Mangrove Litterfall and Its Carbon Contribution: A Study on Coastal Carbon Reserves in Sungai Nibung Village, West Kalimantan

Mega Sari Juane Sofiana[1], Ikha Safitri[1]*, Tomi Mardianto[1], Arthur Muhammad Farhaby[2]

[1]Marine Science Department, Faculty of Mathematics and Natural Sciences, Universitas Tanjungpura
Jl. Prof. Dr. H. Hadari Nawawi, Pontianak, Kalimantan Barat 78124 Indonesia
[2]Aquatic Resources Management Department, Faculty of Agriculture Fisheries and Marine, Universitas Bangka Belitung
Balun Ijuk, Kabupaten Bangka, Kepulauan Bangka Belitung 33172 Indonesia
Email: isafitri@marine.untan.ac.id

Abstract

Mangroves play an essential ecological roles, such as providing habitats for various organisms and contributing to reducing CO_2 emissions from human activities. These emissions are one of the main causes of global warming and climate change. This study aims to analyze the litter production rate and carbon content of mangrove litter in Sungai Nibung Village, Kubu Raya Regency, West Kalimantan. Sampling of mangrove litter was conducted for 14 days using a 1x1 m^2 litter trap with a mesh size of 0.2 cm. The litter traps have been placed in 9 stations. Litter samples were collected on the 7^{th} and 14^{th} days, including parts of mangroves (leaves, twigs, flowers, and fruits) that naturally fell. Result of the study showed the total litter production rate ranged from 4.95 to 30.07 tons/ha/year, and the findings reveal a clear hierarchy in litter production with the composition being leaves > twigs > propagules/fruits > flowers. Leaves litter production rate is notably high, followed by twigs which represent the second-largest portion, then fruits, and flowers. Meanwhile, the total carbon content varied across sampling station, accounting for 2.30–23.59 tons/ha/year. This research provides essential baseline data for Sungai Nibung Village and highlights the potential of mangroves as significant carbon sinks. The results can be utilized for ecosystem-based coastal management and mangrove restoration aligned with regional environmental policies.

Keyword: *Litter Production, Mangroves, Organic Carbon*

INTRODUCTION

Sungai Nibung Village, located in Kubu Raya Regency, West Kalimantan, covers an area of approximately 75.33 km² (BPS Kubu Raya Regency, 2023). Recognizing its ecological importance, the village has been designated as one of West Kalimantan's conservation areas under Regional Regulation No. 1 of 2019 and the Minister of Marine Affairs and Fisheries Decree No. 92/Kepmen-KP/2020. Among the key conservation priorities in this region is the mangrove ecosystem, which spans ±3,058 ha and plays a critical role in maintaining coastal stability, supporting biodiversity, and contributing to global carbon sequestration. Previous studies have documented 18 mangrove species thriving in the area, with dominant genera including *Avicennia*, *Rhizophora*, *Bruguiera*, *Sonneratia*, and *Nypa* (Safitri *et al*., 2024).

Mangrove forests play a crucial ecological role in maintaining the stability and resilience of coastal ecosystems. These unique intertidal forests serve as natural buffers, protecting shorelines from erosion, storm surges, habitat for marine and terrestrial fauna, and rising sea levels (van Hespen *et al*., 2023) underscoring the significance of conservation and sustainable management efforts in Sungai Nibung Village. One of their most significant functions is acting as a highly efficient carbon sink (Choudhary *et al*., 2024), which helps mitigate the impacts of global climate change. Due to their ability to sequester and store large amounts of carbon over long periods, mangrove ecosystems are recognized as an essential component of the global carbon cycle. Research has shown that mangrove forests can absorb up to three times more carbon compared to other forest types, making them one of the most effective ecosystems for carbon storage and climate regulation (Kauffman and Donato, 2012). This high carbon sequestration capacity is attributed to their rapid growth, high productivity, and ability to trap organic material in waterlogged soils, which slows down

Diterima/Received : 03-02-2025, Disetujui/Accepted : 03-03-2025
DOI: https://doi.org/10.14710/jkt.v28i1.25902

decomposition and enhances long-term carbon storage. Mangroves absorb atmospheric CO_2 and convert it into carbohydrates and oxygen through the process of photosynthesis (Quitain, 2024). Studies indicate that mangrove forests can store up to 1,528.8 MgC/ha (Stankovic *et al*., 2023), reinforcing their role as a major carbon reservoir. The carbon captured is then stored in different components of the mangrove ecosystem, including living biomass (leaves, twigs, flowers, and fruits), sediment, and decomposing litter.

Among these, mangrove litter generally contains lower carbon content than biomass and sediment. The composition of litter, which includes carbohydrates, water, and other minerals, significantly influences its carbon storage capacity. Mangrove species with higher lignin and cellulose concentrations tend to produce litter with a greater carbon content compared to species with softer tissue structures, which decompose more rapidly and release carbon back into the environment (Rajaras *et al*., 2023). A study by Islamiah *et al*. (2022) estimated that the average carbon production from mangrove litter is 4.09 tons/ha/year, with variations among species and environmental conditions. Specifically, Zone dominated by *Avicennia*, produces 2.40 tons/ha, while Zone with mainly *Rhizophora* contributes 5.66 tons/ha, and Zone dominated by *Bruguiera* generates 4.23 tons/ha of carbon. These variations highlight the differences in litterfall production and decomposition rates across different mangrove species and habitats.

Despite the high mangrove species diversity in the coastal ecosystem of Sungai Nibung Village, data on the estimated carbon stock in mangrove litter remains scarce. Mangrove litter, composed of leaves, twigs, flowers, and fruits, plays a fundamental role in the carbon cycle by acting as a temporary carbon reservoir before decomposing and contributing to nutrient cycling. However, there has been no specific research dedicated to analyzing the carbon content of mangrove litter in Sungai Nibung Village, leaving a significant gap in understanding the ecological dynamics of this region. Addressing this gap is essential for evaluating the role of mangrove litter in long-term carbon sequestration and improving conservation strategies. Given the importance of mangrove ecosystems in mitigating climate change and supporting biodiversity, this study aims to estimate the production rate and carbon content of mangrove litter in Tanggul River, Sungai Nibung Village, Kubu Raya Regency, West Kalimantan.

MATERIAL AND METHODS

This study was conducted from March 24 to April 7, 2024, in the mangrove area of Tanggul River, Sungai Nibung Village, West Kalimantan (Figure 1). Mangrove litter samples, including leaves, twigs, flowers, and fruits, were collected over 14 days (on the 7th and 14th days) at 8 sampling stations.

Mangrove Litter Collection

The sampling points were determined using the systematic sampling method, with stations placed 500 m apart. At each station, litter traps were installed to collect mangrove litter samples. The traps used were 1x1 m^2 in size with a mesh size of 0.2 cm, positioned 1.5 meters above the ground (Figure 2) to minimize the effects of tidal fluctuations. Over a 14-day period, litter samples were collected every 7 days. The collected mangrove litter samples were then transported to the laboratory for subsequent analysis.

Treatment of Mangrove Litter Samples

The litter samples, collected on days 7 and 14, were immediately weighed to determine their wet weight. Next, in the laboratory, the samples were then carefully wrapped in aluminum foil and placed in an oven set to a temperature range of 70–105°C for 24 hours to dry, until a constant weight was achieved, in accordance with SNI 7724:2019. The samples were dried until they reached a constant weight, ensuring that all moisture was removed. This drying process allowed for the accurate determination of their dry weight. Subsequently, the carbon content of the dried samples was quantified using the methodology described by Farhaby *et al*. (2023).

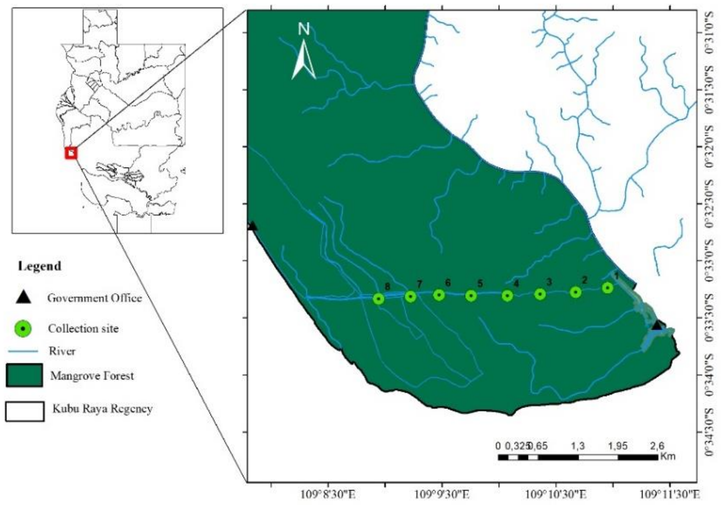

Figure 1. Sampling Location of Mangrove Litterfall and Its Carbon in Sungai Nibung Village, West Kalimantan

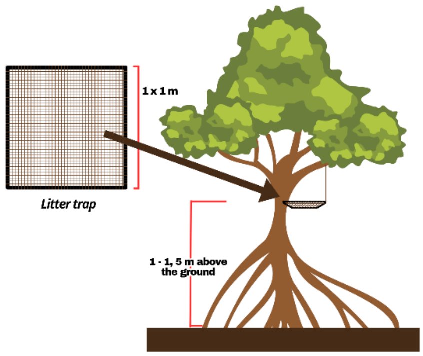

Figure 2. Illustration of Mangrove Litter Collection (adopted from Farhaby *et al*., 2023)

Data Analysis

The rate of mangrove litter production can be calculated using the formula by Dali (2023):

$$X = \frac{W}{A}$$

where X is litter production over a specific time period (g/m²/day), W is dry weight of litter fallen in the litter trap (g), and A is area of the litter trap (1 m²). The organic material (BO) is calculated using the following formula:

$$\mathrm{BO} = \frac{Bks\ x\ Bbt}{Bbs}$$

Where BO is weight of organic material (g), Bks is dry weight of the sample (g), Bbt is total wet weight (g), and Bbs is wet weight of the sample (g). The calculation of mangrove litter carbon content is performed using the following equation:

$$C = BO \times \%C_{org}$$

Where C is carbon concentration (g/m²/day), BO is organic material weight (g), and $\%C_{org}$ is percentage of carbon content (0.47). The data were then statistically analyzed using the Kruskal-Wallis test with a 95% confidence level.

RESULTS AND DISCUSSION

In the mangrove area of Tanggul River, leaves are the dominant component of the litter, ranging from 53.62 to 93.06% across all sampling stations, with an average of 77.75%. The percentage of litter components was followed by twigs (4.13-42.80%), flowers (1.21-45.17%), and fruits (1.21-17.62%) (Table 1). This pattern is consistent with several studies that reported leaves as the main component of litter production in mangrove ecosystems (Rafael and Calumpong, 2018; Dali *et al*., 2023). Purnobasuki *et al*. (2022) reported that leaves accounted for 76.26–78.53% of the mangrove litter in Surabaya East Coast, followed by twigs (9.43-13.27%) and reproductive parts such as flowers and fruits (8.20-14.31%). Similar results have been observed in various mangrove ecosystems across Indonesia, where leaves are consistently the dominant litter component (Pradisty *et al*., 2022; Khoirunisa *et al*., 2022; Rumondang *et al*., 2023; Selviani *et al*., 2024).

In general, the litter production for mangrove forests is estimated to range from 1-20.30 tons/ha/year (Rafael and Calumpong, 2018). The litter production observed in this study is higher compared to previous study in the mangrove areas of Mendalok Village (24.08 tons/ha/year) (Islamiah *et al*., 2022) and Setapuk Besar Village (3.35–27.04 tons/ha/year) (Darwati and Destina, 2022). Several factors can influence litter production, including the composition and density of mangrove species (Ahmed and Kamruzzaman, 2021), air temperature, wind speed, rainfall, salinity levels, freshwater input (Souza *et al*., 2019; Pradisty *et al*., 2022; Dali *et al*., 2023), and geographic location (Clough *et al*., 2000).

According to data from the Meteorology, Climatology, and Geophysics Agency of West Kalimantan (2024), the air temperature at the study site during data collection ranged from 30.6 to 31.5°C, belonged to the rainy season. Temperature is considered as a key factor influencing mangrove litter production. During dry season, high temperatures and low rainfall lead to reduced litter fall, due to the tree being water-stressed, which limits the number of leaves drop. Conversely, in the rainy season, high rainfall and humidity encourage higher litter production (Sukardjo *et al*., 2013). Conversely, during the rainy season, increased rainfall and humidity encourage higher litter production, due to an increase in physiological processes in mangrove plant (Sukardjo *et al*., 2013). At the study site, the average daily rainfall was relatively high at 15.86 mm/day during data collection (BMKG West Kalimantan, 2024), suggesting that precipitation may have played a significant role in increasing mangrove litter production in Sungai Nibung Village. This is supported by findings from Teutli-Hernández *et al*. (2024), who reported that rainfall significantly influences mangrove litter production, with the highest litterfall occurring during high rainfall. Although rainfall and wind speed are important environmental drivers of litterfall, their relationship with litter production is often complex and influenced by multiple interacting factors. Salinity fluctuations, sunlight intensity, soil nutrient composition, tidal inundation frequency, and mangrove species composition and density, also contribute significantly to variations in litter production (Dewiyanti *et al*., 2021; Torres *et al*., 2022).

Wind speed plays a crucial role in influencing the rate of mangrove litter production. Strong winds can increase the amount of fallen litter by causing mechanical damage to the mangrove canopy (Sukardjo, 2014). During the study periods, meteorological data from BMKG recorded an

Table 1. Percentage of Mangrove Litter in Tanggul River, Sungai Nibung Village

Litter Component	Mangrove Litter Percentage (%)							
	I	II	III	IV	V	VI	VII	VIII
Leaves	90,09	93,06	79,27	92,53	53,62	88,08	68,18	57,20
Twigs	4,13	0	6,56	0	0	10,14	14,20	42,80
Flowers	5,78	2,83	1,46	1,21	45,17	0	0	0
Fruits	0	4,11	12,71	6,26	1,21	1,78	17,62	0

average wind speed of 0.97 m/s. While this wind speed is relatively low and unlikely to cause significant mechanical damage, it can still contribute to the detachment of senescent or weakened plant parts, particularly leaves, which may have already reached the final stages of their life cycle. Salinity also plays a significant role in regulating mangrove litter production. Field measurements in the mangrove area of Tanggul River, showed salinity levels ranging from 10 to 13 ppt. High salinity increases osmotic pressure on mangrove trees, affecting their photosynthetic capacity and inhibiting growth, which can lead to a reduction in litter production. In contrast, lower salinity levels generally promote optimal mangrove growth, resulting in higher litterfall. Water availability is another key factor influencing plant physiology, including growth, metabolism, and biomass productivity. Research by Milovančević *et al*. (2024) reported that water deficiency reduces plant height, leaf area, and root length. In mangrove ecosystems, an adequate water supply supports photosynthesis and biomass formation, leading to increased litter accumulation. Conversely, during the dry season, limited water availability can cause physiological stress, restricting biomass growth and reducing litter production.

The total litter production varied across sampling stations, ranging from 4.95 to 30.07 tons/ha/year (Figure 3). Among all stations, station III recorded the highest litter production rate, while station VIII had the lowest. This variation is likely influenced by differences in species composition and mangrove density at each location. Stations I to VII were dominated by *Rhizophora*, known for their high stand density (Manurung, In Press), which significantly contributed to the higher litter production rates. Islamiah *et al*. (2022) found that mangrove forests dominated by *Rhizophora* had a higher litter production rate (11.10 tons/ha/year) compared to *Bruguiera* (8.28 tons/ha/year) and *Avicennia* (4.71 tons/ha/year). Similarly, Selviani *et al*. (2024) reported that *Rhizophora mucronata* produced litter up to 69.62 tons/ha/year, while Khoirunisa *et al*. (2022) found that *R. stylosa* and *R. apiculata* had production rates of 25.81 tons/ha/year and 20.73 tons/ha/year, respectively. Several factors contribute to the higher litter production in *Rhizophora*-dominated areas. One key factor is their dense canopy structure and large leaf biomass, which leads to a higher rate of leaf removal (Hilyana and Rahman, 2022). The physiological characteristics of *Rhizophora* species, including their leaf morphology, also influence litter production rates. Studies have shown that larger and thicker leaves, as found in *Rhizophora* species (Putri and Bashri, 2023), enhance photosynthetic efficiency by capturing more sunlight. This increased photosynthetic activity supports greater biomass accumulation, ultimately leading to higher litterfall. Moreover, the structural properties of *Rhizophora* leaves make them more susceptible to environmental factors such as wind and rainfall. Andrianto *et al*. (2015) and Mulya and Arlen (2018) reported that *R. apiculata* and *R. mucronata* exhibit high litter production due to their larger leaf size, which makes them prone to mechanical damage, accelerating leaf abscission. During periods of strong winds or heavy rainfall, these species tend to experience more rapid leaf shedding, further increasing their contribution to litterfall. Additionally, *Rhizophora* species have relatively high photosynthetic capacity (Chen *et al*., 2022; Pascoalini *et al*., 2022). Efficient photosynthesis enables greater carbohydrate and energy production, which supports plant growth and the development of various tissues, including leaves, twigs, flowers, and fruits (Menzel, 2005).

Station VIII recorded the lowest litter production rate at 4.9 tons/ha/year, which is considered closely linked to the dominance of *Excoecaria agallocha* in this area. This species is reported to have low growth rates (Kader and Sinha, 2022; Chowdhury *et al*., 2023), less number of branches, and tend to have lower photosynthetic ability (Dasgupta et al., 2011), all of which contribute to reduced biomass production. Additionally, *E. agallocha* has leaves with a longer lifespan (Basyuni et al., 2018), leading to a lower frequency of leaf turnover, resulting in lower litter production rates. Beyond species characteristics, structural attributes of the mangrove stand also influence litter production. Tree diameter and height are significant factors affecting litterfall dynamics (Dali *et al*., 2023). Moreover, mangrove density plays a crucial role in determining the quantity of litter produced. Areas with higher tree density typically exhibit greater litterfall due to increased leaf shedding and biomass turnover (Widhitama *et al*., 2016; Dali *et al*., 2023). Study conducted by Mulya and Arlen (2018) in the Karang Gading mangrove area, sites with high mangrove density (1,200 ind/ha) recorded a litter production rate of 0.035 g/ha/day, whereas locations with lower density (766.67 ind/ha) had a significantly lower rate of 0.029 g/ha/day.

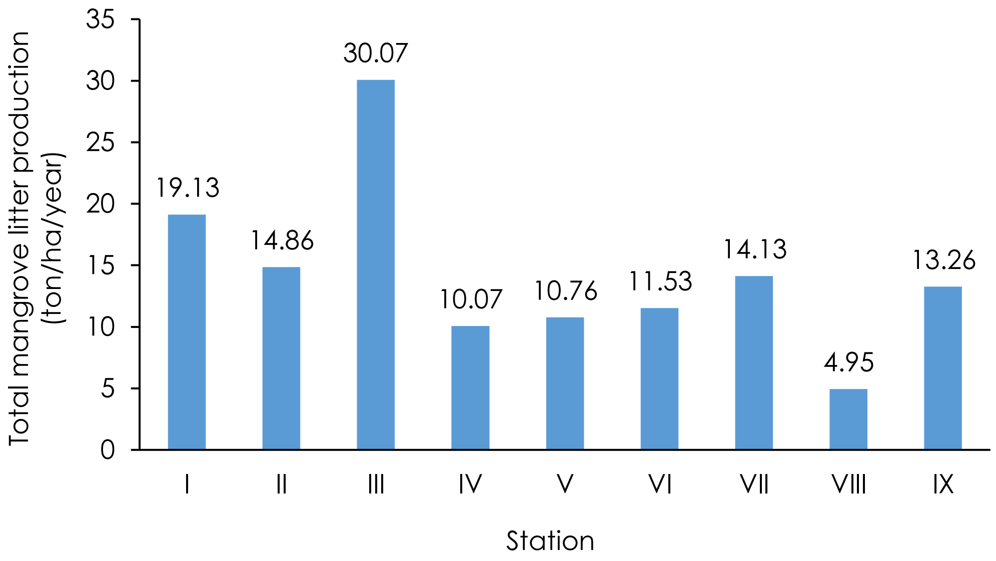

Figure 3. Total Mangrove Litter Production in Tanggul River, Sungai Nibung Village

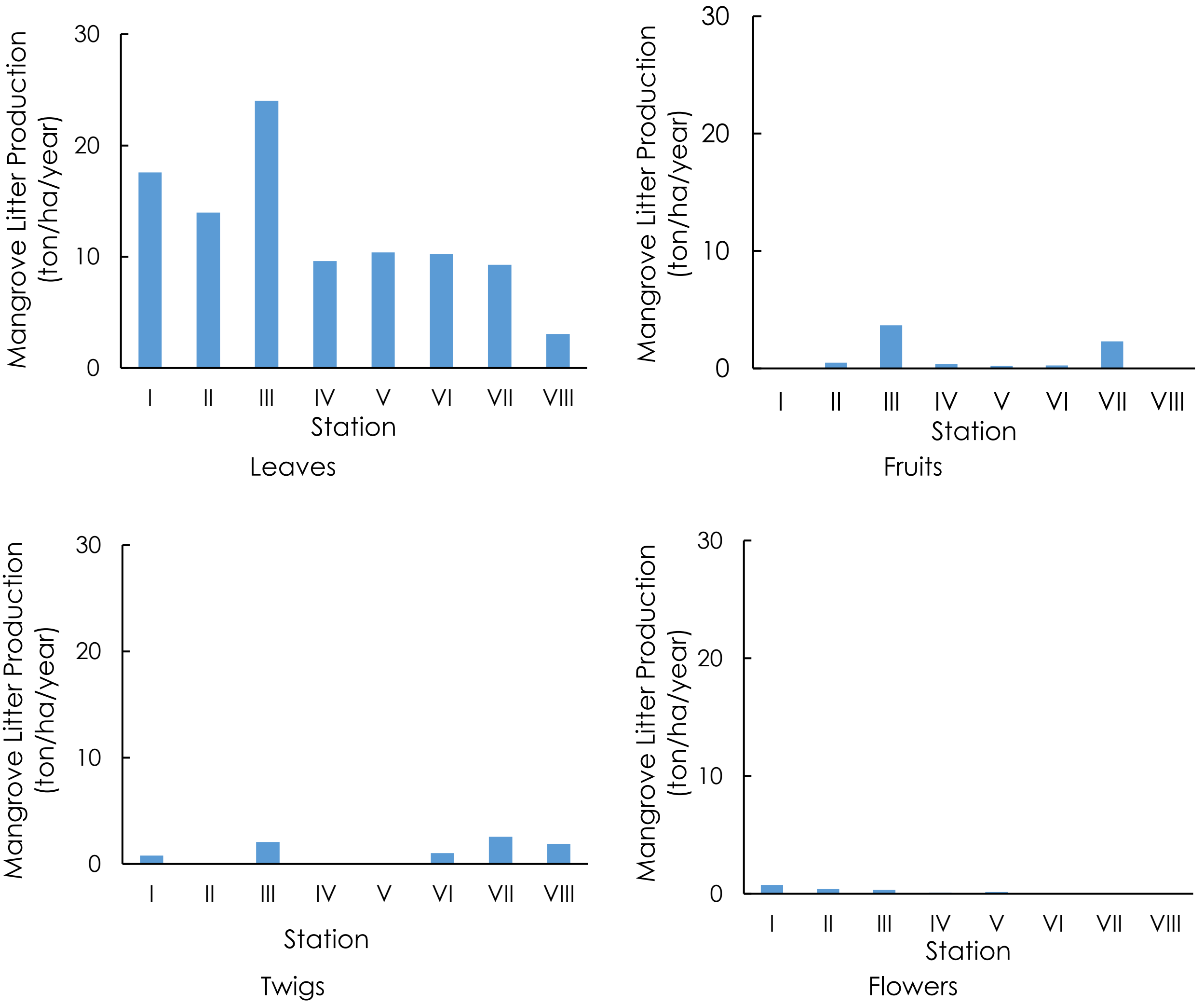

Figure 4. Litter Production of Each Mangrove Part in Tanggul River, Sungai Nibung Village

The findings of the study reveal a clear hierarchy in litter production, with leaves > twigs > propagules/fruits > flowers. The rate of leaf litter production is notably high, ranging from 3.06 to 24.01 tons/ha/year, followed by twigs (0.79-2.55 tons/ha/year) represent the second-largest portion, while fruits account for 0.21-3.67 tons/ha/year, and flowers contribute between 0.09-0.75 tons/ha/year (Figure 4). Leaves are highly exposed to environmental factors such as to wind, rain, and sunlight as they have a large surface area. This exposure significantly accelerates the leaf shedding process, resulting in higher shedding rates (Lenz *et al*., 2021). Compared to the stem or roots, leaves have a generally accelerated life cycle. Leaves are regularly shed and replaced with new leaves to optimize photosynthesis (Russo and Kitajima, 2016; Tanaka *et al*., 2018). Leaves are also often shed due to age, environmental stress, and external disturbances such as rainfall and wind speed. In comparison, flowers are the part that has the lowest litter production rate with an average value of 0.34 tons/ha/year. This is largely due to their relatively small size, shorter lifespan, and limited number. In addition, flower production normally occurs within a certain period associated with the reproductive phase of the plant, making its contribution to total litter smaller than other plant parts that are present throughout the year, such as leaves and twigs.

Carbon content in plants provides valuable insight into how efficiently a plant can absorb CO_2 from the atmosphere. A portion of this carbon is utilized for energy in various physiological processes, while the remaining carbon is incorporated into the plant's structure, contributing to growth and development (Heriyanto and Subiandono, 2012). Mangrove forests are particularly significant in terms of carbon storage, both in biomass and in litter. The findings from this study about organic carbon content in mangrove litter in Tanggul River, Sungai Nibung Village, showed values ranging from 0.04-13.16 tons/ha/year. The data were non-homogeneous and not normally distributed, therefore the Kruskal-Wallis test was used. The results of the Kruskal-Wallis test on mangrove litter carbon content show an Asymp. Sig. value of 0.00 (< 0.05), indicating a significant difference in carbon content among the litter components (Table 2). The results are notably higher compared to a similar study conducted in Mendalok Village West Kalimantan, where the organic carbon content of mangrove litter was found to be 12.29 tons/ha/year (Islamiah *et al*., 2022). Globally, mangrove forests are recognized as one of the most efficient carbon sinks, with an average carbon storage capacity of approximately 885 tonsC/ha/year. In Indonesia, where mangrove ecosystems are extensive, they have the potential to store around 950.5 tonsC/ha/year (Alongi *et al*., 2016).

In this study, the lowest total organic carbon content in mangrove litter was found at station VIII (2.30 tons/ha/year), while the highest value was recorded at station VII (23.59 tons/ha/year). This difference can primarily be attributed to variations in the dominant litter types at each station. At station VII, the high carbon content was largely driven by branch litter, which generally has a higher carbon storage capacity compared to leaf litter. Branches are more complex and denser in structure, composed of woody tissue that contains higher concentrations of lignin, cellulose, and hemicellulose (Yang *et al*., 2007) compared to leaves or fruits. Specifically, branches are made up of approximately 40-43% lignin, 15-20% cellulose, and 20-35% hemicellulose (Wang *et al*., 2024), all of which play important roles in carbon storage and decomposition. Additionally, branches tend to have a longer lifespan and decompose more slowly than other litter components. The decomposition of lignin and cellulose in branch litter is particularly slow, with 39.82-49.84% of the lignin and 15.77-21.34% of the cellulose remaining after the decomposition process (Wu *et al*., 2022). Furthermore, branch litter typically has a lower water content than leaf or fruit litter. When the water content in plant tissue is low, the proportion of organic compounds like lignin, cellulose, and hemicellulose increases, contributing to a higher organic carbon content. In contrast, while leaf litter has a higher rate of production, it tends to contain less organic carbon. Leaves contain numerous cell cavities filled with water and minerals to facilitate photosynthesis (Kusuma *et al*., 2022). This water-filled space takes up a significant portion of the tissue volume, reducing the relative proportion of organic compounds and resulting in a lower concentration of carbon per unit of dry weight. Consequently, although leaf litter is produced in greater quantities, it is less efficient in terms of carbon storage compared to branch litter.

Table 2. Carbon Content of Mangrove Litter in Tanggul River, Sungai Nibung Village

Litter Component	Carbon Content of Mangrove Litter (ton/ha/year)							
	I	II	III	IV	V	VI	VII	VIII
Leaves	8,27	6,57	11,28	10,77	4,88	4,82	13,16	1,43
Fruits	0	0,23	1,72	0,58	4,89	0,13	6,79	0
Twigs	0,37	0	0,97	0	0	0,48	3,64	0,87
Flowers	0,35	0,19	0,15	0,04	0,07	0	0	0
Total	8,99	6,98	14,13	11,39	9,84	5,43	23,59	2,30

CONCLUSION

The total litter production rate ranged from 4.95 to 30.07 tons/ha/year, and the findings reveal a clear hierarchy in litter production with the composition being leaves > twigs > propagules/fruits > flowers. Leaves litter production rate is notably high, followed by twigs which represent the second-largest portion, then fruits, and flowers. Meanwhile, the total carbon content varied across sampling station, accounting for 2.30–23.59 tons/ha/year. This study provides baseline data for the Sungai Nibung area, highlighting the potential of mangroves as carbon sinks. These findings can be utilized for ecosystem-based coastal management and mangrove restoration efforts in alignment with local government policies.

REFERENCES

Ahmed, S. & Kamruzzaman, M.D. (2021). Species-Specific Biomass and Carbon Flux in Sundarbans Mangrove Forest, Bangladesh: Response to Stand and Weather Variables. *Biomass and Bioenergy*, *153*, 106215. doi: 10.1016/j.biombioe.2021.106215.

Alongi, D.M., Murdiyarso, D., Fourqurean, J.W., Kauffman, J.B., Hutahaean, A., Crooks, S., Lovelock, C. E., Howard, J., Herr, D., Fortes, M., Pidgeon, E., & Wagey, T. (2016). Indonesia's Blue Carbon: A Globally Significant And Vulnerable Sink For Seagrass And Mangrove Carbon. *Wetlands Ecology and Management, 24*, 3–13. doi: 10.1007/s11273-015-9446-y.

Andrianto, F., Bintoro, A., & Yuwono, S.B. (2015). Produksi dan Laju Dekomposisi Serasah Mangrove (*Rhizophora* sp.) di Desa Durian dan Desa Batu Menyan Kecamatan Padang Cermin Kabupat. *Jurnal Sylva Lestari*, *3*(1), 9-20. doi: 10.23960/jsl139-20.

Badan Pusat Statistik Kabupaten Kubu Raya. (2023). Statistik Daerah Kabupaten Kubu Raya 2022/2023. BPS Kabupaten Kubu Raya

Basyuni, M., Gulton, K., Fitri, A., Susetya, I.E., Wati, R., Slamet, B., Sulistiyono, N., Yusraini, E., Blake, T., & Bunting P. (2018). Diversity and Habitat Characteristics of Macrozoobenthos in the Mangrove Forest of Lubuk Kertang Village North Sumatra Indonesia. *Biodiversitas*, *19*(1), 311-317. doi: 10.13057/biodiv/d190142

Chen, C.I., Lin, K.H., Huang, M.Y., Wong, S.L., Liao, T.S., Chen, M.N., Weng, J.H., Hsueh, M.L., Lai, Y.H., & Wang, C.W. (2022). Photosynthesis in Response to Different Salinities and Immersions of Two Native Rhizophoraceae Mangroves. *Cells*, *11*(19), 3054. doi: 10.3390/cells11193054

Choudhary, B., Dhar, V., Pawase, A.S. (2024). Blue carbon and the role of mangroves in carbon sequestration: Its mechanisms, estimation, human impacts and conservation strategies for economic incentives. *Journal of Sea Research,*199, 102504.

Chowdhury, Md.Q., Sarker, S.K., Sultana, R., Datta, A., Saimun, Md.S.R., & Rashid, A.Z.M.M. (2023). Synergistic Effects of Climate and Salinity on Radial Growth of *Excoecaria agallocha* L. in the Sundarbans World Heritage Mangrove Ecosystem. *Estuarine, Coastal and Shelf Science*, *280*, 10818. doi: 10.1016/j.ecss.2022.108181.

Clough, B., Tan, D.T., Phuong, D.X., & Buu, D.C. (2000). Canopy Leaf Area Index and Litter Fall in Stands of the Mangrove Rhizophora apiculata of Different Age in the Mekong Delta, Vietnam. *Aquatic Botany*, *66*(4), 311–320. doi: 10.1016/S0304-3770(99)00081-9.

Dali, G.L.A. (2023). Litter production in two mangrove forests along the coast of Ghana. *Heliyon*, 9(6), e17004. doi: 10.1016/j.heliyon.2023.e17004.

Darwati, H. & Destiana. (2022). Produktivitas Serasah di Lahan Rehabilitasi Mangrove Kelurahan Setapuk Besar Kota Singkawang. *Journal Tengkawang*, *12*(2), 147-157.

Dasgupta, N., Nandy, P., & Das, S. (2011). Photosynthesis and Antioxidative Enzyme Activities in Five Indian Mangroves with Respect to Their Adaptability. *Acta Physiologiae Plantarum, 33*, 803–810.

Dewiyanti, I., Syamsiaturrofiah, ElRahimi, S.A., Damora, A., & Ulfah, M. (2021). Mangrove Litter Production in Correlation to Environmental Properties of Water in Pusong Cium, Seruway, Aceh Tamiang. *IOP Conf. Series: Earth and Environmental Science*, *674,* 012030.

Farhaby, A.M., Sapriyadi, Henri, Arizona, M.O. (2023). Analysis of Mangrove Litter Production and Carbon Stock in Sukamandi Village, Belitung Timur Regency. *IOP Conference Series: Earth and Environmental Science*, *1267*(1), 012061. doi: 10.1088/1755-1315/1267/1/012061

Heriyanto, N.M. & Subiandono, E. (2012). Komposisi dan Struktur Tegakan, Biomasa, dan Potensi Kandungan Karbon Hutan Mangrove di Taman Nasional Alas Purwo. *Jurnal Penelitian Sosial dan Ekonomi Kehutanan*, 9(1), 23-32. doi: 10.20886/jphka.2012.9.1.023-032.

Hilyana, S. & Rahman, F.A. (2022). Variabilities of the Carbon Storage of Mangroves in Gili Meno Lake, North Lombok District, Indonesia. *Biodiversitas*, 23(11), 5862-5868.

Islamiah, N., Astiani, D., & Ekamawanti, H.A. (2022). Estimasi Produksi Karbon dari Serasah Hutan Mangrove Desa Mendalok Kecamatan Sungai Kunyit Kabupaten Mempawah. *Jurnal Hutan Lestari*, *10*(2), 424-435. doi: 10.26418/jhl.v10i2.53199.

Kader, A.J. & Sinha, S.N. (2022). Sex-related Differences of *Excoecaria agallocha* L. with a View to Defence and Growth. *Tropical Life Sciences Research*, *33*, 55-74.

Kauffman, J.B. & Donato, D.C. (2012). Protocols for the Measurement, Monitoring and Reporting of Structure, Biomass And Carbon Stocks In Mangrove Forests. Working Paper 86. CIFOR, Bogor.

Heider, C., Norfolk, J., & Payton, F. (2014). Carbon stocks of intact mangroves and carbon emissions arising from their conversion in the Dominican Republic. *Ecological applications: a publication of the Ecological Society of America*, *24*(3), 518–527. doi: 10.1890/13-0640.1

Khoirunisa, Abubakar, S., & Sabar, M. (2022). Produksi Serasah Daun Mangrove di Pulau Manomadehe Kecamatan Jailolo Selatan Kabupaten Halmahera Barat. *Jurnal Ilmu Kelautan Lesser Sunda*, 2(1), 9-19. doi: 10.29303/jikls.v2i1.49.

Kusuma, A.H., Effendi, E., Hidayatullah, M.S., & Susanti, O. (2022). Estimasi Serapan Karbon Pada Vegetasi Mangrove Register 15, Kecamatan Pasir Sakti, Kabupaten Lampung Timur, Provinsi Lampung. *Journal of Marine Research*, *11*(4), 768-778. doi: 10.14710/jmr.v11i4.35605.

Lenz, A.K., Bauer, U., & Ruxton, G.D. (2022). An Ecological Perspective on Water Shedding from Leaves. *Journal of experimental botany*, *73*(4), 1176–1189. doi: 10.1093/jxb/erab479.

Menzel, C.M. (2005). Photosynthesis and Productivity. In: Menzel, C.M., Waite, G.K. (Eds.), Litchi and Longan. Botany, Production and Uses. CABI, Wallingford, UK, pp. 153–182.

Milovančević, M., Trifunović-Momčilov, M., Radulović, O., Milošević, S., & Subotić, A. (2024). Drought Stress Effects and Ways for Improving Drought Tolerance in *Impatiens walleriana* Hook.f. - A Review. *Horticulturae*, *10*(9), 903. doi: 10.3390/horticulturae10090903.

Mulya, M.B. & Arlen, H.J. (2018). Production of Litter and Detritus Related to the Density of Mangrove. *IOP Conf. Series: Earth and Environmental Science*, 130(1), 012033.

Pascoalini, S.S., Tognella, M.M.P., Falqueto, A.R., & Soares, M.L.G. (2022). Photosynthetic Efficiency of Young *Rhizophora mangle* in a Mangrove in Southeastern Brazil. *Photosynthetica*, *60*(3), 337–349.

Pradisty, N. A., Sidik, F., Bimantara, Y., Susetya, I. E., & Basyuni, M. (2022). Litterfall and Associated Macrozoobenthic of Restored Mangrove Forests in Abandoned Aquaculture Ponds. *Sustainability*, *14*(13), 8082. doi: 10.3390/su14138082.

Purnobasuki, H., Sarno, & Hermawan, A. (2022). Litter Fall and Decomposition of Mangrove Species Avicennia marina in Surabaya East Coast, Indonesia. *Pakistan Journal of Botany, 54*(4), 1399-1403.

Putri, R.Y. & Bashri, A. (2023). Anatomical Characteristics of *Rhizophora*'s Leaves as Mangrove Plant Adaptation at Banyuurip Mangrove Center. *Jurnal Riset Biologi dan Aplikasinya*, 5(2), 98-109.

Quitain, R.A. (2024). Biogeochemical Role of Mangroves: Carbon Sequestration, Oxygen Release, and Their Contribution to Ecosystem Sustainability. *Journal of Angiotherapy*, *8*(12),1-6, 10073.

Rafael, H.P. & Calumpong. (2018). Comparison of Litter Production between Natural and Reforested Mangrove Areas in Central Philippines. *Journal AACL Bioflux*, *11,* 1399-1414.

Rajaras, A., Bengtsson, J., Theliander, H., Lundgren, P. (2023). Enhancing Carbon Fiber Properties Through Lignin-Cellulose Composites: A Comparative Study of Hardwood vs. Softwood Lignin Sources. *Electrochemical Society Meeting Abstracts, 244(*8), 3420-3420. doi: 10.13140/RG.2.2. 22547.25126.

Rumondang, A.L., Kusmana, C., Budi, S.W., & Sukarno, N. (2023). Mangrove Litter-Fall Productivity in the All-High Tides Area of Angke Kapuk Protected Forest, Jakarta. *The Seybold Report*, 1742-1754.

Russo, S.E. & Kitajima, K. (2016). The Ecophysiology of Leaf Lifespan in Tropical Forests: Adaptive and Plastic Responses to Environmental Heterogeneity. Springer International Publishing Switzerland. Goldstein, G. & Santiago, L.S. (eds.), In Book *Tropical Tree Physiology*, 6, 357-383.

Safitri, I., Kushadiwijayanto, A.A., Nurdiansyah, S. I., Sofiana, M.S.J., & Andreani. (2023). Inventarisasi Jenis Mangrove di Wilayah Pesisir Desa Sungai Nibung, Kalimantan Barat. *Jurnal Ilmu Lingkungan*, *22*(1), 109-124. doi: 10.14710/jil.22.1.109-124.

Selviani, S., Zamani, N.P., Natih, N.M.N., & Tarigan, N. (2024). Analysis of Mangrove Leaf Litter Decomposition Rate in Mangrove Ecosystem of Muara Pagatan, South Kalimantan. *Jurnal Kelautan Tropis, 27*(1), 103-112. doi: 10.14710/jkt.v27i1.21913.

Souza, S.R., Veloso, M.D.M., Espírito-Santo, M.M., Silva, J.O., Sanches-Azofeifa, A., Sauza e Brito, B.G., & Fernandes, G.W. (2019). Litterfall Dynamics Along a Successional Gradient in A Brazilian Tropical Dry Forest. *Fores Ecosystem*, *6*, 35. doi: 10.1186/s40663-019-0194-y.

Stankovic, M., Mishra, A.K., Rahayu, Y.P., Lefcheck, J., Murdiyarso, D., Friess, D.A., Corkalo, M., Vukovic, T., Vanderklift, M.A., Farooq, S.H., Gaitan-Espitia, J.D., Prathep, A. (2023). Blue Carbon Assessments of Seagrass and Mangrove Ecosystems in South and Southeast Asia: Current Progress and Knowledge Gaps. *Science of The Total Environment*, *904*, 166618.

Sukardjo, S., Alongi, D.M., & Kusmana, C. (2013). Rapid Litter Production and Accumulation in Bornean Mangrove Forests. *Ecosphere*, *4*(7), 79. doi: 10.1890/ES13-00145.1.

Tanaka, T., Kurokawa, C., & Oikawa, S. (2018). Leaf Shedding Increases the Photosynthetic Rate of the Canopy in N2-fixing and non-N2-fixing Woody Species. *Tree Physiology*, *38*(12), 1903–1911.

Teutli-Hernández, C., Cepeda-González, M.F., Montero-Muñoz, J.L., Medina-Gómez, I., Román-Cuesta, R.M., & Herrera-Silveira, J.A. (2024). Relationship of litterfall anomalies with climatic anomalies in a mangrove swamp of the Yucatan Peninsula, Mexico. *PloS one*, *19*(8), e0307376.

Torres, J.R., Villeda-Chávez, E., Arreola-Lizárraga, J.A., Tovilla-Hernández, C., Infante-Mata, D., & Barba-Macías, E. (2022). Review and Analysis of Mangrove Litter Production in Mexico: A Contrasting Regions Approach. *Madera y Bosques*, *30*(4), e3042530.

van Hespen, R., Hu, Z., Borsje, B., De Dominicis, M., Friess, D.A., Jevrejeva, S., Kleinhans, M.G., Maza, M., van Bijsterveldt, C.E.J., Van der Stocken, T., van Wesenbeeck, B., Xie, D., Bouma, T.J. (2023). Mangrove forests as a nature-based solution for coastal flood protection: Biophysical and ecological considerations. *Water Science and Engineering*, *16*(1), 1-13.

Wang, Y., Sun, X., Li, S., & Wei, B. (2024). Lignin and Cellulose Contents in Chinese Red Pine (*Pinus tabuliformis* Carr.) Plantations Varied in Stand Structure, Soil Property, and Regional Climate. *Forests*, *15*(2), 240. doi: 10.3390/f15020240

Widhitama, S., Purnomo, P.W., & Suryanto, A. (2016). Produksi dan Laju Dekomposisi Serasah Mangrove Berdasarkan Tingkat Kerapatannya di Delta Sungai Wulan, Demak, Jawa Tengah. *Management of Aquatic Resources Journal*, *5*(4), 311-319.

Wu, Z., Peng, K., Zhang, Y., Wang, M., Yong, C., Chen, L., Qu, P., Huang, H., Sun, E., & Pan, M. (2022). Lignocellulose Dissociation with Biological Pretreatment Towards the Biochemical Platform: A Review. *Materials Today Bio*, *16,* 100445. doi: 10.1016/j.mtbio.2022.100445.

Yang, H., Yan, R., Chen, H., Lee, D.H., & Zheng, C. (2007). Characteristics of Hemicellulose, Cellulose and Lignin Pyrolysis. *Fuel*, 86(12–13), 1781-1788. doi: 10.1016/j.fuel.2006.12.013.