Analysis of Mangrove Leaf Litter Decomposition Rate in Mangrove Ecosystem of Muara Pagatan, South Kalimantan

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Abstract

Mangroves are the dominant ecosystem in coastal areas and estuaries and one of the most productive ecosystems in the world. Mangroves are an essential component in a complex food chain and have the potential for the life of various marine and terrestrial biotas, microorganisms, and macroorganisms. The decomposition of mangrove leaf litter by fungal bacteria produces nutrient source that is beneficial for fish, shrimps, and crabs. This study discusses the production and decomposition rate of mangrove leaf litter in the mangrove ecosystem of Muara Pagatan, South Kalimantan. With transect and litter trap methods, litter production during the observation ranged from 218.51 - 858.28 g/m^2/45day. Of the four types of mangroves found, the highest litter production was found in *Rhizophora mucronata* mangrove species at 858.28 g/m^2/45day, followed by *Bruguiera gymnorrhiza* species at 268.52 g/m^2/45day, and the lowest litter production was *Avicennia marina* mangrove species at 222.9 g/m^2/45day and *Sonneratia alba* at 218.51 g/m^2/45day. The remaining dry weight during observation ranged from 1.06 g - 2.46 g. In sum, the highest litter productivition and decomposition rate was found in Rhizophora species and litter was not completely decomposed after 45 days.

Keywords: Mangrove, Leave litter production, Decomposition rate, Muara Pagatan

INTRODUCTION

Coastal areas have several main ecosystems, including the mangrove ecosystem, a community that can adapt well in tidal areas (de Santana *et al*., 2021). Mangroves are the dominant ecosystem of coasts and estuaries and one of the most productive ecosystems in the world (Donato *et al*., 2011). Mangrove ecosystems exhibit high primary and secondary productivity in intertidal, tropical, and subtropical coastal areas (Liu dan Lai., 2019). It is an essential component in a complex food chain and has the potential for the life of various marine and terrestrial biotas, microorganisms, and macroorganisms(Carugati *et al*., 2018; de Santana *et al*., 2021). Mangrove roots and litter or dead plant parts are a source of nutrients for marine biota, such as bacteria, algae, and fungi. These nutrients can be used by marine life for growth and development (Reef *et al*., 2010; Abrantes *et al*., 2014; Luo *et al*., 2018).

Litter is dead plant parts such as leaves, twigs, flowers, barks, and roots that spread on the soil surfaces before decomposing(Pradisty *et al*., 2021; Zhang *et al*., 2021). Mangrove leaf litter can be decomposed by fungi and bacteria into nutrients and litter particles which serve as food source for fishes, shrimps, and crabs (Robertson., 1988; Moitinho *et al*., 2022). Macrobenthos and herbivorous biota are some of the early decomposers that will destroy or chop the remains of the leaves into smaller parts which then will be released back as feces. Fungi and bacteria will continue to decompose the feces into protein (Pradisty *et al*., 2021; Zhang *et al*., 2021). Fallen litter can also increase soil organic carbon content through the decomposition mechanism of microorganisms (Vinh *et al*., 2020).

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Mangrove leaf litter is a source of energy for the decomposing organisms. The quality and quantity of mangrove leaf litter will determine the energy available to the decomposing organisms. Decomposer organisms with a lot of energy will be more active in breaking down mangrove leaf litter (Mamidala *et al*., 2023). Several factors, including mangrove type and leaf thickness, influence the quality of mangrove leaf litter. Mangroves with high nutrient and water content will produce suitable quality litter that decomposes quickly. In contrast, mangroves with thick leaves will produce low-quality litter that takes a long time to decompose (Vinh *et al*., 2020). The wide diversity of mangroves in Indonesia causes high variation in the quantity of mangrove litter produced. Differences in mangrove species, environmental conditions, and other factors cause this variation. Indonesia's mangrove forests produce 7.1 to 23.7 tons of waste per hectare each year (Sukardjo & Yamada., 1992). Knowledge on the productivity and decomposition rates of mangrove litter is crucial to understand the condition of mangrove ecosystems in an area. This information can be used for sustainable mangrove ecosystem management.

The Muara Pagatan mangrove area, part of the mangrove ecosystem in coastal South Kalimantan, has been threatened by community activities in the last decade. These activities have led to a reduction of mangrove land area. The diminishing condition of mangroves is feared to reduce the function and impact on the productivity of mangrove ecosystems. Low productivity of mangrove ecosystems can lead to a decrease in the availability of fish resources in these waters. Given the importance of mangrove litter productivity for the survival of biota and fish production in mangrove ecosystems, this study was conducted to determine the productivity and decomposition rate of mangrove litter in the mangrove vegetation structure of Muara Pagatan.

MATERIALS AND METHODS

This research is an exploratory study using a descriptive approach with the line transect method. The placement of research stations was carried out using Purposive Sampling Method, which is a sampling technique with certain considerations (Campbell *et al*., 2020). This study was conducted at 3 research stations that represent the conditions at the study site. Station 1 is located near the pond, Station 2 is located near the beach, and Station 3 is located near an industrial fish canning factory and a rice factory the (Figure 1). Data collection was collected from September to November 2022 and data analysis was performed at the Chemistry Laboratory of the Faculty of Mathematics and Natural Sciences, Lambung Mangkurat University Banjarbaru, South Kalimantan.

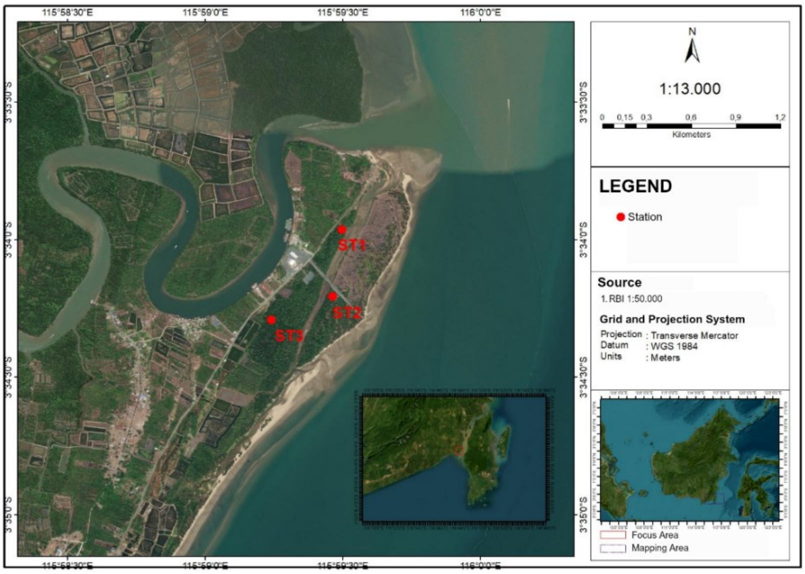

Figure 1. Sampling locations

Mangrove data collection was carried out by counting the species, number and measuring stem diameter in each sample plot measuring 10 x 10 m for trees, 5 x 5 for saplings, and 1 x 1 for seedlings. The measurement mechanism on standard criteria and guidelines for determining mangrove damage refers to the Decree of the Minister of Environment No. 201 of 2004. Density and index of importance of species in trees and saplings were calculated based on (Bengen *et al*., 2023).

$$D_i = \sum BA/A$$

Note: BA = Basal Area, and A = total area of sampling area (total area of sample plot/plot)

$$KR = n_i/\sum n \times 100\%$$

Notes: KR = Relative Density; n_i = the ratio between the number of individuals of species I, and ∑n the total number of stands of all species.

$$FR = F_i/\sum SF \times 100\%$$

Notes: FR = Relative Frequency; F = ratio between frequencies of species i, and SF = sum of frequencies for all species.

$$DR = (D_i/\Sigma D_i) \times 100$$

Notes: DR = Relative species cover; D_i = dominance of individual species, and (ΣD_i) = total dominance of all individuals.

$$NP = KR + FR + DR$$

Note: NP = Importance Value; KR = sum of Relative Density values; FR = Relative Frequency, and DR = Relative Dominance.

Sampling of litter fall in a certain time (litter fall) using a litter trap made of nylon with a size of 1 x 1 m^2 and a mesh of 1 mm (Brown., 1984). Litter trap between the nearest mangrove vegetation with height above the highest tide line in each transect plot. The first litter obtained was used as research material for the decomposition rate of leaf litter, which was differentiated for each mangrove type. The litter obtained was put in plastic clips and labelled according to the repeat station and type then in the oven 105 ^{0}C until the weight is constant (Ashton *et al*., 1999).

$$x_j = \sum_{i=1}^{n} = \frac{xi}{n} \text{ (g/m}^2\text{)}$$

Note: x_j = average litter production of each time period replicate; xi = litter production of each time period replicate (I = 1,2,3..., n) and n = number of litter trap observations.

Measurement of the decomposition rate was conducted by placing 10 gram of the dried leaf litter to a litter bag and then tying the samples at the root of the tree submerged in water at high tide and at the lowest ebb. Data on litter decomposition rate was taken on days 15, 30, and 45 (Indriani., 2008). The bags taken were cleaned and then dried at 105 ^{0}C for 48 hours or completely dry and weighed with an accuracy of 0.001gram and calculated the final weight to determine the rate of litter decomposition Ashton *et al*., 1999).

$$R = (Wo - Wt)/T$$

Notes: R = decomposition rate (g/day); T = observation time (days); Wo = dry weight of initial litter sample (g); Wt = dry weight of litter sample at time t (g)

RESULTS AND DISCUSSION

General conditions in the mangrove ecosystem research area during the study can be described through information on the value of physical-chemical environmental parameters and climatic conditions. Physical parameters of the environment and climate affect the value of productivity and the rate of decomposition of mangrove leaf litter in the mangrove ecosystem area of Muara Pagatan. Microclimate climate conditions are one of the important factors that can affect the presence of microorganisms that play a role in the decomposition process (Tam *et al*., 1998). As for climatic conditions, rainfall ranged from 4.4 - 18.3 mm, temperature 26.2 - 28.0 °C, air humidity 78.6 - 89.7 % and wind speed 1.0 - 1.4 m/s (Table 1). The results of the measurement of water temperature at the research site ranged from 30.33 - 31.00 °C, salinity 23.44 -27.44 ppt, DO 4.37 - 5.34 g/ml, pH 6.61 -6.74, TSS 24.70 - 39.48, soil temperature 28.33 - 29.33 °C, soil salinity 20.56 - 21.440/00 and soil pH 6.43 - 6.74 (Table2).

Temperature can affect the growth and survival of an organism. According to Lyubetsky *et al* (2020), optimum temperatures for bacterial growth are 20 °C - 45 °C, which are in the range of the experimental site. Soil temperature can affect plant growth directly through various mechanisms. Optimal soil temperature can increase plant growth rate, photosynthesis, and nutrient uptake. Optimal soil temperature can also increase soil moisture, soil aeration, soil microorganism activity, and organic matter decomposition (Vinh *et al*., 2020). This activity will be limited at temperatures below 10 °C, the optimum rate of beneficial soil biota activity occurs at 18 °C - 30 °C such as nitrogen-fixing bacteria in well-drained soils (PietikÃ¥inen *et al*., 2025). Trees with dense canopies can block most of the sunlight from reaching the forest floor. This can lead to reduced photosynthesis and understory plant growth (Wu *et al*., 2023).

The condition of the mangrove ecosystem in Muara Pagatan can be known by using four indices, namely the important value index (NP), relative density (KR), relative frequency (FR), and relative closure (RD). Each of these indices has a different role in describing the condition of the mangrove ecosystem. The results of the tree-level mangrove ecosystem index values are presented in Table 3. Vegetation structure determines abiotic conditions, especially microclimate conditions underneath the mangrove (Bernath-Plaisted *et al*., 2023; Mahata *et al*., 2023). Mangrove ecosystems in Muara Pagatan found four types of mangroves namely Rhizophora mucronate, *Avicennia marina*, *Sonneratia alba* and *Bruguiera gymnorrhiza* with an important value index (NP) ranging from 59.66-300%, of the four mangrove species found, R. mucronata has the largest importance index of 300%, and the lowest value index is found in the type of A. marina which is 59.66%.

Table 1. Climate in one year at the study site

Month	Rainfall (mm)	Humidity (°C)	Humidity (%)	Wind speed (m/s)
January	18.3	27.0	86.0	1.3
February	12.2	26.6	89.7	1.3
March	11.6	27.4	85.5	1.0
April	4.4	27.4	86.2	1.1
May	11.4	28.0	82.0	1.1
June	12.3	26.8	78.7	1.2
July	14.0	26.2	80.3	1.2
August	13.2	26.5	78.6	1.4
September	11.8	26.6	84.6	1.4
October	17.8	26.9	83.9	1.4
November	9.2	27.0	84.8	1.3
December	8.9	27.0	84.8	1.4

Source: BMKG 2022.

Table 2. Mean values of environmental physico-chemical parameters at the study site

Station	I	II	III
Temperature (°C)	30.33	30.67	31.00
Salinity (ppt)	23.44	25.11	27.44
DO (mg/l)	5.34	4.68	4.37
pH	6.63	6.61	6.74
TSS	39.48	24.70	36.06
Soil temperature (°C)	29.33	29.11	28.33
Soil salinity (ppt)	20.67	21.44	20.56
Soil pH	6.72	6.43	6.74

Table 1. The importance index value of the Muara Pagatan mangrove ecosystem at the tree level

Station	Species	FR (%)	KR (%)	RD (%)	NP (%)
1	*Rhizophora mucronata*	100.00	100.00	100.00	300.00
	Avicennia marina	33.33	23.94	26.33	59.66
2	*Rhizophora mucronata*	33.33	16.90	17.08	67.31
	Sonneratia alba	33.33	59.15	56.60	149.08
3	*Rhizophora mucronata*	53.98	52.63	50.00	156.61
	Bruguiera gymnorrhiza	46.02	47.37	50.00	143.39

Description: Relative frequency (FR); Relative density of species (KR); Relative cover of species (RD) Index of importance (NP)

The dominant mangrove vegetation type with a high important value index also shows that the species is able to adapt to the environment where it lives compared to other vegetation types (Efriyelsi & Amin, 2022). The importance index value is a measure that indicates the significance of a species in a community. Species with high index values have a significant role in the community. These species are important for maintaining the balance and sustainability of the community (Maciel, 2021). This is probably because the type of substrate in the study site is classified as muddy sand type. Rhizophora has strong supporting roots surrounding the main stem to support its growth in muddy and anoxic areas (Ola *et al*., 2019). Moreover, Dharmawan *et al*., (2016) stated that substrate type strongly influences the dominance of a species in oceanic mangrove areas.

Mangrove conditions can also be seen from the mangrove density itself. The results of mangrove density in Muara Pagatan are presented in Table 4. Mangrove stands on trees at 1 station of the study site, showing at Station 1 130 ind/ha, Station 2 as much as 236ind/ha, and Station 3 as much as 126 ind/ha. is an area that has the largest number of tree stands, the total density is 236 ind/ha, while for mangrove stands on saplings at Station 1 as much as 93 ind/ha, Station 2 as much as 106 ind/ha, and Station 3 as much as 140 ind/ha. The composition of mangrove species density values at the tree level is different when compared to the sapling level, but referring to the criteria for mangroves regulated in KEPMENLH 2004, the condition of mangroves in the Pagatan Estuary is classified as very dense.

Figure 2 present the mangrove litter production for 45 days at the research site, which consists of leaves, twigs, fruits and flowers of each mangrove species. The total litter production of the four mangrove species accumulated from 3 collection station amounted to 1568.21 g/m2/45 days, in which *Rhizophora* and *Sonneratia alba contributes to* the highest and lowest production with 858.28 g/m^2/45 day and 218.52 g/m^2/45 day, respectively. *Rhizophora mucronate* species produced the highest amount of litter compared to other species because it has a high individual density (126.7 trees/ha). Mangrove tree density affects litter production, the higher the tree density, the higher the litter production and vice versa (Ananta *et al*., 2022).

Table 2. Mangrove ecosystem density of Muara Pagatan

Station	Species	Trees	Di (ha)	Seedlings	Di (ha)
1	*Rhizophora mucronata*	39	130.00	28	93.33
Total stand		39	130.00	28	93.33
2	*Avicennia marina*	12	40.00	9	30.00
	Sonneratia alba	54	180.00	18	60.00
	Rhizophora mucronata	5	16.67	5	16.67
Total stand		71	236.67	32	106.67
3	*Rhizophora mucronata*	20	66.67	22	73.33
	Bruguiera gymnorrhiza	18	60.00	20	66.67
Total stand		38	126.67	42	140.00

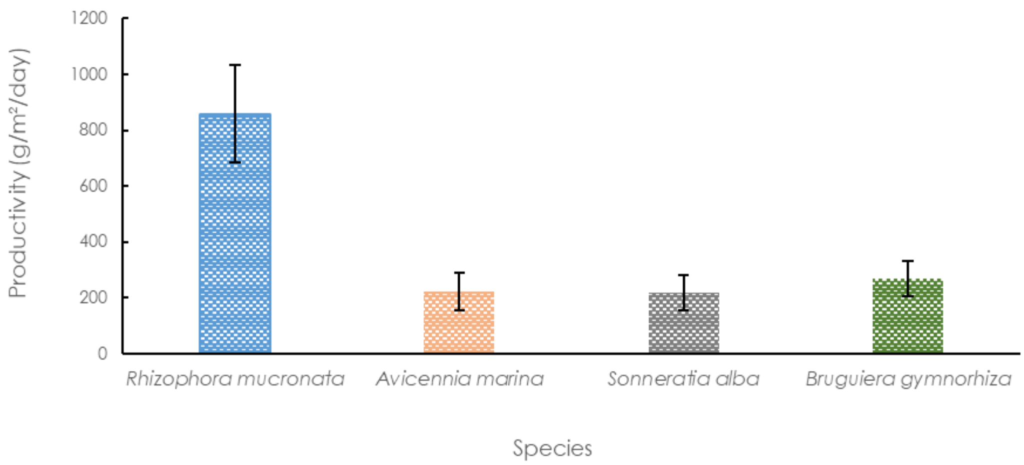

Figure 2. Total litter production in the Muara Pagatan

The process of litter decomposition for 45 days shows that no litter has been decomposed completely (Figure 3). After 45 days, final weight of *Rhizophora mucronata*, *Avicennia marina*, *Sonneratia alba,* and *Bruguiera gymnorrhiza* are 1.06, 2.46, 2.17, and 1.26 g, respectively. The dry weight of the remaining mangrove leaf litter explains that the decomposition process in the type of *Avicennia marina* is lower when compared to other types of litter. The high rate of decomposition of *Rhizophora mucronata* leaf litter caused by its high phosphorus content. The high rate of decomposition of R. macronata leaf litter is due to its high phosphorus content, because high phosphorus content tends to be favored by aquatic microorganisms (Salafiyah & Insafiti, 2020). Additionally, it is also suspected that *Rhizophora mucronata* has thinner leaves, hence, it is easier to decompose. The length of time required is influenced by several factors, including mangrove type, environmental conditions and organic moisture, organic equilibrium and excess microorganisms on mangrove leaves that can affect mangrove litter decomposition (Vinh *et al.,* 2020; Moitinho *et al*., 2022).

Figure 4 shows the rate of decomposition of leaf litter from different mangrove species for 45 days. It can be seen that the speed of leaf litter decomposition rate in each type of mangrove observation tends to decrease on day 45. The decomposition rate is high on day 15 or the first week, compared to day 45 or the following week. This statement is supported by research Hardianto *et al*., (2015) which states that the content of organic matter in the last week has been reduced so that decomposition slows down. In addition, the decomposition rate of mangrove litter is also affected by rainfall in the observation location. The rate of litter decomposition is positively correlated with the amount of rainfal (Austin & Vitousek, 2000; Karina *et al*., 2022; Zhu & Cheng, 2022). Rainfall can control the physical leaching of litter, with high rainfall accelerating litter decomposition (Zhu and Cheng 2022). Low rainfall will affect soil moisture and temperature, which causes litter to dry out, thus affecting biological activity in litter decomposition, and changes in the amount and intensity of rain can affect the speed of litter decomposition in tropical forests (Delsinne *et al*., 2008; Canessa *et al*., 2021). Compared to other months, September-October is considered a period of low rainfall (Table 1).

At first, the value of the decomposition rate will be high and then decrease, means that initially the litter decomposes quickly and then slows down with the more extended period the litter is decomposed (Darmawan *et al*., 2021). This is due to the decreasing amount of available organic matter caused by microbial activity that decomposes organic waste. New litter has a supply of elements that are food for soil microbes or for decomposing organisms, so that litter is quickly destroyed. The element is decreasing, which means that the destruction is also slow until only elements that are not needed by decomposers remain (Yu *et al*., 2019; Giweta, 2020). In addition, the water content contained in the new litter will quickly evaporate so that the dry weight of the litter at the beginning of the week experiences a high decrease, which also makes the decomposition rate faster (Rawlik *et al*., 2021). Decomposition is a complex process that is influenced by various factors. The speed of decomposition can vary over time, depending on factors that affect the growth of the decomposer and factors that affect the material to be decomposed. The decomposition process of organic matter will stop if the microorganisms that play a role in the decomposition process do not get the nutrients, oxygen, or moisture needed. During the decomposition process, the initial volume of the material will shrink. This reduction reaches 30-40% of the initial volume of the material (Haynes, 2014).

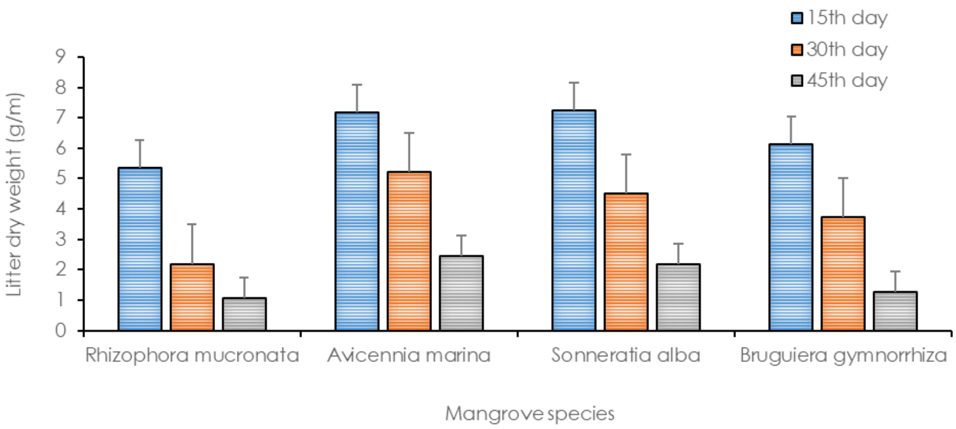

Figure 3. Dry weight of mangrove litter in Muara Pagatan

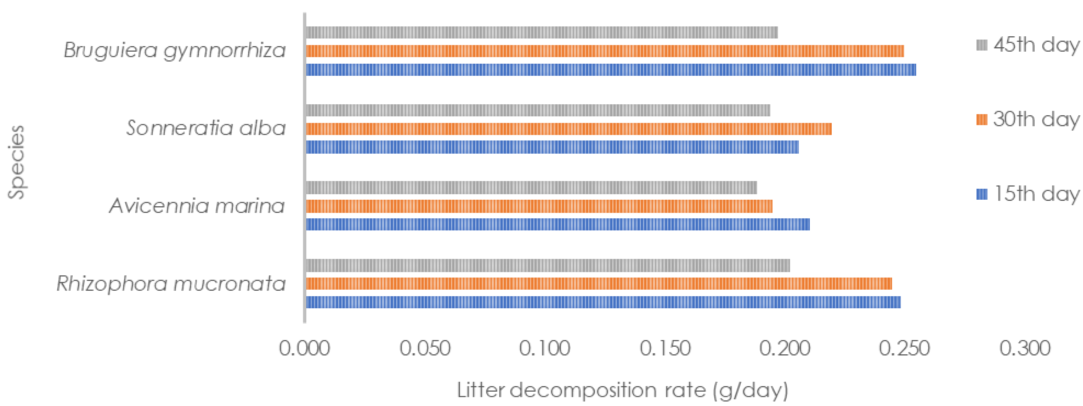

Figure 4. Average decomposition rate of mangrove litter in Muara Pagatan

CONCLUSIONS

The highest productivity was found in the *Rhizophora mucronata* species, and the lowest in the *Avicennia marina* and *Sonneratia alba* species. The decomposition process shows that decomposed type occurs faster in the type of *Rhizophora mucronata* compared to the other three types found.

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