; Ceantury, A.; Tuahatu, J.W.; Lokollo, F. F.; Supusepa, J.; Hulopi, M.; Permatahati, Y. I.; Lewerissa, A. and Wardiatno Y. (2024). Mangrove ecosystem in Southeast Asia region: mangrove extent, blue carbon potential and CO_2 emission in 1996-2020. Science of the Total Environment. 915 (10), 170052. https://doi.org/10.1016/j.scitotenv.2024.170052

Rahmat, D.; Fauziyah. and Sarno. (2015). Pertumbuhan semai *Rhizophora apiculata* di area restorasi mangrove Taman Nasional Sembilang Sumatera Selatan. Maspari Journal 7(2): 11-18. [in indonesian]

Syahid, L.N.; Sakti, A.D.; Ward, R.; Rosleine, D.; Windupranata, W. and Wikantika, K. (2023). Optimizing the spatial distribution of Southeast Asia mangrove restoration based on zonation, species and carbon projection schemes. Estuarine, Coastal and Shelf Science. 293, 108477, https://doi.org/10.1016/j.ecss.2023.108477

World Agroforestry Center. (2024a). wood density of *Avicennia marina.* Accessed via http://db.worldagroforestry.org//wd/species/Avicennia_marina. in April 2024

World Agroforestry Center. (2024b). wood density of *R. mucronata.* Accessed via http://db.worldagroforestry.org//wd/species/Rhizophora_mucronata. in April 2024.