Production and Decomposition of Mangrove Species *Rhizophora apiculata* Blume in Surabaya East Coast Indonesia

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ABSTRACT

The mangrove ecosystem is supported by the production and decomposition of leaf litter, as well as the release of nutrients into the environment and the neighbouring coastal seas. The release of phosphorus and nitrogen contributes significantly to the improvement of the nutritional values, which benefits marine species and the neighbourhood. In the current study, nutrient release, leaf decomposition rate, litter generation, and mangrove habitat at Surabaya East Coast, Java, Indonesia were all examined. Three transects and three plots in each transect were established. The percentage of initial dry mass remaining in the litter bags were determined by using two sample t-test in Statistica 6.0 software. The decomposition of *Rhizophora apiculata* leaves was studied by using litter bag technique. They were made of synthetic nylon with the dimension of 15×15×25 cm and mesh size of 1×1.25 mm^2. Senescent leaves were used because they present major leaves on the forest floor. According to the findings, daily mangrove litter production (dry weight) varied between 2.15 and 3.28 g/m^2. Branch litter (9.43 – 13.27%), reproductive parts (8.20 – 14, 31%), and leaf litter (76.26 – 78.53%) were the other major contributors. The 345.6 ha of mangrove forests along the east coast of Surabaya are the results of reforestation, which has the potential to produce nitrogen and phosphorus at the rates of 109.43 to 173.549 kg/ha/year and 5.467 to 8.12 kg/h/year, respectively. These results imply that decomposition breakdown rates differ across the research area due to the variation in the nutrients availability. Changes in the breakdown of detritus point to variations in nutrient intake, which is crucial for mangrove ecosystems.

Keywords: Aquatic nutrition, ecosystem, mangrove litter, nutrient value

INTRODUCTION

Mangrove trees serve a critical role in preserving the integrity of food webs in coastal habitats by releasing organic chemicals via litter fall. Litter fall, which eventually decomposes and releases nutrients into the water, is primarily responsible for mangrove growth. This high production is directly tied to the detritus-based food chain (Mchenga & Ali, 2017; Kamruzzaman, *et al.,* 2019). An ecosystem's function can only be determined after decomposition has taken place. Decomposition of mangrove litter, especially leaf litter, makes a major contribution to nutrient regeneration in the sediment and nearby seas. Only a small part of the decomposing leaves had been consumed by herbivores and detritus feeder organisms (Imagraben & Dittmann, 2008). The decomposition of trash and efficient nutrient recycling in mangrove habitat, as claimed by Kristiningrum *et al.* (2019), Kathiresan and

Bingham (2001), and Nybakken (1993), enable mangrove forests to sustain extremely productive estuarine ecosystems. This is supported by several research as well (Fernando & Bandeira, 2009; Dewiyanti, 2010; Nugraha *et al.*, 2020). Although it is challenging, assessing productivity in mangrove ecosystems has become a widespread practice, especially when it comes to nutrient recycling. This is on the grounds that waste result is one of the most urgent parts of efficiency (Morrisey *et al.*, 2007; Nagelkerken *et al.,* 2008; Reef *et al.*, 2010; Alongi, 2018). According to Kamruzzaman *et al.* (2019), it has become crucial to evaluate the creation and decay of litter when assessing the productivity of ecosystems. It is important to be aware of information related to supplements in the mangrove ecosystem.

Litterfall contributes significantly to the coastal food chain and maintains the dynamic

state of coastal ecosystems due to the intense biological activity that occurs alongside litter decomposition. According to Hemati *et al.* (2017) and Giweta (2020), decomposition and litter creation are used as the main mechanisms to increase nutrients into the environment, however this varies by location (Rafael & Calumpong, 2018; Kamruzzaman *et al.*, 2019) and season (Kathiresan & Bingham, 2001). For instance, in Malaysia, production and waste are seasonal, peaking during the wet season (Hemati *et al.*, 2017). During the breakdown process, nutrients in the form of nitrogenous and phosphoric chemicals (ammonia, nitrate, and nitrite) are released into estuarine and open-water environments. The quantity and presence of fauna participating in decomposition, the frequency of mangrove species, oxygen availability, tidal flooding, and temperature affect how quickly organic compounds are released from the mangrove environment (Nga *et al.*, 2005; Rahman & Tsukamoto, 2013; Numbere & Camilo, 2017; Alongi, 2018).

Rhizophora apiculata is an essential part of the mangrove forest community that supports the stability of the coastal ecosystem (Katili *et al.*, 2017; Basyuni & Simanjuntak, 2021). The biological activity of this plant also makes a considerable contribution to carbon stocks and litter sources that nourish neighbouring water bodies (Wiyarta *et al.*, 2019; Calderon *et al.*, 2021). Shallow roots on *R. apiculata* have the capacity to store mud. This root catches more dirt and trash in the water between their delicate root intertwining as a result of the onslaught of waves (Amaliyah *et al.*, 2017). There was no earlier exploration on mangrove litterfall in the East Java beach front area, regardless of the way that data on the science and nature of mangrove plants is promptly accessible all through Indonesia. It is absolutely necessary to investigate this in order to stop mangrove regions from rapidly changing for purposes other than protecting the ecosystem.

The main goals of this study were to assess the following: 1) the growth of mangrove leaf litter; 2) the rate of decline of mangrove leaf litter; and 3) the contribution of mangrove leaf litter to the cycling of nutrients in the mangrove ecosystem on the East Coast of Surabaya. This study will provide information on the age of mangrove trash and the significance of disintegration, which releases vital nutrients for estuarine life. The findings of this research will be beneficial for the planning and implementation of mangrove environment board plans, drives for climate change initiatives, waterfront enhancement, and others.
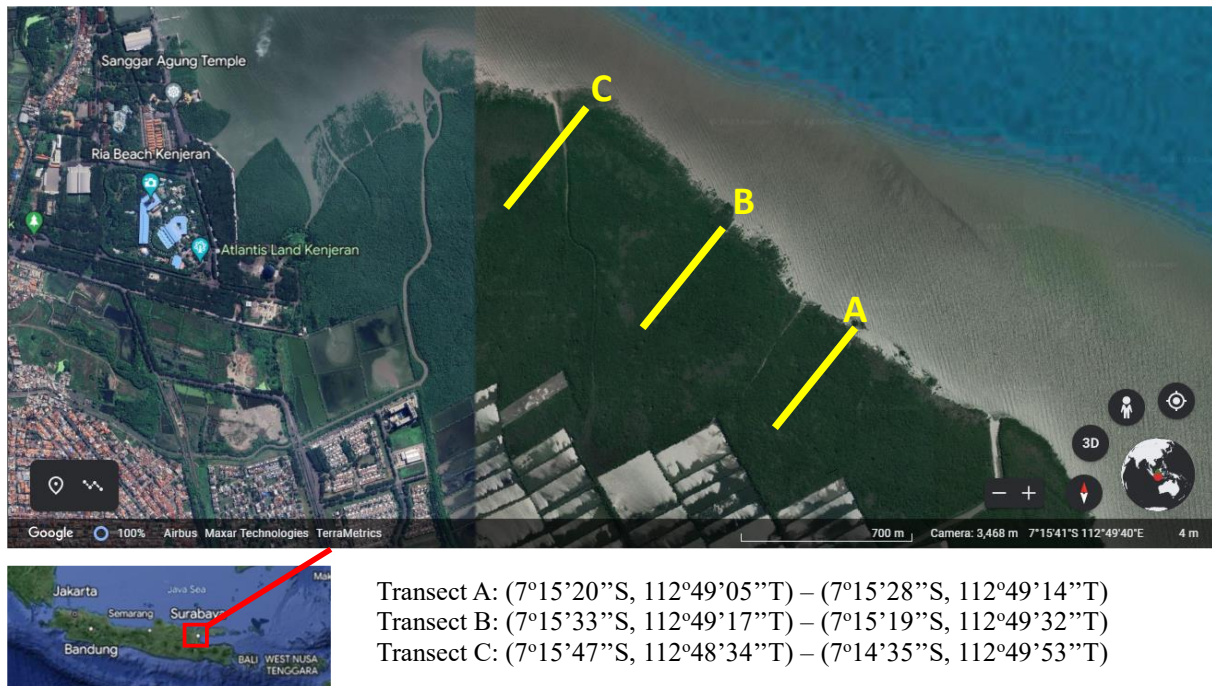
MATERIALS AND METHODS

Study Area

The research was conducted in Surabaya shoreline region of East Java, Indonesia from January – August 2022. Samples of substrate and data on flora were gathered for this study. The study area was dominated by an enormous number of small trees with a typical diameter density distribution. There were seven different varieties of mangrove trees, with *Rhizophora apiculata* predominating (the others being *Avicennia marina, Sonneratia alba, R. stylosa, R. mucronata,* and *Xylocarpus molucensis*) (Susanto *et al.*, 2018). It was in three transect areas (Figure 1). The climate is dominated by rainy and dry season.

Field sampling was conducted six times with a 15-day interval during the course of three months at high tide, when the mangrove forest floor was submerged.

Sampling of Environmental Parameters and Sediment

The *in situ* monitoring of environmental parameters such as water temperature, salinity, dissolved oxygen (DO) and pH were carried out in order to support analyses of decomposition process. Samples of sediment was taken by using a shovel as depth as 10 cm from soil surface. Sample of sediment was transported to the laboratory in order to analyse textures, C, N and P of mangrove sediment. Analyses of sediment were done in Soil Laboratory, UPN Jatim, Surabaya.

Transect A: (7°15'20"S, 112°49'05"T) – (7°15'28"S, 112°49'14"T)
Transect B: (7°15'33"S, 112°49'17"T) – (7°15'19"S, 112°49'32"T)
Transect C: (7°15'47"S, 112°48'34"T) – (7°14'35"S, 112°49'53"T)

Figure 1. Sampling area of vegetation analysis (A, B, and C lines represented the transect). Source: Google.com

Productivity Measurement

Litter traps are the most widely used instrument for tracking garbage production in the mangrove ecosystem (Sukardjo, 2010). At the research site, the plants produced a wide variety of litter, including twigs, leaves, fruit, and flowers. A litter trap of 1 m in length was used to measure litter productivity. Each plot contained five litter traps that were methodically placed beneath the canopies of *R. apiculata* type mangrove stands. This equipment was fastened to the tree branches of *R. apiculata* zones up to 2 m above the forest floor. This height setting was utilised to prevent the equipment from becoming wet during high tide (Kamruzzaman *et al.*, 2019). Litter pickup was done consecutively at intervals of 14 days (14, 28, 42 and 56 days). This cycle of collecting lasted two months in both the dry (July – August) and wet seasons (December – January). In the laboratory, the cleaned and divided litter components (leaves, twigs, fruit, and flowers) were then placed in plastic bag with a label before being dried for 48 hours at 80 °C until the weight was maximum dried condition (Ellis & Bell, 2004; Kristiningrum *et al.*, 2019). To determine the litter's dry weight, it was wrapped in aluminum foil and dried to 100 °C for three days (Woodroffe, 1985; Ellis & Bell, 2004). A 0.05 g precision weigher was then used to measure the dried litter's weight. To examine litter production, the following equation, Eq. (1) was used:

$$X_j = \sum_{j=1}^{n} \frac{X_i}{n} \, (g/m^2)$$

Eq. (1)

Where; X_j is the average litter production per replication during a given amount of time; X_i = litter production for each repeat over a specific time period, n = number of litter trap observations.

Decomposition Measurement

The rate of decomposition of mangrove leaf litter was determined in order to gauge how quickly the nutrients break down (N and P were released from the litter in the mangrove environment) (Pannier, 1984). A trash bag filled with mangrove litter (15 x 15 x 25 cm) was left on the ground in a mangrove forest for 60 days to measure the rate of litter degradation.

Decomposition rate was assessed at study locations by gathering litter fall material from *R. apiculata* using a bag. The leaves must be senescent yellow, easily collected by hand from the trees, or recently fallen in the area (Gallagher *et al*., 2014; Siska *et al*., 2016). The leaves were gathered, air dried for 24 hours, and then

approximately 28 g of leaf material (1 mm^2 mesh size) was deposited in each of 64 plastic bags with dimensions of 15 x 15 x 25 cm (Pandey *et al.*, 2007; Gallagher *et al.*, 2014). The bag was placed on the silt surface and securely fastened to the surface of the root. All bag samples were taken from each location at 14, 28, 42, 56, and 60 days. The materials were then carefully cleaned to remove any adherent silt or other materials. To produce a uniform mass, the debris samples were oven dried for 72 hours at 100 °C.

Decomposition rates (k constant) were estimated according to Olson (1963) through the exponential model $wt = w_0 \cdot e -kt$, where wt is the weight of the remaining material at time t, w_0 is the initial weight, t is the time, k is the constant of the decomposition rate, and e is the base of the natural logarithm. From the k values, it was possible to calculate the time required to decompose 50% ($0.693k -1$) and 95% ($3k -1$) of the leaf material. The relative weight of N and P in the initial sample was used to calculate the N and P content in the remaining samples. A pattern in the rate of organic matter degradation, N, and P as a function of incubation time was looked for in the data.

Initial N and P concentrations were measured in six sub-samples (averaging around 12.00 g per sub-sample) from each type of litter after all litters were air-dried to a uniform weight. Ammonia analyser was used to identify ammonium after semimicro-Kjeldahl digestion was performed to assess the N content. Total P concentration was then calculated colorimetrically after acidified ammonium persulfate digestion.

Nutrient release of the total amount (gg-1 days-1) was calculated as the following formula, Eq. (2):

NUTRIENTt (release) = (DW_0 * NUTRIENTo) - ($DW1$ * NUTRIENT1)　　　　Eq. (2)

where DWo is the starting dry weight of the leaf litter and $DW1$ is the dry weight remaining at time t day. The initial nutrient content is NUTRIENTo, and the residual nutrient content is NUTRIENTt on t day, with t incubation time (days).

Statistical Analysis

The percentage of leaves decomposed were calculated by using formula: D is litter decomposed, B1 is dry weight before decomposition; B2 is dry weight after decomposition. The percentage of initial dry mass remaining in the litter bags were determined by using two sample t-tests in Statistica 6.0 software. It was carried out to investigate the effect of site and time. The t-test method was based on the assumption that the variances in two groups are the same and this method was used to evaluate the differences mean between groups (Dewiyanti, 2010).

The relationship between percentage dry mass remaining in litter bags and sampling time at all sites was best fitted in a negative single exponential model (Ashton *et al.*, 1999). The formula is $Xt=Xoe^{-Kt}$, where Xt is percentage of the initial material, Xo is remaining after time t (days) and K is a decay coefficient (d-1). The times required for decomposition of half the initial material ($t50$) were determined by using the formula: $t50=ln\ 2\ /\ K$

RESULTS AND DISCUSSION

Litter Production

The dry weight of the litter produced by *Rhizophora apiculata* varied daily from 4.15 g to 2.63 g, with an average of 3.45 g. Total litter generation was the highest in Transect A (4.15 g/m^2/day), followed by Transect C (3.58 g/m^2/day), and Transect B (2.63 g/m^2/day). With an average value of 77.41%, leaf litter contributed the most to the total amount of litter produced, followed by branches (ranged between 9.43 and 13.27%) and reproductive components (flowers and fruits), which ranged from 8.20 to 14.31%. In transect A, where the oldest plant age ranged from 10 to 23 years, the greatest reproductive organ output was 8.20%, compared to 12.81% in transect B (plants aged 10 to 14) and 14.31% in transect C (plants aged 7 to 10) (Table 1).

Table 1. Total mangrove leaf litter production (g/m^2/day) and litter component percentages

Transect	Leaves		Branches		Reproduction organ		Total	
	g/m^2/day	%	g/m^2/day	%	g/m^2/day	%	g/m^2/day	Ton/ha/year
A	3.28	78.53[b]	0.48	13.27[b]	0.39	8.20[a]	4.15	12.97
B	2.15	77.44[ab]	0.27	9.75[a]	0.21	12.81[b]	2,63	9.17
C	2.87	76.26[a]	0.39	9.43[a]	0.32	14.31[c]	3.58	11.56
Average	2.76	77.41	0.38	10,82	0.33	11.77	3.45	11.23

Note: Values in each column which have different letters are significantly different (p<0.05)

The overall litter produced for each transect varied due to the age and plant density. According to Nga *et al*. (2005), this overall litter production was less than the total mangrove litter production in Vietnam (3.88 g/m^2/day); Cilacap (2.36 – 4.50 g/m^2/day); and Irian Jaya (Bintuni), which was as high as 3.04 g/m^2/day (Taberima *et al*., 2014). The type of plant and density of the existing mangroves in Cilacap and Bintuni (Central Java), which are naturally growing mangroves, were higher than those in Nguling, Pasuruan (East Java), which are the result of reforestation. The total production of mangrove litter in this study ranged from 2.23 to 3.33 g/m^2/day, which is lower than Soenardjo's (1999) findings in Kaliuntu, Rembang (Center of Java), which was also a regeneration forest and had total production of mangrove litter ranging from 1.93 – 2.84 g/m^2/day. Table 2 compares the total production of *R. apiculata* mangrove litter from various locations to the overall output of *R. apiculata* mangrove litter from this study.

Table 2. Total production of mangrove litter from *Rhizophora apiculata* in various locations

| Location	Production (g/m^2/day)	References
Camau province, Mekong Delta, Vietnam	3.88 ± 1.82	Nga *et al*. (2005)
Can Gio, Vietnam	4.65 ± 0.39	Vinh *et al*. (2020)
Phuket Island, Thailand	0.017 ± 0.18	Holmer & Olsen (2002)
Sinjai, South Sulawesi	4.11 ± 2.17	Firmansyah *et al*. (2020)
Cilacap, Center of Java, Indonesia	4.39 ± 2.31	Affandi (1996)
Bintuni, Papua, Indonesia	3.04 ± 0.63	Taberima *et al*. (2014)
Kaliuntu, Rembang (Center of Java), Indonesia	2.84 ± 1.05	Soenardjo (1999)
Tiris, Indramayu, West Java, Indonesia	0.33 ± 0.15	Sukardjo (2010)
Surabaya East Coast, Indonesia	2.34 ± 3.39	Current research

Litter Decomposition

The typical litter dry weight (percent) lost from litter bags in 80 days was the same at all three transects. At the beginning of the experiment (after 10 days), there was a loss of 37.39 percent of leaf litter. From there, it increased by 46.69% after 20 days, 64.67% after 30 days, 75.95% after 40 days, 91.37% after 60 days, 93.87% after 70 days, and 95.92% after 70 days (80th day). In a study done in the Kaliuntu mangrove forest in Rembang, Central Java, by Soenardjo (1999), who employed the same amount of dry weight of 10 grams of litter per bag, they came to a nearly same conclusion.

The leaching of soluble inorganic and organic components, as well as the presence of microorganisms that serve a purpose in the degradation process, are thought to be related to the existence of microorganisms that play a part in the process. According to Thatoi *et al*. (2013), microorganisms from mangrove habitats are capable of taking part in a variety of activities that include the decomposition and mineralization of leaf litter, and as a result, they considerably increase the productivity of the mangrove ecosystem. They can recycle nutrients, produce and consume greenhouse gases that have an impact on the environment, eliminate pollutants, handle anthropogenic waste, and biologically control pests of both plants and animals. According to Farooqui *et al*. (2014), fungi, in addition to bacteria, are also involved in the early stages of decomposition and are crucial in the loss of both organic and inorganic components in the mangrove ecosystem.

At depths of 0 – 25 m, the half-life (t50) was 25 – 31 days (average 27 days), while at depths of 25 – 50 m, it was 18 – 20 days (average 19 days). The breakdown rate was 0.19 times higher than that of Bosire *et al*. (2005), who reported earlier for *Rhizophora mucronata*, i.e. t50 on the 26th day of the rainy season. However, these results are in agreement. This was as a result of mangroves having fewer decomposer species.
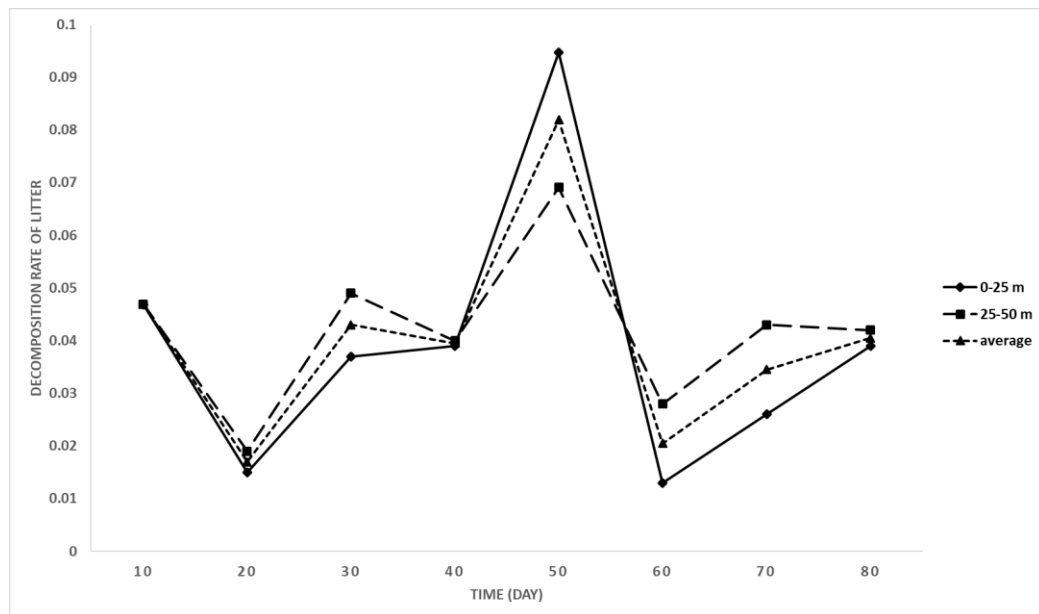
Figure 2. The change of decomposition rate of litter over time

At both the (0 – 25 m and 25 – 50 m) locations, the litter breakdown rate reached its greatest value (0.0819 per day) on the 50th day and its minimum value after 20 and 66 days (Figure 2). The results showed that the rate of decomposition was the same in locations that are 0 – 25 m and 25 – 50 m from the coast. This may result from how long there is standing water between stations. The boost in decomposition rate on the 50th day of observation in this study could be explained by the presence of decomposer animals. The bag of trash decomposers contains macrofauna (amphipoda, decapoda, and polychaeta). They discovered at the beginning, which grew as the process of decomposition continued. It is believed that the dominant species of animals found significantly contributes to the acceleration of the breakdown process (Dewiyanti *et al.*, 2019).

In this study, observations and data collection were limited to litter that could fit in detritus collecting nets. Ecology defines litter as two things: either a layer of rotting plant matter on the soil surface, or plant material that has been taken from a living plant. While there may be differences between the mineral and litter layers, there are differences between the layer that contains recognizable plant materials and the layer that merely contains amorphous organic material (De Marco *et al.*, 2016). The dynamics of the forest ecosystem are significantly impacted by the presence of a lot of litter on the forest floor (Krishna & Mohan, 2017).

At the beginning and at the end of the degradation process, the rate of leaf breakdown was rapid, and it changed over the course of the study period. Guendehou *et al.* (2014) claimed that decomposition begins more quickly than it progresses. This method is based on the elemental makeup of the litter as well as its quality and quantity. It was also mentioned that some litter components first leached or decomposed quickly. According to Davis *et al.*, (2003), leaching can cause the total leaf mass to decrease by up to 33% during the early phase, which can persist anywhere from a few days to weeks. According to Ananda *et al.* (2007), leaching caused dried leaves in a mangrove in Southwest India to lose 38.3% of their initial mass in just one week. High breakdown rates, on the other hand, assist plants in obtaining the nutrients they need. Slow decomposition rates result in the accumulation of organic matter and nutrient stocks in the soil (de Willigen *et al.*, 2008). Seasonal, precipitation, and temperature changes can all have an impact on the presence of bacteria, soil flora, and fauna, which can significantly affect the rate of decomposition. Diversity of the litter has an impact on the activity of soil organisms and processes during decomposition (Chapman & Koch, 2007). The significance of a range of soil creatures in ecosystems, with the exception of ants, termites, and earthworms, is poorly understood (Sofo *et al.*, 2020).

Decomposition of plant litter is a multi-stage process that depends on a number of different environmental factors and plant species. Following are the steps in decomposition: (1) Water-soluble chemical leaching from soil; (2) Microbe-mediated degradation of easily available chemicals during later stages of disintegration (Holmer & Olsen, 2002); (3) Specialised bacteria break down refractory materials, including cellulose and lignin; and (4) the eating behaviour of detritivores animals encourages microbial degradation through a number of mechanisms, including fragmentation and digestion (Benbow *et al.*, 2019). Mangrove litter first decomposes more fast due to the increased leaching of water-soluble chemicals (Krishna & Mohan, 2017). The physical, biological, and chemical breakdown of organic materials into CO_2 and nutrients is referred to as litter decomposition (Hasanuzzaman & Hossain, 2014; Zhan *et al.*, 2021). Through soil microorganisms and animal heterotrophic respiration, it releases carbon into the atmosphere as CO_2 (Gougoulias *et al.*, 2014).

Physical and Chemical Parameters

Water physical and chemical characteristics were measured six times at each station. Temperature, salinity, dissolved oxygen, and pH were the physicochemical parameters that were measured. The physical and chemical characteristics of the waters vary at each station at the research location. Table 3 presents the range and value of physical and chemical parameters of the waters at the study site.

Table 3. Results of measurements of the waters' physical and chemical characteristics

Physical and chemical characteristics	Transect A		Transect B		Transect C	
	range	average	range	average	range	average
Temperature (°C)	29 − 33	31.5[a]	27 − 32	30.3[a]	30 − 32	31[a]
Salinity (ppt)	7 − 16	13.12[c]	6 − 16	11.21[b]	6 − 15	9[a]
pH	6.2 − 7.8	7.23[a]	6.5 − 7.9	7.30[a]	6.3 − 7.8	7.2[a]
DO (mg/l)	2.0 − 3.2	2.74[ab]	2.0 − 3.5	2.85[b]	2.0 − 3.1	2.6[a]

Note: Values in each column which have different letters are significantly different ($p < 0.05$)

The maximum temperature is seen at transect A (33 °C). This is as a result of temperature readings taken at midday. Another issue is that transect A's placement is in an open area where light is received with a high level of intensity, and the transect is shallow enough that sunlight can still reach the seafloor. The transect B temperature reading of 27 °C is the lowest. The low temperature is brought on by the fact that the measurement time falls during a period of rain, which lowers the temperature and makes the waterways muddy. Mangroves can affect light input from the sun into the waterways, which can result in low temperatures, in addition to the vegetation cover. According to Purnobasuki *et al.*, (2022), the temperature of the water decreases as the proportion of vegetation cover increases. The presence of vegetation greatly aids in minimizing light absorption, keeping the water's surface temperature from rising too high.

The salinity value measured at each location and shown in Table 3 ranges from 6 to 16 ppt. The range of salinity readings between stations is 7 − 16 ppt at transect A, 6 − 16 ppt at transect B, and 6 − 15 ppt at transect C. Mangroves have a special ability to adapt to their environment, which is impacted by salinity and tides. Salinity is a key environmental component that affects how mangrove forests evolve, particularly in terms of growth rate, resilience, and species zoning (Raganas & Macandog, 2020). Tide frequency actually determines the occurrence of salinity changes, according to Arief (2003), who also claims that tides and salinity are associated. The amount of salinity is rising as ups and downs occur more frequently. By increasing tree density and allowing for higher macrobenthos density, salinity has an indirect yet direct effect on the density of macrobenthos (decomposers).

Due to transect A's proximity to the seaside, the salinity range there is at its maximum, 7 − 16 ppt, while at its lowest, 6 − 15 ppt, it may be found at transect C. This outcome is regarded as poor, most likely as a result of its proximity to the river's mouth. This is suitable according to Rosmaniar (2008), flowing fresh water entering the sea through river mouths will lower the salinity value. According to Ramli *et al.* (2011), there will be a mixing of two or more separate masses of water in locations where there is a river flow. This is what happens when fresh water enters the water, causing the salinity of the

sea to drop. For mangroves to grow, the ideal salinity varies from 0 to 10 ppt (Kanai *et al.*, 2014).

The transect B pH reaching of 7.9 is the highest in Table 3. At transect A, the pH was 6.2, which was the lowest. Since they disrupt metabolism and respiration, the water's tendency to be very acidic or very alkaline puts organisms' ability to survive at risk. This is in line with the findings of Prescott *et al.* (2004), who claim that one key factor in determining a water's quality is its pH. Many aquatic creatures have varying levels of tolerance for the pH of the water. The range of pH that aquatic organisms can tolerate depends on a number of variables, such as temperature, dissolved oxygen, alkalinity, the presence of different anions and cations, and the type of habitat the organism uses. Aquatic creatures have varying capacities for tolerating the pH of the waters, according to James *et al.*, (2019).

Since oxygen is necessary for the survival of macrobenthos, a decomposer, dissolved oxygen plays a part in the decomposition process. DO value was achieved when the research in Table 3 varied between 2.0 mg/L and 3.0 mg/L for each location. The average DO value at transect B is 3.5 mg/L, while the average DO value throughout all observation stations is 2.0 mg/L. Transect B II has the highest average DO value. These variances are believed to be the result of varying measurement times and seasonal fluctuations. According to the literature, Mucoba (2010) found that daily variations in water's DO levels were caused by factors such as the mixing and turbulence of water masses, the activity of photosynthesis and respiration, as well as the intake of waste into the water.

Mangrove Contributions to Nutrients

According to the data, the amount of phosphorus and nitrogen in decomposing leaf litter grew rapidly until the 50th day, then it slowed and tended to stay constant until more than 80 days

(Figure 2).

Based on data on leaf litter production of 1.78 to 2.53 $g/m^2/day$, or an average of 2.18 $g/m^2/day$, the overall amount of nutrients released by *R. apiculata*, i.e. nitrogen, ranged from 0.0355 to 0.0506 $g/m^2/day$. The amount of phosphorus range from 0.0018 to 0.0025 $g/m^2/day$ (Table 4). Surabaya's East Coast has roughly 345.6 acres of mangrove forests as a consequence of reforestation. Nitrogen and phosphorus contributions ranged from 109.43 to 173.549 kg/ha/year (6.39 to 9.54 tons/year) and 5.467 to 8.12 kg/ha/year (0.34 to 0.41 tons/year), respectively, in this forest.

The decomposition of mangrove waste revealed a crucial stage in the nutrient recycling process. These decompositions can also provide organic matter to the estuarine food web, and they play a significant role in the stability of diverse materials in the environment, such as oxygen quantity balance, estuary substrate, and the activity of estuarine animals (Giweta, 2020). The organic component that enters the mangrove food web as a result of litter breakdown is created in an autochthonous manner (Kristensen *et al.*, 2008; Huzham *et al.*, 2010).

Mangrove leaves contain tannins, which slow down the decomposition process and sources of detritus disintegration. Condensed tannins last longer in the litter than tannins that can be hydrolyzed, which are very soluble in water and drain off quickly (Hernes *et al.*, 2001). Nitrogen is one of the nutrients that accumulates during decomposition and becomes immobilized in microbial biomass (Nardoto & Bustamante, 2003; Averill & Waring, 2017). Fragmentation by detritivore activity increases the surface area of detritus, which encourages bacteria growth and speeds up soluble chemical release. As a result, the detritivores fauna has a significant impact on the breakdown of plant detritus (Moore *et al.*, 2004; Santana *et al.*, 2018; Wissinger *et al.*, 2018).

Table 4. The amount of nitrogen and phosphorus (as nutrients) released by *Rhizophora apiculata* leaf litter

Component	Nutrient released (g/g/day)	Nutrients are released in the forest (g/m²/day)			Average
		Transect 1	Transect 2	Transect 3	
Nitrogen (N)	0.02	0.0446[b]	0.0506[c]	0.0355[a]	0.0436
Phosphor (P)	0.001	0.0022[b]	0.0025[c]	0.0018[a]	0.0022

Note: Values in each column which have different letters are significantly different (p<0.05)

In soils, nitrogen is found in the organic substances, which is responsible for around 5% of the total nitrogen (Prado *et al.*, 2016). Microbes employ ammonium to break down organic materials into smaller particles since organic nitrogen is inaccessible to plants. The mineralisation of organic nitrogen molecules in natural forest soils is a gradual process that is often facilitated by microbial activity due to the limited availability of organic nitrogen. As a result, soil nitrogen cannot be regarded a major source of nitrogen (Ghaly & Ramakrishnan, 2015).

As a controlling nutrient, phosphorus ranks second only to nitrogen. Phosphorus concentration in trash rises during decomposition, just like nitrogen. Due to leaching, the initial concentration is reduced. Plants receive a very modest amount of orthophosphate via litter breakdown (Yang *et al.*, 2021). Organic acids produced by microbial decomposition of plant remnants may condense locally to reach amounts that improve phosphate availability to plants. Phosphorus is a vital nutrient that plays a crucial role in global biogeochemical cycles, according to Singh *et al.* (2015), particularly in mangrove environments. Coastal ecosystems like mangroves are major sinks that can trap large amounts of phosphorus.

Litter decomposition is critical to a forest ecosystem's nutrient budget, as nutrient recycling from plant litter has the greatest impact on flora. According to Siska *et al.* (2016), litter that falls to the forest floor decomposes. During each 80-day monitoring period, the weight of leaf litter dropped. Several elements influenced this state, including leaf form and anatomy, substrate, N element, physical, and environmental factors. For the ecology, it's crucial that nutrients from decaying organic waste are released. If the decomposition process is too fast, nutrients will be lost owing to evaporation and soil leaching. In contrast, if the decomposition process is excessively sluggish, plant growth would be hampered due to nutrient shortages. Litter fall is an important mechanism for restoration of nitrogen to the soil in terrestrial ecosystems. In forests, leaf tissue accounts for more than 70% of the above-ground litter, with stems, tiny twigs, and propagative structures accounting for the rest. Litter decomposition is mediated by a number of mechanisms, the most important of which is the heterotrophic consumption of organic compounds in litter (Quyan & Lee, 2021).

In terms of *R. apiculata* decomposition and carbon storage, there are still a lot of questions to be answered. It is still unclear if the differences in litter degradation rates between mature and immature *Rhizophora* boost CO_2 release into the sky or encourage the storage of organic materials in the sediment. The result to this study will assist us in comprehending the situation, what spatially confined for organic matter turnover dynamics, mangrove clearcutting is a viable option and sediment organic substances reserves. Increasing the blue carbon-storage efficiency of mangrove stands through rather than burning logs as fuel or converting them into charcoal, mangrove forests are frequently rejuvenated through controlled and spatially constrained clearcutting and long-term usage of logs for construction, could be an effective tool (Purnobasuki *et al*., 2017; Zhan *et al.*, 2021).

The biological function of the Surabaya east coast estuary may be impacted by seasonal and species changes in leaf litter decomposition processes. Because of the *Rhizophora* stand's proximity near tidal rivers and their leaves' lability, their breakdown products could be effective in the maintenance of heterotrophic activity in nearby waterways and could even serve as the foundation of the food chain's trophic level. *Rhizophora* leaf litter, on the other hand, may collect in soils, making their decomposition products more accessible to mangrove plants and detritus eaters.

Overall, our findings strongly urge that future research into the degradation and disintegration of detrital sources should be conducted. By providing the foundation for the nutrient availability for vegetation and organic material build-up in mangrove sediments, should take into account not only the litter of various mangrove species, but also diverse types of litter that degrade and disintegrate at varying rates. It also makes a different contribution to carbon storage and nutrient cycling. In the coastal areas of Indonesia, mangrove production, as a result of litter fall and decomposition, plays a vital role in maintaining life's equilibrium, particularly in the estuary area. As a result, it is necessary to keep it alive and safeguarded in order to meet the nutritional needs of coastal waters indefinitely.

CONCLUSION

The tropical planted mangrove ecosystem under investigation has a distinct zonation, with some mangrove trees growing at low intertidal elevations and spontaneously colonizing the lower intertidal zone throughout the shoreline area. This research revealed that the mangrove species had an impact on differences in the quality of leaf litter during processes of decomposition on the forest floor and its placement within the tidal zone.

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