Global J. Environ. Sci. Manage. 10(4): 1-10, Autumn 2024, Serial #40

Global Journal of Environmental Science and Management
(GJESM)

Homepage: https://www.gjesm.net/

Podcasts

SHORT COMMUNICATION

Carbon sequestration rate in sediment mangroves from natural and rehabilitated mangroves

D. Ariyanto[1,2,*], **D. Pringgenies**[2]

[1] *Research Center for Oceanography, National Research and Innovation Agency, Jakarta, Indonesia*

[2] *Department of Marine Science, Faculty of Fisheries and Marine Science, Diponegoro University, Tembalang, Semarang, Central Java, 50275, Indonesia*

ARTICLE INFO

Article History:
Received 25 December 2023
Revised 01 April 2024
Accepted 06 May 2024

Keywords:
Mangrove
Organic carbon
Rhizophoraceae
Sediment
Water quality

DOI: 10.22034/gjesm.2024.04.***

ABSTRACT

BACKGROUND AND OBJECTIVES: A major function of mangroves is carbon sequestration in sediment. This study aimed to determine differences in carbon content in sediments in various types of mangroves and environmental parameters.
METHODS: This study was carried out in Pesawaran as a natural mangrove and in South Lampung as rehabilitated mangrove in Indonesia. Purposive sampling method was used by considering the types of mangroves at the locations. Sediment sampling was taken using a polyvinyl chloride pipe with a diameter of 47.46 milimeters and a height of 30 centimeters. The sediment parameters measured were bulk density, carbon stock, and sequestration. Environmental parameters measured included sediment texture, potential of hydrogen, temperature, salinity, and total dissolved solids. A statistical analysis was conducted using the principal component analysis to determine the relationship between the organic carbon stock and the environmental parameters.
FINDINGS: The study results showed that natural mangroves (Pesawaran) had a higher organic carbon value at 2.2 ± 0.32 percent than rehabilitated mangroves (South Lampung) at 0.9 ± 0.25 percent. The principal component analysis results revealed that organic carbon, carbon dioxide equivalent, carbon stock, and carbon sequestration had positive correlation characteristics influenced by salinity, silt, and clay, while negative correlation characteristics were affected by temperature, total dissolved solids, and sand. The distribution of sediment texture tended to show more silt in rehabilitated mangroves, while natural mangroves tended to have the same composition between sand and silt. The potential of hydrogen conditions in natural and rehabilitated mangroves showed no significant differences in values. The salinity in Pesawaran, which was classified as a natural mangrove, was higher due to the influence of the tides and was directly facing the shoreline. Meanwhile, in South Lampung, which was categorized as a rehabilitated mangrove, the salinity was lower due to the long dry season and the canals being unable to support the water entering the mangroves.
CONCLUSION: The organic carbon content at the research locations was influenced by the older age of the *Rhizophora stylosa* compared to that of the *Rhizophora mucronata* and Ceriop tagal types of mangroves. The carbon sequestration rate values showed 1.65–3.14 for natural mangroves and 0.29–1.25 for rehabilitated mangroves, thus establishing that the rate is higher (2–3 times) in natural mangroves than in rehabilitated mangroves.

NUMBER OF REFERENCES
65

NUMBER OF FIGURES
3

NUMBER OF TABLES
2

*Corresponding Author:
Email: *dafitariyanto676@gmail.com*
Phone: +62813 9870 8053
ORCID: 0000-0001-6749-0997

Note: Discussion period for this manuscript open until January 1, 2025 on GJESM website at the "Show Article".

INTRODUCTION

Mangroves are characterized as unique plants located between land and sea and can be found in the tropics and subtropics. Mangroves are known to have various benefits and play an important role in maintaining the balance of the mangrove ecosystem. They have an ecological function as a habitat for fish and gastropods (Ariyanto *et al.*, 2018a; Ariyanto *et al.*, 2020) and socio-economic function for ecotourism and community participation (Spalding and Parrett, 2019; Listiana and Ariyanto, 2024). Mangroves also have high amino acid contents (Ningsih *et al.*, 2020) and biotechnological potential as an antibacterial (Pringgenies *et al.*, 2021), antifungal (Pringgenies *et al.*, 2023), and antioxidant (Sibero *et al.*, 2022). Their reproductive organs in the form of leaves also have various proximate contents (Ariyanto *et al.*, 2019a). Natural mangroves are mangroves that grow naturally and are carried by tides and sea currents, while rehabilitation mangroves are mangroves that are planted directly through nurseries carried out by the community, non-governmental organizations (NGOs), and the government. Mangroves also play an important role in storing carbon, regulating global climate change, and sediment accretion (Setyadi *et al.*, 2021). The sustainability of the mangrove ecosystem is supported by the tidal cycle of seawater and fresh water input from land. *Rhizophora mucronata* had the highest survival rate of 67 percent but the lowest growth rate, while *Avicennia alba* and *Avicennia marina* had lower survival rates of 35 percent (%) and 21% (van Bijsterveldt *et al.*, 2022), respectively. The influence of sea tides brings nutrients that can be used for the sustainability of the mangrove ecosystem and improve mangrove growth. Furthermore, mangroves cannot grow optimally due to various factors, including high salinity (> 40 practical salinity units), high temperatures as 37.5–42.0 degrees Celsius (°C), reduced rainfall, and limited fresh water supply (Almahasheer *et al.*, 2017). The mangrove ecosystem has the ability to store organic carbon (OC). Research also showed the ability of mangroves to store 692.8 ± 23.1 megagrams of carbon per hectare (Mg/ha) (Alongi, 2022). 76.5% is stored in OC sediments (Kida *et al.*, 2021), and 8–15% of OC is buried in mangroves (Breithaupt *et al.*, 2012). Research in Karimunjawa-Kemujan, Indonesia, showed the above-ground carbon potential of mangroves ranges from 8 to 328 Mg/ha (Wirasatriya *et al.*, 2022). The level of OC storage is influenced by various activities in the mangrove ecosystem. Utilization of mangrove ecosystems for shrimp ponds results in a decrease in soil OC (Eid *et al.*, 2019) and vulnerability to the influence of nutrients and organic matter runoff (Friess *et al.*, 2015). OC storage is also influenced by various factors such as mangrove type, maturity age, species distribution, and soil conditions (Alongi, 2012). In general, carbon sequestration potential increases with increasing plant size and age (Alongi, 2012). Another research also revealed that the contribution of OC caused an increase of 31% due to area protection and 25% due to the burial of OC sediments (Chu *et al.*, 2020). OC comes from various sources including water and mangrove litter (Carreira *et al.*, 2016), and vegetation structure and root density function as sediment stabilizers (Kristensen *et al.*, 2008; Alongi, 2014). The process of leaf decomposition of various mangrove types also supports the contribution of nutrients to the mangrove ecosystem (Ariyanto *et al.*, 2018b). The salinity variation in the mangrove ecosystem in the range of 7.88–30.70 practical salinity units (psu) contributes to OC storage (Yan *et al.*, 2023). Another research (Kamyab *et al.*, 2024) showed carbon sequestration, 65% contributed to C stock sediment (Soeprobowati *et al.*, 2024), and the sequestration rate (CSR) was found dominantly in soil in mangrove ecosystems (Trettin *et al.*, 2021). Mangroves are important for carbon stocks and potential emissions due to mangrove deforestation (Hamilton and Friess, 2018). Climate change and anthropogenic disturbances impact sequestration and carbon storage (Grellier *et al.*, 2017; Pérez *et al.*, 2017). Preventing mangrove loss through natural and rehabilitated mangroves is an effective strategy for climate change mitigation. This hypothesis is about how carbon sequestration differs between natural and rehabilitated mangrove types in mangrove ecosystem sediments and the factors that influence it. This study aimed to determine the relationship between OC sediment content in various types of natural and rehabilitated mangroves and environmental parameters during 2023 in Lampung, Indonesia.

MATERIALS AND METHODS

Study location

This study was conducted from November to December 2023 in Pesawaran as 5.57185° north (N),

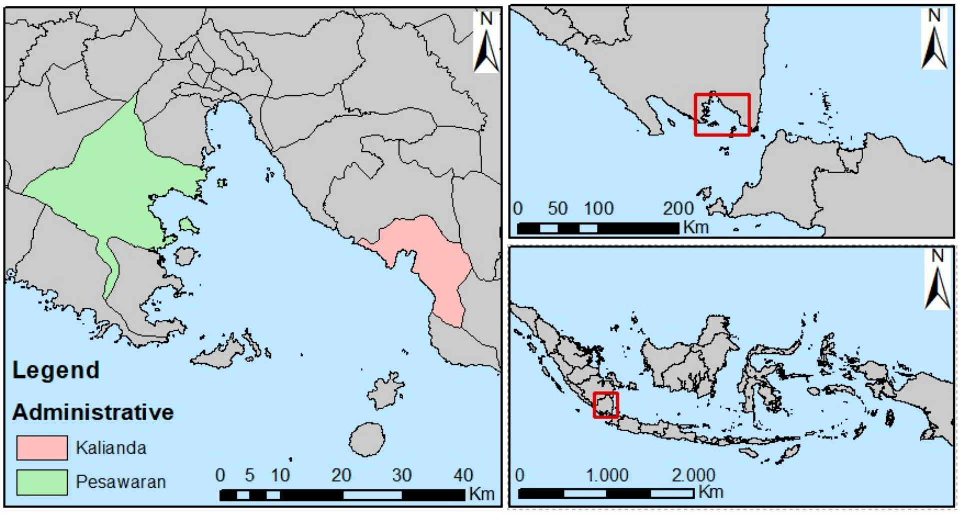

Fig. 1: Geographic location of the study area in Pesawaran and South Lampung, Lampung Province, Indonesia

105.24189° east (E) for the natural mangrove location and in South Lampung for the rehabilitatedmangrove location in Lampung Province, Indonesia (Fig. 1). The study was divided based on the mangrove types in both the study locations, i.e., the mangroves *Rhizophora mucronata* Lamk, *Rhizophora stylosa* Griff, and *Ceriop tagal* C.B. Rob. This location of research has a tropical climate with high rainfall.

Collection

The selection of mangrove types in the research was based on the type of mangrove dominant at the natural and rehabilitated mangrove locations, namely *Rhizopohira stylosa* Griff, *R. mucronata* Lamk, and *Ceriop tagal* C.B. Rob. Sources for mangrove rehabilitation come from locations around natural mangroves. Sediment sampling was carried out using a PVC pipe with a diameter of 47.46 millimeters (mm) and a depth of 30 centimeters (cm). All sediment samples were taken to the laboratory for weighing and drying until the samples became constant. The parameter of the texture condition of each mangrove type was also measured. Physical parameter measurements such as the potential of hydrogen (pH), temperature, salinity, and total dissolved solids (TDS) conditions were performed directly at the study locations using water quality multiparameter equipment.

Data analysis

Carbon stock in mangrove sediments is measured using Eq. 1 (Howard *et al.,* 2014):

Carbon stock (Mg/C/ha) = sediment bulk density as gram per cubic meter (g/cm^3) x C % x depth (cm) (1)

The carbon stock is then converted into equivalent carbon dioxide (eCO$_2$/ha) using Eq. 2 (Iticha, 2017):

$$CO_2e(MgCO_2) = 3.67 * \text{Total carbon stock} \quad (2)$$

The conversion of carbon (C) to carbon dioxide (CO$_2$) used a carbon weight of 3.67 based on the molecular weight ratio of CO$_2$ (44) with C (12); thus, 1 Mg = 3.67 magnesium carbonate (MgCO$_2$) was absorbed.

The average carbon sequestration rate (CSR) was determined based on the mean of soil bulk density (SBD), C, and sediment of 0.28 centimeters per year (cm/y) using Eq. 3 (Alongi, 2014):

CSR (gC^2/y) = mean SBD x mean % C x sequestration rate (SR) (3)

Statistical analysis

Statistical analysis was conducted using statistical software for excel (XLStat) to determine the relationship between the sediment OC and the

Table 1: Soil OC storage in natural and rehabilitated mangroves

Location	Mangrove	OC (%)	SOC (g/cm^3)	Carbon dioxide equivalent (Mg CO_2/ha)	Carbon stock (Mg C/ha)	Carbon sequestration rate MgC/cm/y	Source
Pesawaran	*R. stylosa* Griff	2.52	0.201	55.19	15.21	3.14	This study
	R. mucronata Lamk	1.91	0.223	46.90	12.77	2.9	This study
	C. tagal C.B. Rob	2.37	0.151	39.28	10.70	1.65	This study
South Lampung	*R. stylosa* Griff	1.19	0.136	10.89	2.99	1.25	This study
	R. mucronata Lamk	0.73	0.185	24.19	6.59	0.41	This study
	C. tagal C.B. Rob	0.79	o.109	9.52	2.59	0.29	This study
Natural	Indonesia				483		Kusumaningtyas *et al.,* 2019
Rehabilitated	Indonesia				65.854		Soeprobowati *et al.,* 2024
Restored	Philippines				549	10.2	Salmo *et al.,* 2019

environmental parameters.

RESULTS AND DISCUSSION

Table 1 shows the sediment OC content, bulk density, carbon stock, and carbon sequestration in both natural and unnatural mangroves. The OC content in the two locations showed differences. Natural mangroves (Pesawaran) showed higher OC values at 2.2 ± 0.32% than rehabilitated mangroves (South Lampung) at 0.9 ± 0.25%. Based on the mangrove type, the higher OC content was also obtained in natural mangroves compared to rehabilitated mangroves. The highest OC content was found in the *R. stylosa* species in both natural and rehabilitated mangroves.

The OC content of the three mangrove types was *R. styolsa* > *C. tagal* > *R. mucronata* both in natural and rehabilitated mangroves (Table 1). The OC content at the study locations was influenced by the older age of *R. stylosa* compared to that of *R. mucronata* and *C. tagal*. Compared to other research, the current study showed that the OC content of mangroves at these locations was lower. Another research also reported that high OC stocks are caused by mangrove maturity and stand age (Tang *et al.,* 2023). The OC content values also showed differences in sediment, which are influenced by differences in vegetation communities of 736.8 ± 169 grams per square meter per year ($g/m^2/y$) (Setyadi *et al.,* 2021) and increase with increasing mangrove age (Carnell *et al.,* 2022). This aligns with another research finding that the increase in OC content in sediment was caused by several factors, such as soil depth and increasing mangrove age of 12, 24, and 48 years (Chen *et al.,* 2018). The OC content in this study was lower compared to that of 16 ± 7% in another study (Chu *et al.,* 2023). Mangroves can contribute around 15–19% OC to sediment (Chu *et al.,* 2020). Both natural and rehabilitated mangroves showed the highest and lowest carbon sequestration rate (CSR) values of *R. stylosa* > *R. mucronata* > *C. tagal*. The CSR values were 1.65–3.14 for natural mangroves and 0.29–1.25 for rehabilitated mangroves. Global CSR showed a value of 17.4 $gC/cm^2/y$ (Alongi, 2012). The CSR value of this study is not too far from that obtained in other studies: 4.54 $gC/cm^2/y$ in Nigeria (Nwankwo *et al.,* 2023) and 4.0 $gC/cm^2/y$ in Saudi Arabia (Eid *et al.,* 2019). Previous research further revealed that the soil organic carbon (SOC) content in mangrove forests was higher than in shrimp ponds by 147% (Eid *et al.,* 2019). The increase in SOC is also affected by various factors such as biomass, diameter at breast height (DBH), tree height, and age of mangroves for *S. apetala* (Wang *et al.,* 2019; Wang et al., 2021; Pham *et al.,* 2017). High TOC content was also found in the surface area of mangroves (Perera and Amarasinghe, 2019). The level of CS in natural mangroves is higher than in rehabilitated mangroves. Natural mangrove CS showed 16.00–164.51 Mg C/ha, and planted mangrove showed 3.8 MgC/ha/y (Monga *et al.,* 2022). The existence of carbon stocks in rehabilitated mangroves has an equivalent value for 25 years, considering that the impact of disturbance is controlled and managed (Sasmito *et al.,* 2020). Factors that significantly impact CSR include tree varies, species richness, forest composition, and local condition

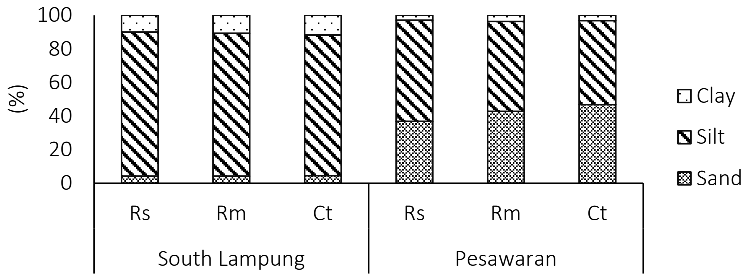

Fig. 2: Distribution of sediment texture in natural and unnatural mangroves (Rs = *R. stylosa* Griff, Rm = *R. mucronata* Lamk, Ct = *Ceriop tagal* C.B. Rob)

Table 2: Environmental parameters in natural and rehabilitated mangroves

Location	Mangrove	pH	Salinity (psu)	Temperature (°C)	TDS (ppm)
Pesawaran	*R. stylosa* Griff	7.01±0.1	22.3 ±2.7	28±0	352 ± 71
	R. mucronata Lamk	6.5±0.3	21.2±1.5	29.6±1.1	358 ± 153
	C. tagal C.B. Rob	6.2±0	21.3±0.6	31±0	283 ± 129
South Lampung	*R. stylosa* Griff	6.7±0.3	15±1	33.6±0.6	957 ± 41
	R. mucronata Lamk	7.13±0.1	17±0.5	32±0	917 ± 11.5
	C. tagal C.B. Rob	6.6±0.3	15.3±0.6	32.6±0.5	976.7 ± 12.4

traits (Augusto *et al.,* 2022). Soil characteristics such as SOC, pH, sand, silt, and clay content also affect carbon (Mensah *et al.,* 2023). Climate, salinity, and forest structure also affect carbon stocks (Kaufman *et al.,* 2020). Fig. 2 shows the distribution of sediment textures in various mangrove types in natural and unnatural mangrove conditions. The distribution of sediment textures was sand, silt, and clay sediments, which ranged from 4.29 ± 0.18%, 84.87 ± %, and 10.83 ± 0.87% in unnatural mangroves, respectively, while in natural mangroves, it ranged from 42.13 ± 5.03%, 54.59 ± %, and 3.27 ± 0.36%, respectively. The two research locations showed differences in sediment texture:unnatural mangroves (South Lampung) tended to have the largest composition of silt, while natural mangroves (Pesawaran) tended to have the same composition between sand and silt. Table 1 also shows that the CSR in natural mangroves was higher than in rehabilitated mangroves.

In terms of mangrove type, it was also revealed that the distribution of sediment texture tended to involve more silt in rehabilitated mangroves, while natural mangroves tended to have the same composition between sand and silt. The conditions of natural and rehabilitated mangroves also illustrated that mangroves can grow and develop well with the support of a finer texture, i.e., silt. However, a sandy texture is also needed for further growth to strengthen and stabilize the roots. Table 2 shows various environmental parameters, including pH, salinity, temperature, and TDS. The pH parameter showed that it ranged from 6.2–7.01 in natural mangroves and from 6.6–7.13 in rehabilitated mangroves. The salinities were between 21.3–23 psu in natural mangroves and between 23–27.3 psu in unnatural mangroves. The temperature ranged from 28–31°C in natural mangroves and from 32–33°C in unnatural mangroves. Meanwhile, TDS was between 283–358 parts per million (ppm) in natural mangroves and between 917–976 ppm in rehabilitated mangroves.

The pH conditions in natural and rehabilitated mangroves showed no significant differences in values. The salinity in Pesawaran, which was classified as a natural mangrove, was higher due to the influence of the tides and directly facing the shoreline. Meanwhile, in South Lampung, which was categorized as a rehabilitated mangrove, the salinity was lower due to the long dry season and the canals being unable to support the water entering the mangroves.

The principal component analysis (PCA) result revealed that the total diversity of F1 and F2 was 93.13%, consisting of F1 diversity of 76.95% and F2 diversity of 16.18%. PCA 1 with factor loading (natural mangrove

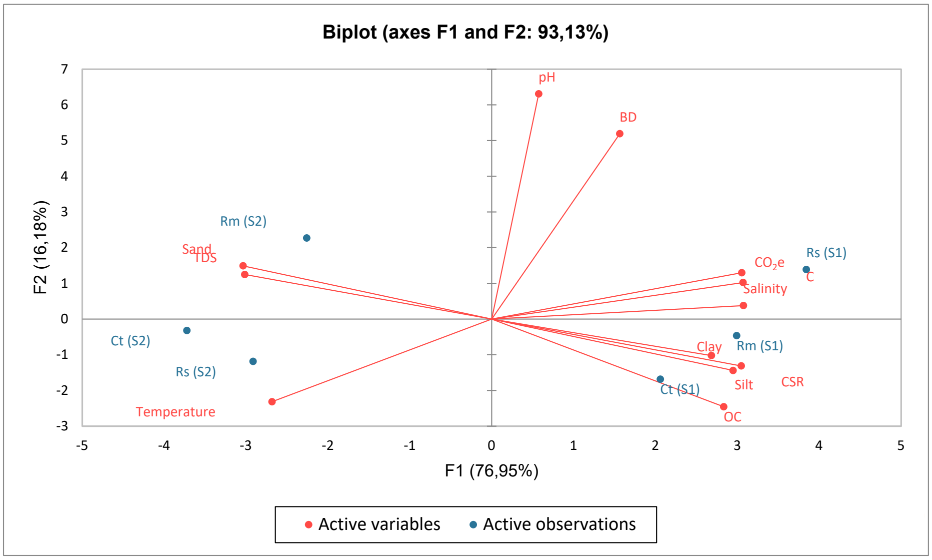

Fig. 3: Principal component analysis to determine the relationship between OC, CSR, and various environmental parameters

= S1 and rehabilitated mangrove = S2) showed a high positive correlation, namely OC (0.909), CO_2e (0.980), Cstock (0.985), and CSR (0.861), with salinity (0.986), silt (0.978), and clay (0.946), and a negative correlation with temperature (-0.861) and TDS (-0.968). PCA 2 showed a correlation of bulk density (BD) (0.764) with pH (0.928) (Fig. 3). Salinity is an important factor in influencing the existence and growth of mangroves and determining mangrove zoning (Nguyen *et al.*, 2015). Another research also reported that the mangrove *C. tagal* was able to grow in the salinity range of 40–60 practical salinity units (psu) and experienced growth inhibition beyond that (Prihantono *et al.*, 2023). Several studies also reported that mangroves responded to dry conditions in mangrove rehabilitation sites by slowing growth rates and tending to require more water. The response of mangroves to high soil salinity resembles the response to drought, including slow growth rates, low stomatal conductance, and increased water use efficiency (Lovelock *et al.*, 2006). This is different from the condition of natural mangroves where there are channels or canals that come from both the sea and land, causing good and effective mangrove growth. The input of fresh water through canals or channels can also reduce high salinity and cause the recovery of mangroves, which contributes to the growth of seedlings (Pérez-Ceballos *et al.*, 2020; Devaney *et al.*, 2021). In Fig. 3, the loading value describes the strength of the principal component analysis (PCA) values. OC, CO_2e, C, and CSR had positive correlation characteristics affected by salinity, silt, and clay. Meanwhile, negative correlation characteristics were influenced by temperature, TDS, and sand. The SOC relationship was influenced by pH; for example, a higher SOC value resulted in a higher pH and vice versa. The C content in mangrove ecosystems depends on various sources, including mangrove composition, soil type, geographical location, tides, and the influence of human activities (Gao *et al.*, 2019). Organic matter content is a high-relationship physicochemical factor that influences mangrove productivity (Ariyanto *et al.*, 2019b). This research also revealed that high clay texture had an impact on high SOC content compared to low clay texture. The high SOC was supported by a high clay composition compared to low clay (Zou *et al.*, 2023). Cs had positive characteristics influenced by salinity. Previous research has confirmed that the number of trees and tree trunk diameter influence carbon sequestration in addition to pH and salinity factors (Hayati *et al.*, 2023). SOC sequestration depended on the regional primary productivity, dynamic-geomorphological conditions, and climate-water environment (Yan *et al.*, 2024) and 80% in sediment (0–1 m) (Rani *et al.*, 2021). Other factors that influence the sustainability of mangrove ecosystems include the availability of nutrients (nitrogen and phosphorus) needed for the growth and survival of mangroves (Reef *et al.,* 2010) and the existence of locations and zoning that are suitable for vegetation regeneration (Uche *et al.,* 2023). For their survival and stability, mangroves also require air quality such as salinity (Chen and Wang, 2017), fresh water (Santini *et al.,* 2015), variations in rainfall and tidal influences (Prihantono *et al.,* 2022), and hydrodynamic processes (Cannon *et al.,* 2020).

CONCLUSION

This study found that natural mangroves had higher OC and soil organic carbon contents compared to those in unnatural mangroves. The OC, CO_2 equivalent, carbon, and carbon sequestration had positive correlation characteristics influenced by salinity, silt, and clay, while negative correlation characteristics were affected by temperature, TDS and sand. The pH parameter showed that it ranged from 6.2–7.01 in natural mangroves and from 6.6–7.13 in rehabilitated mangroves. The salinities were from 21.3–23 psu in natural mangroves and from 23–27.3 psu in rehabilitated mangroves. The temperature ranged from 28–31°C in natural mangroves and from 32–33°C in rehabilitated mangroves. Meanwhile, TDS was from 283–358 parts per million in natural mangroves and from 917–976 parts per million in rehabilitated mangroves. Several studies also reported that mangroves responded to dry conditions in rehabilitated mangrove sites by slowing growth rates and tending to require more water. The soil OC relationship was influenced by pH, as a higher soil OC value resulted in a higher pH and vice versa. In natural mangroves, the high-value soil OC was influenced by salinity, silt, and clay, while in unnatural mangroves, it was influenced by temperature, sand, and TDS. The older age of *R. stylosa* compared to that of *R. mucronata* and *C. tagal* also influenced the OC content in both natural and rehabilitated mangroves. Potential implications of differences in carbon absorption levels between natural mangroves and rehabilitated mangroves for climate change mitigation strategies, namely that both types of growth and development are found to be dominant in sediment storage. This can prevent the risk of sudden carbon losses. The carbon sequestration rate of natural mangroves are higher (2–3 times) than that of rehabilitated mangroves. The presence of sediment in the mangrove ecosystem is very important because it determines the suitability of mangrove zoning. Sediment accumulates in mangrove vegetation if the mangrove plants—both natural and rehabilitated—are in good condition. This cannot be separated from the tidal process, which has an impact on ecological processes in the mangrove ecosystem.

AUTHOR CONTRIBUTIONS

D. Ariyanto, the corresponding author, collected data, interpreted the results, and prepared the final manuscript. D. Pringgenies interpreted the results, wrote the manuscript, and corrected the manuscript. All authors have equal contributions.

ACKNOWLEDGMENT

The authors thank Diponegoro University for the Postdoctoral Program 2023, World Class University Diponegoro University [No: 1161/UN8.A4/KU/X/2023] and the Research Center for Oceanography, National Research and Innovation Agency (BRIN), which supported this study.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

OPEN ACCESS

PUBLISHER'S NOTE

ABBREVIATIONS

%	Percent
°C	Degree Celsius
BD	Bulk density
gC/cm2/y	Gram carbon centimenter per year
cm	Centimeter
Cm/y	Centimeter per year
CO_2e	Carbon dioxide equivalent
CSR	Carbon sequestration rate
CS	Carbon stock
D	Depth
DBH	Diameter at breast height
E	East
eCO_2/ha	Equivalent carbon dioxide
$g/m^2/y$	Gram per square meter per year
kg	Kilogram
MgC/ha	Megagram carbon per hectare
$MgCO_2$	Magnesium carbonate
$MgCO_2/ha$	Megagram carbon dioxide per hectare
Mg/ha	Megagram per hectare
NGOs	non-governmental organizations
mm	milimeter
N	nitrogen
N	North
P	phosphorus
pH	potential of hydrogen
ppm	Part per million
psu	Partical salinity unit
OC	Organic carbon
PCA	Principal component analysis
PVC	Polyvinyl Chloride
SBD	sediment bulk density
SOC	Soil organic carbon
SR	Sequestration rate
TDS	Total dissolved solid
XLstat	Statistical sofware for excel

REFERENCES

Augusto, L.; Boča, A. (2022). Tree functional traits, forest biomass, and tree species diversity interact with site properties to drive forest soil carbon. Nat. Commun., 13: 1097 (**12 pages**).

Almahasheer, H.; Serrano, O.; Duarte, C.M.; Arias-Ortiz, A.; Masque, P.; Irigoien, X., (2017). Low Carbon sink capacity of Red Sea mangroves. Sci. Rep., 7(1): 1–10 **(10 pages).**

Alongi, D.M., (2012). Carbon sequestration in mangrove forests. Carbon Manage., 3(3): 313–322 **(10 pages).**

Alongi, D.M., (2014). Carbon cycling and storage in mangrove forests. Ann. Rev. Mar. Sci., 6: 195–219 **(28 pages).**

Alongi, D.M., (2022). Impacts of climate change on blue carbon stocks and fluxes in mangrove forests. Forests., 12: 1–17 **(17 pages).**

Ariyanto, D.; Bengen, D.G.; Prartono, T.; Wardiatno Y., (2018a). The association of *Cassidula nucleus* (Gmelin 1791) and *Cassidula angulifera* (petit 1841) with mangrove in banggi coast, Central Java, Indonesia. AACL Bioflux. 11(2): 348–361 **(14 pages).**

Ariyanto, D.; Bengen, D.G.; Prartono, T.; Wardiatno Y., (2018b). Short Communication : The relationship between content of particular metabolites of fallen mangrove leaves and the rate at which the leaves decompose over time. Biodiversitas. 19(3): 700–705 **(6 pages).**

Ariyanto, D.; Gunawan, H.; Puspitasari, D.; Ningsih, S.S.; Jayanegara, A.; Hamim., (2019a). Identification of the chemical profile of *Rhizophora mucronata* mangrove green leaves from the eastern coast of Asahan, North Sumatra, Indonesia. Plant Arch., 19(2): 4045–4049 (**5 pages**).

Ariyanto, D.; Bengen, D.G.; Prartono, T.; Wardiatno Y., (2019b). The physicochemical factors and litter dynamics (*Rhizophora mucronata* Lam.and *Rhizophora stylosa* Griff) of Replanted Mangroves, Rembang, Central Java, Indonesia. Environ. Nat. Resour. J., 17(4): 11-19 **(9 pages).**

Ariyanto, D.; Bengen, D.G.; Prartono, T.; Wardiatno Y., (2020). Distribution and abundance of *Cerithideopsilla djadjariensis* (Martin 1899) (potamididae) on *Avicennia marina* in Rembang, Central Java, Indonesia. Egypt. J. Aquatic Biol. Fish. 24(3): 323–332 **(10 pages).**

Breithaupt, J.L.; Smoak, J.M.; Smith, T.J.; Sanders, C.J.; Hoare, A., (2012). Organic carbon burial rates in mangrove sediments: Strengthening the global budget. Global Biogeochem. Cy., 26(3): 1–11 (**11 pages**).

Cannon, D.; Kibler, K.; Donnelly, M.; McClenachan, G.; Walters, L.; Roddenberry, A.; Phagan, J., (2020). Hydrodynamic habitat thresholds for mangrove vegetation on the shorelines of a microtidal estuarine lagoon. Ecol. Eng., 158: 106070 **(11 pages).**

Carnell, P.E.; Palacios, M.M.; Waryszak, P.; Trevathan-Tackett, S.M.; Masqué, P.; Macreadie, P. I., (2022). Blue carbon drawdown by restored mangrove forests improves with age. J. Environ. Manage., 306: 114301 (**8 pages**).

Carreira, R.S.; Cordeiro, L.G.M.S.; Bernardes, M.C.; Hatje, V., (2016). Distribution and characterization of organic matter using lipid biomarkers: A case study in a pristine tropical bay in NE Brazil. Estuar. Coast. Shelf Sci., 168: 1–9 (**9 pages**).

Chen, G.; Gao, M.; Pang, B.; Chen, S.; Ye, Y., (2018). Top-meter soil organic carbon stocks and sources in restored mangrove forests of different ages. For. Ecol. Manage., 422: 87–94 **(8 pages).**

Chu, M.; Sachs, J.P.; Peng, P.; Li H. C.; Ding, Y.; Li, L.; Zhao, M., (2023). Temporal variations of mangrove-derived organic carbon storage in two tropical estuaries in Hainan, China since 1960 CE. Palaeogeogr. Palaeoclimat. Palaeoecol., 627: 111726 **(11 pages)**.

Chu, M.; Sachs, J.P.; Zhang, H.; Ding, Y.; Jin, G.; Zhao, M., (2020). Spatiotemporal variations of organic matter sources in two mangrove-fringed estuaries in Hainan, China. Org. Geochemi., 147: 104066 (**13 pages**).

Devaney J.L., Marone D., McElwain J.C., 2021. Impact of soil salinity on mangrove restoration in a semiarid region: a case study from the Saloum Delta, Senegal. Restor. Ecol., 29(2): 1–10 **(10 pages)**.

Eid, E.M.; Arshad, M.; Shaltout, K.H.; El-Sheikh, M.A.; Alfarhan A.H.; Picó, Y.; Barcelo, D., (2019). Effect of the conversion of mangroves into shrimp farms on carbon stock in the sediment along the southern Red Sea coast, Saudi Arabia. Environ. Res., 176: 108536 **(7 pages)**.

Friess, D.A.; Phelps, J.; Garmendia, E.; Gómez-Baggethun, E., (2015). Payments for Ecosystem Services (PES) in the face of external biophysical stressors. Global Environ. Change., 30: 31–42 (**12 pages**).

Gao, Y.; Zhou, J.; Wang, L.; Guo, J.; Feng, J.; Wu, H.; Lin, G., (2019). Distribution patterns and controlling factors for the soil organic carbon in four mangrove forests of China. Global Ecol. Conserv., 17: e00575 **(14 pages).**

Grellier, S.; Janeau, J.; Nhon, D.H.; Cuc, N.T.K.; Quynh, L.T.P.; Thao, P.T.T.; Nhu-Trang, T.T.; Marchand, C., (2017). Changes in soil characteristics and C dynamics after mangrove clearing (Vietnam). Sci. Total Environ., 593–594: 654-663 (**10 pages**).

Hamilton, S.E.; Friess, D.A., (2018). Global carbon stocks and potential emissions due to mangrove deforestation from 2000 to 2012. Nat. Clim. Change. 8: 240–244 **(7 pages).**

Hayati, A.N.; Afiati, N.; Supriharyono.; Helmi, M., (2023). Carbon sequestration of above ground biomass approach in the rehabilitated mangrove stand at Jepara Regency, Central Java, Indonesia. J. Ilmiah Perikanan dan Kelautan. 15(1): 224–235 **(12 pages).**

Howard, J.; Hoyt, S.; Isensee, K.; Telszewski, M.; Pidgeon, E., (2014). Coastal blue carbon: methods for assessing carbon stocks and emissions factors in mangroves, tidal salt marshes, and seagrasses meadows. 1-184 **(184 pages).**

Iticha, B., (2017). Ecosystem carbon storage and partitioning in chato afromontane forest: its climate change mitigation and economic potential. Int. J. Environ. Agric. Biotechnol., 2(4): 1785–1794 **(10 pages).**

Kida, M.; Watanabe, I.; Kinjo, K.; Kondo, M.; Yoshitake, S.; Tomotsune, M.; Iimura, Y.; Umnouysin, S.; Suchewaboripont, V.; Poungparn, S.; Ohtsuka, T.; Fujitake, N., (2021). Organic carbon stock and composition in 3.5-m core mangrove soils (Trat, Thailand). Sci. Tot. Environ., 801: 149682 **(9 pages).**

Kristensen, E.; Bouillon, S.; Dittmar, T.; Marchand, C., (2008). Organic carbon dynamics in mangrove ecosystems: A review. Aquat. Bot., 89: 201–219 **(19 pages).**

Kusumaningtyas, M.A.; Hutahaean, A.A.; Fischer, H.W.; Pérez-Mayo, M.; Ransby, D.;. Jennerjahn T.C., (2019). Variability in the organic carbon stocks, sources, and accumulation rates of Indonesian mangrove ecosystems. Estuar. Coast Shelf Sci., 218: 310-323 (**14 pages**).

Lovelock C.E.; Ball M.C.; Feller I.C.; Engelbrecht B.M.J.; Ling Ewe, M., (2006). Variation in hydraulic conductivity of mangroves: Influence of species, salinity, and nitrogen and phosphorus availability. Physiol. Plant. 127(3): 457–464 **(8 pages).**

Listiana, I.; Ariyanto, D., (2024). Enhancing coastal community participation in mangrove rehabilitation through structural equation modeling. Global J. Environ. Sci. Manage., 10(2): 873–890 (**18 pages**).

Monga, E.; Mangora, M,M.; Trettin, C.C., (2022). Impact of mangrove planting on forest biomass carbon and other structural attributes in the Rufiji Delta, Tanzania. Global Ecol. Conserv., 35: e02100 (**12 pages**).

Nguyen, H.T.; Stanton, D.E.; Schmitz, N.; Farquhar, G.D.; Ball, M.C., (2015). Growth responses of the mangrove Avicennia marina to salinity: Development and function of shoot hydraulic systems require saline conditions. Ann. Bot., 115(3): 397–407 **(11 pages).**

Ningsih, S.S.; Ariyanto, D.; Puspitasari, D.; Jayanegara, A.; Hamim, H.; Gunawan, H., (2020). The Amino acid contents in mangrove *Rhizophora mucronata* leaves in Asahan, North Sumatra, Indonesia. E3S Web of Conferences. 151: 1–3 (**3 pages**)

Kamyab, H.; SaberiKamarposhti, M.; Hashim, H.; Yusuf, M., (2024). Carbon dynamics in agricultural greenhouse gas emissions and removals: a comprehensive review. Carbon Lett., 34: 265–289 (**25 pages**).

Kauffman, J.B.; Adame, M.F.; Arifanti, V.B.; Schile-Beers, L.M.; Bernardino, A.F.; Bhomia, R.K.; Donato, D.C.; Feller, I.C.; Ferreira, T.O.; Jesus Garcia, M.C.; MacKenzie, R.A.; Megonigal, J.P.; Murdiyarso, D.; Simpson L.; Hernandez Trejo H., (2020). Total ecosystem carbon stocks ofmangroves across broad global environmental and physical gradients. Ecol. Monogr., 90(2):e01405 **(18 pages).**

Mensah, S.; Noulèkoun, F.; Dimobe, K.; Seifert, T.; Kakaï R.G., (2023). Climate and soil effects on tree species diversity and aboveground carbon patterns in semi-arid tree savannas. Sci. Rep., 13:11509 (**13 pages**).

Nwankwo, C.; Tse, A.C.; Nwankwoala, H.O.; Giadom, F.D.; Acra, E.J.; (2023). Below ground carbon stock and carbon sequestration potentials of mangrove sediments in Eastern Niger Delta, Nigeria: Implication for Climate Change. Sci. Afr., 22: e01898 **(9 pages).**

Perera, K.A.R.S.; Amarasinghe, M.D., (2019). Carbon sequestration capacity of mangrove soils in micro tidal estuaries and lagoons: A case study from Sri Lanka. Geoderma., 347: 80–89 **(10 pages).**

Pérez, A.; Machado, W.; Gutierrez, D.; Stokes, D.; Sanders,L.; Smoak, J.M.; Santos, I.; Sanders, C.J., (2017). Changes in organic carbon accumulation driven by mangrove expansion and deforestation in a New Zealand estuary. Estuar. Coast Shelf Sci., 192: 108-116 (**9 pages**).

Pérez-Ceballos, R.; Zaldívar-Jiménez, A.; Canales-Delgadillo, J.; López-Adame, H.; López-Portillo, J.; Merino-Ibarra, M., (2020). Determining hydrological flow paths to enhance restoration in impaired mangrove wetlands. PLoS One., 15(1): 1–20 **(20 pages).**

Pham, V.H.; Luu, V.D.; Nguyen, T.T.; Koji, O., (2017). Will restored mangrove forests enhance sediment organic carbon and ecosystem carbon storage? Reg. Stud. Mar. Sci., 14: 43–52 **(10 pages).**

Prihantono, J.; Nakamura, T.; Nadaoka, K.; Wirasatriya, A.; Adi, N.S., (2022). Rainfall variability and tidal inundation influences on mangrove greenness in Karimunjawa National Park, Indonesia. Sustainability. 14: 8948 **(18 pages).**

Prihantono, J.; Nakamura, T.; Nadaoka, K.; Solihuddin, T.; Pryambodo, D.G.; Ramdhan, M.; Adi, N.S.; Ilham.; Wirasatriya, A.; Widada, S., (2023). Seasonal groundwater salinity dynamics in the mangrove supratidal zones based on shallow groundwater salinity and electrical resistivity imaging data. Wetlands Ecol. Manage., 31(3): 435–448 **(14 pages).**

Pringgenies, D., Setyati, W.A.; Djunaedi, A.; Pramesti, R.; Rudiyanti, S.; Ariyanto, D., (2021). Exploration of antimicrobial potency of mangrove symbiont against multi-drug resistant bacteria. J. Ilmiah Perikanan dan Kelautan. 13(2): 102–112 **(11 pages).**

Pringgenies, D.; Wilis, A.S.; Feliatra, F.; Ariyanto, D., (2023). The antibacterial and antifungal potential of marine natural ingredients from the symbiont bacteria of mangrove. Global J. Environ. Sci. Manage., 9(4): 819–832 **(14 pages).**

Rani, V.; Bijoy Nandan, S.; Schwing, P.T., (2021). Carbon source characterisation and historical carbon burial in three mangrove ecosystems on the South West coast of India. Catena. 197: 104980 (**12 pages**).

Reef, R.; Feller, I.C. Lovelock. C.E., (2010). Nutrition of mangroves.

Tree Physiol., 30 (9):1148-1160 (**13 pages**).

Salmo, S.G.; Malapit, V.; Garcia, M.C.A.; Pagkalinawan, H.M., (2019). Establishing rates of carbon sequestration in mangroves from an earthquake uplift event. Biol. Lett., 15: 20180799 (**4 pages**).

Santini, N.S.; Reef, R.; Lockington, D.A.; Lovelock, C.E., (2015). The use of fresh and saline water sources by the mangrove *Avicennia marina*. Hydrobiology. 745: 59–68 **(10 pages).**

Sasmito, S.D.; Kuzyakov, Y.; Lubis, A.A.; Murdiyarso, D.; Hutley, L.B.; Bachri, S.; Friess, D.A.l Martius, C.; Borchard, N., (2020). Organic carbon burial and sources in soils of coastal mudflat and mangrove ecosystems. Catena., 187: 104414.(**11 pages**).

Setyadi, G.; Sugianto, D.N.; Wijayanti, D.P., Pribadi, R.; Supardy, E., (2021). Sediment Accretion and total organic carbon accumulation among different mangrove vegetation communities in the Kamora Estuary of Mimika Regency, Papua, Indonesia. J. Ecol. Eng., 22(11): 142–156 **(15 pages).**

Sibero, M.T.; Pribadi, R.; Ambariyanto, A.; Haryanti, D.; Kharisma, V.D.; Dewi, A.S.; Patantis, G., Zilda, D.S.; Murwani, R., (2022). Ethnomedicinal bioprospecting of *Rhizophora apiculata* leaves through in silico and in vitro approaches as antioxidant, α-glucosidase inhibitor and anticancer. Biodiversitas. 23(12): 6437–6447 **(11 pages).**

Soeprobowati, T.R.; Sularto, R.B.; Hadiyanto, H.; Puryono, S.; Rahim, A.; Jumari,J.; Gell, P., (2024). The carbon stock potential of the restored mangrove ecosystem of Pasarbanggi, Rembang, Central Java. Mar. Environ. Res., 193: 106257 **(11 pages).**

Spalding, M.; Parrett, C.L., (2019). Global patterns in mangrove recreation and tourism. Mar. Policy. 110: 103540 **(8 pages).**

Tang, D.; Liu, X.; Xia, Z.; Hou, J.; Yang, X.; Li, P.; Yuan, X., (2023). Sources of organic matter and carbon stocks in two mangrove sediment cores and surface sediment samples from Qinglan Bay, China. Sci. Tot. Environ., 893: 164897 **(11 pages).**

Trettin, C.C.; Zhaohua, D.; Tang, W.; Lagomasino, D.; Thomas, N,; Kuk Lee, S.; Simard, M.; Ebanega, M.O.; Stoval, A.; Fatoyinbo T.E., (2021). Mangrove carbon stocks in Pongara National Park, Gabon. Estuar. Coast. Shelf Sci. 259: 107432 **(12 pages).**

Uche, I.; Gundlach, E.; Mbamalu, G., (2023). Survivability and growth performance of using Rhizophora mangrove life stages in the revegetation of mangrove forest. Reg. Stud. Mar. Sci., 67: 103228 **(8 pages).**

van Bijsterveldt, C.E.J.; Debrot, A.O.; Bouma, T.J.; Maulana, M.B.; Pribadi, R.; Schop, J.; Tonneijck, F.H.; van Wesenbeeck, B.K., (2022). To plant or not to plant: when can planting facilitate mangrove restoration? Front. Environ. Sci., 9:1–18 (**18 pages**).

Wang G.; Guan D.; Xiao L.; Peart M.R., (2019). Ecosystem carbon storage affected by intertidal locations and climatic factors in three estuarine mangrove forests of South China. Reg. Environ. Change. 19: 1701–1712 (**12 pages**).

Wang, G.; Zhang, Y.; Guan, D.; Xiao, L.; Singh, M., (2021). The potential of mature Sonneratia apetala plantations to enhance carbon stocks in the Zhanjiang Mangrove National Nature Reserve. Ecol. Indic., 133: 108415 (**9 pages**).

Wirasatriya, A.; Pribadi, R.; Iryanthony, S.B.; Maslukah, L.; Sugianto, D.N.; Helmi, M.; Ananta R.R.; Adi, N.S.; Kepel, T.L.; Ati, R.N.A.; Kusumaningtyas, M.A.; Suwa, R.; Ray, R.; Nakamura, T.; Nadaoka, K., (2022). Mangrove above-ground biomass and carbon stock in the karimunjawa-kemujan islands estimated from unmanned aerial vehicle-imagery. Sustainability. 14(706): 1–15 (**15 pages**).

Yan, L.; Xie, X.; Heiss, J.W.; Peng, K.; Deng, Y.; Gan, Y.; Li, Q.; Zhang, Y., (2023). Isotopic and spectral signatures unravel the sources, preservation and degradation of sedimentary organic matter in the Dongzhai Harbor mangrove estuary, southern China. J. Hydrol., 618: 129256 (**12 pages**).

Yan, R.; Feng, J.; Fu, T.; Chen,Q.; Wang, Z.; Kang, F.; Fang, J.; Huang, G.; Yang, Q., (2024). Spatial variation of organic carbon storage and aggregate sizes in the sediment of the Zhangjiang mangrove ecosystem. Catena. 234: 107545 **(10 pages)**.

Zou, H.; Li, X.; Li, S.; Xu, Z.; Yu, Z.; Cai, H.; Chen, W.; Ni, X.; Wu, E.; Zeng, G., (2023). Soil organic carbon stocks increased across the tide - induced salinity transect in restored mangrove region. Sci. Rep., 13: 1–13 **(13 pages)**.

AUTHOR (S) BIOSKETCHES

Ariyanto, D., Dr., Researcher, Research Center for Oceanography, National Research and Innovation Agency, Jakarta, Indonesia; Department of Marine Science, Faculty of Fisheries and Marine Science, Diponegoro University, Jl. Prof. H. Soedarto, S.H. No.1. Tembalang, Semarang, Central Java, 50275, Indonesia

- Email: *dafitariyanto676@gmail.com*
- ORCID: 0000-0001-6749-0997
- Web of Science ResearcherID: HKO-2609-202
- Scopus Author ID: 57201495950
- Homepage: https://brin.go.id/page/civitas

Pringgenies, D., Ph.D., Professor, Department of Marine Science, Faculty of Fisheries and Marine Science, Diponegoro University, Jl. Prof. H. Soedarto, S.H. No.1. Tembalang, Semarang, Central Java, 50275, Indonesia.

- Email: *pringgenies@yahoo.com*
- ORCID: 0000-0001-7388-0000
- Web of Science ResearcherID: AAV-5332-2020
- Scopus Author ID: 24290899400
- Homepage: https://kelautan.fpik.undip.ac.id/dosen-dan-karyawan/

HOW TO CITE THIS ARTICLE

Ariyanto, A.; Pringgenies, D., (2024). Carbon sequestration rate in sediment mangrove from natural and rehabilitated mangrove. Global J. Environ. Sci. Manage., 10(4): 1-10.

DOI: 10.22034/gjesm.2024.04.***

URL: ***