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Organic Matter in the Sediment of Mangrove Ecosystem Substrates at Tireman Village, Rembang, Central Java

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Abstract

Organic matter is a crucial component of mangrove substrates, determining the physical, chemical, and biological properties of sediments while significantly influencing land productivity. This study aimed to determine substrate organic matter content and mangrove density in Tireman Village, Rembang Regency, Central Java, an area surrounded by dense residential settlements. Sampling was conducted across three distinct stations. Substrate samples were collected using sediment cores at depths of 0–10 cm and 10–30 cm, and organic matter analysis was performed using the Loss on Ignition (LOI) method at 550°C. Concurrently, vegetation observations were carried out using 10 × 10 m plots. To assess the overarching ecological conditions of the habitat, key environmental parameters—specifically temperature, pH, and salinity—were also measured. The results indicated that the organic matter content in the substrate fell into the low to moderate categories. The highest organic matter value was recorded at Station I (10.95%), followed by Station III (9.19%), while the lowest value was found at Station II (6.82%). Ultimately, a positive correlation trend was observed between mangrove vegetation density and sediment organic matter content. Stations characterized by a higher vegetation density (reaching up to 6,000 ind/ha) consistently exhibited greater organic matter content in their substrates. This trend highlights the critical role of dense mangrove stands in contributing organic litter to the sediment, thereby enhancing the overall nutrient profile and productivity of the coastal ecosystem despite the pressures of surrounding human settlements.

1. Introduction

Indonesia is an archipelagic country with approximately 70% of its territory is covered by sea and as the second longest coastline in the world i.e. 95,181 km. This geographical location makes coastal and marine areas strategic in maintaining environmental balance and the sustainability of ecological systems. Climate change, a global environmental issue, has a significant impact on marine and coastal ecosystem (Suryono and Taufiq-Spj, 2026), further to the immune system of marine organism. The ocean plays a crucial role in regulating the Earth's temperatures through its ability to absorb heat and CO2 from the atmosphere. Consequently, over 90% of the heat generated by global warming being absorbed by the ocean (Mulyani, 2021).

Mangrove ecosystems are coastal ecosystems that thrived in transitional areas between land and sea, serving significant ecological functions. In this regard, mangroves provide habitat for a variety of fauna, act as natural coastal protection against abrasion and aid in sediment accumulation. Mangrove ecosystems also have the ability to absorb and store carbon, thus contributing to climate change mitigation (Henriques *et al.*, 2021). This ability is influenced by the unique morphological characteristics of mangroves, including the presence of respiratory roots (pneumatophores) that enable gas exchange between the plant and the environment (Hao *et al.*, 2021).

Organic matter is an important component of mangrove substrates. It is derived from decomposition of leaf

litter, twigs, roots, and the remains of organisms. Organic matter plays a role in determining the physical, chemical and biological properties of the substrate, which influence the fertility and productivity (Machfud *et al.,* 2018) as well as "associate organisms" immunity due to the healthiness of mangrove ecosystem. High organic matter content is generally found in muddy substrates, because the fine sediment fractions are more effective at accumulating organic matter. Environmental factors such as pH, temperature, and salinity also influence the decomposition process and accumulation of organic matter in the sediment. This matter content is closely related to the condition of mangrove vegetation, where high vegetation density results in greater litter production, potentially increasing the accumulation of organic matter in substrate.

Rembang Regency is a coastal area in Central Java that boasts mangrove areas with importance ecological and socio-economic functions. Of the 27 villages in Rembang District, only three villages have mangrove ecosystem i.e. Kabongan Lor, Tireman and Pasarbanggi Village (Nasruddin *et al.,* 2023). Where the villages are surrounded among dens residence along coastal region of Rembang District. The second village (Tireman) is located in the middle area with a mangrove forest areas which also act as a buffer for the other two villages to protect the coast from abrasion and support the activities of the fishing community. Changes in land use, sedimentation, and coastal hydrodynamics have the potential to affect the condition of the mangrove substrate and vegetation. Substrate conditions are a critical factor determining the growth, distribution, and density of mangrove vegetation. Therefore, documentation of mangrove density by analysis of the organic matter content of the mangrove ecosystem substrate in Tireman Village is necessary to determine the condition of sediment fertility and provide scientific information as a basis for sustainable management as well as sustainable conservation of the mangrove ecosystem.

2. Material and methods

2.1 Preparation of alginate oligosaccharides (AOS)

Alginate oligosaccharides (AOS) used in this study were prepared from *Sargassum* sp. following previously published procedures, including alginate extraction (Yudiati *et al.,* 2018) and oxidative depolymerization (Chen *et al.,* 2016), as reported in Rizfa *et al.* (2020). No modifications were applied, and AOS was used directly for the wound-healing experiments.

This research was conducted in the mangrove area of Tireman Village, Rembang (Fig. 1), focusing on mangrove density, organic matter of the substrate and other environmental parameters. The method used was descriptive quantitative through field surveys. Determination of sampling location was carried out using a purposive sampling method based on presence of mangroves stands. Sampling was done at three stations with three plots at each station serving as replicates. For the observation of mangrove vegetation used the line transect method with plot measuring 10 x 10 m, with the distance between plots was 15 m, arranged perpendicular to the coastline. Identification of mangrove species was carried out based on morphological characters with refer to Giesen et al. (2007) and Sidik et al. (2018).

Fig. 1. Study site (station 1, 2 and 3) location map at Tireman Village Rembang

Environmental parameters were measured i.e. temperature, pH, salinity and Dissolved Oxygen (DO). Data analysis included calculating the density of mangrove species and relative density. Sediment samples i.e. 0-10 cm and 10-20 cm were taken for organic matter analysis by using loss on ignition (LoI) method. Sediment samples were first oven-dried e at 105 °C for 48 hours to reach a constant weight, followed by combustion in muffle furnace at 550 °C for 3.5 hours. This procedure is to calculate the

percentage of total organic matter. The organic matter content <3,5% is categorized as very low, 3,5–7% low, 7–17% medium, 17–35% high, and >35% very high (Reynold, 1971).

3. Result

3.1 Condition of Study Area

The mangrove area of Tireman Village is located in the coastal area of Rembang Regency, Central Java (Fig. 1), and is part of the northern coastal ecosystem of Java Island. The mangrove ecosystem in this area thrives in the intertidal zone, influenced by tidal dynamics and river flow from the mainland. Mangroves generally grow in relatively sheltered coastal areas with muddy, clayey, or sandy substrates that experience periodic inundation. Mangrove vegetation found in the Tireman Village i.e. three species of *Rizophora sp.*, *one species of Sonneratia sp.*, and *one species of Avicenia sp.* (Table 2).

3.2 Organic matter in sediment

The organic matter content analysis of mangrove sediment in Tireman Village, Rembang Regency, were analyzed using the Loss on Ignition (LOI) method with heating at 550°C. Almost all stations have medium classification of organic matter, however only in low layer (20-30 cm) sediment at Station II found in low value. Station I had an average organic matter content of 10.95%, Station II 6.82%, and Station III 9.19% (Table 1).

Table 1. Measurement of organic matter in 3 stations of the Mangrove Substrates

Station/ depth	Organic matter (gr)	Organic matter (%)	Classifications
Station I			
ST 1 (0-10 cm)	0.464	9.28	Medium
ST 1 (20-30 cm)	0.631	12.63	Medium
Average	0.547	10.95	Medium
Station II			
ST 2 (0-10 cm)	0.404	8.09	Medium
ST 2 (20-30 cm)	0.277	5.54	Low
Average	0.341	6.82	Low
Station III			
ST 3 (0-10 cm)	0.466	9.32	Medium
ST 3 (20-30 cm)	0.452	9.05	Medium
Average	0.459	9.19	Medium

3.3 Mangrove density level

The results of the mangrove density analysis in the Tireman Village mangrove area showed variations in density levels at each research station (Table 2). Station I had the highest density value of 6000 ind/ha which was dominated by Rhizophora mucronata with a relative density value of 68.89%, and other species such as Rhizophora apiculata, Sonneratia alba, and Avicennia marina were found. Station II had a density value of 1933 ind/ha with a species composition of Rhizophora mucronata, Rhizophora apiculata, Rhizophora stylosa, Sonneratia alba, and Avicennia marina. Meanwhile, at Station III, two types of mangroves were found, namely Rhizophora mucronata and Rhizophora apiculata with a density value of 1400 ind/ha each, resulting in a total density of 2800 ind/ha (Table 2).

Table 2. The results of Mangrove density in every station.

Station/ Species	Σ Individual stands	D (Ind/ha)	RD (%)
Station 1			
Rhizophora mucronata	124	4133.33	68.89
Rhizophora apiculata	46	1533.33	25.56
Sonneratia alba	9	300.00	5.00
Avicennia marina	1	33.33	0.56
Total	**180**	**6000.00**	**100**
Station 2			
Rhizophora mucronata	29	966.67	50.00
Rhizophora apiculata	13	433.33	22.41
Rhizophora stylosa	10	333.33	17.24
Sonneratia alba	3	100.00	5.17
Avicennia marina	3	100.00	5.17
Total	**58**	**1933.33**	**100**
Station 3			
Rhizophora mucronata	42	1400.00	50.00
Rhizophora apiculata	42	1400.00	50.00
Total	**84**	**2800.00**	**100**

3.4 Water parameters

Environmental parameter measurements in the Tireman Village mangrove area indicate that water conditions at all stations remain relatively stable. Water temperature ranges from 27.5–27.9°C, pH between 7.21–7.45, salinity 30–32 ppt, and dissolved oxygen (DO) between 4.53–6.82

ppm. These values indicate that water conditions remain within the range that supports mangrove growth physiologically and ecologically. The results of environmental parameter measurements at each research station can be seen in Table 3.

Table 3. Water parameters measurement at 3 station of Mangrove area in Tireman Village.

Parameters	Station I	Station II	Station III	Unit
Temp.	27.7	27.9	27.5	*℃*
pH	7.33	7.21	7.45	
Salinity	32	32	30	*ppt*
DO	5.24	4.53	6.82	*ppm*

3.5 Relationship between Mangrove Density and Sediment Organic Matter

The results of the study indicate a relationship between mangrove density and sediment organic matter content in the mangrove area of Tireman Village. The results of the linear regression analysis show the equation y = 950.03x - 4959.9 with a coefficient of determination (R^2) of 0.844. This value indicates that mangrove density has an influence of 84.4% on sediment organic matter content, while the remaining 15.6% is influenced by other environmental factors such as current conditions, substrate type, and sedimentation processes. The correlation coefficient (r) value of 0.919 indicates that the relationship between mangrove density and sediment organic matter content is classified as very strong and positive (Table 4 and Figure 2). For the correlation between mangrove density and organic matter in the sediment. As can be seen in Figure 2.

Table 4. The relationship between mangrove density and organic matter in sediment

Station	Density (ind/ha)	Density classification	organic matter in Sediment average (%)	Classification of Organic matter in Sediment
ST 1	6000	High	10.95	Medium
ST 2	1933	Low	6.82	Low
ST 3	2800	Medium	9.19	Medium

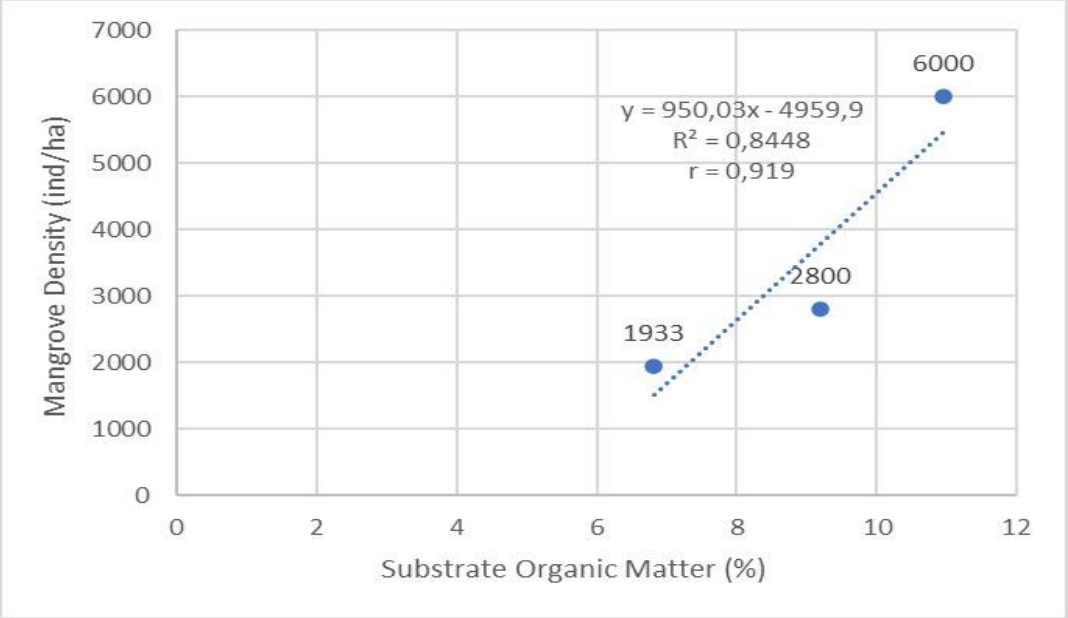

Fig. 2. Correlation between mangrove density and organic matter in the sediment

4. Discussion

Mangrove zoning is generally divided into zones directly adjacent to the sea, transition zones, and zones closer to land which are influenced by variations in substrate and coastal environmental conditions (Lawerissa *et al.,* 2018). The three mangrove species found in the study area are common in tropical mangrove ecosystems. Mangrove root systems plays a role as mechanical trap in capturing sediment and increasing the accumulation of organic matter in the substrate. Good substrate conditions provide nutrients and nutrients that support mangrove growth (Rambu *et al.,* 2019). In addition to natural factors, the condition of the mangrove ecosystem in Tireman Village is also influenced by surrounding land use activities, such as fish and shrimp ponds, salt ponds, and agricultural land. These activities have the potential to contribute organic material to the mangrove ecosystem through surface runoff and rivers. Organic matter in the mangrove substrate generally comes from mangrove litter, the remains of organisms, and decomposed organic material from the land (Machfud *et al.*, 2018).

Based on Ramdani's (2025) classification, the values of organic matter in the mangrove sediment fall into low to moderate category (Table 1). The differences in organic matter content between stations indicate variations in substrate conditions and the intensity of organic matter accumulation in the mangrove ecosystem. The higher organic matter content at Station I is thought to be related to the greater contribution of mangrove litter as a source of autochthonous organic matter derived from fallen leaves, twigs, and other decomposing vegetative parts. Furthermore,

allochthonous organic matter originating from land runoff and coastal activities can also influence the dynamics of organic matter in the sediment (Putri *et al.,* 2024). Mangrove sediments act as a medium for organic matter accumulation, thus supporting the ecological function of coastal ecosystems (Hariyadi and Effendi, 2016).

Sediment organic matter content is also related to mangrove vegetation density, which influences litter production and organic matter accumulation. Station I, with its higher organic matter content, is thought to be associated with greater mangrove density, thus increasing the supply of organic matter from vegetation (Hickmah *et al.,* 2021). In another words, the highest OM at 10-30 cm sediment layer of station I, also indicated as a carbon burial due to the mangrove density has been sequestering carbon effectively over a long period. Conversely, the lower organic matter content at Station II indicates a relatively smaller litter input. In general, sediment organic matter content in Tireman Village remains within a range that supports the ecological function of mangroves and plays a role in sedimentary carbon storage as part of the blue carbon ecosystem (Aldiano and Wijaya, 2022).

Differences in density values between stations indicate variations in mangrove vegetation structure that influence coastal ecosystem dynamics. Station I, with the highest density, exhibits denser vegetation conditions, potentially producing greater amounts of biomass and litter as sources of autochthonous organic matter (Putri *et al.,* 2024). Dense mangrove vegetation can also slow currents and increase the deposition of organic matter and sediment in the substrate (Sektyambodo *et al.,* 2020). Conversely, the lower density at Station II indicates a lower potential for organic matter accumulation. The dominance of Rhizophora mucronata at the study site also plays a role in increasing organic matter accumulation due to its complex root system and high litter production (Syah, et al. 2024).

In general, mangrove density in Tireman Village is related to the distribution of sedimentary organic matter, with stations with higher densities tending to have higher organic matter content. Dense mangrove stands play a crucial role in trapping organic matter and supporting the mangrove ecosystem's function as a blue carbon sink and coastal protector (Susanto *et al.,* 2021; Sulistiana *et al.,* 2017). However, the presence of fish farms and agricultural rice fields, can contribute nitrates and phosphates that can stimulate mangrove growth, which in turn increases litterfall. This indicates that mangrove vegetation density is a crucial factor in maintaining the stability and sustainability of mangrove ecosystems in coastal areas. From the species found i.e *Rhizophora* sp. and *Avicennia* sp., due commonly presence in other ecosystems (Agustini *et al.,* 2016; Hao *et al.,* 2021; Hickmah *et al.,* 2021), seems match to the expected zonation for Central Java.

Indication water temperatures was quite similar among 3 stations of study area (Table 3). Relatively stable water temperatures play a role in controlling the metabolic activity of mangrove vegetation and the decomposition of organic matter in the sediment (Fynnisa *et al.,* 2024). A pH value close to neutral also supports the activity of decomposing microorganisms that play a role in the mineralization of organic matter (Table 3). This condition is related to ability of micro-organism in accepting the hidrogen ion concentration for their metabolic rate (Jin and Kirk, 2018) Relatively homogeneous salinity indicates a consistent tidal influence in coastal areas, while a relatively good DO value indicates that the waters are still able to support the respiration process of organisms around the mangrove ecosystem (Schaduw, 2018). Ecologically, stable environmental parameters can support the growth of mangrove vegetation and increase litter production as a source of organic matter in the sediment. Dense mangrove vegetation also plays a role in slowing currents and increasing the deposition of organic matter in the substrate (Agustini *et al.,* 2016). Thus, the environmental parameters in Tireman Village generally still support the ecological function of the mangrove ecosystem and the accumulation of organic matter in the sediment.

The correlation coefficient between organic matter and mangrove density shows a strong positive value, i.e. r = 0.919 (Fig. 2). Ecologically, stations with higher mangrove densities tend to have higher sediment organic matter content or vice versa. Station I, with a density of 6,000 ind/ha, had an average organic matter content of 10.95%, while Station II, with a density of 1,933 ind/ha, had a lower organic matter content of 6.82%. This condition indicates that the higher the mangrove vegetation density, the greater the accumulation of organic matter in the sediment. This is related to the production of mangrove litter, such as leaves, twigs, and other vegetative parts, which decompose and produce autochthonous organic matter (Audina *et al.,* 2021).

Furthermore, the dense mangrove root system can slow currents and enhance the ecosystem's ability to trap allochthonous organic matter from the surrounding land and waters. The combination of autochthonous and allochthonous organic matter leads to increased organic matter accumulation in mangrove sediments (Zhu and Yan., 2022; Safira and Rusdiana, 2025). Thus, mangrove vegetation density plays a crucial role in controlling sedimentary organic matter dynamics and supporting the mangrove ecosystem's function as a blue carbon sink in coastal areas (Zhu and Yan, 2022; Ismail *et al.,* 2023).

5. Conclusions

Based on the research results, the organic matter content of sediment in the mangrove ecosystem of Tireman Village, Rembang Regency, Central Java is in the low to moderate category i.e. 6.82% to 10.95%, Mangrove density at the research location also showed variations between stations, where the highest density found at Station I (6000 ind/ha), and the lowest found at Station II (1933 ind/ha). The linear regression analysis showed a very strong positive relationship between mangrove density and sediment organic matter content with a coefficient of determination (R^2) of 0.844, and a correlation coefficient (r) of 0.919. The findings demonstrate that the higher the mangrove density corelated to organic matter content. Specifically, due to the high litter production and the ability of mangrove vegetation to retain sediment, resulting in increased organic matter in the substrate, and vice versa. Furthermore, although autochthonous processes appear dominant such as carbon sequestration (blue carbon), allochthonous processes of organic material sources are also contribute to influencinng mangrove performance, and furthermore for Central Java coastal area management

Ethics approval

No permits were required.

Data availability statement

The data use is merely taken by authors which conducted during Oct – Nov 2025. This is part of student dissertation hence the second and third authors were actively involved in this study.

Author contributions

The second author conduct as corresponding authors provide details of co-author contributions to this manuscript. The First (1st), second (2nd) and third (3rd) Authors together made and discuss conceptualization and methodology as well as role of writing. Data curation, software, is merely done by the 1st author. Formal analysis by 2nd author, while project administration and resources were done by 3rd author. For the review editing was done by corresponding (2nd) author.

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Declaration of competing Interest

None

References

Agustini, N. T., Ta'alidin, Z. dan Purnama, D., 2016. Mangrove community structure in Kahyapu village, Enggano Island [INDONESIAN]. *Jurnal Enggano*, 1(1): 19-31.

Aldiano, R. R. dan Wijaya, N. I., 2022. Sedimentary Organic Carbon Estimation in the Gunung Anyar Mangrove Ecosystem, Surabaya [INDONESIAN]. *Jurnal Riset Kelautan Tropis (Journal Of Tropical Marine Research)(J-Tropimar)*, 4(2): 111-123.

Audina, M., Siregar, S. H. dan Amin, B., 2021. The Relationship between Organic Material Content in Sediment and Morphometrics of Mangrove (*Rhizophora apiculata*) in the Western Mangrove Ecosystem of Dumai City, Riau Province [INDONESIAN].. *Jurnal Perikanan Dan Kelautan*, 26(1): 54-61.

Fynnisa, Z., Nugroho, E. D., Sakaria, F. S., Juniatmoko, R., Sinurat, J., Polapa, F. S., ... dan Setyono, B. D. H., 2024. Aquatic Ecology [INDONESIAN]. Widina Pub.

Giesen, W., Wulffraat, S., Zieren, M. and Scholten, L., 2007. Mangrove guidebook for Southeast Asia. Mangrove guidebook for Southeast Asia. FAO and Wetlands International. Dharmasarn Co., Ltd. Bangkok. 781 pp.

Hao, S., Su, W., dan Li, Q. Q., 2021. Adaptive Roots of Mangrove *Avicennia marina*: Structure And Gene Expressions Analyses of Pneumatophores. *Science of The Total Environment*, 757.

Hariyadi, S. dan Effendi, H., 2016. Determiation of Coastal Water Quality Status [INDONESIAN]. Institut Pertanian Bogor, Bogor, 55.

Henriques, M., Granadeiro, J. P., Piersma, T., Leão, S., Pontes, S. dan Catry, T. 2021. Assessing The Contribution of Mangrove Carbon and of Other Basal Sources to Intertidal Flats Adjacent to One of The Largest West African Mangrove Forests. *Marine Environmtntal Research*, 169, 105331.

Hickmah, N., Maslukah, L., Wulandari, S. Y., Sugianto, D. N. dan Wirasatriya, A., 2021. Study of Organic Carbon Stock in Sediment in the Karimunjawa Mangrove Vegetation Area [INDONESIAN]. *Indonesian Journal of Oceanography*, 3(4): 419-426.

Ismail, R. E., Najamuddin, N. A., Inayah, E. S., Wibowo, A. A. S., dan Harahap, Z. A., 2023. Sedimentary Carbon Stores Under Stands of Natural Mangrove Species And Rehabilitated Mangrove. *Jurnal Ilmu Kelautan Kepulauan*, 6(1): 803-814.

Jin Q and Kirk MF. 2018. pH as a Primary Control in Environmental Microbiology: 1. Thermodynamic Perspective. *Front. Environ. Sci*. 6: 21. doi: 10.3389/fenvs.2018.00021

Lawerissa, Y. A., Sangaji, M. dan Latumahina, M. B., 2018. Mangrove Management Based on Substrate Type in the Waters of Ihamahu State, Saparua Island [INDONESIAN]. *Jurnal Triton*, 14(1): 1-9.

Machfud, Y., Mulyani, O., Setiawan, A., Trinurani, E. and Joy, B., 2018. Introduction to Local Organik Material Sources in Ciparay Village [INDONESIAN]. *Jurnal Pengabdian Kepada Masyarakat*, 2(8):84-87.

Mulyani, A. S., 2021. Antisipasi Terjadinya Pemanasan Global Dengan Deteksi Dini Suhu Permukaan Air Menggunakan Data Satelit. *Journal CENTECH*, 2(1), 22-29.

Nasrudin, A. R., Pamaharyani, L. I., Samsidar, S., Ananda, Y. Y. T. dan Wardana, N. K., 2023. Recommendations For Fisheries Extension Strategies In Mangrove Management On The Dimensions Of Organizing Fisheries Extension In Rembang Sub-District. *Aurelia Journal*, 5(2): 379-388.

Putri, K. A., Ulumuddin, Y. I., Maslukah, L. dan Wulandari, S. Y., 2024. Organic Carbon Stock of Mangrove Sediments in Segara Anakan Lagoon [INDONESIAN]. *Buletin Oseanografi Marina*, 13(2): 279-290.

Ramadhan, F. S., 2025. Mangrove Comunity Structure in Kabongan Lor Village, Rembang Regency, Central Java Province. [INDONESIAN]. Undip Repository. https://eprints2.undip.ac.id/id/eprint/32518/1/FADHIL%20SYARIF%20RAMADHAN%2025dik61.pdf

Rambu, L. P., Runtuboi, F. dan Loinenak, F. A., 2019. Keragaman dan Distribusi Mangrove Berdasarkan Tipe Substrat di Pesisir Pantai Kampung Syoribo Distrik Numfor Timur Kabupaten Biak Numfor Provinsi Papua [INDONESIAN]. *Jurnal Sumberdaya Akuatik Indopasifik*, 3(1): 31-44.

Reynold, S. C., 1971. A Manual of Introductor Soil Science and Sampel Soil Analisys Metods, Ed. 2. North Pacific Commision, California.

Safira, D. A., and Rusdiana, O., 2025. Variation of Soil Texture and Organic Matter Based on Canopy Density A Case Study in the Muhammad Sabki City Forest, Jambi City [INDONESIAN]. *Jurnal Silva Tropika*, 9(1): 32-43.

Schaduw, J. N. W., 2018. Distribution and Characteristics of Water Quality in the Mangrove Ecosystem of the Kecil Island of Bunaken National Park

[INDONESIAN]. *Majalah Geografi Indonesia*, 32(1): 40-49.

Sektyambodo, B. M., Sanjoto, T. B. dan Juhadi, J., 2020. Analysis of Vegetation Density on Morphodynamic Processes in the Comal River Delta [INDONESIAN]. Geo-Image Journal, 9(2): 104-113.

Sidik F., Wigati NN., Zaki AR., Hidayat J.J., Kadarisman HP., Islamy F. 2018. Perancak Estuary Mangrove Guide [INDONESIAN]. Balai Riset Observasi Laut. Minister of Marine Affair and Fisheries. 83 pp. http://www bpol litbang kkp.go.id

Sulistiana, S., 2017. The Potential of Mangroves as Indonesia's Blue Carbon for Sustainable Development [Indonesian]. SDGs, 281, 303. https://repository.ut.ac.id/7472/1/13Susi% 20Sulistiana.pdf

Suryono S., Taufiq-Spj, N. 2026. Coastal Resources, Potential and Inventory [Indonesian]. First Ed. *Undip Press*, Semarang, 181 pp

Susanto, S. A., Qayim, I. dan Triadiati, T., 2021. Characteristic of Fallow Land of Differet Ages and Their Effect on Litter Decomposition in Manokwari, West Papua [Indonesian]. *Jurnal Tanah dan Iklim*, 45(2): 117-132.

Syah AF., Basyuni M., Fernanda O., Rahmawati E. 2024. Assessment of mangrove ecosystem conditions in Sepulu District, Bangkalan. 1st TMIC 2023. E3S Web of Conferences 499, 01011. https://doi.org/10.1051/e3sconf/202449901011

Zhu, J. J. and Yan, B., 2022. Blue Carbon Sink Function and Carbon Neutrality Potential of Mangroves. Science of The Total Environment, 822.